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An evaluation of age-structured spatially disaggregated stock assessment models for SNA 1

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J.R. McKenzie

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EXECUTIVE SUMMARY

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In 2005, in preparation for results from the third tagging programme and in recognition of a need for better integration of tagging results into the stock modelling process, the Ministry commissioned the development of a spatially disaggregated SNA 1 stock assessment model. This report is largely a description of the model developed pursuant to that project (SNA2004/01). In light of the now low prospect of a SNA 1 tagging programme the goal of SNA2004/01 was expanded to include a review of alternative interpretations of stock status when a greater level of stock complexity is allowed for, i.e. allowing for spatial disaggregation. The assessment results of 10 fully age-structured stock assessment models were compared, these models being single sub-stock and combined sub-stock movement models with and without seasonal time steps. The combined sub-stock movement models were capable of accounting for tag observations that moved between sub-stocks. The effect of introducing a Beverton and Holt (1957) stock recruit relationship into model productivity dynamics was also explored.

Most models produced similar relative trends in biomass for the observable model history (1970–2004). Basic productivity parameters (B_0, MSY, B_{MSY}, B_{2004}), growth (Von Bertalanffy parameters) selectivity estimates, and the ratio of B_{2004} to B_{MSY} were also similar for the majority of models. This suggests that all of the models are apparently reasonable for assessing SNA 1.

The stock biomass trajectories from the spatial movement models were consistently lower than the single sub-stock estimates (the disparity being largest in the Bay of Plenty estimates), probably as a result of the inclusion of more tags in the analysis, specifically the tag movement recoveries.

The seasonally partitioned spatial model was significantly slower than the single season spatial model but produced a comparable assessment. It was concluded that, unless there were sufficient data available to incorporate a seasonal movement dynamic in the model, the inclusion of seasonal partitions *per se,* is likely to be unwarranted.

Excluding the seasonally stratified models left four candidate models for a future SNA 1 assessment: one fully spatial model and three sub-stock models. Even though the current modelling results suggest that it may prove impractical to conduct a fully Bayesian assessment using the spatial model the MPD results from this model would be useful to contrast with the single area assessment results. It is therefore recommended that all four annual models are used for the next assessment of SNA 1.

Comparisons of model biomass trajectories from the current models and those from past SNA 1 assessments suggest that the age-based modelling approach *per se* might be biased towards over-optimistic predictions of future stock status. Until such time that the projection dynamics of the SNA 1 models are better understood, it is recommended that projections are restricted to five years beyond the final observational year. In interpreting model results more weight should be placed on the trends seen in the recent history of the model than those predicted in the projections.

The stock assessment outcome from the SNA 1 models was highly influenced by the assumptions about steepness and natural mortality. Prior to the next SNA 1 assessment it is recommended that consensus is reached between fisheries scientists, managers and stake-holders as to appropriate values to model for M and steepness. Specifically, this group will need to provide guidance to the modellers as to how the uncertainty on these parameters should be accounted for in the assessment.

1 INTRODUCTION

Snapper (*Pagrus auratus*) is New Zealand's most valuable commercial coastal marine species and, by virtue of its high abundance around the populous regions of northern New Zealand, it is also New Zealand's most important recreational species (Hartill et al. 2007). Most New Zealand snapper stocks have been subject to significant exploitation for over a century; national commercial landings peaked in the 1970s at around 18 000 t per annum (Paul 1977; Ministry of Fisheries 2008). Commercial exploitation of snapper has been constrained by quota since the introduction of the Quota Management System (QMS) in 1986. Non-commercial snapper exploitation is not subject to quota, but is regulated primarily by minimum-legal-size and individual bag limits.

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

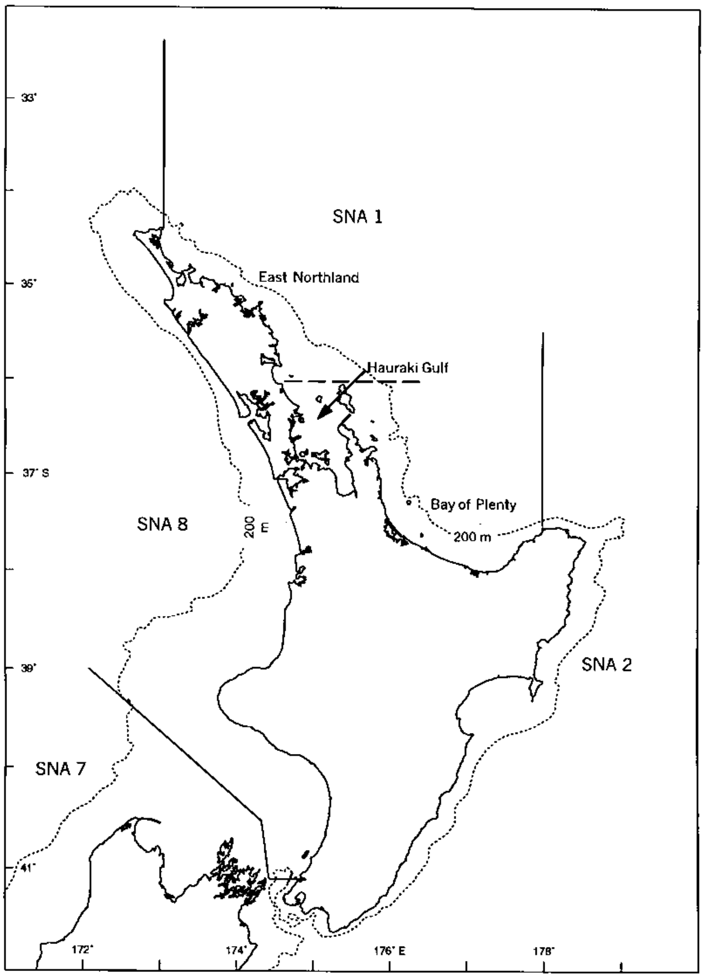

Figure 1: Snapper Quota Management Area boundaries.

Tagging movement, recruitment and growth data suggest that SNA 1 is productively distinct from the other three QMAs (Sullivan 1985; Walsh et al. 2006). Fishing pressure across SNA 1 has not been uniform and this is reflected in differences in age composition between SNA 1's three component subareas: east Northland; Hauraki Gulf; Bay of Plenty (Paul 1977; Sullivan 1985; Davies & Walsh 1995 Figure 1). Recent east Northland longline catches show a wider range of age classes and a higher accumulation of biomass older than 20 years than catches from the other areas, suggesting that it has been less intensely fished (Walsh et al. 2006). The smallest proportion of biomass in the older age classes is seen in Bay of Plenty catches (Walsh et al. 2006), which is believed to be a legacy of a relatively high level of trawl fishing during the 1970s. Despite spatial differences in productivity, tagging observations suggest that the level of mixing between the three sub-stocks is significant (Sullivan et al. 1988; Gilbert & McKenzie 1999). The areas also appear to have similar recruitment characteristics (Walsh et al. 2006).

The spatial complexity of SNA 1 makes it difficult to assess. One assessment approach has been to assess SNA 1 as a unit stock using amalgamated data from two or all sub-stocks. The other approach has been to model sub-stock productivity independently; the overall SNA 1 yield statistic being the combination of the individual assessments (see Appendix 1). Both approaches have problems; amalgamation results in an assessment inherently more uncertain because spatial variability is unaccounted for. Assessing the sub-stocks independently, although accounting for spatial variability, largely ignores connectivity processes and may lead to a biased assessment.

Many millions of dollars have been spent monitoring SNA 1 since the early 1980s. Monitoring programmes have included commercial catch-at-age sampling, recreational harvest surveys, trawl surveys, and tagging programmes to derive estimates of biomass (Appendix 1). Given the wealth of monitoring information available for SNA 1, the preference has been to use age-structured population modelling to estimate its productivity and status (Appendix 1).

The last formal SNA 1 stock assessment was undertaken in 1999 (Gilbert et al. 2000). The Hauraki Gulf/Bay of Plenty component of SNA 1 in the base-case run was predicted to have been at 0.80 B_{MSY} in 1999–2000; the sub-stock was predicted to rebuild over the following 20 years reaching about 1.73 B_{MSY} by 2019–20. The east Northland component of SNA 1 in the base-case run was predicted to have been at or slightly below B_{MSY} in 1999–2000; with 95% probability of the sub-stock biomass increasing over the following 20 years (Appendix 1).

The Ministry of Fisheries had planned to assess the SNA 1 stock again when the results of a third tagging biomass programme became available sometime prior to 2010. In 2008 the Ministry was provided with an estimate of over six million dollars for the next tagging study. The fishing industry, which stood to meet most of the programme cost, then withdrew support for a SNA 1 tagging programme.

In 2005, in preparation for results from the third tagging programme and in recognition of a need for better integration of tagging results into the stock modelling process, the Ministry commissioned the development of a spatially disaggregated SNA 1 stock assessment model. This report is largely a description of the model developed pursuant to that project (SNA200401).

In light of the now low probability of a SNA 1 tagging programme the goal of SNA200401 was expanded to include a review of alternative interpretations of stock status when a greater level of stock complexity is allowed for, i.e. spatial disaggregation. The effect of introducing a Beverton and Holt (1957) stock recruit relationship into model productivity dynamics is also explored.

The results presented in this report are intended to provide insight into the validity of key assumptions underlying past SNA 1 assessments. Although the modelling results provide guidance on how to configure future assessments they should not be interpreted as indicating current stock status. The spatially disaggregated models developed under this project also meet the project’s initial goal in that they could be used to integrate the results from future SNA 1 tagging programmes and provide an updated assessment, as could all of the single area models developed under the SNA200401 project.

2 METHODS

2.1 Model overview

2.1.1 Model structure

The models developed under this project have the same basic structural dynamics as the models used in the 1999–2000 SNA 1 assessment (Gilbert et al. 2000). Specifically they are age structured life-history population models being an adaption of the synthesis modelling approach of Methot (1990). The models were built using NIWA's CASAL (C++ Algorithmic Stock Assessment Laboratory) stock modelling building software (Bull et al. 2010). Model likelihoods and functional equations are described in Bull et al. (2010).

Model recruitment (R_0 estimable parameter) was at age 1. The models had 20 age partitions: 19 age classes (1–19) plus a 20+ amalgamated age class. As with the 1999–00 assessment, the models commence in 1970 at an exploited state. The model commencing (1970) age structures were estimated as 20 individual cohort parameters.

Model history spanned the years 1970 to 2004; 2004 being the 2003–04 "current" fishing year and 1969–70 being the "start" fishing year. For some model runs, annual time steps were subdivided into four seasonal time partitions: spring, summer, autumn and winter. Annual time steps were analogous to fishing years (October through to September; 1970 being the 1969–70 fishing year and so on). Model annual catches were the actual reported catch-by-method. To avoid the unnecessary complication of incrementing ages within an annual time step cohorts were advanced in age at the start of each fishing year (1 October); the observational catch-at-age data was adjusted accordingly.

The models were not sex partitioned; maturation for the purposes of spawning stock biomass (SSB) calculation was assumed to be knife-edged at 25 cm (age 4).

Total mortality in each seasonal time step was achieved by applying half the natural mortality, then applying the mortalities (total catches) from all the fisheries instantaneously, then applying the remaining half of the natural mortality.

Year class strengths (YCS) were estimated as free parameters but only for years where there were at least three independent observations of catch-at-age. The YCS estimation period in the model was also the period over which the R_0 parameter was estimated. YCS estimation conformed to the Haist parameterisation in which the mean of the YCSs is constrained to 1 (Bull et al. 2010). For years in which YCS could not be estimated as a free parameter, YCS was set to 1.

Model calculations of mean weight-at-age were achieved via von Bertalanffy (VB) growth and length-weight functions (Gilbert et al. 2000). The growth function was also used to derive a length frequency distribution of the stock in each fishing-year via a growth transition matrix. This was necessary because, unlike the 1999–2000 and previous SNA 1 stock assessments the new models were required to fit to length-frequency observational data, e.g. tag release and recapture observations. The growth transition matrix was derived from the three VB growth parameters and two coefficients of variation (c.v.) parameters corresponding to the levels of length-at-age variation at age 1 and age 20 (see Bull et al. 2010).

Natural mortality was implemented as a single rate parameter applied over all age classes. For model runs incorporating a stock-recruit relationship the Beverton and Holt model dynamic was used (Bull et al. 2010).

Selectivity functions for all gear methods represented in the model were 3-parameter double-normal functions (Bull et al. 2010). All other model selectivity functions were uniform.

2.1.2 Tagging data integration

Tagging data is powerfully informative on population size, age structure, selectivity, growth, movement, and exploitation. It was considered a failing of the previous SNA 1 assessment models that, by not fitting to the raw tagging observational data, these models had not optimally utilised the information the tagging data contained; information on selectivity in particular. It was deemed that for future SNA 1 stock assessments the models would need to fit the tagging data internally via a likelihood that would allow proper weighting against other observational data such as catch-at-age and CPUE.

2.1.3 Spatial structure

A fundamental operation premise of SNA 1 assessment and monitoring is that the QMA comprises three distinct sub-stocks: east Northland; Hauraki Gulf and Bay of Plenty (Figure 1). In the past the approach has been to model these stocks separately or to model east Northland as distinct from Hauraki Gulf/Bay of Plenty combined. Our modelling approach recognises three sub-stocks each with its own carrying capacity (defined by R0) and patterns in year-class-strength (YCS).

2.1.4 Movement

The main complication in separating the three sub-stocks is movement. The simple approach is to ignore movement (as was done in all previous SNA 1 sub-stock assessments). Ignoring movement becomes problematic for assigning tagged fish that move between sub-stocks. Basically there is no unbiased option to account for tag observations that move. Incorporating sub-stock movement into the modelling process is the more correct approach, but to do this requires a decision as to the nature of the underlying movement dynamic.

There are two fundamental movement dynamics: Markovian and home-fidelity (HF):

Most animal movement models are Markovian in that the parameters governing individual movement are specific to the area in which the animal currently resides. In other words, the animal has no prior "knowledge" of a "home" area or of an area it visited in a previous time step that was "better", it only "knows" the suitability or otherwise of the area in which it currently resides. For stock assessment purposes, the implicit assumption is that once in an area fish take on the productivity characteristics (e.g. growth, natural mortality) of the resident population in that area.

Under the HF movement assumption, movement is an attribute of the individual fish not the area in which it currently resides. This invokes the concept that individual fish have a predisposition to regard a particularly area home i.e., "A" is my home, but on occasion I visit "B". Under the HF dynamic the stocks/sub-stocks are defined by their preferred "home" area. At any instant in time a given area will contain a mixture of different "home" area fish; because it is impossible to distinguish the "home" nature of fish in a given area, HF sub-stocks are therefore cryptic, i.e. defined by movement dynamics not by area. It is important to realise that the yield calculations (MSY, B_{MYS}, B_0, etc) derived by a stock assessment under a HF movement dynamic pertain to the unit "cryptic" stock, not to an area. The actual yield from a specific area is an integration of the cryptic yields of the stocks that reside in that area.

Markovian and HF movement dynamics differ primarily in their equilibrium dynamics. Markovian movement is often modelled as a proportional shift from *i* at time *t* to area *j* over a unit time period (*t*+1*).* Assuming the proportional movement matrix does not vary from one time step to the next, after successive applications of the matrix, tagged fish released in a specific stratum will eventually attain an equilibrium distributed across all strata (Appendix 2). Under a HF movement dynamic the equilibrium distribution of a given cryptic home population A across all spatial areas *i* can be defined as a vector of probabilities (elements P_{Ai} being the probability of an *A* home fish being found in area *i*). The combination of home equilibrium movement vectors gives the equilibrium movement matrix for all areas (Appendix 2).

The key point to grasp from Appendix 2 is that under Markovian movement the equilibrium distribution of tagged fish across all strata is **independent** of the initial release distribution; under HF movement the equilibrium distribution of tagged fish across all strata is **dependent** on the initial release distribution. The choice between the two movement dynamics largely comes down to what fisheries scientists perceive to be the most plausible equilibrium distribution of tagged fish across all sub-stocks. We believe the Markovian movement dynamic is inconsistent with general movement patterns observed in New Zealand snapper. Past SNA 1 tagging studies have shown that the proportional distribution of tagged fish relative to area of release change little through time, with the majority of tagged snapper recovered in their area of release, i.e., tag distributions are dependent upon the area of release (Gilbert & McKenzie 1999). For this reason the HF movement was the dynamic chosen for our spatial SNA 1 model.

The structural implementation of HF movement in CASAL had (in the case of the three sub-stock model) four fishing area partitions with annual migration to and from these areas occurring over seven time steps. Fishing mortality and natural mortality occur in only four of the time steps deemed “real” time steps corresponding to spring, summer, autumn and winter. Movement occurs predominately in the first two and the last time step (these being cryptic time steps). No movement occurs during the period when fishing is taking place and during periods of observational data collection, e.g. trawl surveys.

This structure effectively means the three modelled stocks (east Northland, Hauraki stocks, Bay of Plenty) are cryptic, observations being made only when they are mixed over the three non-cryptic stock areas. The need for a fourth area, termed the “recruitment area” was to get round a CASAL limitation (which has since been rectified) which prevented the initial recruitments (R_0s) being assigned to different fishing area partitions. The time sequence of movements has the initial recruits moving to their home fishing areas in time step one (Figure 2) from a common cryptic recruitment area. In time-step two some fish move to the adjacent fishing area and at the beginning of time step 3 some of these will move to the farthest fishing area (this two-step requirement again because of another CASAL limitation which prevented the model from moving fish from one to two areas in one time step). When the first catches are removed in time step 3 all cryptic stocks are fully mixed (Figure 2). Fish are all moved back to their home fishing areas in time step 7 (another cryptic time step; Figure 2).

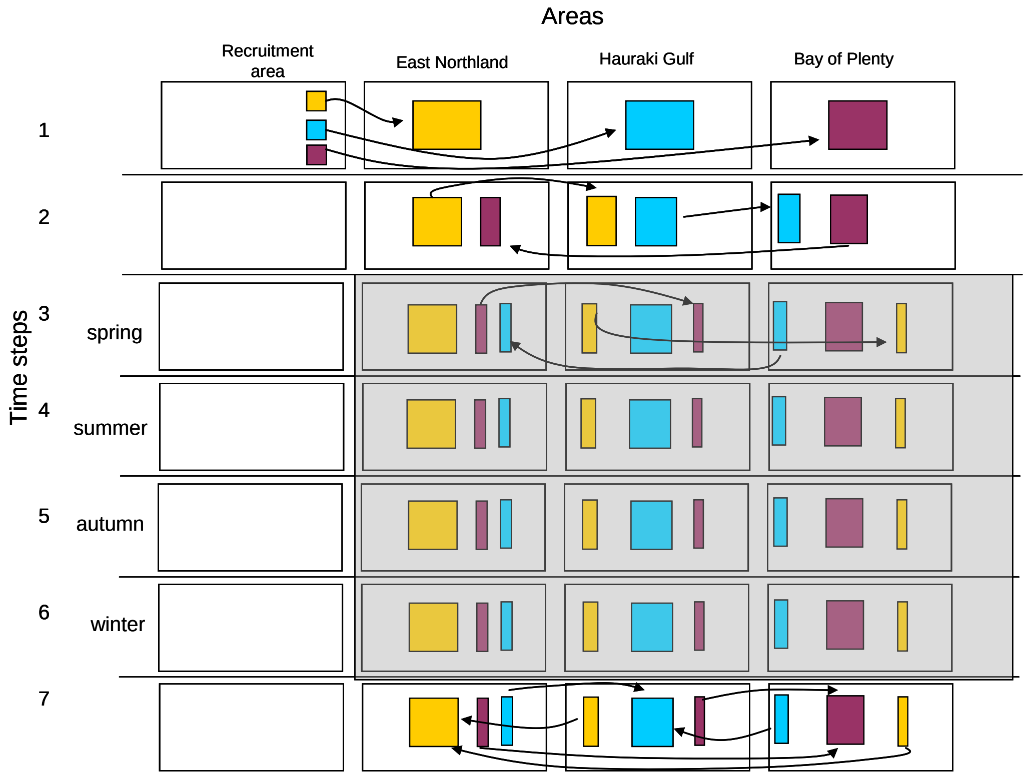

Figure 2: Structural illustration of the implementation of a three sub-stock and four season annual home fidelity movement process in CASAL through the use of cryptic and real/observed seasons (shaded) areas and time-steps.

For model runs with no seasonal time steps the CASAL implementation of HF movement required four time steps, three of these being cryptic (Figure 3).

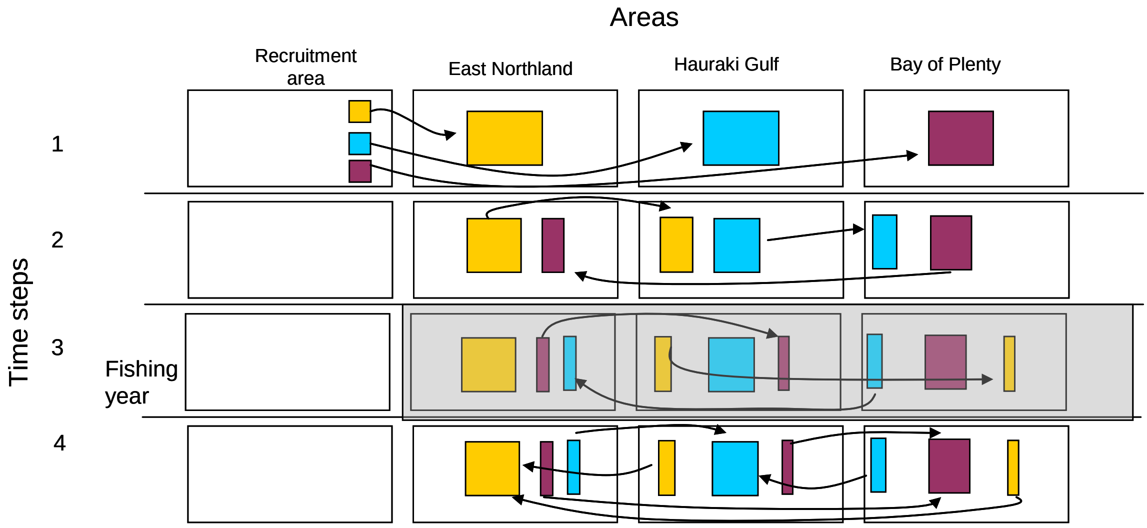

Figure 3: Structural illustration of the implementation of a three sub-stock and one fishing year annual home fidelity movement process in CASAL through the use of cryptic and real/observed seasons (shaded) areas and time-steps.

In the four-season movement model spawning stock biomass is calculated for each stock at the end of time step 7, and after time-step 4 in the single fishing year model.

As CASAL is currently structured it can only provide biomass, yield and other production statistics specific to stocks not stock-areas (this is possibly something that should be incorporated in future CASAL developments). In non-movement models these are usually the same thing, however in our HF model the productivity in the actual stock area is made up from the combined productivity of three "cryptic" stock units. In order to extract area-specific productivity and biomass estimates it was necessary to apply the model estimates of proportional movement to the cryptic stock productivity estimates and sum up the values specific to each stock-area.

2.1.5 Other sources of mortality

In the current modelling we have made no explicit allowance for incidental or unseen mortality. In doing this we reason the combined effect of all historical mortality (both unseen and explicit) is reflected in the fitted observational data (CPUE; catch-at-age) and therefore the unseen component is still **implicit** in the modelling analysis. In other words, although unseen mortality is not included in the model catch history, the yield estimates the model produces as a result of fitting to the observational data still reflect unseen mortality. A stock assessment model would need to increase its productivity (R0, MSY) estimates in order to explicitly account for the additional unseen catch (see for example the effect of changing recreational catch histories on yield estimation in the 2004 SNA 8 assessment; Davies et al. 2006). The downside of this supposed higher model yield is that unseen catch then has to be explicitly allowed for in future catch allocations. If it can be assumed that the inclusion or exclusion of unseen mortality has little effect on yield/exploitation ratio estimates we believe it can be ignored; i.e. unseen mortality is implicit in the explicit catch allocation.

The models made no explicit allowance for customary catch, the assumption being that customary catch was intertwined with recreational catch estimates. It is probably a reasonable assumption that the customary catch is unlikely to be larger than the general uncertainty around the recreational catch estimates (Ministry of Fisheries 2008). For modelling purposes, the recreational catch estimates were entered as fixed values with no error. It was beyond the scope of this project to investigate different assumed recreational catch histories. The same catch histories were used in all area specific model runs; the various model runs, although possibly biased, are therefore comparable.

A similar rationale was applied to the level of illegal catch. It was assumed that the annual level of illegal catch (as used in the 1999–2000 and earlier snapper assessments) was 20% of the reported commercial catch pre QMS and 10% post QMS.

2.2 Observational data

The observational data fitted by the models were: catch-at-age and catch-at length from commercial, recreational and research sampling programmes; tag release and recovery observations from the 1985 and 1994 SNA 1 tagging programmes; recreational harvest survey estimates; recent longline CPUE indices; and commercial catch history by area and method.

The Leigh water temperature time series, used in the 1999–2000 SNA 1 assessment to provide YCS for years where catch-at-age was not available, was not used to inform YCS in the current models; instead mean recruitment was assumed for years where YCS could not be estimated.

2.2.1 Catch histories

The SNA 1 catch history post 1970 was divided into five method fisheries: long line; single bottom trawl; pair bottom trawl; Danish seine; other commercial methods (predominately setnet); and recreational (predominately line).

Commercial

The SNA 1 commercial catch histories for the various method area fisheries after 1989–90 were derived from the Ministry of Fisheries effort reporting data. Historical catches for method area fisheries over the preceding two decades were constructed on the basis of data contained in the fishery characterisation reports of King (1985; 1986; 1987) and Paul & Sullivan (1988). Area method catches were prorated to the SNA 1 annual catch totals given in the 2008 plenary report (Ministry of Fisheries 2008). The commercial catch histories (Figures 4, 5, 6) were fitted in the models with no assumed error. No exploration of alternative catch histories was undertaken.

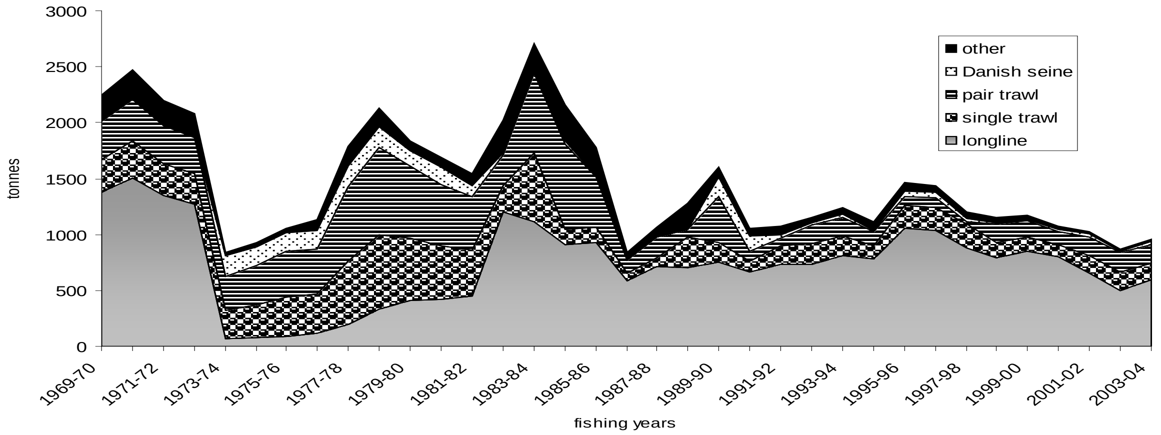

Figure 4: East Northland commercial catch history 1969–70 to 2003–04 for the five main fishing methods.

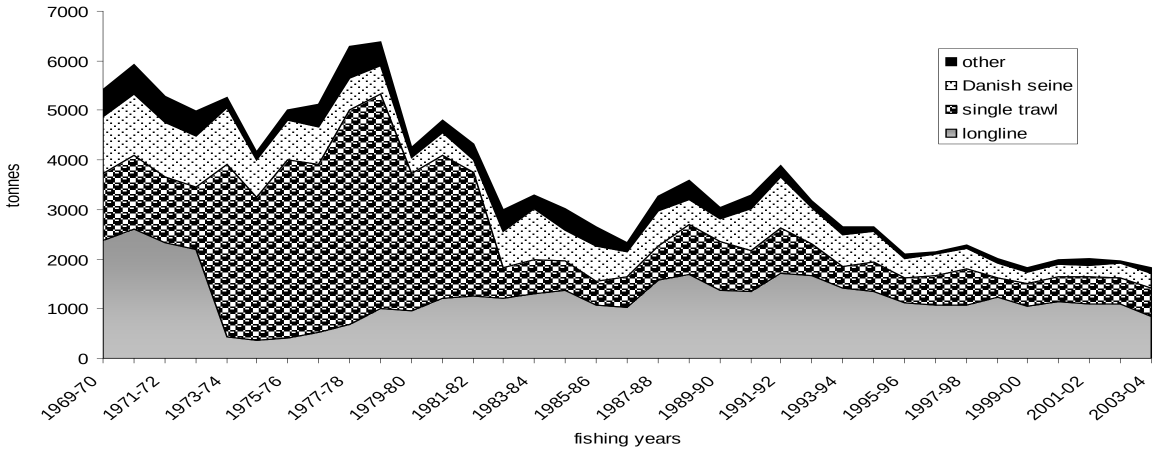

Figure 5: Hauraki Gulf commercial catch history 1969–70 to 2003–04 for the five main fishing methods.

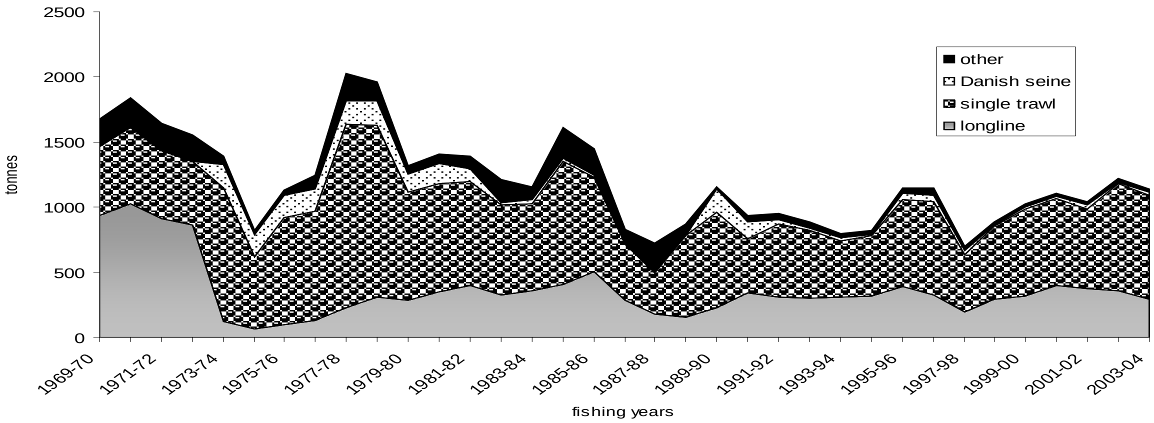

Figure 6: **Bay of Plenty commercial catch history 1969–70 to 2003–04 for the five main fishing methods.**

Non-commercial

Since 1985 there have been six annual surveys of SNA 1 non-commercial harvest (1984–85; 1993–94; 1995–96; 2000–01; 2001–02; 2004–05; Hartill et al. 2007; Ministry of Fisheries 2008). Three methods have been used to estimate recreational harvest (tagging 1984; telephone diary 1994 – 2001; aerial over-flight 2005); however only the aerial over-flight results are believed to be defensible (Hartill et al. 2007). The recreational harvest estimates used in the 1999–00 assessment were an average of the telephone diary and tagging estimates. Because the surveys upon which these estimates were based have now been somewhat discredited there is no compelling reason to continue to use them. The 1999–00 assessment made allowance for the drop in the individual bag limit (30 to 9) in 1993–94 and an increase in the legal minimum size (25 to 27 cm) in 1994–95. The assumption was that these measures would have reduced recreational harvest by approximately 8% (Gilbert et al. 2000). In the absence of any solid evidence on which to decide upon a recreational catch history we were forced to make an informed guess for modelling purposes. We are more confident about the relative distribution of catches across the three SNA 1 sub-stocks as these ratios were relatively consistent across all six recreational surveys. We make the assumption that the 1994–95 MLS and bag limit restrictions would have reduced the SNA 1 recreational harvest by approximately 300 tonnes per annum in the 1994–95 year (Figure 7).

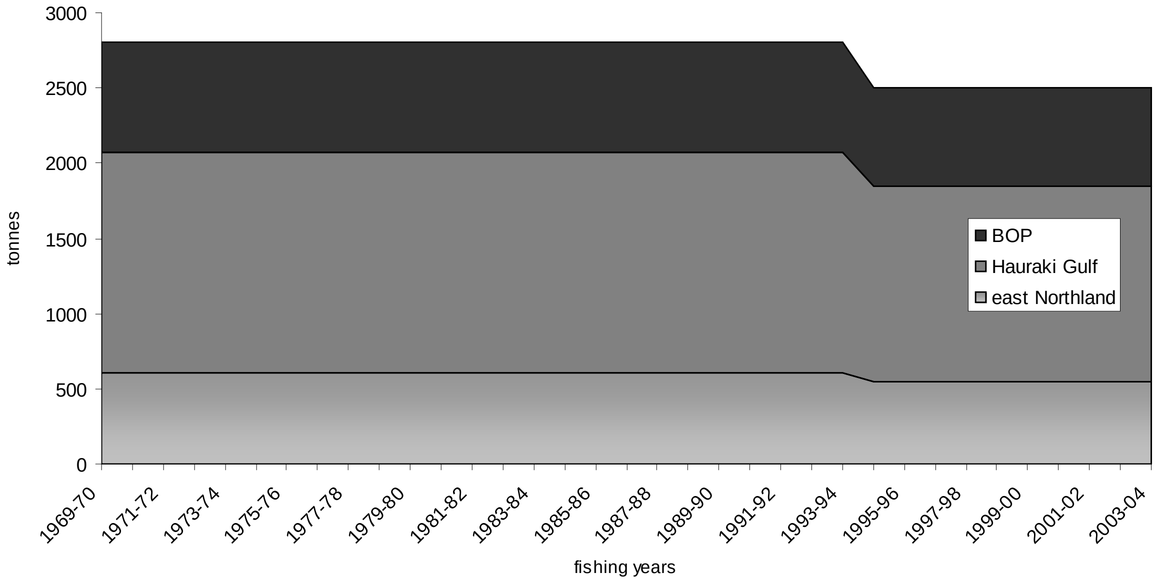

Figure 7: SNA 1 annual non-commercial harvest (tonnes) used in the modelling by sub-stock.

2.2.2 Catch-at-age and length

Catch-at-age observations inform the models on relative year-class strength, growth rates, total mortality, and selectivity. The latter two dynamics are confounded under the current domed selectivity assumptions for snapper (Gilbert et al. 2000); meaning that the models cannot easily disentangle selectivity (i.e. the steepness of the right-hand-limb) and exploitation, from catch-at-age observations alone. The model needs to be given another independent measure of one of these parameters (e.g. selectivity from tagging data) to make sense of the catch-at-age observations.

Catch-at-age and length information is intermittently available from the 1970's and 80s. Since the 1989–90 fishing year it has been collected annually from most SNA 1 sub-stocks (Appendix 3; Appendix 4). The majority of the SNA 1 catch-at-age series is longline; the main justification being that this method is believed to select a broad range of age classes and hence the age composition of the catch is more reflective of the underlying population age structure than the catches of the other methods (trawl; Danish seine; setnet). It is still important to understand the selectivity characteristics of the other major catching methods because selectivity strongly influences their overall fishing mortality. The lack of sampling for methods other than longline (with the exception of recreational line, there has been no catch sampling of the other methods since 1995) is a potential limitation to estimating method specific mortality particularly over the last decade. As there are no catch-at-age pair trawl observations for east Northland or observations for the method classed as "other" (predominantly setnet) in any sub-stock; the models were unable to estimate selectivity for these methods.

Catch-at-length information is available from all three SNA 1 sub-stocks pre and post the 1993–94 change in recreational bag limit and MLS which provides the models with reasonable power to derive a selectivity contrast for these management effects.

The importance of the trawl survey data to inform on variation in year-class-strength has diminished in light of the long time series of longline catch-at-age observations. The trawl survey length frequency data fitted in the model provided information on year class strength for cohorts covered by the survey years; these cohorts are also observed in the catch-at-age data.

2.2.3 Longline CPUE

A standardised CPUE analysis of SNA 1 was undertaken in 2007 and covered 16 fishing-years (1989–90 to 2004–05; McKenzie 2008). The CPUE abundance indices specific to each sub-stock were input to the model with the analytical coefficients of variation.

2.2.4 Mark recapture observations and biomass estimates

Since 1983 there have been three tagging programmes conducted in SNA 1 for the purposes of biomass estimation. The first, conducted in the 1983–84 fishing year, was undertaken in the Bay of Plenty sub-stock only. None of the raw data from this tagging programme remains; the results, however, are reported in Sullivan (1985) and Sullivan et al (1988).

In the 1984–85 fishing year a second tagging programme was undertaken across the Hauraki Gulf and east Northland sub-stocks. Biomass estimates were derived from both programmes using Petersen mark recapture estimators in 1988 (Sullivan 1988), and subsequently updated in 1999 (Gilbert et al. 2000). The raw data from the 1984–85 programme is available in a format suitable for integration into SNA 1 models.

The third SNA 1 tagging programme was conducted in the 1993–94 fishing year across all three sub-stocks (Davies et al. 1999; Gilbert et al. 2000). Biomass estimates were derived from this programme in 1995 and subsequently revised in 1999 (Gilbert et al. 2000) using Petersen-type estimators. In the analyses adjustments were made for initial mortality, tag loss, and under-detection (similar adjustments were also made for the previous tagging analyses, see Sullivan et al. 1988).

Evidence of trap-avoidance bias was found in the analysis of the 1993–94 tagging data (Gilbert et al. 2000); specifically, fish tagged by long-line (approximately 80% of releases) were less likely to be recaptured by longline. The effect of adjusting for trap-avoidance bias was to reduce the biomass estimates by approximately 25% (Gilbert & McKenzie 1999). The presence of trap avoidance bias in the historical tagging data was (and still is) conjectural. The base 1999–2000 assessment did not allow for trap avoidance although model runs using the bias adjusted estimates were included in the sensitivity analyses (Gilbert et al. 2000). CASAL is currently not configured to correct for trap avoidance in tagging data; the model runs presented in this report make no allowance for it.

Due to computational constraints it was not possible to fit both the 1984–85 and the 1993–94 observational tagging data in the models. Instead the 1984–85 Petersen estimates were fitted in the models as fixed biomass estimates (Table 1).

Table 1: 1984–85 sub-stock biomass (tonnes) estimates as derived from tagging. Estimates apply to the recruited stock above 25 cm (age 4) and are not corrected for trap avoidance.

Sub-stock	Recruited (25 cm +) Biomass (t) 1984–85	Assumed c.v.	Reference
East Northland	16 500	0.3	Sullivan et al. 1988; Gilbert et al. 2000
Hauraki Gulf	22 000	0.3	"
Bay of Plenty	6 000	0.3	Sullivan 1985

The 1993–94 tagging data was input to the CASAL models in the form of length-frequency observations. For each sub-stock there was one release event (1 time step) and a series of subsequent recovery events in which catches were examined for tags (5 seasonal time steps in the season models; 2 time steps in the annual models; Appendix 3, Appendix 4). Prior to input to the models the release length frequency data were adjusted for initial mortality (Gilbert 2000). CASAL adjusts the tag recovery expectation for tag loss and under-detection; tag-loss was set at 0.0 (assumed because of the use of internal coded wire tags) and under-detection at 0.25 (based on results from CWT tag detection trials). Values assumed for initial mortality, tag loss and under-detection were the same as used to derive the original Petersen biomass estimates (Davies et al. 1999; Gilbert et al. 2000). The models were also provided with the length frequency of the catch examined for tags in each time-step and sub-stock.

2.3 Spatial model comparisons

The basic purpose of the work is to compare the stock assessment "advice" obtained from a range of SNA 1 assessment models of varying spatial and temporal complexity. The most complex model allows movement between the three SNA 1 sub-stocks and has four annual seasons (Model 1 Table 2). This model provides individual yield estimates for the three SNA 1 sub-stocks while explicitly taking into account the movement dynamics between them. Models 2, 3, and 4 (Table 2) provide individual assessments of the three SNA 1 sub-stocks and are also seasonal models but movement dynamics are not factored into each assessment. Model 5 (Table 2) is analogous to Model 1 but only has one annual season. Models 6, 7, and 8 (Table 2) are area specific annual models.

Models 9 and 10 (Table 2) are included to provide a comparison to the 1999–2000 and previous assessments in which the Hauraki Gulf and Bay of Plenty were combined as one unit sub-stock. Model 9 derives yield estimates for the Hauraki Gulf and Bay of Plenty as separate sub-stocks (i.e. separate R0s) while also accounting for movement between them. Model 10 is simply a combined area model analogous to the 1999 HG/BP assessment model (Gilbert et al. 2000). The observational data fitted in Model 10 is mostly Hauraki Gulf data (catch sampling data, trawl surveys and CPUE). The tag release and recovery data fitted in Model 10 are simply a combination of the individual sub-stock data, likewise the catch histories. In Model 10 only one R0 (carrier-capacity) and one set of yield parameters are estimated (e.g. one B_{MSY}).

Tag observational data were fitted in all 10 models, but tag movement observations could only be correctly represented in the two spatially disaggregated movement models (Models 1 and 5; Table 2). For the single and reduced area models tag recovery observations made outside the area of release were ignored. The likely direction of bias introduced by ignoring the movement recoveries is to over-estimate the biomass of the tag release year.

Adopting a more complex modelling approach for the SNA 1 assessment is likely to more than double the monitoring information requirements compared to an assessment process having only one annual cycle that does not allow for sub-stock movement (compare the number of fitted data sets between Appendix 3 and Appendix 4). Another drawback of complex assessment models is that they are computationally expensive (i.e. they take much longer to run), and as a result fewer model options can be explored and there is potentially more doubt that the models have converged on the optimum solution space.

Table 2: Comparison of model complexity and SNA 1 assessment outcomes for the ten models used.

Model number	Model name	Model label	Movement	Number of areas	Number of seasons	Number of tagging likelihoods	Number of catch likelihoods	Number of CPUE likelihoods	Number of biomass likelihoods
1	SNA 1 spatial/seasonal	SNA1_sp_sea	yes	3	4	45	235	3	3
2	east Northland seasonal	ENLD_sea	no	1	4	5	59	1	1
3	Hauraki Gulf seasonal	HAGU_sea	no	1	4	5	97	1	1
4	Bay of Plenty seasonal	BOP_sea	no	1	4	5	79	1	1
		Total		*3*	*4*	*15*	*235*	*3*	*3*
5	SNA 1 spatial/annual	SNA1_sp_ann	yes	3	1	18	114	3	3
6	east Northland annual	ENLD_ann	no	1	1	2	25	1	1
7	Hauraki Gulf annual	HAGU_ann	no	1	1	2	53	1	1
8	Bay of Plenty annual	BOP_sea	no	1	1	2	36	1	1
		Total		*3*	*1*	*6*	*114*	*3*	*3*
9	Hauraki Gulf BoP spatail	HGBOP_sp_ann	yes	2	1	8	89	2	2
10	Hauraki Gulf BoP combined	HGBOP_com_ann	no	1	1	2	53	1	1

2.4 Model fitting

2.4.1 Model time sequence

The sequence of events within each time step was as follows:

- Ageing;
- Recruitment;
- Maturation;
- Migration (if the model included more than one area);
- Growth;
- Natural and fishing mortality;
- Tag release;
- Tag shedding.

For all seasonal time step models the total annual growth, natural mortality and catch occurred evenly in each non-cryptic time step (the shaded time steps in Figure 2). Ageing and recruitment occurred in time step 1 in all models, this being a cryptic time step in the movement models. Tagging events occurred in time step 1 in all models, this being a cryptic time step in the movement models. For the movement models the effect of tagging in time step 1 was that all sub-stocks were tagged in their respective home areas prior to mixing. All tag recovery observations occurred in "real" time steps after mixing had occurred. The cryptic time step process enables CASAL to approximate a home fidelity movement dynamic. Under a true home fidelity dynamic the home sub-stocks would be mixed over all areas at all times such that tags released in one area would be unlikely to result in just one sub-stock being tagged; it is currently not possible to implement this in CASAL. All mortality events occurred after the stock had fully mixed. Spawning stock biomass was calculated in the last annual time step in all models after growth and mortality had occurred; in the case of the movement models this was after the cryptic sub-stocks had moved back to their home areas.

2.4.2 Likelihoods

A full description of the model likelihoods can be found in the CASAL manual (Bull et al. 2010). Depending upon the likelihood function observation error is typically provided as a coefficient of variation (c.v.) or, in the case a multinomial likelihood, a sample frequency.

In addition to the observational data likelihoods a number of penalty likelihood terms were specified, to prevent the model from choosing parameterisations leading to extinction or a violation of fundamental constraints.

Due to the large amount of length and age data available, the influence of the catch-at-age likelihoods often had to be down-weighted in past assessments in order to obtain more balanced fits to the other observational data; the single tagging biomass observations in particular (Davies et al. 1999). Since the 1999–2000 SNA 1 assessment the more accepted approach to balancing model likelihood terms is to adjust their individual variance components so that the standard deviation of their standardised residuals is close to 1, i.e. the residuals conform to a standard normal distribution. CASAL allows a process error value to be specified on each likelihood. To achieve a normalised residual fit the process error terms of the catch length/age likelihoods (Appendix 3, Appendix 4) sometimes required adjustment.

The analytical c.v.s from the longline CPUE standardisations were implausibly small (McKenzie 2008). Longline CPUE has typically been down-weighted in previous SNA 1 assessments on the grounds that the method is not likely to be precisely reflective of abundance (Annala 1994; Gilbert et al. 2000). Francis (1999) in his review of CPUE standardisation methods suggested that the underlying assumption of constant catchability (q) is unlikely to hold in most CPUE time series. Francis recommended that additional process error in the order of 0.2–0.3 should be applied to most CPUE series to allow for underlying variability in q. In light of this rationale, the longline CPUE indices were entered in the models with their analytical c.v.s and a constant process error term of 0.3 (the variances being additive).

The c.v. on the 1983–84 biomass estimate was set at 0.3, the value used in the 1999–2000 assessment (Gilbert et al. 2000).

CASAL uses a binomial likelihood for fitting tagging observations (Bull et al. 2010). The CASAL tagging likelihoods can be adjusted by use of a robustifying constant and a dispersion factor. The CASAL default values were used in all model runs.

2.4.3 Model parameters and priors

The number of free parameters estimated in the individual and multi-stock models ranged from 57 to 171 (Table 3). A full SNA 1 stock assessment required 24 fewer parameters in the full spatial models than the combined number of parameters needed for the individual sub-stock models; the saving being the need to estimate common selectivity parameters (Table 3).

Table 3: Number of free parameters estimated by model type.

Model number	Model name	R0	Growth (vb)	Selectivity	YCS	CPUE q	1970 Numbers-at-age	Movement	Total
1	SNA 1 spatial/seasonal	3	9	18	72	3	60	6	171
2	east Northland seasonal	1	3	12	20	1	20	0	57
3	Hauraki Gulf seasonal	1	3	18	29	1	20	0	72
4	Bay of Plenty seasonal	1	3	18	23	1	20	0	66
	Total	*3*	*9*	*48*	*72*	*3*	*60*	*0*	*195*
5	SNA 1 spatial/annual	3	9	18	72	3	60	6	171
6	east Northland annual	1	3	12	20	1	20	0	57
7	Hauraki Gulf annual	1	3	18	29	1	20	0	72
8	Bay of Plenty annual	1	3	18	23	1	20	0	66
	Total	*3*	*9*	*48*	*72*	*3*	*60*	*0*	*195*
9	Hauraki Gulf BoP spatial	2	6	18	49	2	40	2	119
10	Hauraki Gulf BoP combined	1	3	18	23	1	20	0	66

Virgin recruitment (R0)

A separate mean or virgin recruitment R0 parameter was estimated for each sub-stock. The R0 priors were uniform-log (Bull et al. 2010) bounded suitably low and high ($10^5 – 10^8$).

Von Bertalanffy Growth

Growth was modelled using a length-age transition matrix which was specified on the basis of a five-parameter von Bertalanffy (vb) growth function (three von Bertalanffy parameters and two c.v. parameters). The two c.v. parameters relate to the c.v. around mean length-at-age for the minimum and maximum age cohort in the model (i.e. age 1 and age 20+). The c.v. parameters were fixed at 0.1 and 0.2 respectively for all model fits. The c.v.s about all intervening age cohorts were derived by linear interpolation. The other three parameters were estimable. These parameters were constrained by a normal prior with a c.v. of 0.1 (Appendix 5). The mean values for *Linf* and *k* used in the priors were obtained by fitting to longline length and age data collected in the 2004–05[*] fishing year from each sub-stock external to the model (Appendix 5).

Selectivity

All gear-method selectivities were specified using age-based double normal functions (Bull et al. 2010). Parameters were constrained by bounded uniform priors: age of maximum selectivity 2 – 15 years; left and right descending limbs 0.5 – 1000. Selectivity parameters for most of the sub-stock gear-methods could be estimated (Appendix 6). Selectivity parameters for the two exceptions (pair trawl and other methods; Figure 8; Appendix 6) were loosely based on selectivities used in previous

[*] Note: being from the 2004–05 FY these data were otherwise not used in model.

SNA 1 and 8 assessments (Gilbert et al. 2000; Davies et al. 2006; Bian et al. 2009). It was not possible to estimate single trawl and Danish seine selectivity in the stand alone east Northland model runs because there are no catch-at-age observations for these methods from this area; the parameters used came from earlier runs of the Hauraki Gulf standalone model (Figure 8; Appendix 6).

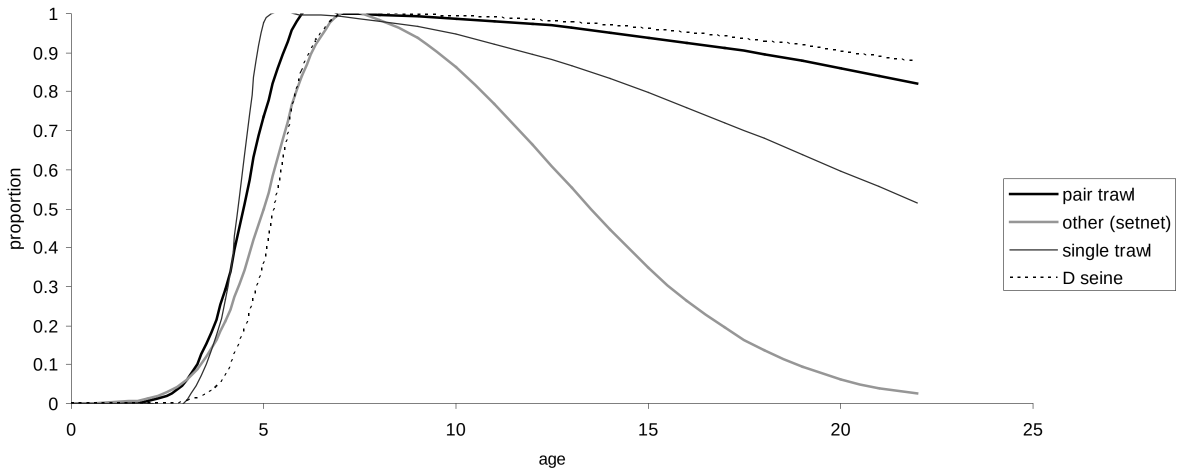

Figure 8: Shape of the fixed selectivity curves used in the assessment models.

Year class strength

The models were free to estimate year class strength parameters for years where the catch age/length data provided at least three independent observations of year class strength. For east Northland 20 free years could be estimated (1978 – 1997); for Hauraki Gulf 29 free parameter years (1969 – 1997); and for Bay of Plenty 23 years (1975 – 1997). The YCS estimates were constrained by bounded uniform priors (0.01 – 20.0).

CPUE catchability coefficient (q)

Individual catchability coefficients (q) were estimated for each sub-stock longline CPUE series. Bounded uniform-log priors (Bull et al. 2010) were used to inform the fitting process (10^{-7} – 1.0).

Sub-stock age frequency in model starting year (1969–70)

There were two options for setting up the initial model population age structure:

1. Estimating a pre-1970 total mortality rate and running the model through a suitable number of iterations with a fixed R0 to achieve equilibrium (this was the method used in the 1999–2000 SNA 1 assessment Gilbert et al. 2000);

2. Estimating each age cohort as a free parameter (20 parameters).

The individual sub-stock models were configured for both parameterisations, and in general the initial runs of the two model structures produced very similar starting age compositions. It was not possible, however, to implement the single initial mortality parameterisation option in CASAL multi-stock models; so for consistency all 10 models were run estimating the initial cohorts as free parameters.

The initial cohort parameters were estimated using bounded normal priors with a c.v. of 0.3. The mean values used as the priors in all the final model runs came from earlier runs of the individual pre-1970 mortality parameter configured sub-stock models.

Movement

The number of free parameters necessary to describe movement between *n* spatial areas of a closed system is n^2-*n*. The three sub-stock SNA 1 models necessitated estimating six movement parameters; the Hauraki Gulf/Bay of Plenty model (Model 9) had two estimable parameters. All movement parameters were estimated using uniform priors bounded between 0 and 1.

Steepness and Natural Mortality (M)

The basic assumption of no stock recruit relationship (i.e. steepness = 1.0) was made in all previous SNA 1 assessments. For the base runs a Beverton and Holt recruitment model was used with the steepness parameter set to 1.0.

There is a long standing conjecture as to what value of natural mortality is appropriate to assume for snapper, the base value in most assessments has been set at 0.06 but values of 0.075 and 0.09 have been used (Langley 2010). Since the objective of the project was largely to compare the effect of varying spatial complexity, and not an investigation of M *per se*, all ten base models were run with M fixed at 0.06.

2.4.4 Model fitting

The optimum fit of the model to the observational data was determined using Maximum Likelihood through the use of an auto-diff minimiser. CASAL uses the auto-diff minimiser ADOL-C (developed by the Technical University of Dresden's department of applied computing; http://www.coin-or.org/projects/ADOL-C.xml) to find the maximum likelihood estimate (MLE) of the parameterisation space. It was not feasible to generate sufficiently long MCMC chains for the spatial models because of the long computational time required to do so; model comparisons were therefore made on the basis of MLE optimisations only.

2.5 Model outputs

2.5.1 Stock status

The purpose of the model runs was not to provide definitive stock assessments, but to compare the overall prognoses of the various models. For this purpose a set of basic productivity parameter estimates were output from each model run, i.e. B_0, B_{MSY}, MSY, B_{2004}.In addition the probability of the stock being above B_{MSY} after 20 years (P[B_{2024}> B_{MSY}]) and above current biomass (P[B_{2024}> B_{2004}]) were derived from 1000 bootstrap projections. Stochasticity in the projections came from random resampling of the estimated recruitment parameters (with replacement; refer Bull et al. 2010).

2.5.2 Selectivity estimates

Part of the power of assessing the three SNA 1 sub-stocks together in one model is that it provides more data to estimate shared parameters, specifically selectivity. The various derived selectivity curves from the 10 models were compared.

2.6 Exploration of stock-recruit steepness

All ten models were run with steepness (Beverton and Holt) value of 0.8.

3 RESULTS

3.1 Model comparisons

3.1.1 CASAL and ADOL-C performance

It became apparent very early on in this project that the full spatial and seasonal model (SNA1_sp_sea) was pushing the boundaries of CASAL and the ADOL-C minimiser. The original construct of the model included fitting the 1985 tagging observational data. However, due to CASAL partition space limitations it proved impossible to get this model to run. Even after the 1985 tagging data were dropped CASAL still struggled with the large partition space and was computationally slow. It took three runs of the ADOL-C minimiser before a robust minimum was reached and a successful convergence reported (Table 4). The initial run took in excess of 11 hours of CPU time, and the last run three hours (Table 4). Although this model seems to have eventually produced an acceptable MLE, as indicated by the final successful convergence, it would be impractical to use this model for generating millions of MCMC runs.

Table 4: ADOL-C minimiser convergence issues.

Model number	Model name	Model label	Convergence time of first run	Number of model runs required	Final run convergence criteria met
1	SNA 1 spatial/seasonal	SNA1_sp_sea	11 hours	3	Y
2	east Northland seasonal	ENLD_sea	5 minutes	2	Y
3	Hauraki Gulf seasonal	HAGU_sea	5 minutes	2	Y
4	Bay of Plenty seasonal	BOP_sea	5 minutes	2	Y
5	SNA 1 spatial/annual	SNA1_sp_ann	3 hours	2	Y
6	east Northland annual	ENLD_ann	1 minute	1	Y
7	Hauraki Gulf annual	HAGU_ann	2 minutes	1	Y
8	Bay of Plenty annual	BOP_sea	2 minutes	1	Y
9	Hauraki Gulf BoP spatail	HGBOP_sp_ann	40 minutes	1	Y
10	Hauraki Gulf BoP combined	HGBOP_com_ann	2 minutes	1	Y

The annual SNA 1 spatial model (SNA1_sp_ann) required approximately 20% of the full seasonal model's partition space and was consequently faster in the first run (3 hours compared to 11 hours; Table 4). Although significantly faster than SNA1_sp_sea, SNA1_sp_ann is still likely to be too slow to provide a full SNA 1 assessment.

In contrast to the spatially disaggregated movement models, the more typical single stock area models all converged within minutes (Table 4).

Raw parameter, likelihood values, and other statistics from each model run are given in the appendices (Appendices 6–14).

3.1.2 East Northland model estimates

Four models provided stock status estimates for east Northland (Table 5). The general model trajectories from all models were similar (Figure 9). Another general consistency is that all models estimated the current (2004) status of the stock at below B_{MSY} (range 40–95%; Table 5). The two annual models (Models 5 and 6) produced similar estimates for most biomass and derived parameters (Table 5).

The SNA1_sp_sea (Model 1) put the 2004 biomass at almost half the other model estimates (Table 5) and overall produced the steepest declining trajectory (Figure 9). For most of the other parameters the Model 1 estimates were consistent with those of the other models. The standard deviations of the Model 1 recreational LF likelihood standardised residuals are not ideal (Appendix 7), indicating that some were over-fitted and others under-fitted. Due to the length of time needed for the SNA1_sp_sea model to converge it was not practical to rerun the models in order to optimise the likelihood residual fits.

The ENLD_sea model (Model 2) put the stock at well above the predicted biomass of the other models over the main observation period (1978–1997) and was the only model to predict a continued decline through the projection years (2005–2024) (Figure 9). This lack of consistency suggests that this model may not have performed as well as the other models. The high number of correlated parameters is also evidence of poor performance (Appendix 8).However, the standard deviations of the Model 2 likelihood standardised residuals were mostly close to 1 indicating that the relative weighting of model terms was acceptable (Appendix 8).

The likelihood standardised residuals from the two annual model fits (Models 5 and 6) were reasonably close to 1 indicating that the relative likelihood weightings were largely acceptable (Appendix 9; Appendix 10).

Table 5: East Northland model production parameter estimates. MSY and B_{MSY} values are deterministic. Projection risk probabilities were derived from boot-strap random recruitments.

Model name	Model num	Steepness (BH)	M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	$P[B_{2024} > B_{MSY}]$	$P[B_{2024} > B_{2004}]$
SNA1_sp_sea*	1	1.0	0.06	72148	5612	14258	1957	0.08	0.39	0.20	0.132	0.955
ENLD_sea	2	1.0	0.06	58138	10577	11085	1519	0.18	0.95	0.19	0.208	0.265
SNA1_sp_ann*	5	1.0	0.06	83741	10638	16155	2193	0.13	0.66	0.19	0.904	1
ENLD_ann	6	1.0	0.06	73412	10012	16635	1772	0.14	0.60	0.23	0.56	0.97

* movement corrected estimates

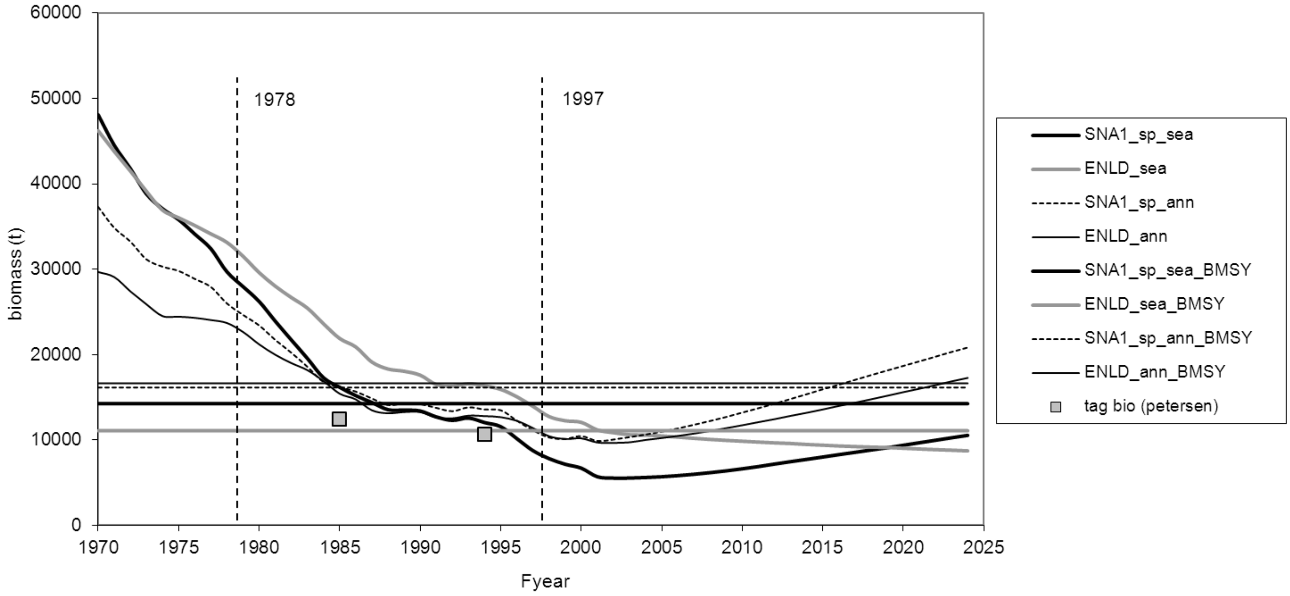

Figure 9: East Northland model stock trajectories. Model projection space shaded; estimated YCS lie between the vertical dotted lines (1978–1997). Independent Petersen biomass estimates are shown (note: only the 1985 estimate was fitted directly in the models).

3.1.3 Hauraki Gulf model estimates

Five models provided stock status estimates for the Hauraki Gulf (Table 6). The overall general model trajectories were the same (Figure 10). Likewise the model parameter estimates and risk probabilities were similar (Table 6); all models predict current (2004) biomass to be in the order of 70–80% of BMSY; all models show a steep increase in biomass over the projection years (Figure 10) with a 92–100% probability of the stock being above BMSY by 2024.

Table 6: Hauraki Gulf model production parameter estimates. MSY and B_{MSY} values are deterministic. Projection risk probabilities were derived from boot-strap random recruitments

Model name	Model num	Steepness (BH)	M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	$P[B_{2024}> B_{MSY}]$	$P[B_{2024}> B_{2004}]$
SNA1_sp_sea*	1	1.0	0.06	173634	26730	33260	5036	0.15	0.80	0.19	0.92	0.98
HAGU_sea	3	1.0	0.06	151931	24358	29317	4589	0.16	0.83	0.19	1.00	1.00
SNA1_sp_ann*	5	1.0	0.06	187113	28520	35025	4939	0.15	0.81	0.19	0.99	1.00
HAGU_ann	7	1.0	0.06	180584	26318	38013	4711	0.15	0.69	0.21	0.99	1.00
HGBOP_sp_ann*	9	1.0	0.06	195611	29623	34454	5413	0.15	0.86	0.18	1.00	1.00

* movement corrected estimates

As already mentioned, model 1 recreational likelihood standardised residual variances were less than ideal, an indication that the relative weightings of these likelihoods might have been inappropriate (Appendix 7). The likelihood standardised residual variances from all the other Hauraki Gulf model fits (Table 6) were largely within acceptable margins (Appendix 9, Appendix 11, Appendix 12, Appendix 13).

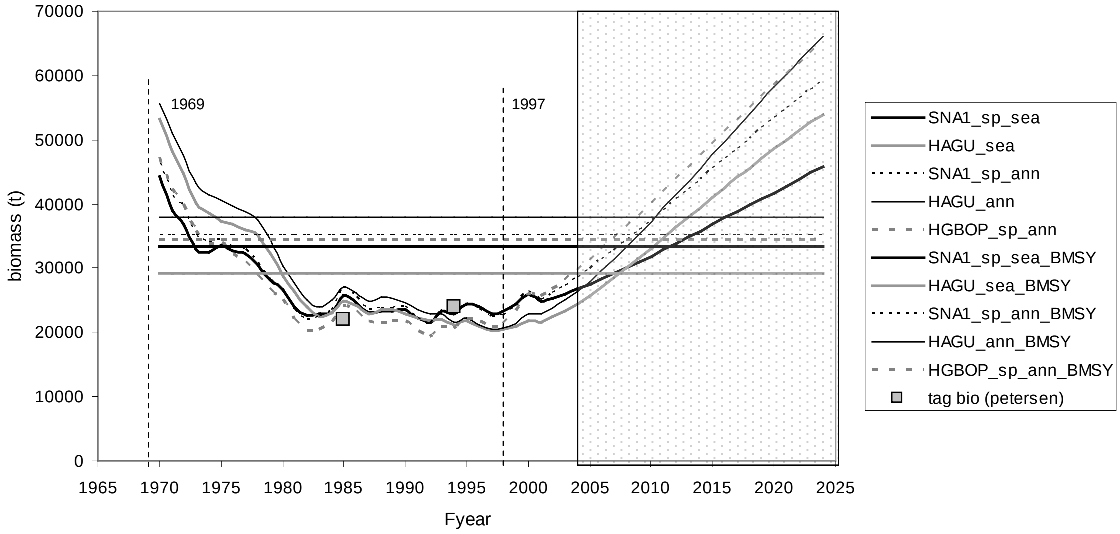

Figure 10: Hauraki Gulf model stock trajectories. Model projection space shaded; estimated YCS lie between the vertical dotted lines (1969–1997). Independent Petersen biomass estimates are shown (note: only the 1985 estimate was fitted directly in the models).

3.1.4 Bay of Plenty model estimates

The general results from the five Bay of Plenty assessment models suggest that the status of this sub-stock is less optimistic than the other sub-stocks. The current (2004) status relative to B_{MSY} is consistently lower than the other stocks (0.44–0.57) with at best only a 54% probability of attaining B_{MSY} by 2024 (Table 7).

A clear dichotomy is evident between the spatial and single area model biomass trajectories; the spatial model biomass being consistently lower than the single-stock model estimates (Figure 11). Although predicting a higher overall biomass trajectory, the projection scenarios of the single area models are markedly less optimistic with a 45% probability that the stock will be below 2004 levels in 2024 (Table 7).

The difference in spatial and single-area model outcomes is likely to be due to the former's ability to account for tag observations recovered outside the release area. By not accounting for out-of-area tag recoveries the Bay of Plenty single-stock models were prone to overestimate the Bay of Plenty biomass. Although the same biases also apply to the Hauraki Gulf and east Northland single-area assessment models; the reason why the dichotomy is most evident in the Bay of Plenty results is likely to be due to there being proportionally more Bay of Plenty tags recovered outside the Bay of Plenty than the other sub-stock areas. The models use the tag observations to estimate the relative sub-stock mixing rates; the relatively high degree of Bay of Plenty mixing is reflected in these estimates (Appendix 17).

As already mentioned, the model recreational likelihood standardised residual variances were less than ideal, indicating that the relative weightings of these likelihoods may have been inappropriate (Appendix 7). The likelihood standardised residual variances for the two single area models (Models 4 and 8) are given in Appendix 14 and Appendix 15. The standard deviations of the standardised residuals were reasonable for both models (most being around 1.0). Like the east Northland single area seasonal model fits (Model 2; Appendix 8) the Bay of Plenty season model MLE fit resulted in a large number of correlations between recruitment parameters, this is not ideal and may indicate sub-optimal model performance.

Table 7: Bay of Plenty model production parameter estimates. MSY and B_{MSY} values are deterministic. Projection risk probabilities were derived from boot-strap random recruitments. Single area model results are shaded.

Model name	Model num	Steepness (BH)	M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	$P[B_{2024} > B_{MSY}]$	$P[B_{2024} > B_{2004}]$
SNA1_sp_sea*	1	1.0	0.06	28142	2179	4700	837	0.08	0.46	0.17	0.23	0.92
BOP_sea	4	1.0	0.06	66253	6309	12135	1805	0.10	0.52	0.18	0.10	0.43
SNA1_sp_ann*	5	1.0	0.06	39894	3239	6483	1109	0.08	0.50	0.16	0.51	0.98
BOP_ann	8	1.0	0.06	75832	8455	14808	1870	0.11	0.57	0.20	0.16	0.45
HGBOP_sp_ann*	9	1.0	0.06	45904	3177	7302	1307	0.07	0.44	0.16	0.54	0.99

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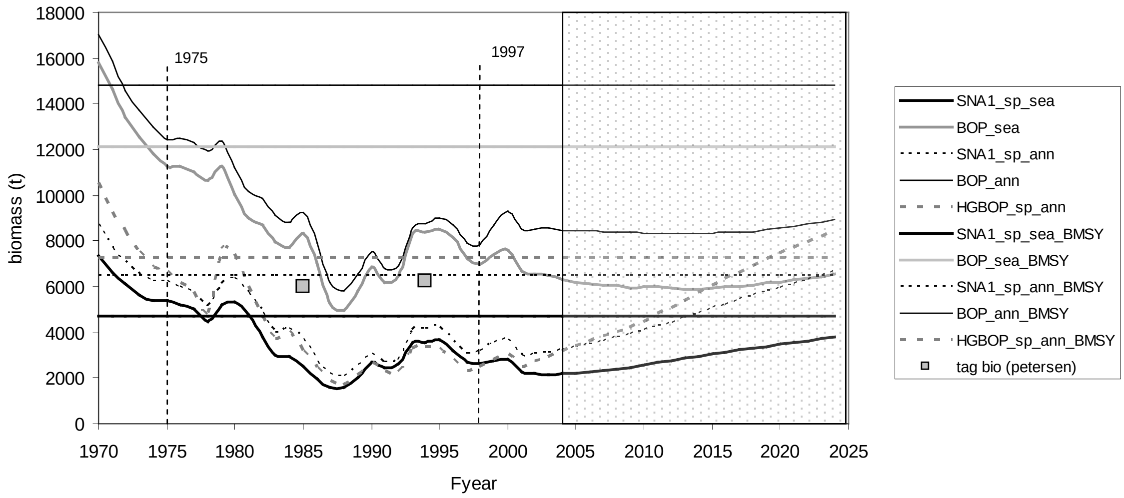

Figure 11: Bay of Plenty model stock trajectories. Model projection space shaded; estimated YCS lie between the vertical dotted lines (1975–1997). Independent Petersen biomass estimates are shown (note: only the 1985 estimate was fitted directly in the models).

3.1.5 Hauraki Gulf/Bay of Plenty combined sub-stocks

A combined Hauraki Gulf/ Bay of Plenty assessment is included to allow comparison to previous assessments. Adding the results from the 10 model runs provided six separate modelling assessments for the Hauraki Gulf/ Bay of Plenty stock unit (Table 8). The results of the six models were largely consistent, probably reflecting the strong dominance of the Hauraki Gulf observational data (Table 8). The general prognosis is for the current (2004) biomass to be in the order of 70–80% of B_{MSY}; all projections predict a strong rebuild trajectory through to 2024 (Figure 12); the probability of the biomass exceeding B_{MSY} by 2024 being in the order of 90–100% (Table 8).

A similar dichotomy as seen in the Bay of Plenty results in the biomass trajectories of the spatial models (1, 5, and 9) and combined/single stock area models is evident (Figure 12); again the inclusion of tag movement observations (especially from the Bay of Plenty) probably explains the lower spatial model biomass estimates.

Model 10 gave the most optimistic biomass trajectory of all the models (Figure 12). Model 10 is closest in configuration to the previous assessment models and has the lowest level of spatial complexity of the 6 models. However, the results of Model 10 were almost identical to those produced by combining the results of annual models 7 and 8 (Table 8; Figure 12).

The likelihood standardised residual variances from the MLE fit of Model 10 were generally indicative of a satisfactory fit (few correlated parameters; standardised residual variances on most likelihoods were close to 1.0; Appendix 16).

Table 8: Hauraki Gulf/Bay of Plenty combined model production parameter estimates. MSY and B_{MSY} values are deterministic. Projection risk probabilities were derived from boot-strap random recruitments.

Model name	Model num	Steepness (BH)	M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	$P[B_{2024} > B_{MSY}]$	$P[B_{2024} > B_{2004}]$
SNA1_sp_sea*	1	1.0	0.06	201776	28909	37960	5873	0.14	0.76	0.19	0.88	0.98
HAGU_sea + BOP_sea	3 & 4	1.0	0.06	218184	30667	41452	6394	0.14	0.74	0.19	0.98	1.00
SNA1_sp_ann*	5	1.0	0.06	227006	31759	41508	6047	0.14	0.77	0.18	0.99	1.00
HAGU_ann + BOP_ann	7 & 8	1.0	0.06	256416	34773	52821	6581	0.14	0.66	0.21	0.94	1.00
HGBOP_sp_ann*	9	1.0	0.06	241515	32800	41756	6720	0.14	0.79	0.17	0.99	1.00
HGBOP_com_ann	10	1.0	0.06	242633	35237	52109	6692	0.15	0.68	0.21	0.92	1.00

* movement corrected estimates

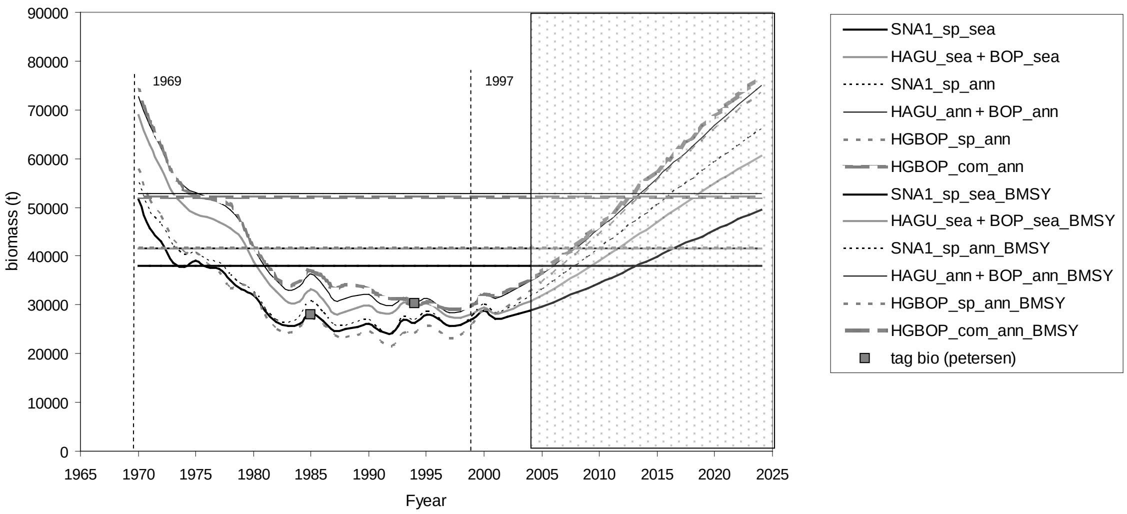

Figure 12: Hauraki Gulf/Bay of Plenty combined model stock trajectories. Model projection space shaded; estimated YCS lie between the vertical dotted lines (1969–1997). Independent Petersen biomass estimates are shown (note: only the 1985 estimate was fitted directly in the models).

3.1.6 SNA 1 combined sub-stock estimates

The SNA 1 combined modelling results were reasonably consistent; putting the amalgamated stock unit at within 65 to 80% of B_{MSY} in 2004, with most models predicting a high probability of SNA 1 being above B_{MSY} by 2024 (90–99%; Table 9). The spatial model trajectories, although closer to the single area (non-mixing) models, were consistently lower for reasons discussed above (Figure 13).

Table 9: SNA 1 sub-stock combined model production parameter estimates. MSY and B_{MSY} values are deterministic. Projection risk probabilities were derived from boot-strap random recruitments.

Model name	Model num	Steepness (BH)	M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	$P[B_{2024} > B_{MSY}]$	$P[B_{2024} > B_{2004}]$
SNA1_sp_sea	1	1.0	0.06	273924	34521	52218	7830	0.13	0.66	0.19	0.72	0.99
SNA1_comb_sea	2-4	1.0	0.06	276322	41244	52537	7913	0.15	0.79	0.19	0.96	0.99
SNA1_sp_ann	5	1.0	0.06	310747	42397	57663	8240	0.14	0.74	0.19	0.99	1.00
SNA1_comb_ann	6-8	1.0	0.06	329828	44785	69456	8353	0.14	0.64	0.21	0.93	1.00
EN+HGBOP_sp_ann	6 & 9	1.0	0.06	314927	42812	58391	8492	0.14	0.73	0.19	0.99	1.00
EN+HGBOP_com_ann	6 & 10	1.0	0.06	316045	45249	68744	8464	0.14	0.66	0.22	0.92	1.00

* movement corrected estimates

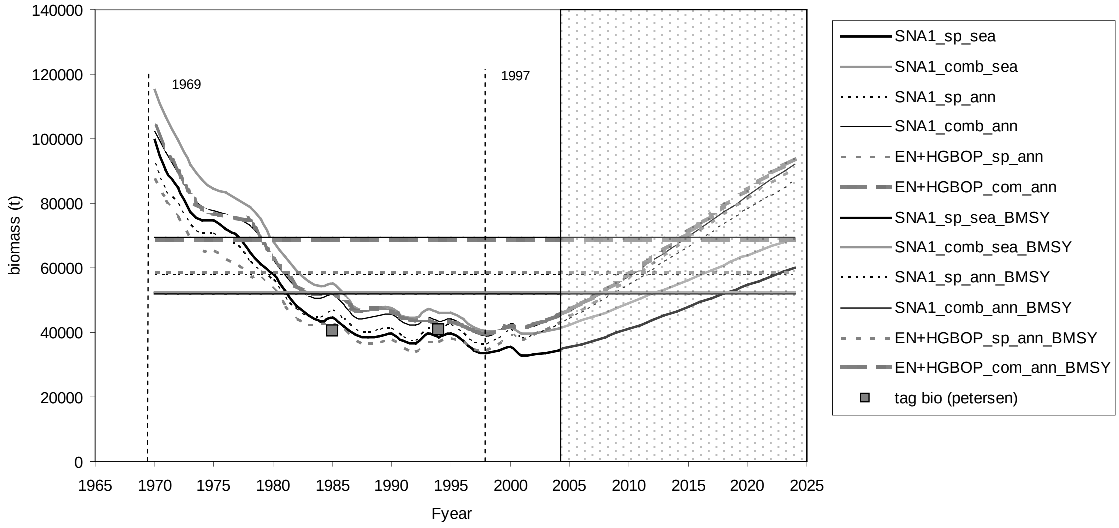

Figure 13: SNA 1 sub-stock combined stock trajectories. Model projection space shaded; estimated YCS lie between the vertical dotted lines. Independent Petersen biomass estimates are shown (note: only the 1985 estimate was fitted directly in the models).

3.1.7 1999 SNA 1 assessment comparisons

The Hauraki Gulf/Bay of Plenty combined area model results can be directly compared to the 1999 assessment results for this sub-stock unit. Although all models predict the sub-stock as rebuilding into the future, the more recent modelling produced a flatter stock trajectory up to 2004 than predicted by the 1999 assessment (Figure 14). Although some of the departure from the 1999 trajectory may have been due to differences in model structure, the principal likely cause is that the updated models are fitted to observational data covering an additional five years of the fishery. Specifically: five more years of longline catch-age age observations, a longer CPUE time series; recreational length frequency; and an updated catch history. In other words, the magnitude of rebuild after 1995 predicted in the 1999 assessment is inconsistent with the observational data collected after 1999. This raises some doubt as to the magnitude of the projected rebuild the models predict after 2005. The 1999 comparison suggests that Hauraki Gulf/Bay of Plenty stock assessment modelling may be prone to overly optimistic rebuilds when projecting beyond the range of the observational data. The 1999 and updated modelling results all suggest the sub-stock had achieved an upward trajectory by 1999. The optimism in the projections relates not to whether the stock will continue to rebuild but the rate at which rebuild occurs.

The inclusion of an additional five years of observational data in the updated east Northland modelling also produced less optimistic stock trajectory predictions post 1995 (Figure 15). Whereas the 1999 assessment predicted that the inflection point of a progressively declining stock trajectory occurred in 1999 (the final model year), the updated modelling had the stock continuing to decline after 1999 to an inflection point (in three of the four models; Figure 9) in 2004 (again the final model year). An important point to note is that, unlike the Hauraki Gulf/Bay of Plenty model results, the upward biomass trajectory predicted by the 1999 assessment is not observed in the biomass trajectories of the current models during the observational period.

The combined SNA 1 modelling comparisons are similar to the Hauraki Gulf/Bay of Plenty comparisons and the same conclusions apply (Figure 16).

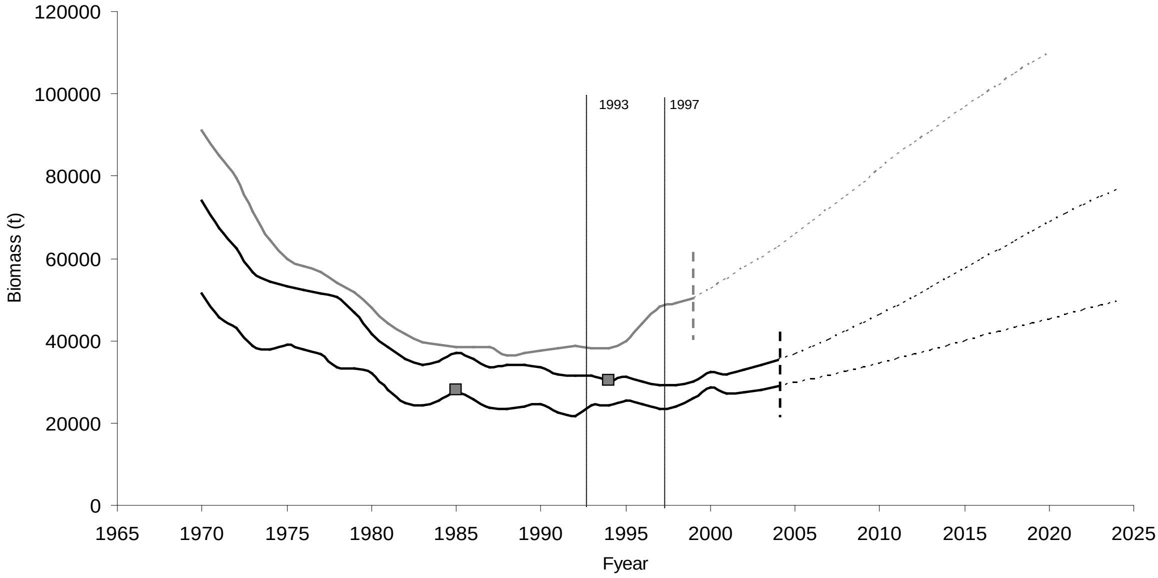

Figure 14: **Hauraki Gulf/Bay of Plenty combined stock model projection comparison to 1999 base case model stock trajectory. The two darker lines are maximum and minimum ranges from the six model groups given in Table 8. Dotted lines denote model projection space. The last fitted year class in the 1999 assessment was 1993; the last fitted in the 2004 modelling was 1997 (vertical lines). Petersen biomass estimates are also shown.**

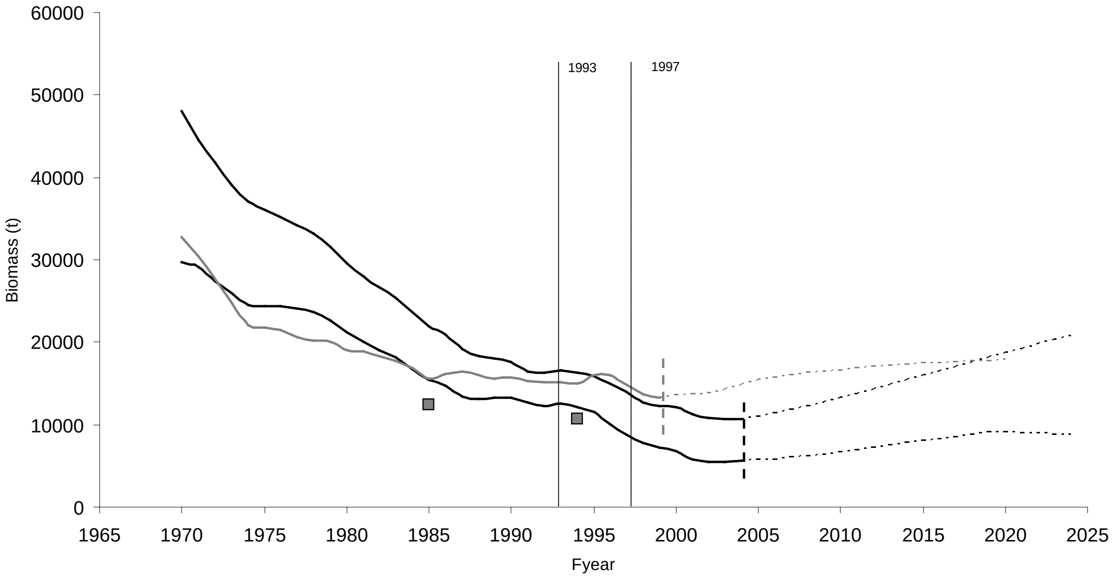

Figure 15: **East Northland stock model projections comparison to 1999 base case model stock trajectory. The two darker lines are maximum and minimum ranges from the six model groups given in Table 8. Dotted lines denote model projection space. The last fitted year class in the 1999 assessment was 1993; the last fitted in the 2004 modelling was 1997 (vertical lines). Petersen biomass estimates are also shown.**

Figure 16: **SNA 1 combined stock model projections comparison to 1999 base case model stock trajectory. The two darker lines are maximum and minimum ranges from the six model groups given in Table 8. Dotted lines denote model projection space. The last fitted year class in the 1999 assessment was 1993; the last fitted in the 2004 modelling was 1997 (vertical lines). Petersen biomass estimates are also shown.**

3.2 Model Selectivity and growth estimates

As well as explicitly accounting for movement (out-of-area tag recoveries) the spatial models also have greater power to estimate shared parameters, specifically selectivity-at-age, the underlying assumption being that gear selectivity-at-age is independent of sub-stock area. This assumption may be violated if gear selectivity by length is the same in each sub-stock but growth rates differ. A better approach would be to estimate length based selectivity, but there are intrinsic problems in implementing length-based selectivity in an aged-based model (more on this in the discussion).

The method specific selectivity estimates often differed between the 10 models (in some cases quite markedly). In interpreting the results it has been assumed that the selectivity estimates from the spatially disaggregated models (Models 1,5 and 9) have more credence because they are derived from a greater amount of observational data (i.e. a greater number of model likelihood terms). Selectivity has a major influence on the productivity estimates coming out of the assessments. Another way to evaluate how the various models performed is to compare selectivity estimates.

The Von Bertalanffy growth parameter estimates are also influential as they determine mean weight-at-age used for calculating stock biomass and are used to derive the expected length frequency distributions for fitting the length-frequency likelihoods.

3.2.1 Model growth (VB) parameter estimates

The initial rate of growth as determined by the VB models strongly influences selectivity-at-age, in particular the age at maximum selectivity (a) and the slope of the left hand selection curve (S_L). The k and t_0 parameters largely define the initial rate of growth in the VB growth curve. Model estimates of k and t_0 were generally consistent within each sub-stock, but differences between sub-stocks are apparent, the most obvious being between the Bay of Plenty and the other sub-stocks (Table 10; Figure 17); the Bay of Plenty growth curves are nearly linear with huge negative t_0 values.

The model growth curves suggest slightly faster initial growth in east Northland than the Hauraki Gulf (Table 10; Figure 17) but differences are less extreme when compared to the Bay of Plenty growth curves. The east Northland seasonal model (Model 2) growth rate is similar to Bay of Plenty models, being inconsistent with growth rates estimated by the other three east Northland models (Table 10; Figure 17). If the east Northland Model 2 growth estimates are excluded from comparison, the initial east Northland and the Hauraki Gulf model-predicted growth rates appear more similar (Figure 17).

In Table 10 Bay of Plenty growth curves are nearly linear with huge negative t_0 values. These are not really appropriate (also seen in Model 2 for East Northland) and may be the cause of the problem with the longline selectivity estimated for these models.

Table 10: Model *VB* growth parameter estimates.

Sub-stock	Model number	Model label	Linf	k	t0
east Northland	1	SNA1_sp_sea	59.81	0.12	-0.06
	2	ENLD_sea	57.91	0.07	-5.47
	5	SNA1_sp_ann	56.34	0.13	-0.69
	6	ENLD_ann	52.16	0.14	-1.05
Hauraki Gulf	1	SNA1_sp_sea	46.82	0.15	-0.71
	3	HAGU_sea	44.64	0.17	-0.62
	5	SNA1_sp_ann	52.65	0.10	-2.90
	7	HAGU_ann	52.99	0.10	-2.32
	9	HGBOP_sp_ann	53.28	0.11	-1.58
Bay of Plenty	1	SNA1_sp_sea	50.36	0.06	-9.29
	4	BOP_sea	56.04	0.06	-7.74
	5	SNA1_sp_ann	52.46	0.06	-8.79
	8	BOP_ann	59.67	0.06	-6.12
	9	HGBOP_sp_ann	54.80	0.06	-6.86

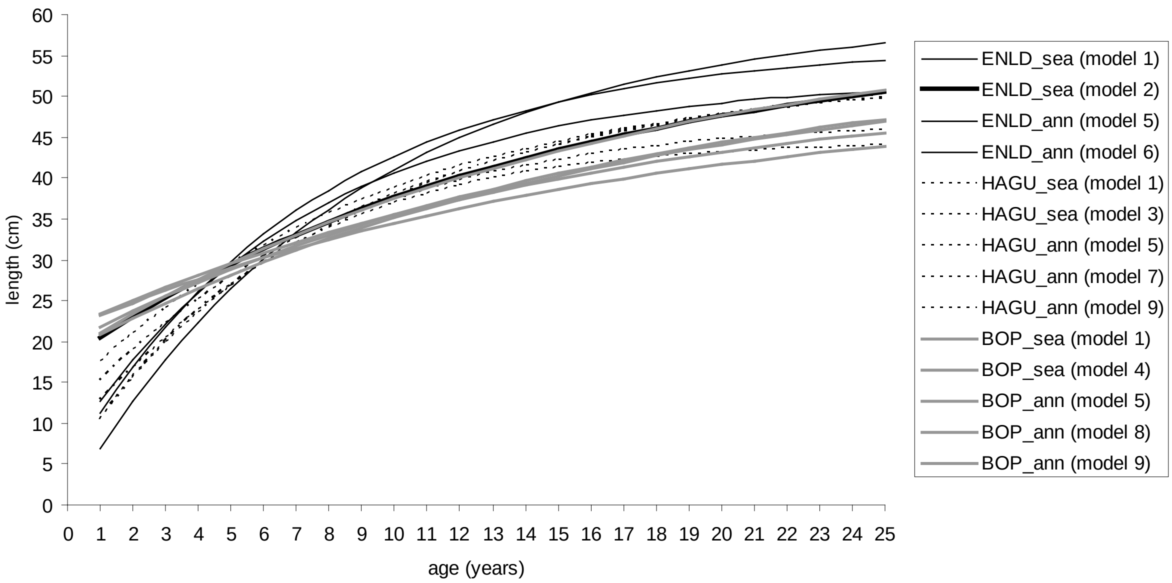

Figure 17: Model VB curve plots.

3.2.2 Long line selectivity-at-age parameter estimates

All the models benefited from the relatively long time series of longline catch-at-age data available from each sub-stock (Table 11); the expectation was that longline selectivity should be well estimated. Encouragingly, all the single area models (with one exception) produced similar estimates for left and right hand descending slopes (S_L and S_R; Table 11, Figure 18). The right hand descending limb (S_R) is highly influential in the models as it scales the oldest and heaviest component of the stock to match what the gear "observes". A steep right hand limb means the model has to account for a large "unseen" biomass of old fish. The seasonal east Northland model (model 2) was the only single area model to estimate a relatively steep S_R parameter (11.58; Table 11; Figure 18) which may explain why the biomass trajectory predicted by this model lay well above those of the other models (Figure 9).

The area model selectivity estimates differed in the age at which maximum selectivity occurs (parameter *a*; Table 11). The two Bay of Plenty single area model estimates are approximately two years to the left (6 compared with 8 years) of the two Hauraki area model estimates (Models 3 and 7) and the annual east Northland model estimate (Model 6) (Table 11; Figure 18); this shift may be a consequence of the large negative T_0 estimates for Bay of Plenty growth (Table 10) meaning that the selectivity curves are possibly biased.

These results are consistent with the sub-stock growth estimates; given faster initial growth in the Bay of Plenty, it is plausible that longline is selecting younger fish in the Bay of Plenty. If this is truly the case the assumption behind estimating a single set of longline selectivity parameters in the spatial models (Models 1,5 and 9) is invalid. The spatial model longline selectivity parameters were closest to the east Northland and Hauraki Gulf parameters and were likely to have been less ideal for the Bay of Plenty (Table 11; Figure 19).

Table 11: Model specific double-normal (Bull et al. 2010) selectivity parameter estimates for longline. Also given is the number of individual model likelihood terms on which the estimates are based and the number of years the observational data spans.

	SNA1_sp_sea	ENLD_sea	HAGU_sea	BOP_sea	SNA1_sp_ann	ENLD_ann	HAGU_ann	BOP_ann	HGBOP_sp_ann
a	7.78	6.91	7.96	5.83	7.81	7.87	8.69	5.87	8.00
S_L	1.94	1.77	1.87	1.00	1.96	2.19	2.21	1.02	1.91
S_R	79.78	11.58	999.49	999.99	710.51	74.27	380.57	1000.00	317.76
No. likelihoods	92	28	34	30	42	13	16	13	29
No. of years	16	13	16	13	16	13	16	13	16

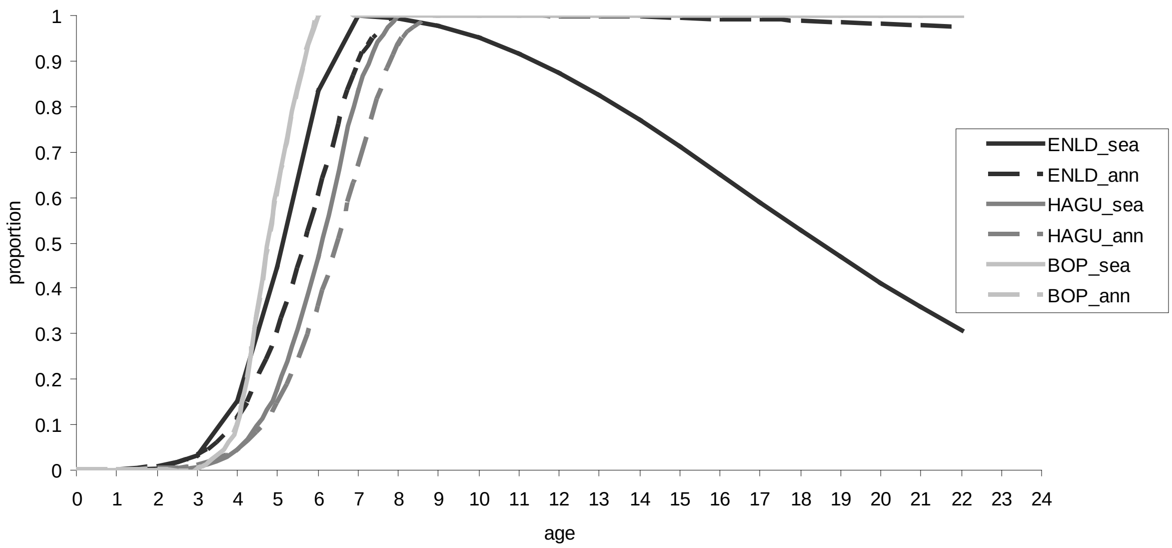

Figure 18: Longline selectivity curves (parameters given in Table 11) as estimated from the six individual sub-stock models (Models 2, 3, 4, 6, 7, and 8).

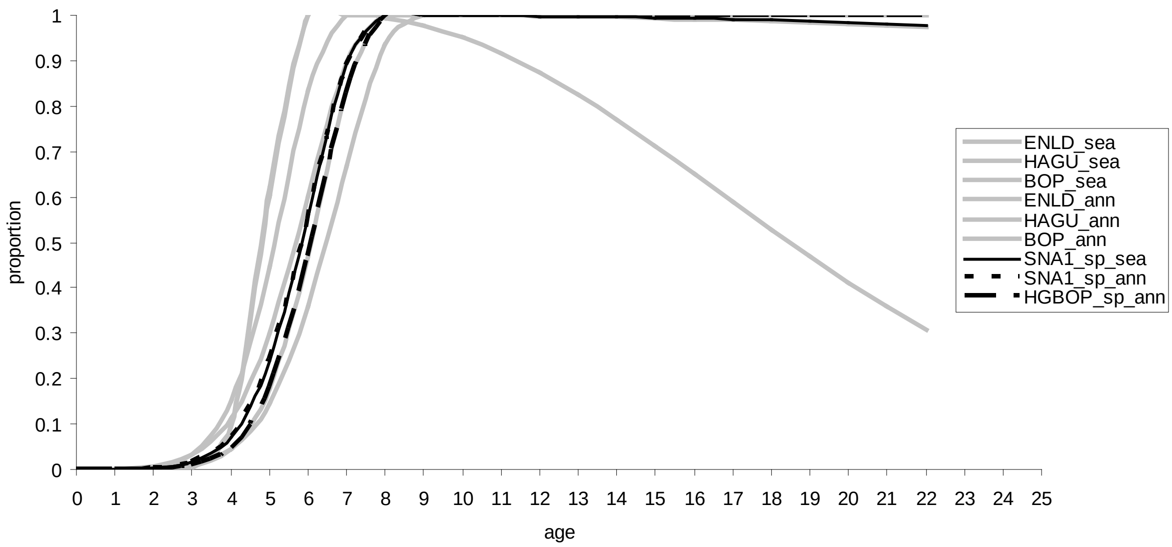

Figure 19: Comparison of longline selectivity curves (parameters given in Table 11) from the three spatial models (Models 1, 5, and 9) to those from the single area models.

3.2.3 Single trawl selectivity-at-age parameter estimates

There were fewer single trawl catch-at-age observations than longline and these spanned fewer years (see Table 11 compared with Table 12). It is likely that the models had less power to estimate single trawl selectivity than longline. The seasonal and annual model selectivity curves (Models 3, 4, 7, and 8) were similar for each sub-stock but differed between sub-stocks (Table 12; Figure 20). Although the age of maximum selectivity was similar in the Hauraki Gulf and Bay of Plenty sub-stock curves, the Bay of Plenty left hand curve (S_L) again was to the left of the Hauraki Gulf curves (Figure 20) a plausible result again consistent with faster Bay of Plenty growth. Sub-stock differences in the right hand slope (S_R) estimates (Table 12; Figure 20), may also be due to differences in growth (Figure 17).

The selectivity curves predicted by the three spatial models (Models 1,5, and 9) were mostly central to the Hauraki Gulf and Bay of Plenty single sub-stock curves (Figure 21).

Table 12: Model specific double-normal (Bull et al. 2010) selectivity parameter estimates for single trawl. Also given is the number of individual model likelihood terms on which the estimates are based and the number of years the observational data spans.

	SNA1_sp_sea	HAGU_sea	BOP_sea	SNA1_sp_ann	HAGU_ann	BOP_ann	HGBOP_sp_ann
a	5.09	5.03	4.69	4.78	5.19	4.82	4.87
S_L	0.87	0.50	0.79	0.72	0.81	0.82	0.76
S_R	42.01	24.24	15.04	17.88	22.38	16.46	18.04
No. likelihoods	24	12	12	11	6	5	11
No. of years	6	6	5	6	6	5	6

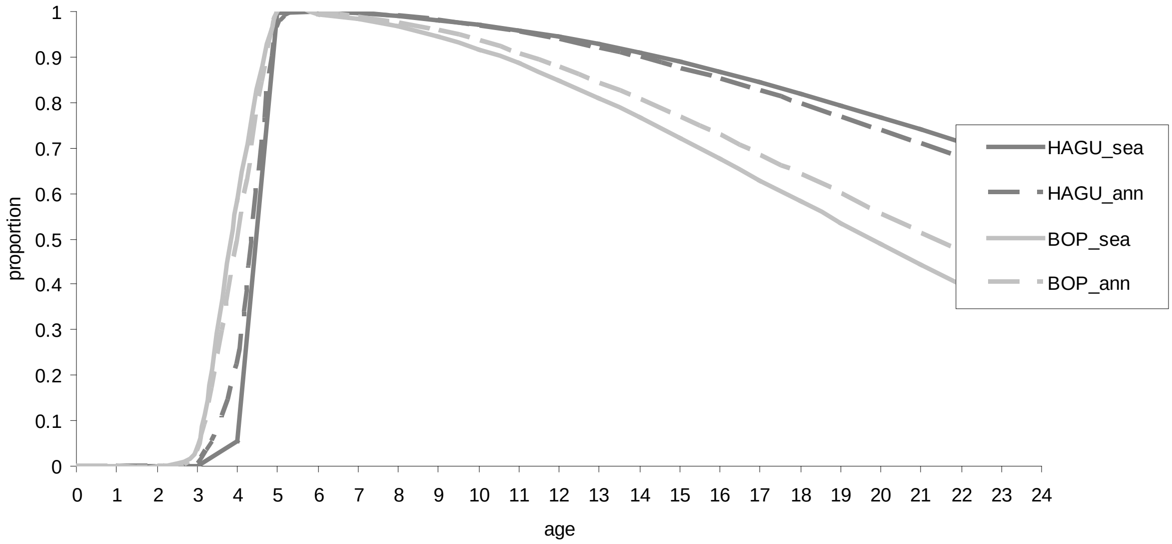

Figure 20: Single trawl selectivity curves (parameters given in Table 12) as estimated from the four individual sub-stock models (Models 3, 4, 7, and 8).

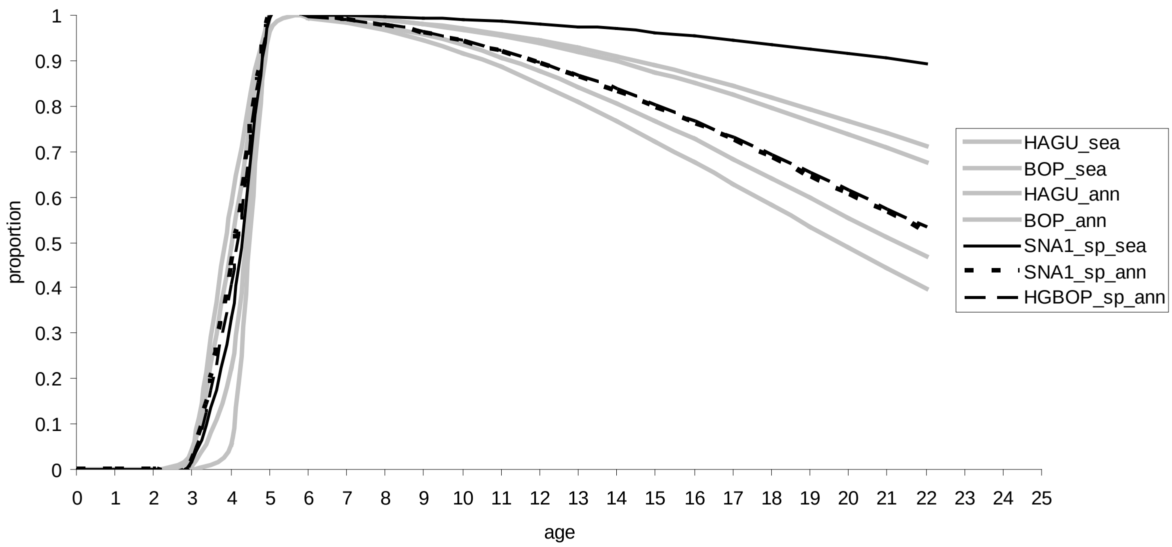

Figure 21: Comparison of single trawl selectivity curves (parameters given in Table 12) from the three spatial models (Models 1, 5, and 9) to those from the single area models.

3.2.4 Danish seine selectivity-at-age parameter estimates

Differences in selectivity estimated by the Hauraki Gulf and Bay of Plenty sub-stock models (Models 3, 4, 7, and 8) are also seen for Danish seine (Table 13; Figure 22). Although growth may be a factor in these differences a more likely explanation is the paucity of Bay of Plenty observational data with which to estimate selectivity. There were only 2 years of Danish seine catch-at-age data from the Bay of Plenty compared to 11 from the Hauraki Gulf meaning that the models had more power to estimate selectivity in the Hauraki Gulf.

Selectivity estimates from the three spatial models (Models 1,5, and 9) were similar to the Hauraki Gulf single sub-stock estimates; possibly reflective of the dominance of Hauraki Gulf Danish seine data in the models (Table 13; Figure 23).

Table 13: Model specific double-normal (Bull et al. 2010) selectivity parameter estimates for Danish Seine. Also given is the number of individual model likelihood terms on which the estimates are based and the number of years the observational data spans.

	SNA1_sp_sea	HAGU_sea	BOP_sea	SNA1_sp_ann	HAGU_ann	BOP_ann	HGBOP_sp_ann
a	5.85	5.53	4.85	4.79	5.68	4.77	5.51
S_L	0.91	0.69	0.50	0.50	0.82	0.50	0.89
S_R	77.24	26.07	8.74	42.28	31.49	4.82	26.17
No. likelihoods	21	17	4	13	11	2	13
No. of years	11	11	2	11	11	2	11

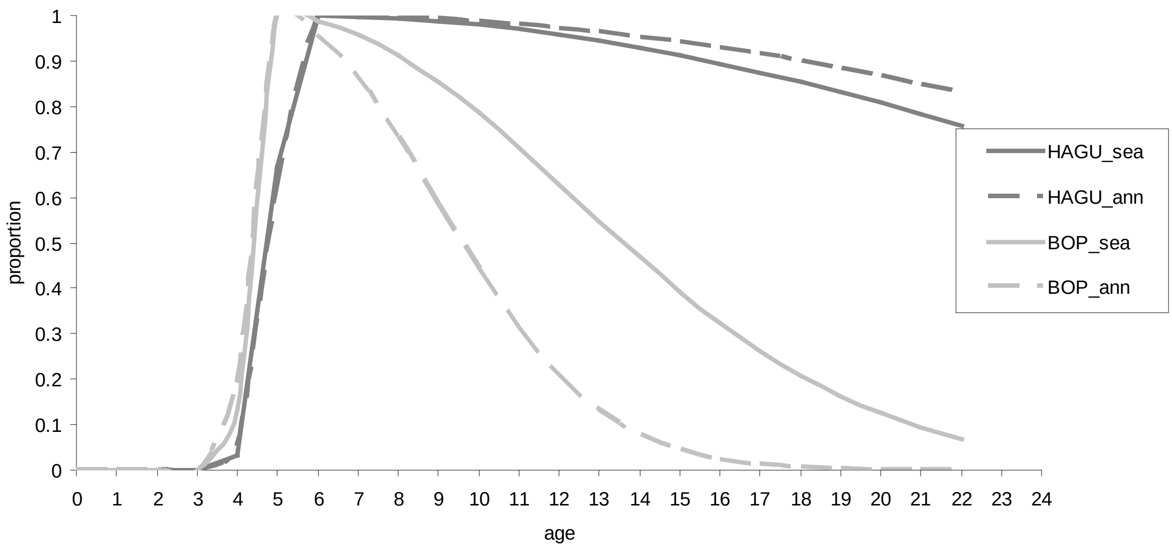

Figure 22: **Danish seine selectivity curves (parameters given in Table 13) as estimated from the four individual sub-stock models (Models 3, 4, 7, and 8).**

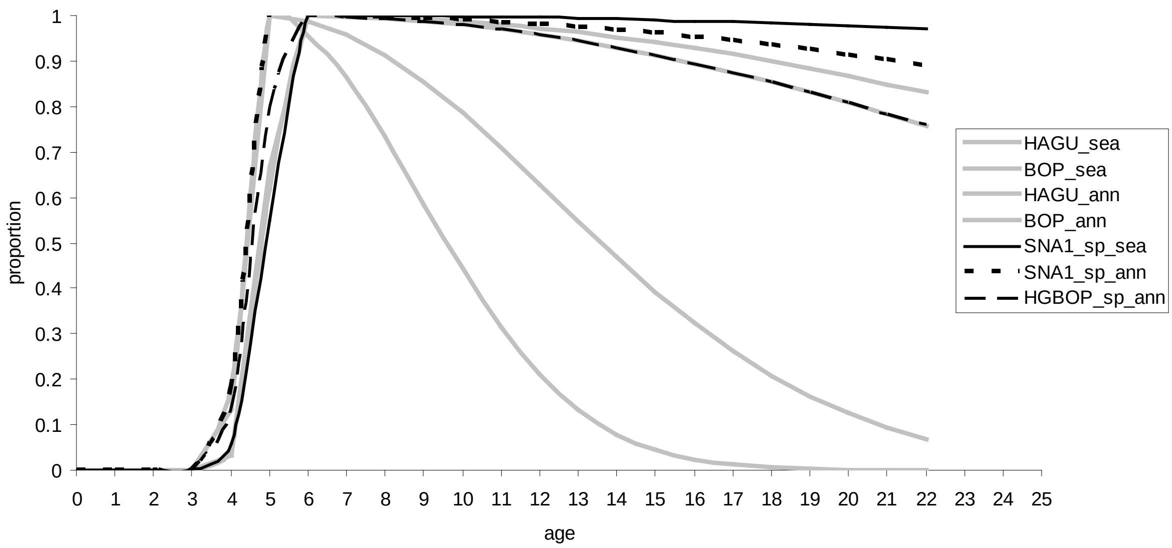

Figure 23: **Comparison of Danish Seine selectivity curves (parameters given in Table 13) from the three spatial models (Models 1, 5, and 9) to those from the single area models.**

3.2.5 Pre-1995 recreational line selectivity-at-age parameter estimates

Despite fitting to only two years of pre 1995 recreational length frequency observations all the model estimates of the left and right limbs of the selectivity curves (S_L S_R) were reasonably consistent (Table 14; Figure 24). The east Northland seasonal model (Model 2) again produced an age at maximum selectivity estimate inconsistent with the other models, being well to the left of the other model curves (*a* = 3 years compared with over 4; Table 14; Figure 24). Disregarding the east Northland Model 2 result, the Bay of Plenty model (Models 4 and 8) selectivity maximum (a = 4 years; Table 14) was 1 year to the left of the Hauraki Gulf and annual east Northland model estimates (a = 5 years; Table 14) (Models 3, 6, and 7; Table 14; Figure 24), again a difference consistent with faster Bay of Plenty growth.

The selectivity curves predicted by the three spatial models (Models 1,5, and 9) varied between the Bay of Plenty (a = 4 years; Table 14) and Hauraki Gulf (a = 5 years; Table 14) maximum selectivity values (Table 14; Figure 25).

Table 14: Model specific double-normal (Bull et al. 2010) selectivity parameter estimates for Pre-1995 recreational line. Also given is the number of individual model likelihood terms on which the estimates are based and the number of years the observational data spans.

	SNA1_sp_sea	ENLD_sea	HAGU_sea	BOP_sea	SNA1_sp_ann	ENLD_ann	HAGU_ann	BOP_ann	HGBOP_sp_ann
a	5.03	3.03	5.20	4.27	4.03	4.55	5.01	4.04	4.10
S_L	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
S_R	11.09	11.30	10.78	10.33	9.77	10.10	9.99	10.02	9.96
No. likelihoods	16	5	5	6	6	2	2	2	4
No. of years	2	2	2	2	2	2	2	2	2

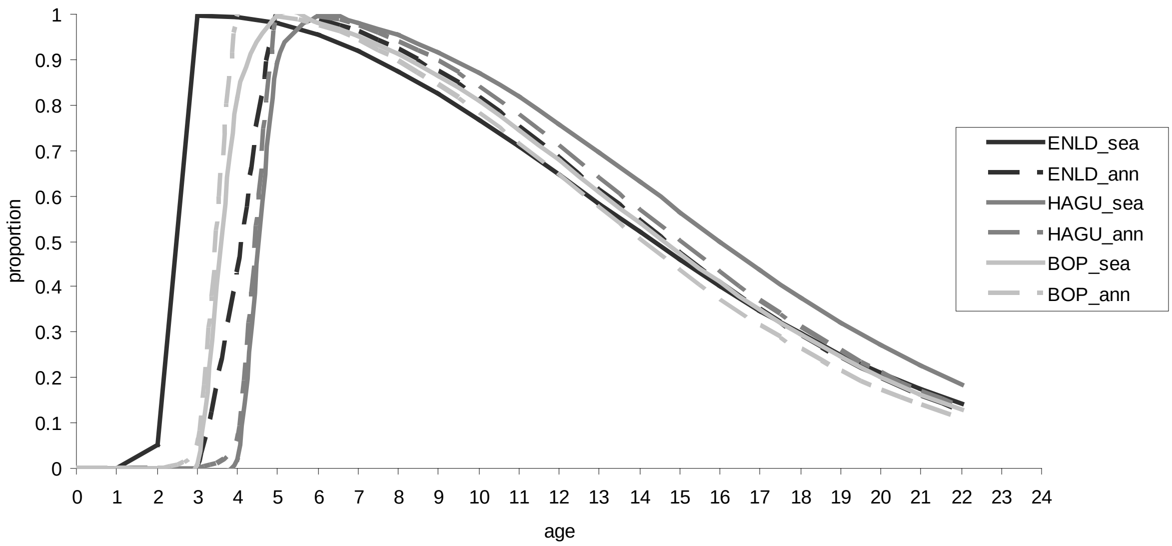

Figure 24: Pre-1995 recreational line selectivity curves (parameters given in Table 14) as estimated from the six individual sub-stock models (Models 2, 3, 4, 6, 7, and 8).

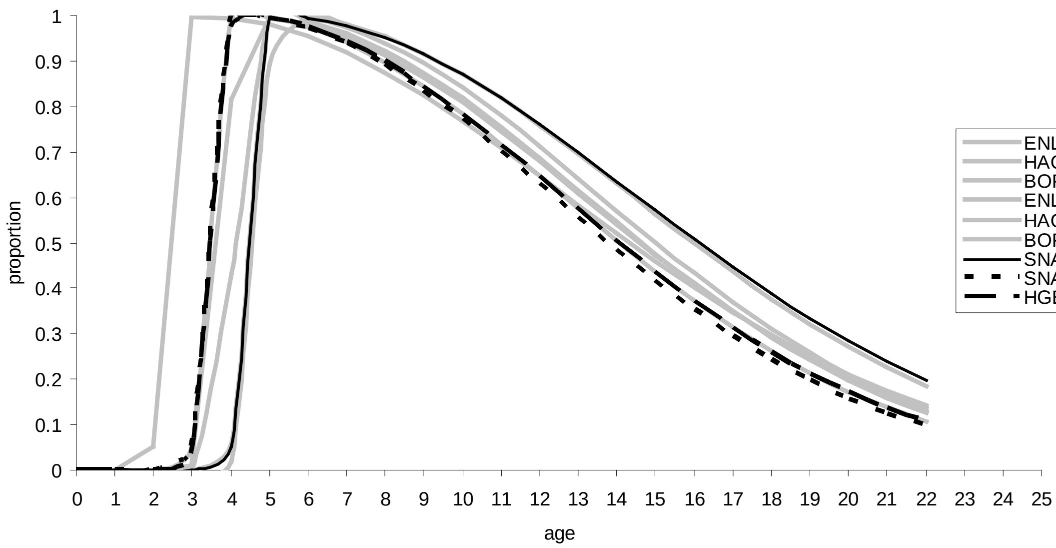

Figure 25: Comparison of Pre-1995 recreational line selectivity curves (parameters given in Table 14) from the three spatial models (Models 1, 5, and 9) to those from the single area models.

3.2.6 Post-1995 recreational line selectivity-at-age parameter estimates

As with the pre-1995 recreational line estimates, the left and right selectivity curves for the post–95 period (S_L S_R) were reasonably consistent, with curves differing mainly in the estimation of age at maximum selectivity (*a*; Table 15; Figure 26). The annual models (Models 2, 3, 4, 6, 7, and 8) produced generally dichotomous estimates of maximum selectivity age, i.e. 5 or 6 years (Table 15; Figure 26). This time however the two Bay of Plenty models did not produce the same estimate (Table 15; Figure 26). Estimates of the age at maximum selectivity for the three spatial models were likewise dichotomous (Table 15; Figure 27).

The pre and post-1995 age at maximum selectivity parameters from each of the models all increased by at least 1 year (*a* parameter values Table 14 compared with Table 15), consistent with the increase in minimum legal size after 1995.

Table 15: Model specific double-normal (Bull et al. 2010) selectivity parameter estimates for Post-1995 recreational line. Also given is the number of individual model likelihood terms on which the estimates are based and the number of years the observational data spans.

	SNA1_sp_sea	ENLD_sea	HAGU_sea	BOP_sea	SNA1_sp_ann	ENLD_ann	HAGU_ann	BOP_ann	HGBOP_sp_ann
a	6.09	5.02	6.14	5.86	5.18	6.01	6.05	5.08	5.26
S_L	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
S_R	10.29	11.37	10.07	11.02	10.52	10.75	10.07	10.47	9.81
No. likelihoods	64	24	19	21	23	8	8	7	15
No. of years	8	8	8	7	8	8	8	7	8

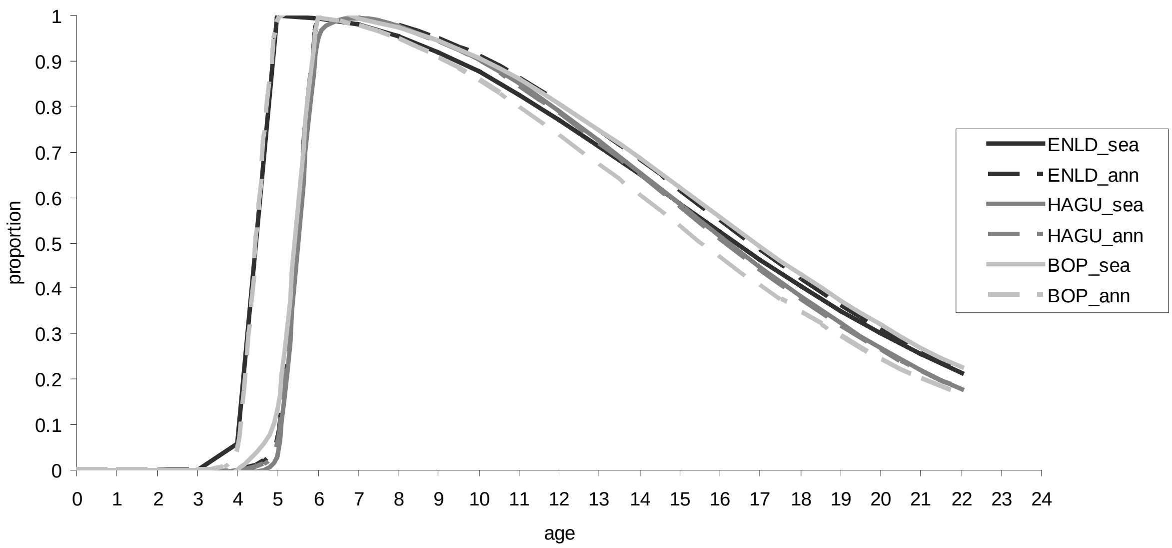

Figure 26: **Post-1995 recreational line selectivity curves (parameters given in Table 15) as estimated from the six individual sub-stock models (Models 2, 3, 4, 6, 7, and 8).**

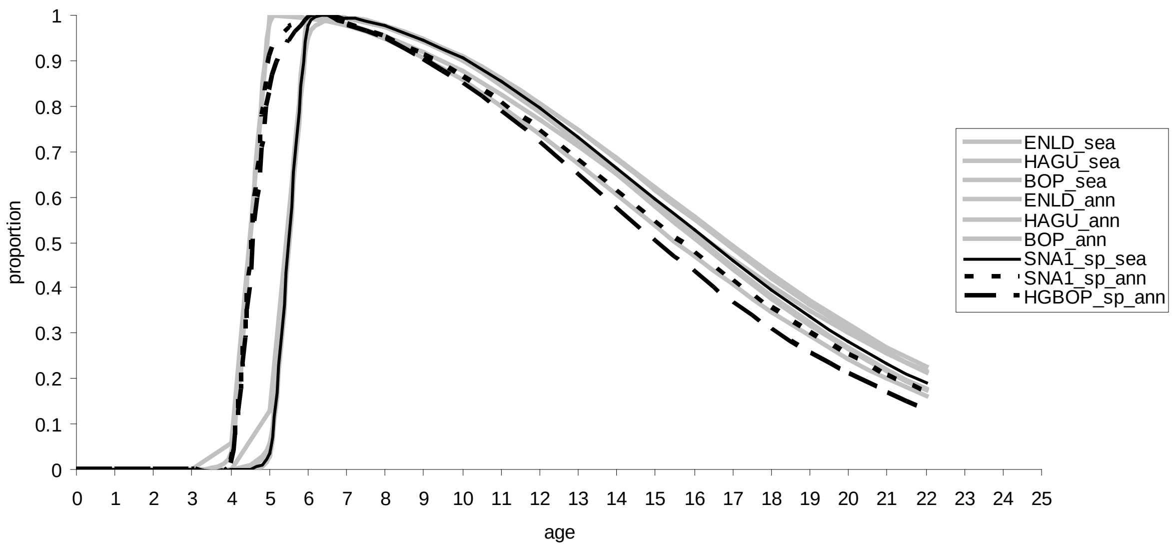

Figure 27: **Comparison of Post-1995 recreational line selectivity curves (parameters given in Table 15) from the three spatial models (Models 1, 5, and 9) to those from the single area models.**

3.2.7 Research trawl selectivity-at-age parameter estimates

Research trawl selectivity estimates from the single sub-stock models (Models 2, 3, 4, 6, 7, and 8) differed between sub-stocks (Table 16; Figure 28). The Hauraki Gulf curves were based on 11 years of observational data and the annual and spatial models produced similar maximum selectivity (a) and right-hand selectivity curves (S_R; Table 16; Figure 28). There were fewer annual trawl length-frequency observations available for east Northland (2 years; Table 16) and Bay of Plenty (6 years; Table 16); this may account for some of the variability in model selectivity estimates. The expectation would be that due to faster growth the Bay of Plenty model curves should have been further to the left (younger age selection), but contrary to expectation the curves were furthest to the right (Table 16; Figure 28).

The spatial model selectivity estimates (Models 1, 5, and 9) were more consistent (Table 16; Figure 29).

Table 16: Model specific double-normal (Bull et al. 2010) selectivity parameter estimates for research trawl. Also given is the number of individual model likelihood terms on which the estimates are based and the number of years the observational data spans.

	SNA1_sp_sea	ENLD_sea	HAGU_sea	BOP_sea	SNA1_sp_ann	ENLD_ann	HAGU_ann	BOP_ann	HGBOP_sp_ann
a	2.00	2.35	2.00	5.14	3.53	4.35	2.00	5.16	2.00
S_L	0.93	79.68	0.93	3.93	3.09	1.58	65.88	3.46	62.82
S_R	5.29	6.35	5.02	7.48	3.82	3.67	5.02	3.64	4.97
No. likelihoods	19	2	11	6	19	2	11	6	17
No. of years	14	2	11	6	14	2	11	6	14

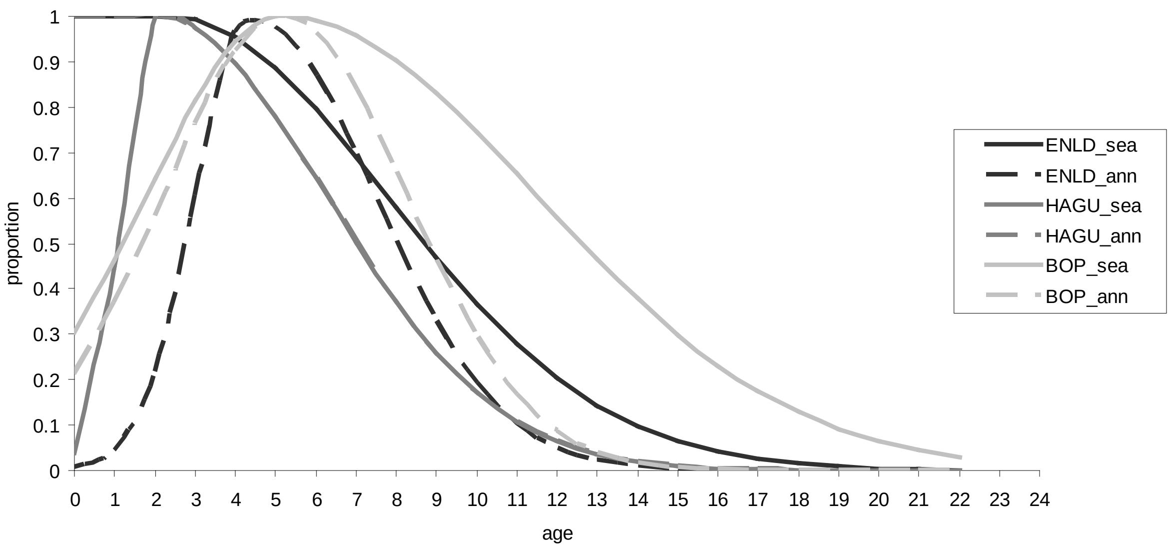

Figure 28: Research trawl selectivity curves (parameters given in Table 16) as estimated from the six individual sub-stock models (Models 2, 3, 4, 6, 7, and 8).

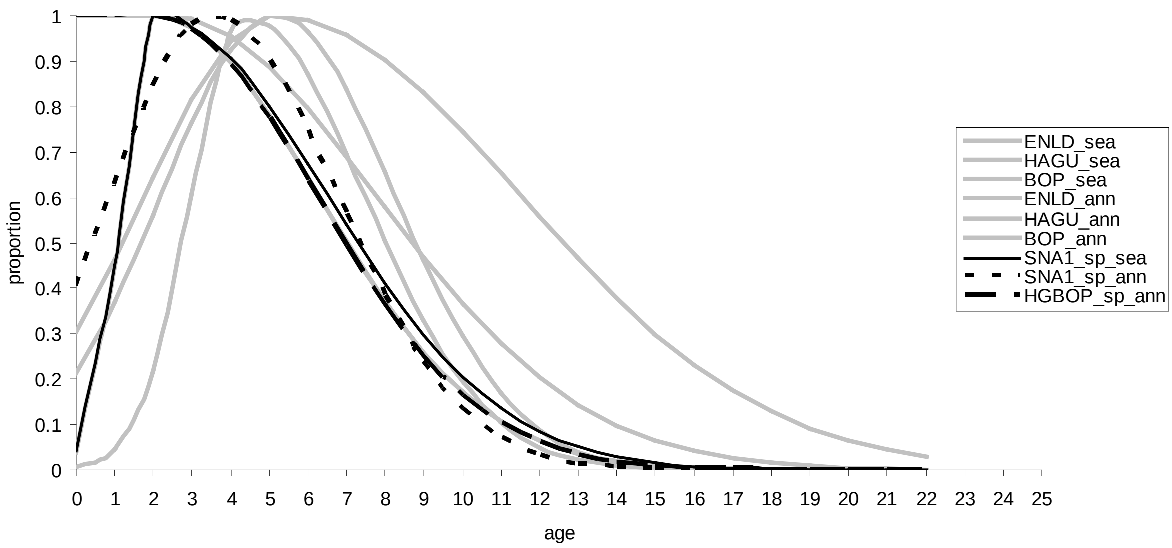

Figure 29: **Research trawl selectivity curves (parameters given in Table 16) as estimated from the three spatial models (Models 1, 5, and 9).**

3.3 Exploration of stock recruit hypothesis (steepness) and alternative values of M

3.3.1 Likelihood profile for natural mortality (M) using the Hauraki Gulf single area annual model (Model 7) as an example

Fitting the annual Hauraki Gulf model (Model 7) at various levels of M provided insight into the influence of natural mortality assumptions on model productivity and outcomes (Table 17). Model estimates of B_0 (the Hauraki Gulf maximum carrier capacity) increased (exponentially) as natural mortality decreased (Table 17). MSY (productivity) also increased with decreasing M but not at the same relative scale to B_0 (Table 17). The B_{MSY}:B_0 ratio remained constant over all values of M (approximately 0.21; Table 17).

Table 17: **Hauraki Gulf annual model (Model 7) MLE fits at various fixed values of M. Note: steepness (Beverton and Holt) was fixed at 1.0 (no stock-recruit) for all fits (base model results shaded).**

M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	Likelihood
0.01	771498	25648	167410	6680	0.03	0.15	0.22	1446.08
0.02	458426	25609	94662	5806	0.06	0.27	0.21	1446.67
0.03	328304	25813	67571	5361	0.08	0.38	0.21	1448.14
0.04	257255	26034	52819	5061	0.10	0.49	0.21	1449.37
0.05	211727	26173	42910	4853	0.12	0.61	0.20	1452.10
0.06	180584	26318	38013	4711	0.15	0.69	0.21	1455.74
0.07	158653	26474	33881	4612	0.17	0.78	0.21	1460.43
0.075	148108	27023	27832	4562	0.18	0.97	0.19	1465.71
0.08	141960	26653	29591	4548	0.19	0.90	0.21	1466.23
0.09	147143	28685	32688	4908	0.19	0.88	0.22	1476.39

A negative log-likelihood (in which lower values represent better model fits to the data) profile on M for the Hauraki Gulf model (Model 7) shows that the model has an innate "preference" towards lower values of M (Figure 30); possibly because lower M corresponds to a higher model B_0 and better explains the continued persistence of the stock given its catch history and age structure. Model estimates of mortality can be strongly determined by the selectivity assumed by the model, it is therefore usually not reasonable to estimate both natural mortality and selectivity unless one or both sets of parameters are to be bonded by strong priors. Independent mortality estimates based on historical snapper catch-at-age indicate that a plausible range for M is in the order of 0.06 – 0.09. The Hauraki Gulf model likelihood profiling results highlight a problem also evident in the 1999 assessment (Gilbert et al. 2000), that small changes in the assumed value of M can produce markedly different estimates of current stock status; for example, going from an M of 0.06 to 0.075 shifted the estimate of current stock status (B_{2004}) relative to B_{MSY} from 70 to 100% of (Table 17).

The yield curves corresponding to an M of 0.06 and 0.02 are similar, with both being relative flat (Figure 31). The two yield curves suggest the stock is likely to be robust (productivity still high relative to MSY) even at half B_{MSY} regardless of the assumed value of M (Figure 31).

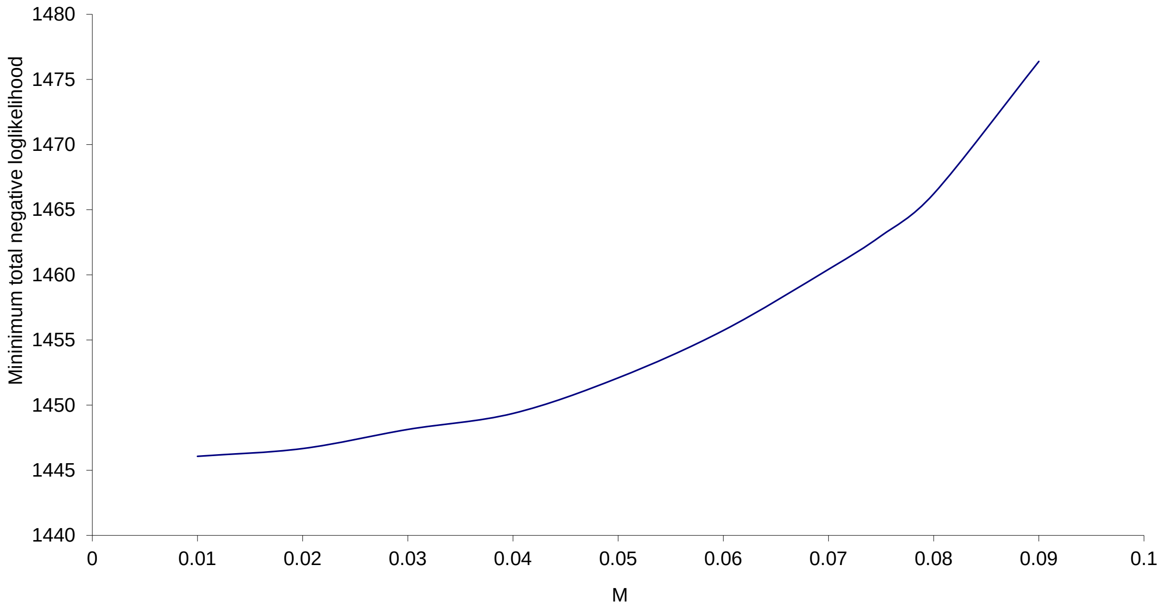

Figure 30: Hauraki Gulf annual model (Model 7) minimised negative log-likelihood profile for M (natural mortality).

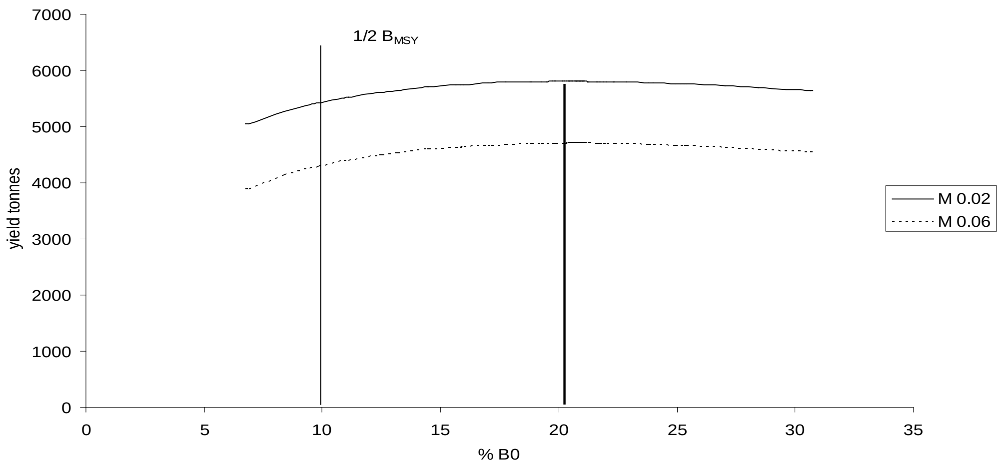

Figure 31: **Hauraki Gulf (Model 7) MLE deterministic surplus yield curves corresponding to an M of 0.06 or 0.02**

3.3.2 Likelihood profile for the magnitude of a stock-recruit relationship (steepness) using the Hauraki Gulf single area annual model (Model 7) as an example

Again the level of stock-recruit relationship assumed by the model significantly influenced the B_0 and MSY estimates; stock productivity increasing exponentially with declining steepness (Table 18). Unlike changing M, a linear change in the ratio of B_{MSY} to B_0 is observed as steepness decreases (B_{MSY}/B_0; Table 17 compared with Table 18); the effect being that the stock yield curve (i.e. B_{MSY}) is progressively shifted to the right (Figure 32).

Table 18: **Hauraki Gulf annual model (Model 7) MLE fits at various fixed values of steepness (Beverton and Holt stock recruitment relationship). Note: M was fixed at 0.06 for all fits (base model results shaded).**

Steepness (BH)	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	Likelihood
1	180584	26318	38013	4711	0.15	0.69	0.21	1455.74
0.95	192762	25683	44861	4801	0.13	0.57	0.23	1455.68
0.9	208895	25007	51805	4964	0.12	0.48	0.25	1455.66
0.85	231120	24300	61642	5233	0.11	0.39	0.27	1455.67
0.8	263916	23544	74986	5679	0.09	0.31	0.28	1455.72
0.75	316920	22736	94253	6460	0.07	0.24	0.30	1455.85
0.7	416712	21864	130859	8011	0.05	0.17	0.31	1456.15

A more important consequence of different assumed values for steepness is seen in the model surplus yield curves (Figure 32). The surplus yield to biomass curve assuming no stock recruit relationship is relatively flat (a.; Figure 32) meaning that the stock is relatively uniformly productive (current annual yield CAY close to MSY) at biomasses down to at least half B_{MSY}. For example, under the no stock recruit assumption the Hauraki Gulf fishery would only achieve a small increase in yield moving from its current 2004 biomass to B_{MSY} (Figure 32).

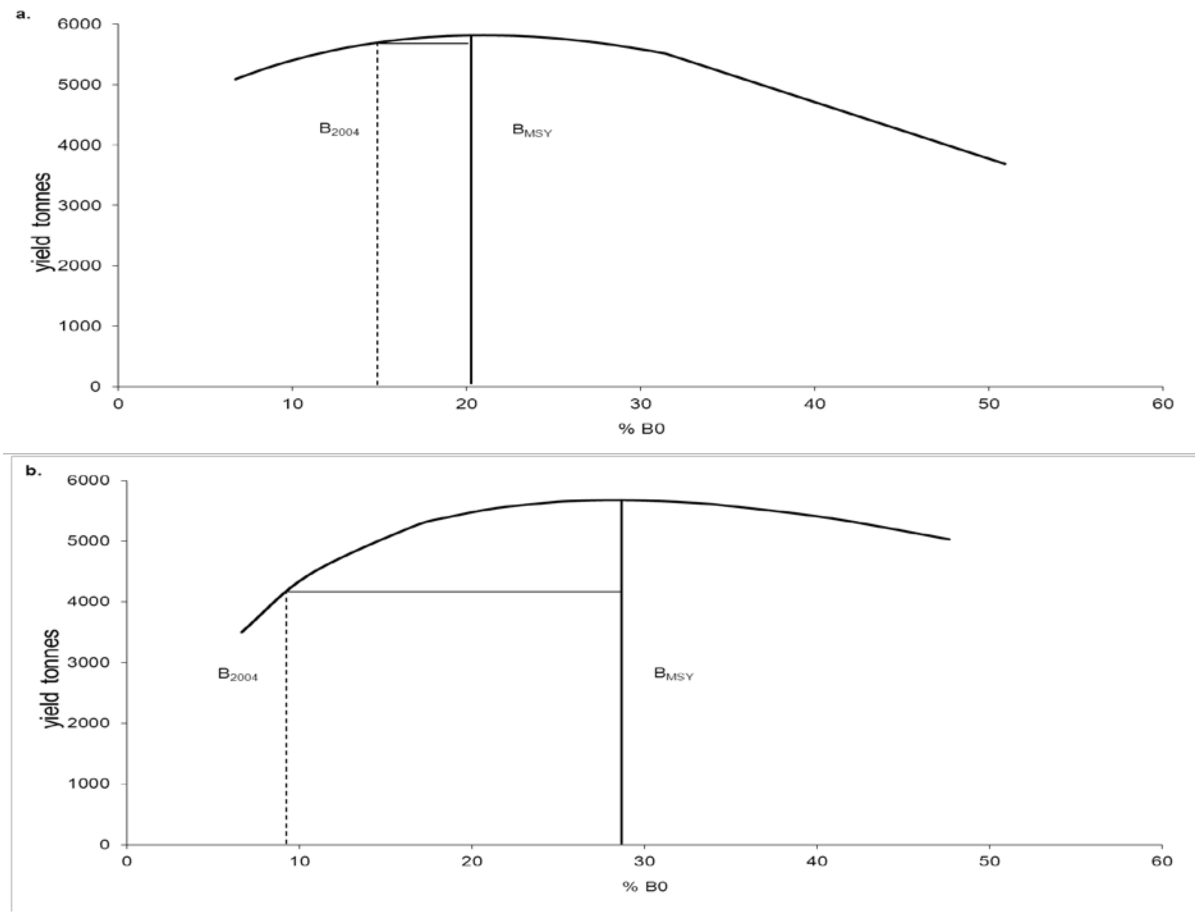

Figure 32: Hauraki Gulf (Model 7) MLE deterministic surplus yield curves corresponding to steepness 1.0 (a) and steepness 0.80 (b).

The surplus yield to biomass curve becomes markedly more domed at a steepness of 0.8 (Figure 32). When steepness is 0.8 the current (2004) Hauraki Gulf biomass is predicted to be 30% of B_{MSY}, which corresponds to a surplus yield 75% that of MSY (Figure 32). Of more concern is that at a steepness of 0.8, the current (2004) stock biomass is positioned on the steeply declining left-hand limb of the surplus yield curve; in that position only a small decline in stock size is needed to achieve a significant decline in stock productivity, i.e. the sub-stock is likely to be more vulnerable to runaway stock collapse.

There is very little contrast in the steepness likelihood profile of Hauraki Gulf annual model (Model 7; Table 18) to suggest an optimum value for steepness; on the basis of model fit, steepness values as low as 0.8 are equally reasonable as the current assumption of no stock recruit relationship (i.e. steepness equal to 1.0).

3.3.3 SNA 1 model results with steepness at 0.8

3.3.3.1 East Northland model estimates

With steepness at the 0.8 the model biomass trajectories through to 2004 were similar to those of the east Northland base model results (Figure 9 compared with Figure 33). The models differed mostly in the projection space, the 0.8 models predicting significantly lower probabilities for stock rebuild

(Table 5 compared with Table 19). With steepness at 0.8 all the east Northland models put the stock at a much lower position relative to B_{MSY} in 2004 than the base models, and none predicted the stock would achieve B_{MSY} by 2024 (Table 19).

Table 19: East Northland (steepness 0.8) model production parameter estimates. MSY and B_{MSY} values are deterministic. Projection risk probabilities were derived from boot-strap random recruitments.

Model name	Model num	Steepness (BH)	M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	$P[B_{2024} > B_{MSY}]$	$P[B_{2024} > B_{2004}]$
SNA1_sp_sea*	1	0.8	0.06	124654	7413	32550	3109	0.06	0.23	0.26	0	0.433
ENLD_sea	2	0.8	0.06	64905	9296	17910	1380	0.14	0.52	0.28	0	0
SNA1_sp_ann*	5	0.8	0.06	135190	9347	37904	2989	0.07	0.25	0.28	0	0.703
ENLD_ann	6	0.8	0.06	94344	8581	27105	1914	0.09	0.32	0.29	0	0.102

* movement corrected estimates

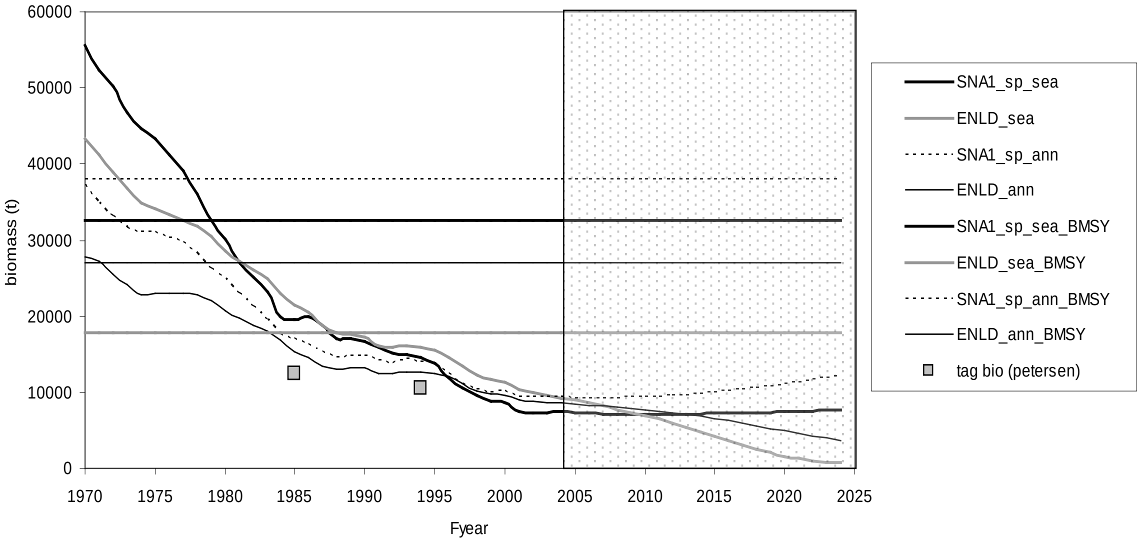

Figure 33: East Northland model stock trajectories (steepness 0.8). Model projection space shaded. Independent Petersen biomass estimates are shown (note: only the 1985 estimate was fitted directly in the models).

3.3.3.2 Hauraki Gulf model estimates

Stock trajectories from the Hauraki Gulf 0.8 models were again similar to those predicted by the base models through to 2004 (Figure 10 compared with Figure 34). Most of the 0.8 models predict a significant stock rebuild through to 2024 (Figure 34; with the exception of spatial Model 1) but unlike the base model projections most give a very low probability of the stock attaining B_{MSY} by 2024 (Table 20).

Table 20: Hauraki Gulf (steepness 0.8) model production parameter estimates. MSY and B_{MSY} values are deterministic. Projection risk probabilities were derived from boot-strap random recruitments.

Model name	Model num	Steepness (BH)	M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	$P[B_{2024} > B_{MSY}]$	$P[B_{2024} > B_{2004}]$
SNA1_sp_sea*	1	0.8	0.06	242123	19656	65026	5845	0.08	0.30	0.27	0.00	0.65
HAGU_sea	3	0.8	0.06	212902	28575	57715	5275	0.13	0.50	0.27	0.76	1.00
SNA1_sp_ann*	5	0.8	0.06	305604	26633	96517	6551	0.09	0.28	0.32	0.01	1.00
HAGU_ann	7	0.8	0.06	263916	23544	74986	5679	0.09	0.31	0.28	0.16	1.00
HGBOP_sp_ann*	9	0.8	0.06	323909	25767	86809	7189	0.08	0.30	0.27	0.02	1.00

* movement corrected estimates

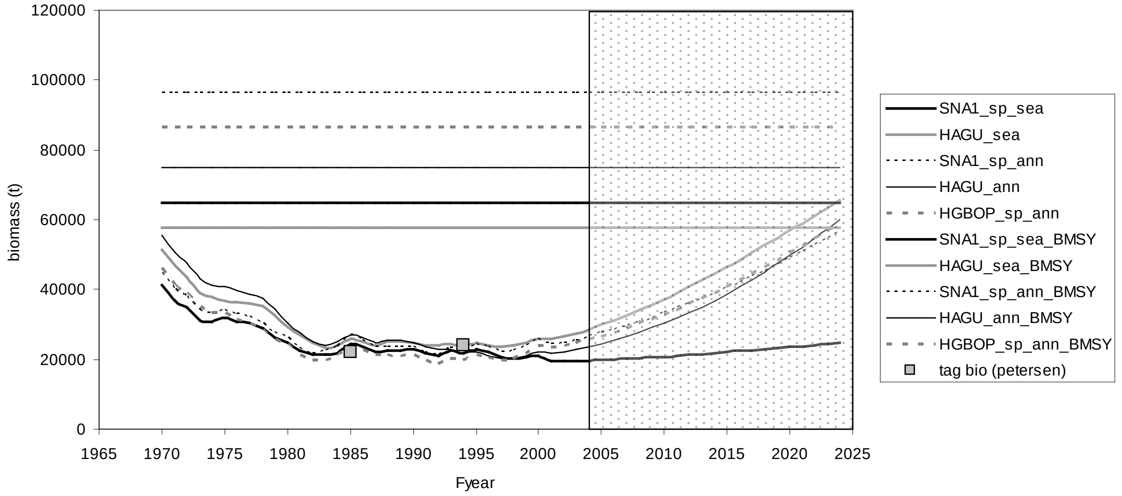

Figure 34: Hauraki Gulf model stock trajectories (steepness 0.8). Model projection space shaded. Independent Petersen biomass estimates are shown (note: only the 1985 estimate was fitted directly in the models).

3.3.3.3 Bay of Plenty model estimates

The Bay of Plenty steepness 0.8 model stock trajectories were again similar to the base model projections up to 2004 (Figure 11 compared with Figure 35). The dichotomy in biomass trajectory between the spatial (movement tags included) and single area (movement tags excluded) is still evident in the 0.8 models (Figure 35). The 0.8 models stock projections are more pessimistic than the base model projections with most models giving a 0% probability of the stock attaining B_{MSY} by 2024, and the majority indicating a significant probability of the stock to decline out to 2024 (Table 21).

Table 21: Bay of Plenty (steepness 0.8) model production parameter estimates. MSY and B_{MSY} values are deterministic. Projection risk probabilities were derived from boot-strap random recruitments.

Model name	Model num	steepness (BH)	M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	$P[B_{2024} > B_{MSY}]$	$P[B_{2024} > B_{2004}]$
SNA1_sp_sea*	1	0.8	0.06	58825	2151	15309	1449	0.04	0.14	0.26	0.00	0.30
BOP_sea	4	0.8	0.06	122453	5791	33367	2705	0.05	0.17	0.27	0.00	0.04
SNA1_sp_ann*	5	0.8	0.06	80953	2735	21218	1897	0.03	0.13	0.26	0.00	0.44
BOP_ann	8	0.8	0.06	129521	10180	34663	2754	0.08	0.29	0.27	0.07	0.69
HGBOP_sp_ann*	9	0.8	0.06	110208	2888	28431	2598	0.03	0.10	0.26	0.00	0.80

* movement corrected estimates

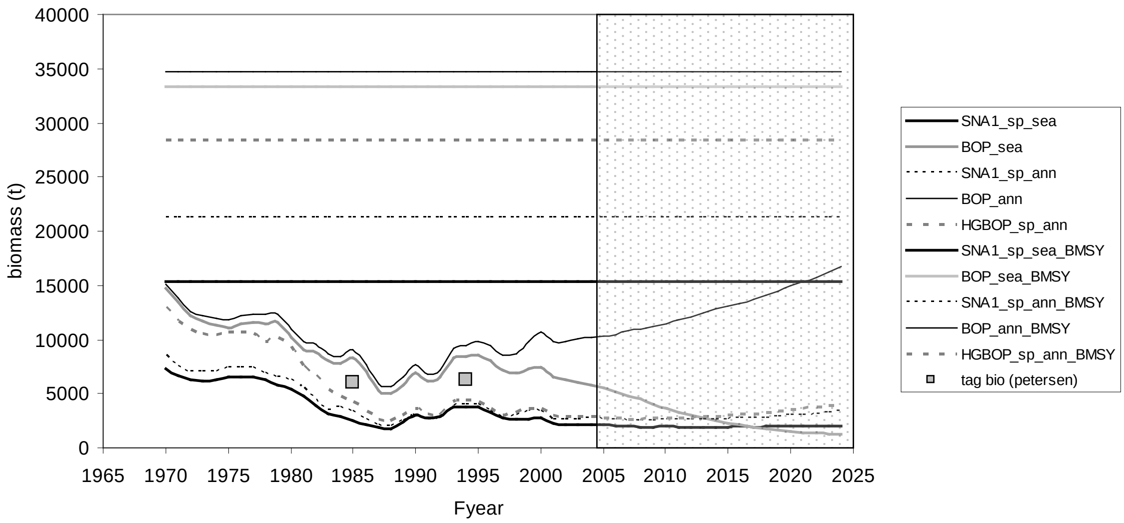

Figure 35: Bay of Plenty model stock trajectories (steepness 0.8). Model projection space shaded. Independent Petersen biomass estimates are shown (note: only the 1985 estimate was fitted directly in the models).

3.3.3.4 Combined SNA 1 model estimates

The SNA 1 combined results are similar to the Hauraki Gulf 0.8 model outcomes, with most models predicting the combined stock to increase out to 2024, but it being highly unlikely that SNA 1 will achieve B_{MSY} by this date (Table 22, Figure 36).

Table 22: Combined SNA 1 model (steepness 0.8) production parameter estimates. MSY and BMSY values are deterministic. Projection risk probabilities were derived from boot-strap random recruitments.

Model name	Model num	steepness (BH)	M	B_0	B_{2004}	B_{MSY}	MSY	B_{2004}/B_0	B_{2004}/B_{MSY}	B_{MSY}/B_0	$P[B_{2024} > B_{MSY}]$	$P[B_{2024} > B_{2004}]$
SNA1_sp_sea*	1	0.8	0.06	425602	29220	112884	10403	0.07	0.26	0.27	0.00	0.58
SNA1_comb_sea	2-4	0.8	0.06	400260	43662	108992	9360	0.11	0.40	0.27	0.00	0.99
SNA1_sp_ann*	5	0.8	0.06	521747	38715	155640	11437	0.07	0.25	0.30	0.00	0.99
SNA1_comb_ann	6-8	0.8	0.06	487781	42305	136754	10347	0.09	0.31	0.28	0.01	0.99
EN+HGBOP_sp_ann*	6 & 9	0.8	0.06	528461	37235	142345	11701	0.07	0.26	0.27	0.00	1.00
EN+HGBOP_com_ann*	6 & 10	0.8	0.06	448567	43818	125513	11084	0.10	0.35	0.28	0.01	0.88

* movement corrected estimates

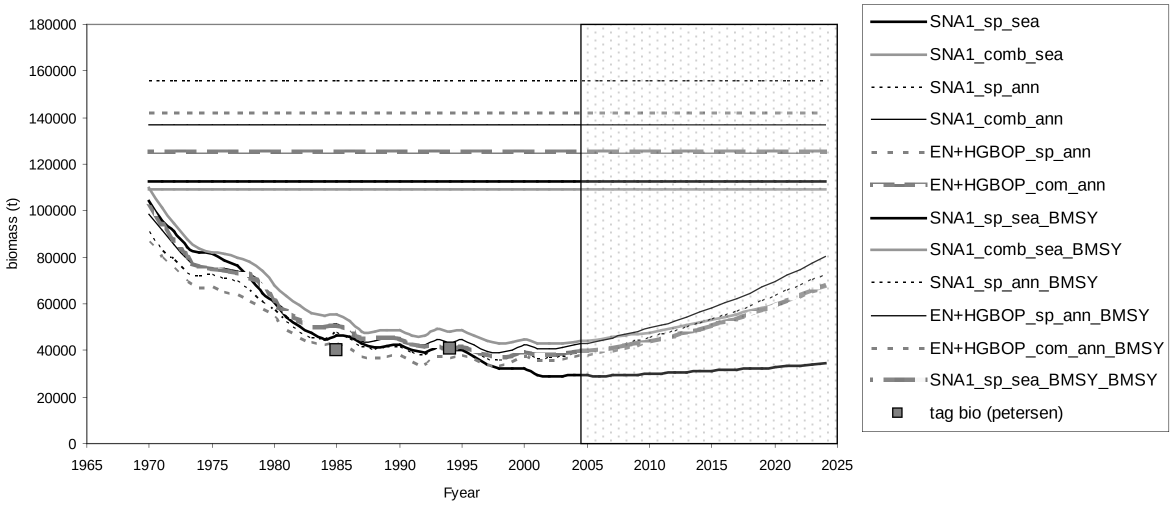

Figure 36: SNA 1 model stock trajectories (steepness 0.8). Model projection space shaded. Independent Petersen biomass estimates are shown (note: only the 1985 estimate was fitted directly in the models).

4 DISCUSSION

Differences in age composition and growth are seen in data collected from the east Northland, Hauraki Gulf and Bay of Plenty areas for SNA 1 (Walsh et al. 2006, Appendix 1), and ideally these differences (which point to spatial differences in recruitment across SNA 1) should be accounted for in future SNA 1 assessments. The simplest approach to account for regional differences is to assess the three SNA 1 sub-stock areas independently. The main problem in doing this is that it ignores the possible effect sub-stock movement may have on area yield. Dealing with movement is particularly a problem when fitting tag recapture data in the assessment models as ignoring movement may bias the assessment results. Modelling movement explicitly in an assessment requires a choice to be made between Markovian and home fidelity movement dynamics. An important outcome under Markovian movement is that all tagged fish will eventually attain the same spatial distribution, i.e. one independent of the initial release area. Home fidelity movement predicts that the spatial pattern of tag fish recoveries will change very little through time, i.e. long term recovery patterns are dependent on release area. The pattern of recoveries from the 1985 and 1994 tagging programmes was consistent with home fidelity and inconsistent with Markovian movement.

Under the home fidelity dynamic, movement is an attribute of the fish, not the area in which it currently resides, for the purpose of assessment modelling stocks are not specific to areas and are therefore cryptic. However, since fisheries managers are likely to be more interested in area-based rather than stock-based yield estimates the assessment process needs to provide area-based advice. These are relatively straightforward to derive from the stock assessment results by summing up the individual cryptic stock yields in each area.

The spatial and four seasonal SNA 1 CASAL model (Model 1) proved to be computationally demanding and iteratively slow to run despite the use of a fast computer. The ADOL-C minimiser had difficulty in locating an MLE, with the result that three minimisation runs were typically required. The standard deviations of standardised residuals on some of the likelihood terms were less than ideal (less than or greater than 1.0), suggesting that model likelihood weightings may not have been appropriate. There was less evidence of inappropriate likelihood weighting in the annual spatial model (Model 5) fit. Although faster to run than Model 1, the annual SNA 1 spatial model (Model 5) was still impractically slow and two minimisation runs were required to achieve a stable MLE. Both spatial models are likely to be impractical for undertaking a full Bayesian assessment of SNA 1, as the generation of MCMC posteriors would take too long. Not all options for increasing the efficiency of the CASAL code were explored; it may be possible to make significant gains in performance that may enable a MCMC to run. In fact, the efficiency of the SNA 1 single season CASAL model was improved in a later project (McKenzie pers comm.)

The spatial models (1, 5, and 9) predicted pre–2004 biomass trajectories that were consistently lower than the single sub-stock model predictions; the discrepancy being most apparent in the Bay of Plenty model comparisons. The difference was most likely due to a higher number of tags included in the spatial modelling, i.e. area movement tag recoveries.

Most of the model projections predict that the sub-stocks will rebuild significantly beyond 2004 levels out to 2024; the expected status of the Hauraki Gulf in 2024 being markedly optimistic. Optimistic rebuild predictions are a common feature of nearly all snapper age-based stock assessments: SNA 7 (Gilbert & Philips 2003); SNA 8 (Davies et al. 2006, Bian et al. 2009); SNA 2 (Langley 2010); SNA 1 1999 (Gilbert et al. 2000). However, the stock biomass trajectories predicted in the 1999 SNA 1 assessment differ significantly to those generated fitting to actual data in the current modelling. A similar disparity is also seen between the Davies (1999) and Davies et al. (2006) SNA 8 assessments. The lack of consistency between the 1999 and 2004 model biomass trajectories suggests that snapper age-based models may have a tendency to over-estimate future stock status in the projections. The 2004 assessment models benefit from a longer time series of catch-at-age observations, commercial and recreational harvest estimates. The strength of this information means the model pre 2004 biomass trajectories are likely to be reasonable, i.e. the models are informative as to where the sub-stocks have been. Caution is advised in interpreting the updated model projections more than five years beyond the last observation data year (i.e. 8–10 years beyond the last estimable year class; and five years beyond the last total mortality (Z) observation). We should not necessarily believe that a rebuild is occurring until we see evidence for it over the historical period of the model. Since the Hauraki Gulf sub-stock models all indicate that an upward trend in biomass occurred after 1997, we can have some confidence that this sub-stock was likely to be rebuilding in 2004 and was probably likely to continue to do so for at least the next five years. The pre 2004 biomass trajectories in the other two sub-stocks are less encouraging; for the Bay of Plenty the biomass direction is ambiguous after 1985, the east Northland biomass has been systematically declining since 1970. Despite the optimistic model projections we should have less confidence that these sub-stocks are rebuilding.

The power in the modelling to provide a good understanding of historical SNA 1 sub-stock biomass is due to the past high investment in monitoring (tagging programmes, a long time series of catch-at-age observations, recreational survey data). It can be reasoned that similar levels of monitoring will be required in the future.

There was general consistency in the model growth estimates; although Bay of Plenty growth rates were markedly faster than the other two sub-stocks; and there was some evidence that Hauraki Gulf fish grow slightly slower than east Northland fish. BOP growth rates resulted from a bad fit to the VB curve with the large negative t_0 values making the growth almost linear.

All the selectivity curves used in the SNA 1 models were age-based. There was reasonable consistency between models in the general shape of longline selectivity right and left hand slopes. The models had reasonable power to estimate longline selectivity (overall) because the observational data spanned many model years. Despite fewer years of observational data, the models also provided reasonably consistent estimates of single trawl, Danish seine and recreational line selectivity. However future assessments would benefit from the collection of more recent catch-at-age observations for Danish seine and single trawl, as there is currently no observational data for these methods after 1995. The selectivity estimates for research trawl were least consistent between models and sub-stocks. Misspecification of research trawl selectivity is unlikely to have biased the assessment results significantly; research trawl is principally providing estimates of year-class-strength with most research trawl recruitment years also covered by catch-at-age observations. With no plans to resume research trawls the research trawl likelihoods could possibly be dropped from future assessments.

The gear-specific selectivity curves differed between the Bay of Plenty and other sub-stocks mainly in the age at which maximum selectivity occurred (probably as a result of area differences in growth). Differences in the Bay of Plenty selectivity curves were consistent with faster growth of Bay of Plenty fish (the exception being research trawl), i.e. curves were shifted left (younger age selection). Because the spatial model selectivity estimates were generic i.e. not specific to sub-stock, they were probably not optimal for the Bay of Plenty.

It may be more reasonable to assume that the various fishing methods are selecting consistently between sub-stocks on the basis of length rather than age. A generic single gear selectivity curve based on length would not be biased by differences in growth between areas, making it preferable to assess SNA 1 using length based selectivity. However, although CASAL supports the use of length-based selectivity ogives in age-based models the projection matrix CASAL uses to convert from age to length in the models may produce biased predictions when used to convert from length to age. In an age-based CASAL assessment the specific purpose of the age-length transition matrix is to convert the underlying model age frequency to length frequency for the fitting of length frequency likelihoods (e.g. fitting to the recreational line data in the SNA 1 models). The error in the projection matrix is specifically in the dimension length-about-age, i.e. the column vector in the matrix is a probability density. For the back transformation of length to age the row vectors of the CASAL matrix are used. However, these do not necessary represent a true density of age-about-length. CASAL needs to transform and back transform age observations to apply length-based selectivity, a process which may result in error. This highlights a general problem with age-based stock assessment models where a number of key dynamics e.g. weight-at-age and selectivity are length based.

One way of more correctly accounting for length and age based selectivity, and other length-based effects such as inter-annual growth variability, is to use a length-age based model. At the core of a length-age model is a length-age matrix in which the cumulative effects of recruitment, growth and mortality are stored. The matrix carries forward both length and age information across sequential annual time steps in the model (compare this with age based models in which only age information, i.e. YCS and total mortality, is carried forward in time). CASAL is not capable of explicit length-age based modelling, but such a model does exist for SNA 1, being principally designed for the Hauraki Gulf sub-stock (CALEN: Gilbert et al. 2006). The main rationale for developing CALEN (Catch at Age and LENgth) was to better account for inter-annual variability in growth (Gilbert et al. 2006). Evidence for inter-annual growth variability is seen in the SNA 1 catch-at-age and appears to be strongly correlated with annual changes in sea surface temperature (Millar et al. 1999). The initial CALEN modelling results were encouraging; CALEN fitted the observation data well and results were consistent with the aged-based assessments (Davies & Gilbert 2008). CALEN needs further development before it could be used as a formal SNA 1 stock assessment tool. It is, however, still possible to account for inter-annual growth variability in an age-based assessment, e.g. by providing the model with annual estimates of mean-weight-at-age or year specific growth parameters. The question of whether CALEN performs sufficiently better than aged-based models to warrant its continued development has not been adequately resolved. Ministry of Fisheries funding for CALEN ceased in 2008.

In common with the spatially disaggregated snapper models (Models 1 and 5) CALEN took appreciably longer to find an MLE than the base Hauraki Gulf aged-based model (Davies & Gilbert 2008). This highlights a general problem in fisheries modelling and assessment centred on the key question of “how much complexity to include?”. In the case of SNA 1 the impetus for complex modelling has been driven by a need to account for complex patterns in the observation data e.g. tag observations that move (spatial Models 1 and 5), and complex variability in an important process, e.g. inter-annual growth variability (CALEN). It could be argued that the best SNA 1 model would be both spatially disaggregated and length-age structured. CALEN was slow to run and it was not spatially disaggregated; spatial models 1 and 5, although not length-aged based, are too slow to be practical for Bayesian risk assessment. A combination of the two would be likely to be unworkable at the current time. In the long term, the complex nature of SNA 1 growth, spatial distribution, movement, and recruitment justifies a more complex assessment process than is currently feasible with CASAL or CALEN. The solution will almost certainly require a move to distributed or parallelised computing.

In the immediate future complex models have two roles in SNA 1 management. Firstly they can be used to help guide the interpretation of results from simpler models, and may also serve to help formulate more informed priors. Secondly, complex models can be used in a simulation mode to generate pseudo observational data for evaluating simpler (more tractable) assessment approaches, monitoring options, and management strategies (i.e. Management Strategy Analysis).

The investigation of M and steepness effectively illustrates the long-held understanding of the structuring power of these parameters in stock assessment generally. Varying M had the effect of changing stock productivity but did not significantly change the shape of the yield curve or the relative position of B_{MSY} to B_0. Shifting M from 0.06 to 0.075 (both plausible values for snapper; Gilbert 2000) had a marked effect on the model estimates of current stock status; B_{2004}:B_{MSY} shifted from 0.70 to 0.97. Changing steepness had a more profound effect on stock productivity, not only changing yield but also the shape of the yield curve and the relative position of B_{MSY} to B_0. The relationship between steepness and the relative position of B_{MSY} is documented in the literature (Punt et al. 2008) and has been shown to be the main life-history parameter governing this ratio (Hilborn & Stokes 2010). The current assumed steepness of 1 for the SNA 1 assessment is the most optimistic value in terms of risk and also provides the least incentive to rebuild the stock to B_{MSY} as only minimal gains in productivity are expected. Adopting a steepness of 0.8 did not significantly change the model historical and current (B_{2004}) biomass estimates, but significantly altered the future status predictions. The current modelling and observational data provide little guidance as to what steepness and M should be. The choice of values of these parameters will have the most bearing on the future assessment of SNA 1 and thus need careful consideration.

5 CONCLUSIONS AND RECOMMENDATIONS

1. Most models produced similar relative trends in biomass for the observable model history (1970–2004). Basic productivity parameters (B_0, MSY, B_{MSY}, B_{2004}), growth (VB) selectivity estimates, and the ratio of B_{2004} to B_{MSY} were also similar for the majority of models. This suggests that all the models are at face value reasonable for assessing SNA 1.

2. The most important dynamic added by the two spatial models was the incorporation of additional tag observations, i.e. out of area recoveries. This is likely to be the reason why the spatial model biomass trajectories were consistently lower than the single sub-stock estimates; the disparity being particularly marked in the Bay of Plenty estimates.

3. It may be desirable to have seasonal time steps in the SNA 1 assessment models to account for seasonal differences in growth and to account for seasonal migrations. However, since none of the models used in the evaluations specifically included these dynamics, there seemed to be little benefit in including seasonal partitions in the modelling. The spatial model (Model 1) was significantly slower because of the inclusion of seasonal partitions, and there were more inconsistencies seen in seasonal model estimates than the annual models (e.g. east Northland Model 2). Unless future CASAL assessment models are configured for seasonal dynamics the inclusion of seasonal partitions is unlikely to have much value.

4. Excluding the seasonal, season-spatial models and Hauraki Gulf/BOP combined models leaves four candidate models for a future SNA 1 assessment: spatial Model 5 and annual sub-stock models 6, 7 and 8. It is likely that the a full SNA 1 Bayesian assessment would only be practical using the single area models (6,7 and 8). It would be advisable, however, to contrast these results with the MLE predictions from the spatial model (Model 5); the expectation is that the spatial model outcomes should be similar; evidence to the contrary would warrant further investigation; a process that hopefully will lead to a more robust outcome. It is recommended that all four annual models are used for the next assessment of SNA 1.

5. There is evidence that the current SNA 1 models might be biased towards optimistic projections. Until such time that the projection dynamics of the SNA 1 models are better understood, or trends corroborated by future modelling, it is recommended that projections are restricted to five years beyond the final observational year. In interpreting model results, more weight should be placed on the trends seen in the recent history of the model than those predicted in the projections.

6. Prior to modelling it is recommended that consensus is reached between fisheries scientists, managers and stake-holders as to appropriate values for M and steepness. This group will need to provide guidance to the modellers as to how the uncertainty surrounding these parameters is to be accounted for in the assessment.

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8 APPENDICES

Appendix 1: History of SNA 1 stock assessment and monitoring 1985–2005.

Significant exploitation of the SNA 1 sub-stocks particularly in the Hauraki Gulf dates back to European colonial times (1850). The long catch-history creates difficulties for stock assessment, particularly where catch history models are used. Long catch history modelling has to deal with two inherent uncertainties:

1. There is strong anecdotal evidence that significant quantities of snapper landed prior to 1980 went unreported, largely for tax avoidance reasons; thus calling into doubt the accuracy of the published catch records dating back to 1910 (Paul 1977). A more serious deficit in SNA 1 catch history knowledge is the non-commercial harvest. Data on SNA 1 non-commercial extraction dates from the early 1980s, but it is only the most recent formal surveys that provide credible harvest estimates (Hartill et al. 2007). Our understanding of non-commercial SNA 1 harvest diminishes back in time such that annual extraction levels prior to 1970 are highly uncertain.

2. The implicit model assumption that productivity characteristics of the SNA 1 sub-stocks are the same now as they were in 1850 is highly questionable in the light of the significant urbanisation and land development that has occurred around snapper coastal habitats during the twentieth century. For example, the extent of sea grass (*Zostera capricorni*) beds in northern New Zealand harbours is known to have decreased significantly since the 1940s. Recent work by NIWA has shown that seagrass habitats are very important for juvenile snapper (Morrison et al. 2009).

Assessing the yield potential of the SNA 1 sub-stocks became a high priority in the early 80s as a prerequisite to snapper's introduction to the QMS. Given the importance of snapper the approach taken was to base the initial SNA 1 stock assessment on stock biomass estimates derived from mid 1980s tagging studies. Yield-per-recruit (YPR) analysis was used to provide optimal sub-stock fishing mortalities (F); these were then applied to the absolute biomass values to produce sustainable harvest estimates (Sullivan et al. 1988). There are two main limitations of the absolute biomass YPR stock assessment approach. Firstly; SNA 1 mark-recapture experiments were (and still are) too expensive to be undertaken on a regular basis. Secondly; the approach largely assumes the stock to be in a state of equilibrium (i.e. not going up or down) in relation to current exploitation. More stock assessment surety is provided by catch-history modelling approaches which, as the name implies, take into account historical changes in abundance, catch, and recruitment. These models are strongly reliant on having a reasonably long time series of stock monitoring data.

During the1980s three SNA 1 monitoring programmes were established, primarily to track stock productivity trends over the intervals between tagging assessments; these were:

1. Juvenile research trawl surveys: to monitor strength of recruiting year classes;
2. Annual catch sampling for length and age: to monitor population age composition, exploitation and growth rates;
3. Catch and effort data collection: to monitor changes in relative stock abundance.

In 1993 a SNA 1 assessment was undertaken using an age structured population model (Gilbert & Sullivan 1994). The model calculated the productivity status of the SNA 1 stock by modelling forward from tagging derived estimates of the 1985 starting age composition and population size to 1992. The model was specific to SNA 1 as a whole, being an amalgamation of the three sub-stocks. Inputs to the model were:

- post 1985 SNA 1 commercial reported catch;

- year class strengths from 1982 to 1992 derived from trawl surveys and a water temperature correlation;
- a longline CPUE index of abundance from 1985 to 1991.

Natural mortality was fixed at 0.06. Recruitment was assumed to be knife-edge at age four. Gear selectivities, derived from the 1985 tagging assessment, were held constant (Sullivan et al. 1988). Non-commercial catch was derived for each model year relative to a fixed fishing mortality (F) of 0.04, being derived from the 1985 tagging estimate of non-commercial harvest. Fitting the model involved estimating mean recruitment (R_0) and the longline catchability coefficient (*q*). No stock recruitment relationship was assumed in the model. The 1993 assessment proved conjectural on a number of grounds, not least of all because the estimate of mean recruitment proved highly sensitive to the commercial CPUE index, resulting in wide confidence intervals on the Current Biomass (1993) and Surplus Production (CSP) estimates (Annala 1994). The power of the 1993 assessment unfortunately rested largely on the strength of the assumption that longline CPUE indices were strongly reflective of underlying stock abundance; the 1993 Ministry Working Group, in general, was not comfortable with this assumption.

Francis (1993) undertook an analysis of the early trawl survey recruitment series finding a strong correlation between summer sea surface temperatures (SST) in the Hauraki Gulf (as measured at the University of Auckland Leigh marine laboratory) and year class strength. Water temperature and local Auckland air temperature were subsequently shown to be well correlated; it was therefore reasoned that a combination of these temperature series could be used to derive estimates of annual snapper recruitment strength back to the early 1900s (Gilbert 1994). Confidence in the water temperature recruitment relationship was such that the frequency of recruitment trawl surveys declined through the 1990s, largely only occurring in extreme water temperature years for the purposes of strengthening the SST correlation.

In light of the availability of an annual recruitment index back to 1910, a total catch history model was developed for SNA 1 in 1994 (Gilbert 1994). The model was fully age structured, commencing in an assumed unexploited state in 1850; again recruitment was assumed knife-edged at age 4. The commercial catch history used in the model came from records dating back to 1931. Non-commercial catch was assumed to be relatively constant back to 1931 being set at mid-1980s levels derived from tagging. Different assumed levels for catch history prior to 1931 were tested in the model. The model was fitted to the 1985 tag biomass estimate and a longline CPUE stock index. The modelling results were never used for a formal stock assessment, but the sensitivity analyses from the assessment are informative. The productivity estimates were relatively insensitive to the assumed annual catch prior to 1931, and to a lesser degree the assumed non-commercial catch history. The model was highly sensitive to the assumed natural mortality (M) rate. It was also highly sensitive to the historical interval over which mean recruitment was calculated. Estimates of CSP(1994) ranged from 6000 t, when mean recruitment was based on the period 1910 to 1991, to 8800 t when only the recent (1967–91) water temperature series interval was used (Gilbert 1994).

A second SNA 1 tagging programme was undertaken in 1993; this provided recruited biomass estimates for the three SNA 1 sub-stocks, relative to November 1993. An assessment of SNA 1 was conducted in 1996 utilising the 1993 tag biomass estimates. Three modelling approaches were used in this assessment:

1. a YPR current stock biomass model or equilibrium model as used in 1988;
2. the 1985-1994 stock projection model as used in 1993;
3. the Gilbert (1994) total catch history model

For the 1996 assessment East Northland was assessed separately from the Hauraki Gulf and Bay of Plenty sub-stocks. The Hauraki Gulf and Bay of Plenty sub-stocks were assessed as one combined area. The same recruitment time series was assumed for both areas, being essentially the Hauraki Gulf SST index. Also available for inclusion in the 1996 assessment were non-commercial catch estimates for 1994 obtained from a nationwide telephone dairy survey (Teirney et al. 1997). The 1994 recreational harvest estimates were nearly double the 1985 tagging estimates. The recreational catch history used in the model assumed recreational catch had increased linearly between 1985 and 1994; prior to 1985 it was assumed to be approximately 25% the commercial catch (Gilbert et al. 1996). The longline CPUE index, used in previous assessments was not included in the projection (2) and total catch history (3) models; the only estimable parameter in both models was virgin recruitment (R0). Again the catch history model showed high sensitivity to the assumed natural mortality value, and the period used to estimate mean recruitment. Basing mean recruitment on the recent years (1967–95) produced higher maximum sustainable yield (MSY) estimates, but the implication was that both sub-stocks were further below MSY thus requiring a greater catch reduction to rebuild them. The working group at the time accepted a more parsimonious set of working assumptions for the base model. Under these assumptions the Hauraki Gulf/Bay of Plenty combined sub-stock was predicted to be 0.5 the biomass corresponding to the MSY (B_{MSY}); East Northland, in contrast, was predicted to be on or near B_{MSY}. Despite being significantly below B_{MSY} the Hauraki Gulf/Bay of Plenty model produced a relatively flat biomass trajectory after 1980; the implication being that the stock was likely to be at equilibrium, i.e., current catches were sustainable. The East Northland sub-stock trajectory was declining steadily implying that current catches were unsustainable, i.e., the stock was not at equilibrium with exploitation. For the Hauraki Gulf/Bay of Plenty the assessment findings from all three models were similar. The equilibrium model gave slightly higher estimates of mean recruitment and lower MSY values than the other models, however the stock status was similar in all three models, being between 12.1 to 13.9% of virgin biomass (Gilbert et al. 1996). For East Northland the catch history and projection models produced similar assessments, putting the then current status at between 24 and 28% of virgin biomass. Estimates of productivity were higher from the equilibrium model; the stock predicted to be 18% of virgin stock size. The equilibrium model results were considered not valid for East Northland because the stock was unlikely to be at equilibrium (Gilbert et al. 1996).

The overall prognosis of the 1996 assessment was that the exploitation rate in SNA 1 needed to be reduced in order to achieve a rebuild of the Hauraki Gulf/Bay of Plenty sub-stock and to prevent collapse of the East Northland population. The assessment results led to a Ministerial decision to reduce the SNA 1 total allowable commercial catch (TACC) by nearly 1500 t down to 3500 t. This decision was legally challenged by the fishing industry, both on scientific and socio-economic grounds. Part of case against the science was that the assessment had failed to take into account the possibility of a larger historical catch, specifically, illegal fishing, and exploitation, during the 1960s and 70s, by Japanese long liners. The assessment also did not adequately consider the productivity implications of higher natural mortality (M) rates. The legal challenge was upheld and the TACC reduction was overturned, the TACC remained at 5000t.The 1996 legal challenge ushered in a new SNA 1 assessment era by introducing the concept of risk into the assessment process. New modelling approaches that took greater account of underlying uncertainty were developed. The new generation of models are broadly termed observational error models.

The next SNA 1 assessment, which was for the 1997–98 fishing year, was the first to incorporate observational error using a frequentist bootstrapping approach (Davies 1999). The model specified a number of likelihood terms for each of the observational data sets. The optimum parameter solution was deemed to be the combined minimum log-likelihood fit to the observational data. Uncertainty (variance) on estimable parameters and the evaluation of risk was achieved by regenerating observation data based on their error distributions, i.e., by parametric bootstrap, and refitting the model. As with the 1996 assessment the East Northland and Hauraki Gulf/Bay of Plenty subareas were modelled from an assumed virgin state in 1850. The model used was a revised version of the Gilbert (1994) total catch history model and spanned the period from 1850 to 1998. As with the Gilbert model it was age structured. In the new model there were 16 age cohorts (4–19 years) and a 20+ amalgamated age class. The catch history used was broken down by method, with annual catches being applied in the model, mediated through selectivity ogives. The foreign (Japanese) and recreational catch histories were problematic. The assessments were run using three levels of historical Japanese catch. Independent estimates of recreational harvest were available for 1994, 1995, 1996, the last estimate following an increase in the minimum legal size and a drop in bag limit. The assessment explored uncertainty in both past and future recreational harvest; different model runs were again done to explore the uncertainty about these assumptions. Observational data fitted in the model were the two tagging biomass estimates and a trawl/SST recruitment time series index used in the previous assessments and a time series of annual catch-at-age observations commencing in 1989. For the first time in any SNA 1 assessment model, catch-at-age observational data were fitted directly. These catch-at-age data not only provided estimates of year class strength but also enabled the estimation of selectivity. The model estimate of mean recruitment was based on the observed year class strengths from 1971 to 1997. Year class strengths (YCS) for years 1974–88 (1978–88 for East Northland) were estimated as free parameters derived from fitting the catch-at-age observations. The YCS assumed for remaining years were derived from a SST index. A normalisation process occurred in the model to ensure the mean YCS of the fixed and free years equalled one. As with the 1996 model no stock recruit relationship was assumed, this assumption had now become entrenched in the working group thinking and remained an unquestioned feature of all SNA 1 stock assessments that followed. The 1997–98 assessment explored 0.075 and 0.09 as alternative natural mortality rates.

The 1997–98 modelling provided the first real insight into the how uncertainty around the various observational data inputs and model parameterisations influence the stock status prognosis. The assumed selectivity-at-age parameterisations were found to be the main source of uncertainty in the models of both sub-stocks. Because of confounding in the estimation of recruitment parameters and method-specific selectivity parameters, estimates of selectivity-at-age could not be derived from model fits to catch-at-age data. Instead, selectivity estimates, independently derived from tagging data (Davies 1999), were used in the final analyses. Although there was some evidence that an M of 0.09 was too high, as a generality, varying natural mortality and historical catch tended to have direct scaling effect on MSY, B_{MSY} and B_0 but did not overly change the most recent stock trajectory. The recent stock trajectory was most sensitive to the level of weighting accorded the catch-at-age observational data. Model weightings that favoured the catch-at-age data tended to result in increases in recent biomass the Working Group felt were implausibly high relative to the 1985 and 1994 tagging based biomass estimates. The 1997–98 final agreed assessments were based on a compromise of model parameterisation that was largely toward the middle range of the parameter space. In the final assessment east Northland was predicted to be at or around B_{MSY} but projected to decline under (then) current levels of exploitation. The Hauraki Gulf/Bay of Plenty sub-stock was predicted to be around 60% B_{MSY} and likely to decline at current exploitation levels. The assessment indicated that a 700-1400 t reduction in TACC could turn this prognosis around. The quota reduction that followed was 500 t.

The next SNA 1 assessment was for the 1998–99 fishing year (Gilbert et al. 1999). This assessment used basically the same model structure as the previous assessment. The main difference between the two assessments was to commence the 1998–99 models in 1970 at an exploited equilibrium age structure and biomass. Commencing the models in 1970 removed the need to include the highly uncertain pre-1970 catch history (the Japanese and recreational histories in particular) and also the influence of the, equally dubious, air temperature derived time series of year-class-strengths. The 1970 age structure was generated from a pre-1970 total mortality rate, i.e. the combination of a constant pre-1970 fishing mortality and natural mortality; the pre-1970 F being an estimable parameter. Another difference to the previous assessments was that the SST recruitment relationship parameters had previously been estimated from trawl survey year-class-strength indices from the Hauraki Gulf, and SST data outside the model. In the 1998–99 assessments these parameters were derived by fitting the data within the model. In addition to including another year of longline catch-at-age observations the 1998–99 assessment was also fitted to revised tagging biomass estimates for 1985 and 1994 (Davies 1999). Of particular relevance in the 1998–99 assessment were the model projections which were now based on the lower 4500 t TACC. The results put the Hauraki Gulf/Bay of Plenty sub-stock again being below B_{MSY} (66%); however the new model structure suggested that east Northland was more likely to be above B_{MSY} (130%). Bootstrap projections predicted that under (then) current levels of commercial exploitation and estimated recreational harvest, the Hauraki Gulf/Bay of Plenty sub-stock would move toward B_{MSY}, and the east Northland sub-stock would remain at or above B_{MSY}.

The next formal SNA 1 stock assessment was undertaken the following year, including the 1999–2000 fishing year (Gilbert et al. 2000). The 1999–2000 assessment models built on the previous assessment models, being for the most part structurally the same. Two key differences were the inclusion of a longline CPUE likelihood and a renewed attempt to estimate selectivity parameters for longline, single trawl and Danish seine. Key new inputs to the models were: the inclusion of the 1997–98 longline catch-at-age data; longline CPUE indices covering nine fishing years (1990–91 – 1998–99); Danish seine catch-at-age observations for the 1974–75 and 1975–76 fishing years from the Hauraki Gulf. The CPUE indices were accorded a relatively high c.v. (0.35) to reflect the WG consensus view that longline effort was likely to only loosely track abundance. The Hauraki Gulf/Bay of Plenty base-case assessment was more optimistic than the 1998–99 assessment; 1998–99 stock size predicted to be 0.80 B_{MSY} (c.f. 0.67). The stock projection was also more optimistic with the stock predicted to be well above B_{MSY} (1.73) by 2019–20. None of the stochastic base-case model projections predicted a 2020 stock size that was smaller than B_{MSY}. The assessment explored model sensitivities to: 1) relative weightings of the catch-age-date and other likelihoods; 2) a range of assumed M (0.6 – 0.9); and 3) fixing selectivity to 1985 tagging estimates. Charging the model parameterisations produced similar changes on the productivity characteristics (B_{MSY}, MSY), current stock status, and stock trajectory outcomes as seen in previous assessments. The overall prognoses of all runs, however, were for the stock to rebuild to levels above B_{MSY} by 2020. In contrast to Hauraki Gulf/Bay of Plenty results, the 1999–00 east Northland assessment was less optimistic than the 1998–99 assessment. The base-case and many of the sensitivity runs put the 1999–2000 biomass at, or slightly below, B_{MSY} compared with 1.30 B_{MSY} in the 1998–99 base-case assessment. The differences in stock status between the two assessments appeared to largely relate to the use of fixed selectivities in the 1998–99 assessment. Most of the stochastic base-case model projections (95%) had the east Northland stock increasing over the next 20 years (until 2020), with a 67% probability of the stock being at or above B_{MSY} in 2020.

As of 2010 there had been no further formal SNA 1 stock assessments since the 1999–2000 assessment. However between 2000 and 2010 there has been continued high investment in the collection of information needed to monitor and assess SNA 1; these data being used for: annual catch-at-age monitoring; updated CPUE analyses; and four additional annual recreational harvest surveys (2000; 2001; 2004; 2005). The monitoring information and anecdotal evidence from both the commercial and recreational harvest sectors suggests that neither the east Northland nor the Hauraki Gulf/Bay of Plenty sub-stock complex are likely to have declined in abundance or productivity since 2000.

The main reason for the lack of a formal SNA 1 stock assessment has been the lack of independent stock biomass estimate from tagging. Of all the information that goes into the SNA 1 stock assessment it is the tagging estimates that have the greatest influence on current and future (1–5 year) stock status. Assessments (Bian et al. 2010) have shown that, if the tagging estimates are down weighted or removed in the modelling, there is a tendency for the other observational data, particularly the catch-at-age data, to draw the model into an optimistic rebuild projection space. The assumed gear selectivity has a strong bearing on the model interpretation of catch-age-age, and generally gear selectivity is not well estimated. The stock assessment modelling has shown that the choice of selectivity parameterisation strongly influences stock trajectory predictions.

Appendix 2: Markovian and Home Fidelity equilibrium movement dynamics

Markovian equilibrium

An example of a Markovian movement matrix Θ would be a matrix of annual proportional movements of tagged fish between 3 sub-stocks, e.g.

$$\begin{vmatrix} 0.7 & 0.05 & 0.05 \\ 0.2 & 0.8 & 0.35 \\ 0.1 & 0.15 & 0.6 \end{vmatrix} = \Theta$$

The distribution of tagged fish relative to release sub-stock area after 2 years is Θ^2 the distribution after i years is Θ^i. The proportional equilibrium distribution of tagged fish is attained after n years such that $\Theta^n = \Theta^{n+1} = E$.

It is an algebraic truism that the column vectors of the matrix satisfying the condition $\Theta^n = \Theta^{n+1}$ will always be equal, e.g.

$$\begin{vmatrix} 0.7 & 0.05 & 0.05 \\ 0.2 & 0.8 & 0.35 \\ 0.1 & 0.15 & 0.6 \end{vmatrix} = \Theta \quad \therefore \Theta^n = \begin{vmatrix} 0.14 & 0.14 & 0.14 \\ 0.6 & 0.6 & 0.6 \\ 0.26 & 0.26 & 0.26 \end{vmatrix} = E$$

This means that the proportional equilibrium distribution E of tagged fish across all sub-stocks is always independent of the initial release distribution under Markovian movement. The only exception to this is where the movement matrix is the identity matrix (all the diagonal values are 1); under this scenario there is no movement.

Home Fidelity equilibrium

The equilibrium distribution of a given cryptic home population H_i across all sub-stocks can be defined as a vector of probabilities (element P_{ij} being the probability of an H_i fish being found in sub-stock j at any given instant in time).

The individual movement probability vectors H_i can be combined into a movement probability matrix Ψ. Ψ is analogous to the Markovian movement matrix Θ but unlike this matrix, Ψ is by definition an equilibrium matrix. Under home fidelity movement the matrix of observed proportional tagged fish movements E can be derived from an integration of cryptic home population movements Ψ such that after a suitable mixing period, say one year, $\Theta^1 = E$. Under home fidelity movement there is no algebraic constraint for the column vectors of E to be equal. The implication of this dynamic is that under home fidelity movement the equilibrium distribution of tagged fish across all strata is dependent of the initial release distribution.

Appendix 3: SNA 1 seasonal model catch at length/age observational data

a. East Northland

likelihood label	likelihood	method	season	fishing year(s)	type	no fishing years
EN_LL_age_aut	multinomial	long line	autumn	2004	age	1
EN_LL_age_old	normal-log	long line	spring	1985	age	1
EN_LL_age_spr	multinomial	long line	spring	1994-2004	age	11
EN_LL_age_sum	multinomial	long line	summer	1994-2004	age	11
EN_LL_age_win	multinomial	long line	winter	2004	age	1
EN_LL_len_aut	multinomial	long line	autumn	1994	length	1
EN_LL_len_sum	multinomial	long line	summer	1992	length	1
EN_LL_len_win	multinomial	long line	winter	1994	length	1
EN_REC_len_aut_post95	multinomial	recreational line	autumn	1996, 1998, 2000-2004	length	7
EN_REC_len_aut_pre95	multinomial	recreational line	autumn	1991, 1994	length	2
EN_REC_len_spr_post95	multinomial	recreational line	spring	1996-2001	length	6
EN_REC_len_spr_pre95	multinomial	recreational line	spring	1991	length	1
EN_REC_len_sum_post95	multinomial	recreational line	summer	1996, 1997, 1998, 2000-2004	length	8
EN_REC_len_sum_pre95	multinomial	recreational line	summer	1991, 1994	length	2
EN_REC_len_win_post95	multinomial	recreational line	winter	1996, 1998, 2000	length	3
EN_RES_len	multinomial	research trawl	summer	1990, 1993	length	2

b. Hauraki Gulf

likelihood label	likelihood	method	season	fishing year(s)	type	no fishing years
HG_BT_age_old	normal-log	bottom trawl	spring	1975, 1976, 1985	age	3
HG_BT_age_spr	multinomial	bottom trawl	spring	1991	age	1
HG_BT_age_sum	multinomial	bottom trawl	summer	1990, 1991, 1994	age	3
HG_BT_len_aut	multinomial	bottom trawl	autumn	1990, 1991, 1994	length	3
HG_BT_len_win	multinomial	bottom trawl	winter	1990, 1991	length	2
HG_DS_age_old	normal-log	Danish seine	spring	1970-1973, 1975, 1976, 1985	age	7
HG_DS_age_spr	multinomial	Danish seine	spring	1992, 1995, 1996	age	3
HG_DS_age_sum	multinomial	Danish seine	summer	1992, 1994, 1995, 1996	age	4
HG_DS_len_aut	multinomial	Danish seine	autumn	1992, 1994	length	2
HG_DS_len_win	multinomial	Danish seine	winter	1994	length	1
HG_LL_age_aut	multinomial	long line	autumn	2004	age	1
HG_LL_age_old	normal-log	long line	spring	1985	age	1
HG_LL_age_spr	multinomial	long line	spring	1992- 2004	age	13
HG_LL_age_win	multinomial	long line	winter	2004	age	1
HG_LL_len_aut	multinomial	long line	autumn	1994	length	1
HG_LL_len_win	multinomial	long line	winter	1994	length	1
HG_LL_sum	multinomial	long line	summer	1990-2004	age	15
HG_REC_len_aut_post95	multinomial	recreational line	autumn	1996, 2000 - 2004	length	6
HG_REC_len_aut_pre95	multinomial	recreational line	autumn	1991, 1994	length	2
HG_REC_len_spr_post95	multinomial	recreational line	spring	1997, 2000, 2001, 2004	length	4
HG_REC_len_spr_pre95	multinomial	recreational line	spring	1991	length	1
HG_REC_len_sum_post95	multinomial	recreational line	summer	1996, 1997, 2000-2004	length	7
HG_REC_len_sum_pre95	multinomial	recreational line	summer	1991, 1994	length	2
HG_REC_len_win_post95	multinomial	recreational line	winter	1996, 2000	length	2
HG_RES_len_spr	multinomial	research trawl	spring	1985-1988, 1990, 1991, 1993, 1994, 1995, 1998, 2001	length	11

c. Bay of Plenty

likelihood label	likelihood	method	season	fishing year(s)	type	no fishing years
BP_BT_age_spr	multinomial	bottom trawl	spring	1990, 1992, 1995	age	3
BP_BT_age_sum	multinomial	bottom trawl	summer	1990, 1991, 1992, 1995	age	4
BP_BT_len_aut	multinomial	bottom trawl	autumn	1990, 1991, 1992, 1994	length	4
BP_BT_len_win	multinomial	bottom trawl	winter	1990, 1994	length	2
BP_DS_age_spr	multinomial	Danish seine	spring	1995	age	1
BP_DS_age_sum	multinomial	Danish seine	summer	1995	age	1
BP_DS_len_aut	multinomial	Danish seine	autumn	1994	length	1
BP_DS_len_win	multinomial	Danish seine	winter	1995	length	1
BP_LL_age_aut	multinomial	long line	autumn	2004	age	1
BP_LL_age_spr	multinomial	long line	spring	1990 - 2004	age	13
BP_LL_age_sum	multinomial	long line	summer	1990 - 2004	age	13
BP_LL_age_win	multinomial	long line	autumn	2004	age	1
BP_LL_len_aut	multinomial	long line	autumn	1994	length	1
BP_LL_len_win	multinomial	long line	winter	1994	length	1
BP_REC_aut_post95	multinomial	recreational line	autumn	1996, 1998, 2000-2003	length	6
BP_REC_len_aut_pre95	multinomial	recreational line	autumn	1991, 1994	length	2
BP_REC_len_spr_post95	multinomial	recreational line	spring	1997, 1998, 1999, 2000, 2001	length	5
BP_REC_len_spr_pre95	multinomial	recreational line	spring	1991	length	1
BP_REC_len_sum_post95	multinomial	recreational line	summer	1996, 1998, 2000-2004	length	7
BP_REC_len_sum_pre95	multinomial	recreational line	summer	1991, 1994	length	2
BP_REC_len_win_post95	multinomial	recreational line	winter	1996, 1998, 2000	length	3
BP_RES_len	multinomial	research trawl	summer	1983, 1986, 1990, 1992, 1996, 1999	length	6

Appendix 4: SNA 1 fishing-year model catch at length/age observational data

a. East Northland

likelihood label	likelihood	method	season	fishing year(s)	type	no fishing years
EN_LL_age	multinomial	long line	fishing year	1994-2004	age	11
EN_LL_age_old	normal-log	long line	fishing year	1985	age	1
EN_LL_len	multinomial	long line	fishing year	1992	length	1
EN_REC_len_post95	multinomial	recreational line	fishing year	1996, 1997, 1998, 2000-2004	length	8
EN_REC_len_pre95	multinomial	recreational line	fishing year	1991, 1994	length	2
EN_RES_len	multinomial	research trawl	fishing year	1990, 1993	length	2

a. Hauraki Gulf

likelihood label	likelihood	method	season	fishing year(s)	type	no fishing years
HG_BT_age	multinomial	bottom trawl	fishing year	1990, 1991, 1994	age	3
HG_BT_age_old	normal-log	bottom trawl	fishing year	1975, 1976, 1985	age	3
HG_DS_age	multinomial	Danish seine	fishing year	1992, 1994-1996	age	4
HG_DS_age_old	normal-log	Danish seine	fishing year	1970-1973, 1975, 1976, 1985	age	7
HG_LL_age	multinomial	long line	fishing year	1990-2004	age	15
HG_LL_age_old	normal-log	long line	fishing year	1985	age	1
HG_REC_len_post95	multinomial	recreational line	fishing year	1996, 1997, 2000- 2004	length	7
HG_REC_len_pre95	multinomial	recreational line	fishing year	1991, 1994	length	2
HG_RES_len	multinomial	research trawl	fishing year	1985-1988, 1990, 1991, 1993, 1994, 1995, 1998, 2001	length	11

b. Bay of Plenty

likelihood label	likelihood	method	season	fishing year(s)	type	no fishing years
BP_BT_age	multinomial	bottom trawl	fishing year	1990, 1991, 1992, 1995	age	4
BP_BT_len	multinomial	bottom trawl	fishing year	1994	length	1
BP_DS_age	multinomial	Danish seine	fishing year	1995	age	1
BP_DS_len	multinomial	Danish seine	fishing year	1994	length	1
BP_LL_age	multinomial	long line	fishing year	1990 - 2004	age	13
BP_REC_len_post95	multinomial	recreational line	fishing year	1996-1998, 2000-2004	length	8
BP_REC_len_pre95	multinomial	recreational line	fishing year	1991, 1994	length	2
BP_RES_len	multinomial	research trawl	fishing year	1983, 1986, 1990, 1992, 1996, 1999	length	6

Appendix 5: Specification of model growth parameter priors by sub-stock

substock	parameter	prior	mu	cv	lower bound	upper bound
east Northland	Linf	normal	48.430	0.1	30	70
east Northland	k	normal	0.142	0.1	0.04	0.4
east Northland	T0	uniform	-	-	-4	0
east Northland	cv 1	uniform	-	-	0	0.4
east Northland	cv 2	uniform	-	-	0.1	0.6
Hauraki Gulf	Linf	normal	50.152	0.1	30	70
Hauraki Gulf	k	normal	0.099	0.1	0.04	0.4
Hauraki Gulf	T0	uniform	-	-	-4	0
Hauraki Gulf	cv 1	uniform	-	-	0	0.4
Hauraki Gulf	cv 2	uniform	-	-	0.1	0.6
Bay of Plenty	Linf	normal	62.763	0.1	30	70
Bay of Plenty	k	normal	0.064	0.1	0.04	0.4
Bay of Plenty	T0	uniform	-	-	-4	0
Bay of Plenty	cv 1	uniform	-	-	0	0.4
Bay of Plenty	cv 2	uniform	-	-	0.1	0.6

Appendix 6: Model selectivity parameterisations by sub-stock

sub-stock	gear method	amax (age)	Lleft	Lright	prior
east Northland	Longling	free	free	free	uniform
east Northland	Pair trawl	6	1.5	30	-
east Northland	single trawl*	5.155023	0.835889	17.21431	-
east Northland	Danish seine*	6.648807	1.35788	34.94152	-
east Northland	rec line pre 1994	free	free	free	uniform
east Northland	rec line post 1994	free	free	free	uniform
east Northland	other (setnet)	7	2	6.5	-
Hauraki Gulf	Longling	free	free	free	uniform
Hauraki Gulf	single trawl	free	free	free	uniform
Hauraki Gulf	Danish seine	free	free	free	uniform
Hauraki Gulf	rec line pre 1994	free	free	free	uniform
Hauraki Gulf	rec line post 1994	free	free	free	uniform
Hauraki Gulf	other (setnet)	7	2	6.5	-
Bay of Plenty	Longling	free	free	free	uniform
Bay of Plenty	single trawl	free	free	free	uniform
Bay of Plenty	Danish seine	free	free	free	uniform
Bay of Plenty	rec line pre 1994	free	free	free	uniform
Bay of Plenty	rec line post 1994	free	free	free	uniform
Bay of Plenty	other (setnet)	7	2	6.5	-

* Parameters derived from Hauraki Gulf base model runs

Appendix 7: SNA1_sp_sea (Model 1) correlation (Pearson) and likelihood statistics

Correlated parameters

```
migration[EN_HG_2].prop_1     size_at_age[HAGU].k_1  0.830832
migration[EN_HG_2].prop_1     size_at_age[HAGU].Linf_1      -0.836785
recruitment[ENLD].YCS_10      recruitment[ENLD].YCS_11      0.943987
recruitment[ENLD].YCS_12      recruitment[ENLD].YCS_26      -0.816523
recruitment[ENLD].YCS_12      recruitment[ENLD].YCS_28      0.820238
recruitment[ENLD].YCS_12      selectivity[Sel_STRAWL].all_3 -0.942305
selectivity[Sel_LLINE].all_1  selectivity[Sel_LLINE].all_2  0.915605
selectivity[Sel_STRAWL].all_1 selectivity[Sel_STRAWL].all_2 0.864547
selectivity[Sel_DSEINE].all_1 selectivity[Sel_DSEINE].all_2 0.846138
size_at_age[BOP].k_1   size_at_age[BOP].Linf_1       -0.882733
size_at_age[HAGU].k_1  size_at_age[HAGU].Linf_1      -0.916706
```

Likelihood summary

	label	likelihood	Like comp.	sddr
9	HG_RES_len_spr	1051.380000	0.0764731	1.0839099
41	EN_REC_len_aut_pre95	1029.870000	0.0749085	21.0367578
55	HG_LL_age_sum	646.461000	0.0470209	1.3074309
63	HG_REC_len_sum_post95	644.975000	0.0469128	1.0377357
45	EN_REC_len_sum_pre95	606.403000	0.0441073	16.2654605
59	HG_REC_len_aut_post95	583.129000	0.0424144	1.0764464
54	HG_LL_age_spr	528.577000	0.0384465	1.1788270
34	EN_LL_age_spr	465.880000	0.0338862	1.2845297
40	EN_REC_len_aut_post95	444.767000	0.0323505	0.5895227
35	EN_LL_age_sum	430.387000	0.0313046	1.2316943
44	EN_REC_len_sum_post95	400.883000	0.0291586	0.6662508
24	BP_REC_len_aut_post95	400.512000	0.0291316	0.8431693
7	BP_RES_len	370.556000	0.0269527	1.3133495
61	HG_REC_len_spr_post95	342.540000	0.0249150	1.1746947
20	BP_LL_age_sum	325.287000	0.0236600	1.0421670
28	BP_REC_len_sum_post95	297.299000	0.0216243	0.6334431
19	BP_LL_age_spr	295.630000	0.0215029	0.9130672
42	EN_REC_len_spr_post95	276.714000	0.0201270	0.7622530
126	prior_on_initialization[ENLD].Cinitial	275.419000	0.0200328	0.0000000
69	HG_ST_len_aut	229.427000	0.0166876	0.9044294
64	HG_REC_len_sum_pre95	198.405000	0.0144312	0.8773849
65	HG_REC_len_win_post95	172.365000	0.0125371	1.2521477
60	HG_REC_len_aut_pre95	163.217000	0.0118717	0.6716732
8	EN_RES_len	158.398000	0.0115212	0.8460268
26	BP_REC_len_spr_post95	156.300000	0.0113686	1.2926885
46	EN_REC_len_win_post95	148.476000	0.0107995	0.7224545
30	BP_REC_len_win_post95	132.126000	0.0096103	0.7384359
29	BP_REC_len_sum_pre95	122.148000	0.0088845	0.7159259
25	BP_REC_len_aut_pre95	121.986000	0.0088728	0.6929450
49	HG_DS_age_sum	115.761000	0.0084200	1.2341348
12	BP_BT_len_aut	100.688000	0.0073236	0.6450121
50	HG_DS_len_aut	99.403500	0.0072302	0.5750226
68	HG_ST_age_sum	88.946300	0.0064696	1.1464787
70	HG_ST_len_win	86.239900	0.0062727	0.7019630
48	HG_DS_age_spr	80.702800	0.0058700	1.1118740
11	BP_BT_age_sum	77.030700	0.0056029	0.7961242
62	HG_REC_len_spr_pre95	72.624500	0.0052824	1.3243163
43	EN_REC_len_spr_pre95	71.424800	0.0051951	1.4107151
143	prior_on_size_at_age[HAGU].k	70.573100	0.0051332	0.0000000
38	EN_LL_len_sum	70.325900	0.0051152	0.8790767
13	BP_BT_len_win	69.660900	0.0050668	0.6593498
10	BP_BT_age_spr	64.316100	0.0046781	1.0767954
114	1995HAGU_HAGU_Tags_season1	61.942400	0.0045054	0.9617369
22	BP_LL_len_aut	60.124800	0.0043732	1.2358282
39	EN_LL_len_win	59.730200	0.0043445	0.6645026
27	BP_REC_len_spr_pre95	55.792000	0.0040581	1.4213889
37	EN_LL_len_aut	55.073100	0.0040058	0.9042249
95	1994HAGU_HAGU_Tags_season2	54.516200	0.0039653	0.8887904
31	BP_REC_len_win_pre95	52.389300	0.0038106	1.4599245
96	1994HAGU_HAGU_Tags_season3	48.871100	0.0035547	0.8890835
57	HG_LL_len_aut	44.442700	0.0032326	0.6901466
85	1994ENLD_ENLD_Tags_season4	43.245900	0.0031455	0.6788306
58	HG_LL_len_win	43.081500	0.0031336	0.5251503
106	1995ENLD_ENLD_Tags_season1	43.049900	0.0031313	0.6201891
32	EN_LL_age_aut	40.708800	0.0029610	1.8715124

51	HG_DS_len_win	39.470400	0.0028709	0.6438355
16	BP_DS_len_aut	38.190400	0.0027778	0.7031223
23	BP_LL_len_win	36.008800	0.0026191	0.5475034
17	BP_DS_len_win	35.952700	0.0026151	0.7147247
115	1995HAGU_HAGU_Tags_season2	35.411500	0.0025757	0.5352316
97	1994HAGU_HAGU_Tags_season4	35.273400	0.0025656	0.5665878
56	HG_LL_age_win	33.299200	0.0024220	1.3884559
18	BP_LL_age_aut	30.046800	0.0021855	1.4117394
47	HG_DS_age_old	-29.460400	0.0021428	0.8647234
110	1995HAGU_BOP_Tags_season1	28.349600	0.0020620	0.3270238
84	1994ENLD_ENLD_Tags_season3	27.906800	0.0020298	0.6514018
52	HG_LL_age_aut	26.538100	0.0019303	1.0126964
21	BP_LL_age_win	26.403200	0.0019205	1.1417288
79	1994BOP_HAGU_Tags_season4	25.366700	0.0018451	0.3737566
83	1994ENLD_ENLD_Tags_season2	25.138500	0.0018285	0.5136109
67	HG_ST_age_spr	24.798600	0.0018037	0.9192963
15	BP_DS_age_sum	23.297800	0.0016946	1.3238254
111	1995HAGU_BOP_Tags_season2	22.954100	0.0016696	0.2396934
89	1994HAGU_BOP_Tags_season2	19.257500	0.0014007	0.2480160
107	1995ENLD_ENLD_Tags_season2	18.771500	0.0013654	0.4155693
14	BP_DS_age_spr	18.519300	0.0013470	0.5235750
73	1994BOP_BOP_Tags_season4	17.790300	0.0012940	0.4343434
118	prior_on_initialization[BOP].R0	17.218000	0.0012524	0.0000000
72	1994BOP_BOP_Tags_season3	17.029600	0.0012387	0.3831254
88	1994ENLD_HAGU_Tags_season4	16.222100	0.0011799	0.3623377
127	prior_on_initialization[HAGU].Cinitial	15.082400	0.0010970	0.0000000
112	1995HAGU_ENLD_Tags_season1	14.222600	0.0010345	0.3020550
6	HG_LLcpue90_04	-14.187300	0.0010319	0.7597775
36	EN_LL_age_win	14.000700	0.0010184	1.3349672
71	1994BOP_BOP_Tags_season2	13.639200	0.0009921	0.3566054
66	HG_ST_age_old	-13.243400	0.0009633	1.2251098
103	1995BOP_HAGU_Tags_season2	11.694800	0.0008506	0.2292081
33	EN_LL_age_old	-11.480900	0.0008351	1.5532399
87	1994ENLD_HAGU_Tags_season3	11.425100	0.0008310	0.3603564
138	prior_on_size_at_age[BOP].Linf	11.135500	0.0008100	0.0000000
108	1995ENLD_HAGU_Tags_season1	10.707800	0.0007788	0.3393765
141	prior_on_size_at_age[ENLD].Linf	10.602500	0.0007712	0.0000000
113	1995HAGU_ENLD_Tags_season2	10.333200	0.0007516	0.2676405
99	1995BOP_BOP_Tags_season2	10.266300	0.0007467	0.2610286
148	prior_on_q_q_HG_LLcpue90_04	-9.743260	0.0007087	0.0000000
98	1995BOP_BOP_Tags_season1	9.504850	0.0006913	0.2833314
147	prior_on_q_q_EN_LLcpue90_04	-9.174570	0.0006673	0.0000000
94	1994HAGU_ENLD_Tags_season4	7.774220	0.0005655	0.2033499
53	HG_LL_age_old	-7.769720	0.0005651	1.0209827
146	prior_on_q_q_BP_LLcpue90_04	-7.564980	0.0005502	0.0000000
82	1994ENLD_BOP_Tags_season4	7.239920	0.0005266	0.2896276
86	1994ENLD_HAGU_Tags_season2	7.024950	0.0005110	0.2367179
104	1995ENLD_BOP_Tags_season1	7.016000	0.0005103	0.2894478
109	1995ENLD_HAGU_Tags_season2	6.853070	0.0004985	0.2212567
93	1994HAGU_ENLD_Tags_season3	6.389020	0.0004647	0.2142597
92	1994HAGU_ENLD_Tags_season2	6.346130	0.0004616	0.1926431
81	1994ENLD_BOP_Tags_season3	5.765300	0.0004193	0.2858831
90	1994HAGU_BOP_Tags_season3	5.708570	0.0004152	0.1827808
80	1994ENLD_BOP_Tags_season2	5.257660	0.0003824	0.2339089
100	1995BOP_ENLD_Tags_season1	4.625060	0.0003364	0.1421830
101	1995BOP_ENLD_Tags_season2	4.564220	0.0003320	0.1317818
76	1994BOP_ENLD_Tags_season4	4.088920	0.0002974	0.1825571
78	1994BOP_HAGU_Tags_season3	4.079450	0.0002967	0.1880736
74	1994BOP_ENLD_Tags_season2	3.771230	0.0002743	0.1407945
75	1994BOP_ENLD_Tags_season3	3.443940	0.0002505	0.1617011
77	1994BOP_HAGU_Tags_season2	3.444250	0.0002505	0.1652826
105	1995ENLD_BOP_Tags_season2	3.066010	0.0002230	0.1941385
102	1995BOP_HAGU_Tags_season1	2.169320	0.0001578	0.1219410
226	YCS_mean_1	2.139560	0.0001556	0.0000000
144	prior_on_size_at_age[HAGU].Linf	1.731480	0.0001259	0.0000000
117	prior_on_initialization[HAGU].R0	1.616850	0.0001176	0.0000000
125	prior_on_initialization[BOP].Cinitial	1.557270	0.0001133	0.0000000
3	HG_Tag_bio	-1.242620	0.0000904	0.0000000
116	prior_on_initialization[ENLD].R0	1.242190	0.0000904	0.0000000
1	BP_Tag_bio	1.088380	0.0000792	0.0000000
91	1994HAGU_BOP_Tags_season4	1.052430	0.0000765	0.1130024
5	EN_LLcpue90_04	-0.992439	0.0000722	1.6648465
135	prior_on_selectivity[Sel_RECR_post95].all	0.789629	0.0000574	0.0000000
4	BP_LLcpue90_04	-0.590617	0.0000430	1.7862155
137	prior_on_size_at_age[BOP].k	0.476876	0.0000347	0.0000000
134	prior_on_selectivity[Sel_RECR_pre95].all	0.328750	0.0000239	0.0000000
2	EN_Tag_bio	-0.098493	0.0000072	0.0000000

140	prior_on_size_at_age[ENLD].k	0.037237	0.0000027	0.0000000
119	prior_on_migration[EN_HG_2].prop	0.000000	0.0000000	0.0000000
120	prior_on_migration[EN_BP_3].prop	0.000000	0.0000000	0.0000000
121	prior_on_migration[HG_EN_2].prop	0.000000	0.0000000	0.0000000
122	prior_on_migration[HG_BP_3].prop	0.000000	0.0000000	0.0000000
123	prior_on_migration[BP_HG_2].prop	0.000000	0.0000000	0.0000000
124	prior_on_migration[BP_EN_3].prop	0.000000	0.0000000	0.0000000
128	prior_on_recruitment[ENLD].YCS	0.000000	0.0000000	0.0000000
129	prior_on_recruitment[HAGU].YCS	0.000000	0.0000000	0.0000000
130	prior_on_recruitment[BOP].YCS	0.000000	0.0000000	0.0000000
131	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
132	prior_on_selectivity[Sel_STRAWL].all	0.000000	0.0000000	0.0000000
133	prior_on_selectivity[Sel_DSEINE].all	0.000000	0.0000000	0.0000000
136	prior_on_selectivity[Sel_RESTRAWL].all	0.000000	0.0000000	0.0000000
139	prior_on_size_at_age[BOP].t0	0.000000	0.0000000	0.0000000
142	prior_on_size_at_age[ENLD].t0	0.000000	0.0000000	0.0000000
145	prior_on_size_at_age[HAGU].t0	0.000000	0.0000000	0.0000000

Appendix 8: ENLD_sea (Model 2) correlation (Pearson) and likelihood statistics

Correlated parameters

recruitment.YCS_13	recruitment.YCS_18	0.817311
recruitment.YCS_13	recruitment.YCS_19	0.80712
recruitment.YCS_13	recruitment.YCS_20	0.832901
recruitment.YCS_13	recruitment.YCS_21	0.845697
recruitment.YCS_13	recruitment.YCS_22	0.82748
recruitment.YCS_13	recruitment.YCS_23	0.832969
recruitment.YCS_13	recruitment.YCS_27	0.812692
recruitment.YCS_13	recruitment.YCS_28	0.812307
recruitment.YCS_14	recruitment.YCS_18	0.817933
recruitment.YCS_14	recruitment.YCS_19	0.811062
recruitment.YCS_14	recruitment.YCS_20	0.835046
recruitment.YCS_14	recruitment.YCS_21	0.8515
recruitment.YCS_14	recruitment.YCS_22	0.828914
recruitment.YCS_14	recruitment.YCS_23	0.836525
recruitment.YCS_14	recruitment.YCS_27	0.816491
recruitment.YCS_14	recruitment.YCS_28	0.818166
recruitment.YCS_17	recruitment.YCS_18	0.836289
recruitment.YCS_17	recruitment.YCS_19	0.844228
recruitment.YCS_17	recruitment.YCS_20	0.882418
recruitment.YCS_17	recruitment.YCS_21	0.892129
recruitment.YCS_17	recruitment.YCS_22	0.88397
recruitment.YCS_17	recruitment.YCS_23	0.884885
recruitment.YCS_17	recruitment.YCS_24	0.803893
recruitment.YCS_17	recruitment.YCS_25	0.836209
recruitment.YCS_17	recruitment.YCS_26	0.826147
recruitment.YCS_17	recruitment.YCS_27	0.866698
recruitment.YCS_17	recruitment.YCS_28	0.865775
recruitment.YCS_18	recruitment.YCS_19	0.853868
recruitment.YCS_18	recruitment.YCS_20	0.895409
recruitment.YCS_18	recruitment.YCS_21	0.90371
recruitment.YCS_18	recruitment.YCS_22	0.897473
recruitment.YCS_18	recruitment.YCS_23	0.890169
recruitment.YCS_18	recruitment.YCS_24	0.816786
recruitment.YCS_18	recruitment.YCS_25	0.849973
recruitment.YCS_18	recruitment.YCS_26	0.833438
recruitment.YCS_18	recruitment.YCS_27	0.876791
recruitment.YCS_18	recruitment.YCS_28	0.883767
recruitment.YCS_19	recruitment.YCS_20	0.866945
recruitment.YCS_19	recruitment.YCS_21	0.896263
recruitment.YCS_19	recruitment.YCS_22	0.883384
recruitment.YCS_19	recruitment.YCS_23	0.883303
recruitment.YCS_19	recruitment.YCS_24	0.816322
recruitment.YCS_19	recruitment.YCS_25	0.854234
recruitment.YCS_19	recruitment.YCS_26	0.83904
recruitment.YCS_19	recruitment.YCS_27	0.879241
recruitment.YCS_19	recruitment.YCS_28	0.868898
recruitment.YCS_20	recruitment.YCS_21	0.916919
recruitment.YCS_20	recruitment.YCS_22	0.911824

recruitment.YCS_20	recruitment.YCS_23	0.914996
recruitment.YCS_20	recruitment.YCS_24	0.830507
recruitment.YCS_20	recruitment.YCS_25	0.866819
recruitment.YCS_20	recruitment.YCS_26	0.85473
recruitment.YCS_20	recruitment.YCS_27	0.908508
recruitment.YCS_20	recruitment.YCS_28	0.901636
recruitment.YCS_20	recruitment.YCS_29	0.802097
recruitment.YCS_21	recruitment.YCS_22	0.916279
recruitment.YCS_21	recruitment.YCS_23	0.923583
recruitment.YCS_21	recruitment.YCS_24	0.851327
recruitment.YCS_21	recruitment.YCS_25	0.878231
recruitment.YCS_21	recruitment.YCS_26	0.874723
recruitment.YCS_21	recruitment.YCS_27	0.908594
recruitment.YCS_21	recruitment.YCS_28	0.913532
recruitment.YCS_21	recruitment.YCS_29	0.801628
recruitment.YCS_22	recruitment.YCS_23	0.909038
recruitment.YCS_22	recruitment.YCS_24	0.826161
recruitment.YCS_22	recruitment.YCS_25	0.864491
recruitment.YCS_22	recruitment.YCS_26	0.85692
recruitment.YCS_22	recruitment.YCS_27	0.90259
recruitment.YCS_22	recruitment.YCS_28	0.898288
recruitment.YCS_22	recruitment.YCS_29	0.803329
recruitment.YCS_23	recruitment.YCS_24	0.832466
recruitment.YCS_23	recruitment.YCS_25	0.863031
recruitment.YCS_23	recruitment.YCS_26	0.862062
recruitment.YCS_23	recruitment.YCS_27	0.904745
recruitment.YCS_23	recruitment.YCS_28	0.906362
recruitment.YCS_23	recruitment.YCS_29	0.80067
recruitment.YCS_24	recruitment.YCS_27	0.817159
recruitment.YCS_24	recruitment.YCS_28	0.836555
recruitment.YCS_25	recruitment.YCS_26	0.818097
recruitment.YCS_25	recruitment.YCS_27	0.864247
recruitment.YCS_25	recruitment.YCS_28	0.868163
recruitment.YCS_26	recruitment.YCS_27	0.844144
recruitment.YCS_26	recruitment.YCS_28	0.854758
recruitment.YCS_27	recruitment.YCS_28	0.89896
recruitment.YCS_27	recruitment.YCS_29	0.808213
recruitment.YCS_28	recruitment.YCS_29	0.808767
selectivity[Sel_LLINE].all_1	selectivity[Sel_LLINE].all_2	0.934422
selectivity[Sel_RESTRAWL].all_1	selectivity[Sel_RESTRAWL].all_2	-0.999717
selectivity[Sel_RESTRAWL].all_1	selectivity[Sel_RESTRAWL].all_3	-0.93845
selectivity[Sel_RESTRAWL].all_2	selectivity[Sel_RESTRAWL].all_3	0.938501
size_at_age.k_1	size_at_age.Linf_1	-0.888153
size_at_age.k_1	size_at_age.t0_1	0.866586

Likelihood summary

Total Likelihood: 4061.702843

	label	likelihood	Like	comp.sddr
12	EN_REC_len_aut_post95	813.122000	0.1956336	1.1075843
16	EN_REC_len_sum_post95	634.748000	0.1527176	1.1259836
7	EN_LL_age_sum	405.645000	0.0975964	1.0711489
6	EN_LL_age_spr	389.419000	0.0936925	0.9700701
14	EN_REC_len_spr_post95	314.738000	0.0757246	1.0586548
25	prior_on_initialization.Cinitial	286.622000	0.0689600	0.0000000
13	EN_REC_len_aut_pre95	239.354000	0.0575875	1.0745132
17	EN_REC_len_sum_pre95	205.861000	0.0495293	0.9403251
18	EN_REC_len_win_post95	189.996000	0.0457122	1.0683716
10	EN_LL_len_sum	112.414000	0.0270463	1.0596468
11	EN_LL_len_win	107.597000	0.0258874	1.1051037
9	EN_LL_len_aut	57.745300	0.0138933	0.9563722
31	prior_on_size_at_age.k	54.606300	0.0131380	0.0000000
22	1995ENLD_Tags_season1	43.712600	0.0105171	0.7077346
21	1994ENLD_Tags_season4	43.585900	0.0104866	0.6937778
15	EN_REC_len_spr_pre95	35.564900	0.0085568	0.9722720
3	EN_RES_len	32.555800	0.0078328	0.6189118
20	1994ENLD_Tags_season3	31.281200	0.0075261	0.5566359
19	1994ENLD_Tags_season2	28.521700	0.0068622	0.0000000
23	1995ENLD_Tags_season2	20.016000	0.0048158	0.5753117
4	EN_LL_age_aut	16.366800	0.0039378	0.9196448
5	EN_LL_age_old	-15.773800	0.0037951	1.2282954
24	prior_on_initialization.R0	14.743700	0.0035473	0.4770609
8	EN_LL_age_win	13.600500	0.0032722	1.2131043
26	prior_on_recruitment.YCS	-10.933300	0.0026305	0.0000000
2	EN_LLcpue90_04	-10.890300	0.0026202	1.0319917

34	prior_on_q_q_EN_LLcpue90_04	-9.067710	0.0021817	0.0000000
32	prior_on_size_at_age.Linf	7.667910	0.0018449	0.0000000
63	YCS_mean_1	4.235430	0.0010190	0.0000000
28	prior_on_selectivity[Sel_RECR_pre95].all	3.520410	0.0008470	0.0000000
29	prior_on_selectivity[Sel_RECR_post95].all	1.786270	0.0004298	0.0000000
1	ENLD_Tag_bio	-0.658767	0.0001585	0.0000000
27	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
30	prior_on_selectivity[Sel_RESTRAWL].all	0.000000	0.0000000	0.0000000
33	prior_on_size_at_age.t0	0.000000	0.0000000	0.0000000

Appendix 9: SNA1_sp_ann (Model 5) correlation (Pearson) and likelihood statistics

Correlated parameters

selectivity[Sel_LLINE].all_1	selectivity[Sel_LLINE].all_2	0.95095
selectivity[Sel_STRAWL].all_1	selectivity[Sel_STRAWL].all_2	0.898689
selectivity[Sel_RESTRAWL].all_1	selectivity[Sel_RESTRAWL].all_2	0.890353
selectivity[Sel_RESTRAWL].all_1	selectivity[Sel_RESTRAWL].all_3	-0.883253

Likelihood summary

	label	likelihood	Like comp.	sddr
20	EN_REC_len_post95	557.297000	0.1134535	0.9938528
24	HG_LL_age	517.817000	0.1054162	1.0290589
26	HG_REC_len_post95	455.192000	0.0926671	0.7369324
17	EN_LL_age	418.323000	0.0851614	1.1970339
14	BP_LL_age	372.227000	0.0757773	1.1755850
15	BP_REC_len_post95	282.573000	0.0575257	1.1817531
58	prior_on_initialization[ENLD].Cinitial	274.019000	0.0557843	0.0000000
27	HG_REC_len_pre95	200.123000	0.0407407	0.9124592
16	BP_REC_len_pre95	184.485000	0.0375571	1.0401314
21	EN_REC_len_pre95	175.939000	0.0358173	0.8743680
9	HG_RES_len	139.371000	0.0283729	0.8912565
8	EN_RES_len	134.398000	0.0273605	0.5694767
10	BP_BT_age	101.242000	0.0206107	0.9940765
11	BP_BT_len	89.047700	0.0181282	1.8491999
22	HG_DS_age	83.579600	0.0170150	1.0364828
38	1994HAGU_HAGU_Tags	82.691900	0.0168343	1.3488388
19	EN_LL_len	78.924700	0.0160673	0.7500230
7	BP_RES_len	67.845800	0.0138119	0.5186047
47	1995HAGU_HAGU_Tags	63.556300	0.0129387	1.0425237
34	1994ENLD_ENLD_Tags	52.248900	0.0106367	0.9339627
43	1995ENLD_ENLD_Tags	44.596100	0.0090788	0.6268997
13	BP_DS_len	42.792900	0.0087117	0.7410478
45	1995HAGU_BOP_Tags	40.801200	0.0083062	0.3883853
23	HG_DS_age_old	-32.296400	0.0065748	0.8557317
28	HG_ST_age	29.826800	0.0060721	0.4602044
30	1994BOP_BOP_Tags	26.588800	0.0054129	0.6008681
32	1994BOP_HAGU_Tags	26.182500	0.0053302	0.4038486
12	BP_DS_age	24.542500	0.0049963	0.8418331
35	1994ENLD_HAGU_Tags	22.196600	0.0045187	0.4080335
36	1994HAGU_BOP_Tags	19.047900	0.0038777	NA
6	HG_LLcpue90_04	-16.919400	0.0034444	0.4290380
49	prior_on_initialization[HAGU].R0	15.911800	0.0032393	0.0000000
39	1995BOP_BOP_Tags	15.390100	0.0031331	0.3524171
46	1995HAGU_ENLD_Tags	15.168500	0.0030880	0.3247333
50	prior_on_initialization[BOP].R0	15.055800	0.0030650	0.0000000
48	prior_on_initialization[ENLD].R0	14.397000	0.0029309	0.0000000
59	prior_on_initialization[HAGU].Cinitial	14.196400	0.0028901	0.0000000
18	EN_LL_age_old	-12.535900	0.0025520	1.5220819
44	1995ENLD_HAGU_Tags	12.226600	0.0024891	0.3334690
5	EN_LLcpue90_04	-11.221400	0.0022844	1.0014259
41	1995BOP_HAGU_Tags	11.139500	0.0022678	0.2382583
29	HG_ST_age_old	-10.852400	0.0022093	0.9536223
25	HG_LL_age_old	-10.850200	0.0022089	1.1560133
37	1994HAGU_ENLD_Tags	10.702700	0.0021788	0.2538560
33	1994ENLD_BOP_Tags	10.267500	0.0020902	0.3141232
80	prior_on_q_q_HG_LLcpue90_04	-9.771130	0.0019892	0.0000000
79	prior_on_q_q_EN_LLcpue90_04	-9.150870	0.0018629	0.0000000
4	BP_LLcpue90_04	-8.052540	0.0016393	1.2735377
31	1994BOP_ENLD_Tags	7.819000	0.0015918	0.2658584
40	1995BOP_ENLD_Tags	7.614810	0.0015502	0.1899570

78	prior_on_q_q_BP_LLcpue90_04	-7.487390	0.0015243	0.0000000
42	1995ENLD_BOP_Tags	6.178460	0.0012578	0.2677398
70	prior_on_size_at_age[BOP].Linf	5.370220	0.0010933	0.0000000
73	prior_on_size_at_age[ENLD].Linf	5.341660	0.0010874	0.0000000
101	YCS_mean_1	1.765910	0.0003595	0.0000000
2	EN_Tag_bio	-1.219320	0.0002482	0.0000000
1	BP_Tag_bio	-1.035280	0.0002108	0.0000000
72	prior_on_size_at_age[ENLD].k	0.933388	0.0001900	0.0000000
69	prior_on_size_at_age[BOP].k	0.889653	0.0001811	0.0000000
3	HG_Tag_bio	-0.815674	0.0001661	0.0000000
66	prior_on_selectivity[Sel_RECR_pre95].all	0.593342	0.0001208	0.0000000
76	prior_on_size_at_age[HAGU].Linf	0.495987	0.0001010	0.0000000
75	prior_on_size_at_age[HAGU].k	0.446892	0.0000910	0.0000000
57	prior_on_initialization[BOP].Cinitial	0.271558	0.0000553	0.0000000
67	prior_on_selectivity[Sel_RECR_post95].all	0.031345	0.0000064	0.0000000
51	prior_on_migration[EN_HG_2].prop	0.000000	0.0000000	0.0000000
52	prior_on_migration[EN_BP_3].prop	0.000000	0.0000000	0.0000000
53	prior_on_migration[HG_EN_2].prop	0.000000	0.0000000	0.0000000
54	prior_on_migration[HG_BP_3].prop	0.000000	0.0000000	0.0000000
55	prior_on_migration[BP_HG_2].prop	0.000000	0.0000000	0.0000000
56	prior_on_migration[BP_EN_3].prop	0.000000	0.0000000	0.0000000
60	prior_on_recruitment[ENLD].YCS	0.000000	0.0000000	0.0000000
61	prior_on_recruitment[HAGU].YCS	0.000000	0.0000000	0.0000000
62	prior_on_recruitment[BOP].YCS	0.000000	0.0000000	0.0000000
63	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
64	prior_on_selectivity[Sel_STRAWL].all	0.000000	0.0000000	0.0000000
65	prior_on_selectivity[Sel_DSEINE].all	0.000000	0.0000000	0.0000000
68	prior_on_selectivity[Sel_RESTRAWL].all	0.000000	0.0000000	0.0000000
71	prior_on_size_at_age[BOP].t0	0.000000	0.0000000	0.0000000
74	prior_on_size_at_age[ENLD].t0	0.000000	0.0000000	0.0000000
77	prior_on_size_at_age[HAGU].t0	0.000000	0.0000000	0.0000000

Appendix 10: ENLD_ann (Model 6) correlation (Pearson) and likelihood statistics

Correlated parameters

recruitment.YCS_17	recruitment.YCS_20	0.818245
recruitment.YCS_17	recruitment.YCS_21	0.850704
recruitment.YCS_17	recruitment.YCS_22	0.815651
recruitment.YCS_17	recruitment.YCS_23	0.82566
recruitment.YCS_17	recruitment.YCS_27	0.802504
recruitment.YCS_18	recruitment.YCS_20	0.834285
recruitment.YCS_18	recruitment.YCS_21	0.872521
recruitment.YCS_18	recruitment.YCS_22	0.835926
recruitment.YCS_18	recruitment.YCS_23	0.845782
recruitment.YCS_18	recruitment.YCS_27	0.818895
recruitment.YCS_18	recruitment.YCS_28	0.818767
recruitment.YCS_19	recruitment.YCS_21	0.830393
recruitment.YCS_19	recruitment.YCS_22	0.8184
recruitment.YCS_19	recruitment.YCS_23	0.830146
recruitment.YCS_19	recruitment.YCS_28	0.804982
recruitment.YCS_20	recruitment.YCS_21	0.851031
recruitment.YCS_20	recruitment.YCS_22	0.831411
recruitment.YCS_20	recruitment.YCS_23	0.852943
recruitment.YCS_20	recruitment.YCS_27	0.825462
recruitment.YCS_20	recruitment.YCS_28	0.814033
recruitment.YCS_21	recruitment.YCS_22	0.838864
recruitment.YCS_21	recruitment.YCS_23	0.86315
recruitment.YCS_21	recruitment.YCS_27	0.844469
recruitment.YCS_21	recruitment.YCS_28	0.843566
recruitment.YCS_22	recruitment.YCS_23	0.834979
recruitment.YCS_22	recruitment.YCS_27	0.827182
recruitment.YCS_22	recruitment.YCS_28	0.815766
recruitment.YCS_23	recruitment.YCS_27	0.83364
recruitment.YCS_23	recruitment.YCS_28	0.839771
recruitment.YCS_27	recruitment.YCS_28	0.821078
selectivity[Sel_LLINE].all_1	selectivity[Sel_LLINE].all_2	0.943803
selectivity[Sel_RESTRAWL].all_1	selectivity[Sel_RESTRAWL].all_2	0.932312
size_at_age.k_1	size_at_age.Linf_1	-0.834239

Likelihood summary

Total Likelihood: 1771.180213

	label	likelihood	Like comp.	sddr
7	EN_REC_len_post95	581.919000	0.3107877	1.1177511
4	EN_LL_age	405.272000	0.2164452	1.0762515
12	prior_on_initialization.Cinitial	274.432000	0.1465670	0.0000000
8	EN_REC_len_pre95	180.225000	0.0962535	0.9113232
3	EN_RES_len	129.103000	0.0689505	0.6163338
6	EN_LL_len	110.994000	0.0592790	0.9985124
9	1994ENLD_Tags	66.685200	0.0356148	1.0554427
10	1995ENLD_Tags	52.064000	0.0278060	0.7714349
5	EN_LL_age_old	-16.831500	0.0089893	1.1776487
11	prior_on_initialization.R0	14.855900	0.0079341	0.0000000
2	EN_LLcpue90_04	-12.168500	0.0064989	0.9284512
13	prior_on_recruitment.YCS	-11.206900	0.0059853	0.0000000
21	prior_on_q_q_EN_LLcpue90_04	-9.049070	0.0048329	0.0000000
29	YCS_mean_1	4.290320	0.0022913	0.0000000
1	ENLD_Tag_bio	-1.354010	0.0007231	0.0000000
19	prior_on_size_at_age.Linf	1.183640	0.0006322	0.0000000
15	prior_on_selectivity[Sel_RECR_pre95].all	0.412388	0.0002202	0.0000000
18	prior_on_size_at_age.k	0.311353	0.0001663	0.0000000
16	prior_on_selectivity[Sel_RECR_post95].all	0.042392	0.0000226	0.0000000
14	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
17	prior_on_selectivity[Sel_RESTRAWL].all	0.000000	0.0000000	0.0000000
20	prior_on_size_at_age.t0	0.000000	0.0000000	0.0000000

Appendix 11: HAGU_sea (Model 3) correlation (Pearson) and likelihood statistics

Correlated parameters

recruitment.YCS_16	recruitment.YCS_21	0.836332
recruitment.YCS_17	recruitment.YCS_20	0.805703
recruitment.YCS_17	recruitment.YCS_21	0.852161
recruitment.YCS_17	recruitment.YCS_23	0.810788
recruitment.YCS_18	recruitment.YCS_21	0.84823
recruitment.YCS_18	recruitment.YCS_23	0.800706
recruitment.YCS_20	recruitment.YCS_21	0.807124
recruitment.YCS_20	recruitment.YCS_23	0.806233
recruitment.YCS_21	recruitment.YCS_23	0.839573
selectivity[Sel_LLINE].all_1	selectivity[Sel_LLINE].all_2	0.937801
selectivity[Sel_DSEINE].all_1	selectivity[Sel_DSEINE].all_2	0.898825
size_at_age.k_1	size_at_age.Linf_1	-0.946586

Likelihood summary

Total Likelihood: 4762.167535

	label	likelihood	Like comp.	sddr
20	HG_REC_len_sum_post95	633.263000	0.1288470	1.0319230
3	HG_RES_len_spr	607.493000	0.1236037	0.6422954
16	HG_REC_len_aut_post95	577.814000	0.1175651	1.0852025
12	HG_LL_age_sum	456.996000	0.0929828	0.9308481
11	HG_LL_age_spr	421.448000	0.0857500	0.9921576
18	HG_REC_len_spr_post95	260.786000	0.0530609	1.0864674
26	HG_ST_len_aut	257.341000	0.0523599	1.0657184
21	HG_REC_len_sum_pre95	199.971000	0.0406871	1.0319230
7	HG_DS_len_aut	167.186000	0.0340165	0.9442826
17	HG_REC_len_aut_pre95	166.180000	0.0338119	1.0852025
22	HG_REC_len_win_post95	131.718000	0.0268000	1.0435019
27	HG_ST_len_win	127.813000	0.0260055	1.0198694
6	HG_DS_age_sum	90.806000	0.0184759	1.0798606
15	HG_LL_len_win	72.298000	0.0147101	0.9192595
5	HG_DS_age_spr	69.577100	0.0141565	1.0480358
8	HG_DS_len_win	67.259900	0.0136851	0.9631520
31	1995HAGU_Tags_season1	63.472500	0.0129144	1.0832150
14	HG_LL_len_aut	61.515200	0.0125162	0.9534330
25	HG_ST_age_sum	55.902800	0.0113743	1.1335161
28	1994HAGU_Tags_season2	52.346900	0.0106508	0.8780327
19	HG_REC_len_spr_pre95	46.651300	0.0094919	1.0829208
29	1994HAGU_Tags_season3	46.295700	0.0094196	0.9187217
32	1995HAGU_Tags_season2	41.404800	0.0084244	0.6053615
30	1994HAGU_Tags_season4	38.937700	0.0079225	0.6344076

4	HG_DS_age_old	-31.169800	0.0063420	0.8802089
9	HG_LL_age_aut	23.877000	0.0048581	0.9459361
13	HG_LL_age_win	23.064100	0.0046927	0.9752013
42	prior_on_size_at_age.k	22.735800	0.0046259	0.0000000
34	prior_on_initialization.Cinitial	20.344900	0.0041395	0.0000000
2	HG_LLcpue90_04	-16.484100	0.0033539	0.4899913
33	prior_on_initialization.R0	15.910100	0.0032372	0.0000000
23	HG_ST_age_old	-12.686300	0.0025812	1.2656516
24	HG_ST_age_spr	11.889500	0.0024191	2.3349234
45	prior_on_q_HG_LLcpue90_04	-9.611590	0.0019556	0.0000000
10	HG_LL_age_old	-5.128860	0.0010435	1.5514367
70	YCS_mean_1	4.299450	0.0008748	0.0000000
1	HAGU_Tag_bio	-1.257810	0.0002559	0.0000000
39	prior_on_selectivity[Sel_RECR_pre95].all	0.791867	0.0001611	0.0000000
43	prior_on_size_at_age.Linf	0.603665	0.0001228	0.0000000
40	prior_on_selectivity[Sel_RECR_post95].all	0.512713	0.0001043	0.0000000
35	prior_on_recruitment.YCS	0.000000	0.0000000	0.0000000
36	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
37	prior_on_selectivity[Sel_STRAWL].all	0.000000	0.0000000	0.0000000
38	prior_on_selectivity[Sel_DSEINE].all	0.000000	0.0000000	0.0000000
41	prior_on_selectivity[Sel_RESTRAWL].all	0.000000	0.0000000	0.0000000
44	prior_on_size_at_age.t0	0.000000	0.0000000	0.0000000

Appendix 12: HAGU_ann (Model 7) correlation (Pearson) and likelihood statistics

Correlated parameters

selectivity[Sel_LLINE].all_1	selectivity[Sel_LLINE].all_2	0.961446
selectivity[Sel_DSEINE].all_1	selectivity[Sel_DSEINE].all_2	0.929431

Likelihood summary

Total Likelihood: 1455.736772

	label	likelihood	Like comp.	sddr
6	HG_LL_age	497.669000	0.3082320	0.9905173
8	HG_REC_len_post95	456.604000	0.2827983	0.7670054
9	HG_REC_len_pre95	193.588000	0.1198990	0.8487524
12	1994HAGU_Tags	108.906000	0.0674511	1.3863430
13	1995HAGU_Tags	75.247700	0.0466048	1.2088450
4	HG_DS_age	75.036200	0.0464738	0.8998491
3	HG_RES_len	63.629000	0.0394087	0.6646176
5	HG_DS_age_old	-36.255700	0.0224550	0.8142319
10	HG_ST_age	28.878200	0.0178858	0.4352839
2	HG_LLcpue90_04	-16.410200	0.0101637	0.4971541
14	prior_on_initialization.R0	15.875200	0.0098323	0.0000000
15	prior_on_initialization.Cinitial	15.402000	0.0095392	0.0000000
11	HG_ST_age_old	-10.176900	0.0063031	1.0505068
26	prior_on_q_HG_LLcpue90_04	-9.489580	0.0058774	0.0000000
7	HG_LL_age_old	-5.837870	0.0036157	1.5188351
33	YCS_mean_1	3.414870	0.0021150	0.0000000
1	HAGU_Tag_bio	-1.257610	0.0007789	0.0000000
21	prior_on_selectivity[Sel_RECR_post95].all	0.445859	0.0002761	0.0000000
20	prior_on_selectivity[Sel_RECR_pre95].all	0.248832	0.0001541	0.0000000
24	prior_on_size_at_age.Linf	0.159700	0.0000989	0.0000000
23	prior_on_size_at_age.k	0.060071	0.0000372	0.0000000
16	prior_on_recruitment.YCS	0.000000	0.0000000	0.0000000
17	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
18	prior_on_selectivity[Sel_STRAWL].all	0.000000	0.0000000	0.0000000
19	prior_on_selectivity[Sel_DSEINE].all	0.000000	0.0000000	0.0000000
22	prior_on_selectivity[Sel_RESTRAWL].all	0.000000	0.0000000	0.0000000
25	prior_on_size_at_age.t0	0.000000	0.0000000	0.0000000

Appendix 13: HGBOP_sp_ann (Model 9) correlation (Pearson) and likelihood statistics

Correlated parameters

recruitment[BOP].YCS_8	recruitment[BOP].YCS_11	-0.861167
recruitment[BOP].YCS_10	selectivity[Sel_LLINE].all_3	0.986548
recruitment[BOP].YCS_10	selectivity[Sel_RESTRAWL].all_2	0.872444

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selectivity[Sel_LLINE].all_1  selectivity[Sel_LLINE].all_2  0.946775
selectivity[Sel_LLINE].all_3  selectivity[Sel_RESTRAWL].all_2      0.88744
selectivity[Sel_STRAWL].all_1 selectivity[Sel_STRAWL].all_2 0.930452
selectivity[Sel_DSEINE].all_1 selectivity[Sel_DSEINE].all_2 0.870386
size_at_age[BOP].Linf_1       size_at_age[BOP].t0_1  0.84085
```

Likelihood summary

	label	likelihood	Like comp.	sddr
18	HG_REC_len_post95	548.867000	0.1794469	0.8704435
16	HG_LL_age	501.237000	0.1638747	1.0033581
11	BP_LL_age	310.866000	0.1016347	1.0494990
12	BP_REC_len_post95	282.236000	0.0922744	1.2562677
19	HG_REC_len_pre95	213.328000	0.0697456	0.9711604
13	BP_REC_len_pre95	210.404000	0.0687896	1.1858838
6	HG_RES_len	140.213000	0.0458413	1.4339148
7	BP_BT_age	103.426000	0.0338142	1.0633254
14	HG_DS_age	80.241200	0.0262341	0.9793573
5	BP_RES_len	77.028400	0.0251837	1.9876831
25	1994HAGU_HAGU_Tags	74.115600	0.0242314	1.2895271
10	BP_DS_len	68.643200	0.0224422	1.0851104
29	1995HAGU_HAGU_Tags	65.940700	0.0215587	1.1335989
8	BP_BT_len	39.815700	0.0130174	1.0288545
28	1995HAGU_BOP_Tags	35.166600	0.0114974	0.4080640
15	HG_DS_age_old	-35.142900	0.0114896	0.8250793
20	HG_ST_age	29.971400	0.0097989	0.4690217
22	1994BOP_BOP_Tags	27.659300	0.0090429	0.6687744
9	BP_DS_age	25.241600	0.0082525	0.9343350
23	1994BOP_HAGU_Tags	21.321700	0.0069709	0.4390969
24	1994HAGU_BOP_Tags	20.430600	0.0066796	0.3564172
26	1995BOP_BOP_Tags	17.469200	0.0057114	0.3532111
4	HG_LLcpue90_04	-17.453700	0.0057063	0.3490723
30	prior_on_initialization[HAGU].R0	15.915100	0.0052033	0.0000000
31	prior_on_initialization[BOP].R0	14.846100	0.0048538	0.0000000
35	prior_on_initialization[HAGU].Cinitial	14.347900	0.0046909	0.0000000
27	1995BOP_HAGU_Tags	11.327800	0.0037035	0.2851290
21	HG_ST_age_old	-10.444000	0.0034146	1.0092053
3	BP_LLcpue90_04	-10.327900	0.0033766	1.0378916
51	prior_on_q_q_HG_LLcpue90_04	-9.818330	0.0032100	0.0000000
17	HG_LL_age_old	-7.753170	0.0025348	1.4218060
50	prior_on_q_q_BP_LLcpue90_04	-7.290390	0.0023835	0.0000000
45	prior_on_size_at_age[BOP].Linf	3.221490	0.0010532	0.0000000
64	YCS_mean_1	1.823450	0.0005962	0.0000000
1	BP_Tag_bio	-1.164450	0.0003807	0.0000000
47	prior_on_size_at_age[HAGU].k	1.036360	0.0003388	0.0000000
48	prior_on_size_at_age[HAGU].Linf	0.777291	0.0002541	0.0000000
42	prior_on_selectivity[Sel_RECR_post95].all	0.643595	0.0002104	0.0000000
44	prior_on_size_at_age[BOP].k	0.625158	0.0002044	0.0000000
2	HG_Tag_bio	-0.611266	0.0001998	0.0000000
41	prior_on_selectivity[Sel_RECR_pre95].all	0.279409	0.0000914	0.0000000
34	prior_on_initialization[BOP].Cinitial	0.164739	0.0000539	0.0000000
58	CatchMustBeTaken_BP_LLINE	0.004726	0.0000015	0.0000000
59	CatchMustBeTaken_BP_STRAWL	0.004726	0.0000015	0.0000000
60	CatchMustBeTaken_BP_DSEINE	0.004726	0.0000015	0.0000000
61	CatchMustBeTaken_BP_OTHER	0.004726	0.0000015	0.0000000
62	CatchMustBeTaken_BP_RECR_pre95	0.004726	0.0000015	0.0000000
32	prior_on_migration[HG_BP_2].prop	0.000000	0.0000000	0.0000000
33	prior_on_migration[BP_HG_2].prop	0.000000	0.0000000	0.0000000
36	prior_on_recruitment[HAGU].YCS	0.000000	0.0000000	0.0000000
37	prior_on_recruitment[BOP].YCS	0.000000	0.0000000	0.0000000
38	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
39	prior_on_selectivity[Sel_STRAWL].all	0.000000	0.0000000	0.0000000
40	prior_on_selectivity[Sel_DSEINE].all	0.000000	0.0000000	0.0000000
43	prior_on_selectivity[Sel_RESTRAWL].all	0.000000	0.0000000	0.0000000
46	prior_on_size_at_age[BOP].t0	0.000000	0.0000000	0.0000000
49	prior_on_size_at_age[HAGU].t0	0.000000	0.0000000	0.0000000

Appendix 14: BOP_sea (Model 4) correlation (Pearson) and likelihood statistics

Correlated parameters

recruitment.YCS_13	recruitment.YCS_17	0.828439
recruitment.YCS_13	recruitment.YCS_18	0.83673
recruitment.YCS_13	recruitment.YCS_20	0.820707
recruitment.YCS_13	recruitment.YCS_21	0.846918
recruitment.YCS_13	recruitment.YCS_22	0.815606
recruitment.YCS_13	recruitment.YCS_27	0.801854
recruitment.YCS_16	recruitment.YCS_17	0.843928
recruitment.YCS_16	recruitment.YCS_18	0.860975
recruitment.YCS_16	recruitment.YCS_20	0.855119
recruitment.YCS_16	recruitment.YCS_21	0.874081
recruitment.YCS_16	recruitment.YCS_22	0.839566
recruitment.YCS_16	recruitment.YCS_23	0.835308
recruitment.YCS_16	recruitment.YCS_26	0.828101
recruitment.YCS_16	recruitment.YCS_27	0.836881
recruitment.YCS_16	recruitment.YCS_28	0.825312
recruitment.YCS_17	recruitment.YCS_18	0.917396
recruitment.YCS_17	recruitment.YCS_19	0.843866
recruitment.YCS_17	recruitment.YCS_20	0.907002
recruitment.YCS_17	recruitment.YCS_21	0.93589
recruitment.YCS_17	recruitment.YCS_22	0.897525
recruitment.YCS_17	recruitment.YCS_23	0.892246
recruitment.YCS_17	recruitment.YCS_24	0.815302
recruitment.YCS_17	recruitment.YCS_25	0.801169
recruitment.YCS_17	recruitment.YCS_26	0.883093
recruitment.YCS_17	recruitment.YCS_27	0.895907
recruitment.YCS_17	recruitment.YCS_28	0.879632
recruitment.YCS_18	recruitment.YCS_19	0.848963
recruitment.YCS_18	recruitment.YCS_20	0.90924
recruitment.YCS_18	recruitment.YCS_21	0.942221
recruitment.YCS_18	recruitment.YCS_22	0.90266
recruitment.YCS_18	recruitment.YCS_23	0.89824
recruitment.YCS_18	recruitment.YCS_24	0.824223
recruitment.YCS_18	recruitment.YCS_25	0.813518
recruitment.YCS_18	recruitment.YCS_26	0.891784
recruitment.YCS_18	recruitment.YCS_27	0.900656
recruitment.YCS_18	recruitment.YCS_28	0.88546
recruitment.YCS_19	recruitment.YCS_20	0.832902
recruitment.YCS_19	recruitment.YCS_21	0.864906
recruitment.YCS_19	recruitment.YCS_22	0.83146
recruitment.YCS_19	recruitment.YCS_23	0.826774
recruitment.YCS_19	recruitment.YCS_26	0.818806
recruitment.YCS_19	recruitment.YCS_27	0.8281
recruitment.YCS_19	recruitment.YCS_28	0.812896
recruitment.YCS_20	recruitment.YCS_21	0.919934
recruitment.YCS_20	recruitment.YCS_22	0.884332
recruitment.YCS_20	recruitment.YCS_23	0.87215
recruitment.YCS_20	recruitment.YCS_24	0.806345
recruitment.YCS_20	recruitment.YCS_26	0.8769
recruitment.YCS_20	recruitment.YCS_27	0.876598
recruitment.YCS_20	recruitment.YCS_28	0.870487
recruitment.YCS_21	recruitment.YCS_22	0.911989
recruitment.YCS_21	recruitment.YCS_23	0.897833
recruitment.YCS_21	recruitment.YCS_24	0.820898
recruitment.YCS_21	recruitment.YCS_25	0.81193
recruitment.YCS_21	recruitment.YCS_26	0.895544
recruitment.YCS_21	recruitment.YCS_27	0.910456
recruitment.YCS_21	recruitment.YCS_28	0.895773
recruitment.YCS_22	recruitment.YCS_23	0.851918
recruitment.YCS_22	recruitment.YCS_26	0.85677
recruitment.YCS_22	recruitment.YCS_27	0.871491
recruitment.YCS_22	recruitment.YCS_28	0.855217
recruitment.YCS_23	recruitment.YCS_26	0.854401
recruitment.YCS_23	recruitment.YCS_27	0.860577
recruitment.YCS_23	recruitment.YCS_28	0.846747
recruitment.YCS_26	recruitment.YCS_27	0.845197
recruitment.YCS_26	recruitment.YCS_28	0.852934
recruitment.YCS_27	recruitment.YCS_28	0.845401
selectivity[Sel_LLINE].all_1	selectivity[Sel_LLINE].all_2	0.913918
selectivity[Sel_RESTRAWL].all_1	selectivity[Sel_RESTRAWL].all_2	0.942809

Likelihood summary

Total like 3706.8

	label	likelihood	Like comp.	sddr
22	BP_REC_len_sum_post95	469.775000	0.1256217	1.0011078
18	BP_REC_len_aut_post95	402.005000	0.1074994	0.8965099
14	BP_LL_age_sum	391.322000	0.1046427	1.2501026
6	BP_BT_len_aut	314.991000	0.0842312	1.6351815
13	BP_LL_age_spr	294.624000	0.0787849	0.8286577
20	BP_REC_len_spr_post95	230.545000	0.0616496	2.0032715
24	BP_REC_len_win_post95	205.050000	0.0548321	1.2675197
29	1995BOP_Tags_season2	191.363000	0.0511720	0.3502434
19	BP_REC_len_aut_pre95	126.694000	0.0338790	0.8014830
23	BP_REC_len_sum_pre95	124.079000	0.0331797	0.7521986
7	BP_BT_len_win	121.962000	0.0326136	1.0873146
5	BP_BT_age_sum	98.074700	0.0262260	0.8799735
10	BP_DS_len_aut	85.441100	0.0228477	1.2547277
3	BP_RES_len	79.817900	0.0213440	2.1996572
4	BP_BT_age_spr	76.303200	0.0204041	1.0639732
11	BP_DS_len_win	68.265200	0.0182547	1.2987381
27	1994BOP_Tags_season4	68.088100	0.0182073	0.6292883
21	BP_REC_len_spr_pre95	68.069400	0.0182023	1.9185375
17	BP_LL_len_win	45.757200	0.0122359	0.6522349
16	BP_LL_len_aut	38.960300	0.0104183	0.8156561
26	1994BOP_Tags_season3	35.161900	0.0094026	0.4178971
25	1994BOP_Tags_season2	30.504100	0.0081570	0.4048619
15	BP_LL_age_win	29.142900	0.0077931	1.2034876
8	BP_DS_age_spr	28.468300	0.0076127	1.2029587
28	1995BOP_Tags_season1	26.264000	0.0070232	0.3265538
9	BP_DS_age_sum	24.094900	0.0064432	1.0770364
12	BP_LL_age_aut	21.944500	0.0058681	0.9675490
30	prior_on_initialization.R0	15.057300	0.0040264	0.0000000
42	prior_on_q_q_BP_LLcpue90_04	-8.556390	0.0022880	0.0000000
2	BP_LLcpue90_04	-6.961600	0.0018616	1.3617981
34	prior_on_selectivity[Sel_STRAWL].all	3.857620	0.0010316	0.0000000
39	prior_on_size_at_age.k	3.014490	0.0008061	0.0000000
40	prior_on_size_at_age.Linf	2.296310	0.0006141	0.0000000
32	prior_on_initialization.Cinitial	1.300880	0.0003479	0.0000000
1	BP_Tag_bio	-0.882256	0.0002359	0.0000000
37	prior_on_selectivity[Sel_RECR_post95].all	0.844117	0.0002257	0.0000000
36	prior_on_selectivity[Sel_RECR_pre95].all	0.062241	0.0000166	0.0000000
31	prior_on_recruitment.YCS	0.000000	0.0000000	0.0000000
33	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
35	prior_on_selectivity[Sel_DSEINE].all	0.000000	0.0000000	0.0000000
38	prior_on_selectivity[Sel_RESTRAWL].all	0.000000	0.0000000	0.0000000
41	prior_on_size_at_age.t0	0.000000	0.0000000	0.0000000

Appendix 15: BOP_ann (Model 8) correlation (Pearson) and likelihood statistics

Correlated parameters

recruitment.YCS_16	recruitment.YCS_18	0.803476
recruitment.YCS_16	recruitment.YCS_21	0.828807
recruitment.YCS_17	recruitment.YCS_18	0.862185
recruitment.YCS_17	recruitment.YCS_20	0.809101
recruitment.YCS_17	recruitment.YCS_21	0.860603
recruitment.YCS_17	recruitment.YCS_22	0.81984
recruitment.YCS_18	recruitment.YCS_20	0.820502
recruitment.YCS_18	recruitment.YCS_21	0.880483
recruitment.YCS_18	recruitment.YCS_22	0.834214
recruitment.YCS_20	recruitment.YCS_21	0.833502
recruitment.YCS_20	recruitment.YCS_22	0.804888
recruitment.YCS_21	recruitment.YCS_22	0.85676
recruitment.YCS_21	recruitment.YCS_27	0.80124
selectivity[Sel_LLINE].all_1	selectivity[Sel_LLINE].all_2	0.905559
selectivity[Sel_RESTRAWL].all_1	selectivity[Sel_RESTRAWL].all_2	0.927426
selectivity[Sel_RESTRAWL].all_1	selectivity[Sel_RESTRAWL].all_3	-0.810115

Likelihood summary

Total like 1431.8

	label	likelihood	Like comp.	sddr
8	BP_LL_age	334.823000	0.2273358	1.0071698
9	BP_REC_len_post95	283.385000	0.1924108	1.1901406
12	1995BOP_Tags	240.916000	0.1635755	0.4747010
10	BP_REC_len_pre95	193.712000	0.1315252	1.1071363
11	1994BOP_Tags	107.535000	0.0730134	0.7410175
4	BP_BT_age	100.476000	0.0682205	0.9028763
7	BP_DS_len	68.579100	0.0465634	1.0754911
5	BP_BT_len	43.233500	0.0293544	1.1374854
3	BP_RES_len	37.494000	0.0254574	1.3852604
6	BP_DS_age	25.075600	0.0170257	1.2969456
13	prior_on_initialization.R0	15.011500	0.0101924	0.0000000
2	BP_LLcpue90_04	-11.891400	0.0080739	0.9533947
25	prior_on_q_q_BP_LLcpue90_04	-8.614730	0.0058492	0.0000000
17	prior_on_selectivity[Sel_STRAWL].all	0.551419	0.0003744	0.0000000
23	prior_on_size_at_age.Linf	0.484274	0.0003288	0.0000000
22	prior_on_size_at_age.k	0.447574	0.0003039	0.0000000
19	prior_on_selectivity[Sel_RECR_pre95].all	0.247355	0.0001679	0.0000000
1	BP_Tag_bio	0.163765	0.0001112	0.0000000
15	prior_on_initialization.Cinitial	0.141203	0.0000959	0.0000000
20	prior_on_selectivity[Sel_RECR_post95].all	0.030026	0.0000204	0.0000000
14	prior_on_recruitment.YCS	0.000000	0.0000000	0.0000000
16	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
18	prior_on_selectivity[Sel_DSEINE].all	0.000000	0.0000000	0.0000000
21	prior_on_selectivity[Sel_RESTRAWL].all	0.000000	0.0000000	0.0000000
24	prior_on_size_at_age.t0	0.000000	0.0000000	0.0000000

Appendix 16: HGBOP_com_ann (Model 10) correlation (Pearson) and likelihood statistics

Correlated parameters

selectivity[Sel_LLINE].all_1	selectivity[Sel_LLINE].all_2	0.966775
selectivity[Sel_LLINE].all_3	selectivity[Sel_DSEINE].all_3	0.999885
selectivity[Sel_LLINE].all_3	selectivity[Sel_RESTRAWL].all_1	0.964667
selectivity[Sel_STRAWL].all_1	selectivity[Sel_STRAWL].all_2	0.828769
selectivity[Sel_DSEINE].all_1	selectivity[Sel_DSEINE].all_2	0.918157
selectivity[Sel_DSEINE].all_3	selectivity[Sel_RESTRAWL].all_1	0.964295
selectivity[Sel_RECR_pre95].all_2	selectivity[Sel_RESTRAWL].all_1	-0.810574
size_at_age.k_1	size_at_age.Linf_1	-0.960587
size_at_age.k_1	size_at_age.t0_1	0.815197

Likelihood summary

	label	likelihood	Like comp.	sddr
8	HGBOP_REC_len_post95	639.125000	0.2691392	1.0598297
3	HGBOP_RES_len	567.783000	0.2390967	0.6007952
6	HGBOP_LL_age	507.999000	0.2139213	1.0290776
9	HGBOP_REC_len_pre95	209.180000	0.0880869	0.9876524
12	1994HAGUBOP_Tags	122.433000	0.0515572	1.6001639
13	1995HAGUBOP_Tags	76.896200	0.0323814	1.1624897
4	HGBOP_DS_age	75.356900	0.0317332	0.9105123
10	HGBOP_ST_age	51.751300	0.0217928	0.7092936
5	HGBOP_DS_age_old	-30.242900	0.0127355	0.9003129
15	prior_on_initialization.Cinitial	23.284200	0.0098051	0.0000000
2	HGBOP_LLcpue90_04	-16.469000	0.0069352	0.4869675
14	prior_on_initialization.R0	16.323400	0.0068739	0.0000000
11	HGBOP_ST_age_old	-11.326300	0.0047696	1.3168257
26	prior_on_q_HGBOP_LLcpue90_04	-9.799260	0.0041265	0.0000000
23	prior_on_size_at_age.k	5.895190	0.0024825	0.0000000
33	YCS_mean_1	3.991760	0.0016810	0.0000000
7	HGBOP_LL_age_old	-2.670880	0.0011247	1.6956440
21	prior_on_selectivity[Sel_RECR_post95].all	1.732290	0.0007295	0.0000000
1	HAGUBOP_Tag_bio	-1.280370	0.0005392	0.0000000
20	prior_on_selectivity[Sel_RECR_pre95].all	1.052050	0.0004430	0.0000000
24	prior_on_size_at_age.Linf	0.108675	0.0000458	0.0000000
16	prior_on_recruitment.YCS	0.000000	0.0000000	0.0000000
17	prior_on_selectivity[Sel_LLINE].all	0.000000	0.0000000	0.0000000
18	prior_on_selectivity[Sel_STRAWL].all	0.000000	0.0000000	0.0000000

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19      prior_on_selectivity[Sel_DSEINE].all   0.000000    0.0000000 0.0000000
22    prior_on_selectivity[Sel_RESTRAWL].all   0.000000    0.0000000 0.0000000
25                  prior_on_size_at_age.t0   0.000000    0.0000000 0.0000000
```

Appendix 17: Cryptic stock proportional movement estimates

Base models (steepness 1.0)

		models
Movement	SNA1_sp_sea	SNA1_sp_ann
EN_EN	0.874	0.897
EN_HG	0.095	0.068
EN_BP	0.031	0.036
HG_HG	0.913	0.894
HG_EN	0.061	0.083
HG_BP	0.026	0.023
BP_BP	0.430	0.533
BP_HG	0.155	0.176
BP_EN	0.415	0.291

	model
Movement	HGBOP_sp_ann
HG_HG	0.957
HG_BP	0.043
BP_BP	0.717
BP_HG	0.283

Stock recruit models (steepness 0.8)

		models
Movement	SNA1_sp_sea	SNA1_sp_ann
EN_EN	0.817	0.884
EN_HG	0.154	0.078
EN_BP	0.029	0.038
HG_HG	0.841	0.888
HG_EN	0.129	0.087
HG_BP	0.030	0.025
BP_BP	0.380	0.490
BP_HG	0.137	0.149
BP_EN	0.483	0.362

	model
Movement	HGBOP_sp_ann
HG_HG	0.947
HG_BP	0.053
BP_BP	0.819
BP_HG	0.181