Using information for 'data-rich' species to inform assessments of 'data-poor' species through Bayesian stock assessment methods

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Objectives:

1. Expand the database of production parameters for SEF-like species.
2. Develop prior probability distributions for steepness and the coefficient of variation about the stock-recruitment relationship using Bayesian meta-analysis.
3. Develop a Bayesian framework within which the results for data-rich species can 'inform' assessments for data-poor species.
4. Apply the framework to three case-studies to determine the robustness of the framework.
5. Test the framework by means of Monte Carlo simulation

Non Technical Summary:

The ‘Integrated Analysis’ approach to fisheries stock assessment has become the most common method for conducting stock assessments in the Southern and Eastern Scalefish and Shark Fishery (SESSF) for several reasons. These reasons include that ‘Integrated Analysis’ has been shown using Monte Carlo simulation to perform better than alternative methods such as production models. ‘Integrated Analysis’ can make use of most of the data available for assessment purposes. However, predictions based on this approach will be very uncertain unless biological information and an extensive time-series of catch-at-age data and abundance indices are available. For many of the ‘low priority’ species in the SESSF (and the by-product and by-catch species), the only data collected ‘routinely’ are catch and effort statistics, in most

cases length-frequencies (at least for quota species), and in some cases 'snapshots' of age-composition. It is, and will likely remain, almost impossible to conduct stock assessments for all of the species for which they are needed unless inferences for 'data-poor' stocks are based in part on information for 'data-rich' stocks, and, more generally, on knowledge for other species and stocks. Formally, this information can be included in assessments in the form of 'prior distributions' (or penalty functions).

This report considers two ways to include 'prior distributions' in assessments. First, whether the data for 'data-rich' species/stocks can be used to develop prior distributions for some of the key input parameters included in stock assessment models is examined. The results indicate that the best way to estimate the rate of natural mortality is Hoenig's equation (or the variant thereof based on the data analysed in this report) while the method developed by Pauly seems very sensitive to whether data for species with high M are included in the analysis. Several relationships among biological parameters are identified, but the predictive ability of most of these is reasonably weak. The fact that ℓ_∞ was found to correlate well with several other biological parameters highlights the importance of conducting ageing studies for as many species as possible (even if the sample sizes are only sufficient to estimate the parameters of a growth curve) and/or to conduct a catch-curve analysis.

Stock and recruitment data were analysed to estimate priors for the steepness of the stock-recruitment relationship. These data suggest that steepness for Clupeiformes, Pleuronectiformes, and Gadiformes is higher than that for "other" species. This needs to be accounted for when selecting the data on which to base priors for steepness for SESSF species as only blue grenadier is in this group of "high steepness" fishes. In contrast, steepness is notably lower for species not in these three families and this should therefore be expected of most of the species in the SESSF. The reasons for this difference are unclear. Also no covariates that explain steepness were found (although the sample sizes for some of the covariates are quite small) except whether the fish is a Clupeiform, Pleuronectiform, or Gadiformes. The results can be used to develop base-case priors for steepness and the extent of variation in recruitment, and the values for these quantities to be used in tests of sensitivity. It is recommended that if a single default point estimate for steepness is to be used in a stock assessment based on the Beverton-Holt stock-recruitment relationship, that default should be 0.907 for Clupeiformes, Gadiformes and Pleuronectiformes and 0.757 for 'other' species.

The second approach to make use of information for 'data-rich' species when conducting assessments for 'data-poor' species is to conduct assessments of several species ('data-rich' and 'data-poor') simultaneously and to impose penalties on the differences in biological parameters among species/stocks.

It is clearly not possible to share values of parameters (such as the age-at-maturity) among different species. However, it seems plausible that if multiple stocks/species are exploited by the same fleet (where fleet is defined as a group of vessels fishing in the essentially the same fishing grounds at the same time), the trend in fishing mortality for that fleet should be similar for all of the stocks/species. It also seems likely that the annual deviations in recruitment about the stock-recruitment relationship for different stocks/species would be correlated (positively or negatively) due to the impact of common environmental variables, and that selectivity as a function of length (before discarding) should be relatively similar across various fleets. However, there are also good reasons related to the behaviour of fishers and fish, that parameters for different stocks/species should not be identical. The approach of this report therefore allows for stock-specific values for all of the model parameters, but adds penalties on how different the values for these parameters may be across stocks. This basic approach has been used previously for multiple stocks of the same species, but this is the first time multiple stocks of several species have been assessed simultaneously.

The technical details of the method are described, tested by means of simulation and applied to data for eight stocks (seven species) in the SESSF. The example application is based on five fleets (four trawl fleets and a non-trawl fleet) and eight stocks: blue grenadier (data-rich), eastern gemfish, spotted warehou and pink ling (data-moderate), and western gemfish, mirror dory, king dory and ocean perch (data-poor). The data available included catch and effort, discard rates, length-frequencies and age-compositions by fleet and stock, values for biological parameters, and survey estimates of the spawning biomass of blue grenadier in 1994 and 1995.

The results of the simulations and the example application confirm that there is value in imposing cross-stock/species constraints. However, the effects may be quite small, and the consequences, in terms of bias and precision, may be negative for some of the 'data-rich' species. Nevertheless, the expectations of improved stability and precision are largely borne out – the results of the analyses, specifically the trends in the abundance of ocean perch, king dory and western gemfish, differ fairly substantially when among-stock constraints are taken into account. Furthermore, the precision of some of the key outputs from an assessment (the trends in spawning biomass and spawning biomass expressed relative to the unfished level) for the 'data-poor' stocks is much greater when among-stock constraints are taken into account

The approaches outlined in this report cannot turn a 'data-poor' stock into a 'data-rich' stock, but will, at the very least, be of value to identify species that should be the focus of increased data collection and analysis. In this study, the results suggest that the stock of western gemfish may be depleted (although it should be noted that the fishery is at the eastern end of the species' range) while there are declining trends in ocean perch and king dory that warrant further data collection and analysis.

Outcomes Achieved

The main outcome from this project is the development and testing of an analytical tool that can be applied to the many low value species in the SESSF to help formally assess the status of the stocks. As SESSRAG is currently developing harvest strategies for the fishery, the results of this project provide an improved ability to advise fishery managers on appropriate indicators and reference points for some "data-poor" quota species that will probably provide better indicators of trend that either CPUE or age-structure alone, because the approach integrates all of the available data. Ultimately it will provide a costs-effective means of undertaking more formal assessments of the many SESSF species that currently have no formal assessment. At the very least, the approach developed here will be of value to identify species that should be the focus of increased data collection and analysis.

Benefits of this project also flow to many of the fisheries managed by AFMA and state agencies because the priors and relationships developed can be used for assessments other than for those of SESSF species.

Keywords:

Bayesian, Hierarchical meta-analysis. Multi-species modelling, Simulation evaluation, Technical interactions

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Chapter 1: Introduction

Background

The ‘Integrated Analysis’ approach to fisheries stock assessment has become the most common method for conducting stock assessments in the SESSF for several reasons (Smith *et al.* 2001). These reasons include that ‘Integrated Analysis’ has been shown using Monte Carlo simulation to perform better than alternative methods such as production models (Punt *et al.* 2002a). ‘Integrated Analysis’ can make use of most of the data available for assessment purposes. However, predictions based on this approach will be very uncertain unless biological information and an extensive time-series of catch-at-age data and abundance indices are available. Furthermore, there is a need for ‘contrast’ in the data to enable biomass to be estimated reliably. For many of the ‘low priority’ species in the SESSF (and the by-product and by-catch species), the only data collected ‘routinely’ are catch and effort statistics, in most cases length-frequencies (at least for quota species), and in some cases ‘snapshots’ of age-composition. Application of ‘Integrated Analysis’ to the data for these species will therefore lead to highly uncertain results, even though some level of ongoing assessment is required to meet strategic assessment under EPBC.

The question is, of course, why we should aim for a formal stock assessment of these species. Formal stock assessments provide crucial insights into the status of fish stocks, but, more importantly, provide a predictive capacity that enables managers to assess alternate management or harvest strategies. The results of population projections form the key basis for management advice. Simply put, stock assessment allows managers to be proactive rather than reactive.

Koopman *et al.* (2000) demonstrated the utility of using information for ‘similar’ species when conducting assessments for SESSF species. The key parameters that form the basis for assessments of fish stocks are the virgin biomass, the rate of natural mortality, and the ‘steepness’ of the stock-relationship relationship. Of these parameters, ‘steepness’ is the hardest to estimate, usually due to lack of data ‘contrast’.

However, information for other stocks / species can be used to infer ranges for steepness (and the extent of variability in recruitment). These ranges can be used in the assessments of SESSF species so long as the other species are ‘similar’ to the SESSF species for which information on steepness is needed. Information on natural mortality, steepness, the extent of recruitment variability, and a range of other biological parameters was obtained for 15 of the SESSF quota species and 52 other stocks / species by Koopman *et al.* (2000). A simple formula was developed for identifying ‘similar’ stocks / species to a species for which production parameters are required, using information on maximum age, depth, habitat preference, and diet. The results of the application of this algorithm were consistent with subjective judgements. In addition, an algorithm was developed for constructing prior probability distributions for steepness and the extent of variability in recruitment using the results from analyses for similar species. The resultant distributions from this algorithm could be used in Bayesian stock assessments and as the basis for sensitivity tests when applying other methods of stock assessments.

Koopman *et al* (2000) argued that the approach used to identify similar species appeared to be relatively successful with few obvious ‘errors’. However, the approach used to develop probability distributions could be extended further in several key ways: (a) the database developed during the project could be extended considerably to include more stocks, and (b) the approach for developing probability distributions only took account of whether a species was similar to the SESSF species under consideration. It ignored whether the estimates of steepness for the ‘other’ species were sufficiently reliable themselves to be used to infer values for SESSF species. For example, several of the values used were themselves ‘guestimates’ rather than estimates based on actual data. Koopman *et al.* (2000) noted that it should be possible to apply Bayesian hierarchical meta-analysis (Gelman *et al.*, 1995; Liermann and Hilborn, 1997) to obtain prior probability distributions for steepness and recruitment variation.

Development of prior probability distributions for use in Bayesian stock assessment approaches (e.g. Punt and Hilborn, 1997; McAllister and Ianelli, 1997) should reduce uncertainty when conducting assessments. For example, prior probability distributions for steepness and the extent of depensation are already included in the assessment of the eastern stock of gemfish (Smith and Punt, 1998). However, given the lack of data (other than catches) for many of the species in the SESS, even having prior probability distributions for production parameters will be insufficient to restrict the value of the virgin biomass, B_0. For such species, uncertainty will remain high if assessments are only based on the data for the species for which an assessment is required.

In principle, the assessments for well-studied ('data-rich') species (e.g. blue grenadier, flathead, and eastern gemfish in the SESSF) provide information on, for example, trends in fishing intensity by area and even perhaps the relative strength of recruitment that are relevant to assessments of 'data-poor' species. However, this information cannot presently be included formally in stock assessments for 'data-poor' species.

Need

Over 300 species are caught in the SESSF, of which around 100 have commercial value. Twenty five species comprise around 90% of the landed catch. Each year, however, quotas are set for only around 17 species. Formal stock assessments (that may not occur every year) are available for ten of these species. No formal assessment is undertaken for any of the remaining quota species and for some of the more important non-quota species, and the only assessment for these species is an investigation of trends in catch, effort, and size distribution, and anecdotal input from scientists and industry. There are insufficient resources to undertake formal stock assessments for the wide range of commercial species landed in the SESSF. Yet, each of these species is an important component of the catch of fishers. If the fishery is to continue to operate in its current form, and meet the strategic assessments required under the EPBC Act, some form of formal assessment is required.

Koopman *et al*. (2000) demonstrated the utility of using information for 'similar' species when conducting assessments for SESSF species. Using key parameters such as the virgin biomass, the rate of natural mortality, and the 'steepness' of the stock-relationship relationship for a wide range of species, and a simple formula for identifying 'similar' stocks / species, an algorithm was developed for constructing prior probability distributions for these parameters. The resultant distributions could be used in Bayesian stock assessments and as the basis for sensitivity tests when applying other methods of stock assessments. The current project refines the prior distributions for two of the production parameters and develops and test methods of stock assessment that use the results of assessments for well-studied species in a formal manner to inform assessments of 'data-poor' species.

Objectives

- Expand the database of production parameters for SEF-like species.
- Develop prior probability distributions for steepness and the coefficient of variation about the stock-recruitment relationship using Bayesian meta-analysis.
- Develop a Bayesian framework within which the results for data-rich species can 'inform' assessments for data-poor species.
- Apply the framework to three case-studies to determine the robustness of the framework.
- Test the framework by means on Monte Carlo simulation

Organisation of this report

The body of this report is organised into a series of discrete chapters.

Chapter 2 provides a meta-analysis of production parameters and presents an examination of biological parameters and their inter-relationships. In the absence of comprehensive data on the population dynamics of a stock that would allow the application of formal stock assessment methods, 'rapid assessments' are an increasingly important tool that rely on basic life-history parameters only. Commonly-used approaches include the empirical formulae developed by Pauly (1980) and Hoenig (1983) to calculate *M*.

Chapter 3 conducts a Bayesian hierarchical meta-analysis of stock and recruitment data to develop prior distributions for steepness and the extent of variation in recruitment using data for other stocks /species. Hierarchical meta-analysis is a Bayesian technique that can be used to combine data from several independent sources (species / stocks) and represent the outcome in the form of a probability distribution for a quantity of interest.

Chapter 4 summarizes the data that will be used in the example application of the method developed in Chapter 5. SESSF data, including catches, discards, age- and length-compositions and biological information are extracted for blue grenadier, eastern and western gemfish, pink ling, spotted warehou, mirror dory, king dory, and offshore ocean perch. Data are presented separately for four trawl fleets and one non-trawl fleet.

Chapter 5 describes an approach that informs the assessment of ‘data-poor’ species using information for ‘data-rich’ species. It therefore extends previous work based on several stocks of the same species to several species. An example application of the method based on the data summarized in Chapter 4 is included in this chapter.

It is necessary to evaluate all new methods of analysis to show that they perform at least as well as, and preferably better than, existing methods, given that a poor analysis method can have substantial economic, social, and biological consequences. Chapter 6 conducts this evaluation for the method outlined in Chapter 5.

Chapter 2: Meta-Analysis of Production Parameters

Introduction

Biological parameters are often used to characterise species and stocks. The most common of these parameters are: a) the parameters of the growth curve (e.g. L_∞, κ and t_0 for the von Bertalanffy form of the relationship between length and age), b) the rate of natural mortality, M, c) the age- and length-at-maturity, T_m and L_m, and d) the maximum age, t_{max}. Correlations among biological parameters have been used primarily to obtain empirical formulae to estimate M (Beverton, 1992). Relationships among κ, L_∞, T_m , L_m, M and t_{max} were investigated by Beverton and Holt (1959) who found that they are somewhat invariant across species, and across populations within a species (Jenson, 1996). From such studies, the relationships between; a) L_m, L_∞ and M, b) L_∞, κ and M, and c) M and t_{max} became known and empirical formulae were developed to calculate M (e.g. Pauly, 1980; Hoenig, 1983).

More recently, examination of biological parameters and their inter-relationships have been used to assess or categorise the vulnerability of a stock to fishing pressure (e.g. Frisk *et al.* 2001). In the absence of comprehensive data on the population dynamics of a stock which would allow the application of formal stock assessment methods, 'rapid assessments' are an increasingly important tool that rely on basic life-history parameters only. The increasing wealth of information available for well-studied species, however, could give rise to methods of estimating unknown parameters for a 'data-poor' species, from those for 'data-rich' species. While it is more desirable to have direct estimates of life history parameters for each species, the value/importance of some species, especially those that are not target species, may impede funding for the necessary research. Assessments based on data for previously well-studied species potentially offer insights into the biological characteristics of poorly-studied species, necessary for informed management, at relatively small cost.

Information on the biological parameters of fish stocks is often 'locked' away in grey literature, spread out amongst the plethora of literature, or 'hidden' on the hard drives or in the filing cabinets of individual scientists. Myers (2000) addressed this issue by collating information from more than 700 fish stocks made up of over 160 species. The data assembled by Myers (2000) includes not only biological parameters but also spawner-recruit time-series. These data are stored in a format that is easily accessible to external users.

This chapter describes a meta-analysis of production parameters and presents an examination of biological parameters and their inter-relationships.

Methods

Species characteristics

The species/stocks considered in this chapter are characterised roughly according to their biological parameters, their diet and depth preferences, and their habitat usage. Characterisations were based on the descriptions of biology from FishBase. Non-numerical quantities (for diet, depth and habitat) are allocated numeric codes to enable rough comparisons to be made among species to allow 'similar' species to be identified automatically, and with relative ease. Reported values were used for all numeric fields.

Values are reported for the following quantities (units, where applicable, in parenthesis):

the maximum age, t_{max}, (years);

the rate of natural mortality, M (yr^{-1});

the parameters of the von Bertalanffy growth equation:

$$L_a = L_\infty(1-\exp(-\kappa(a-t_0)))$$

where the units for L_∞ and t_0 are cm and years respectively;

a) the age at 50% maturity, T_m (years);
b) the length at 50% maturity, L_m (cm);
c) the extent of variation in recruitment, quantified by the standard deviation of deviations in recruitment about the stock recruitment relationship, σ_r ;
d) the steepness of the stock-recruitment relationship (the fraction of the number of recruits to be expected when the spawner biomass is reduced to 20% of its unfished size), z;
e) diet preference (1 = Phytoplankton or zooplankton; 2 = Salps; 3 = Invertebrates; 4 = Invertebrates and fish);
f) depth preference (1 = Shelf (0-200m); 2 = Shelf-slope (0-700m); 3 = Upper slope (200-700m); 4 = Lower slope (700m+));
g) habitat usage (1 = Demersal; 2 = Benthopelagic; 3 = Pelagic);
h) the latitude of spawning (a positive number means north, a negative number means south);
i) the yield (kg) per recruit at $F = 0$;
j) average water temperature;
k) fecundity, and
l) parameters of the length-weight relationship (a and b).

These biological parameters have been chosen because of their availability. They were used in further analyses depending on whether:

1) they are well-defined so that most analysts estimate comparably-defined quantities,
2) they are readily available for a large number of fish stocks, and
3) they are important when conducting stock assessments, performing population projections, and for developing fisheries reference points.

Identification of data sets

Information was extracted from 443 stocks (Table1). Biological characteristics were obtained primarily from Ransom Myers' Stock Recruitment DataBase, the Fishbase website, and the websites of various fisheries institutes. References are included Table 1 as available. Complementary data were obtained from the literature found by searching Current Contents and the Aquatic Sciences and Fisheries Abstracts. Leading authorities on particular species were also contacted by e-mail in an attempt to obtain unpublished or 'grey' literature. Biological parameters of SESSF species are shown in Table 2.

Biological correlates

The values for the parameters were log-transformed (base 10) and plotted against each other to assess which (if any) of the parameters are able to predict some of the other parameters. The choice of log-transformation was motivated by its use by Pauly (1980) in his model for M. The parameters included in this analysis were: a) the parameters of the length-weight relationship (a and b), b) the asymptotic length (L_∞), c) the von Bertalanffy growth coefficient (κ), d) the length-at-maturity (L_m) for both sexes and for females only, e) the age-at-maturity (T_m) for both sexes and for females only, f) the maximum age (t_{max}), and f) the rate of natural mortality (M). All combinations of these parameters were plotted, and axes were reversed in all cases (e.g. x on y as well as y on x). Duplicates were removed from analyses where the values for all of the parameters examined were equal to reduce the influence of identical data for multiple stocks of the same species. 95% confidence intervals for the fitted regression line, adjusted R^2s, and probability that the slope of the regression differs from zero were calculated.

The relationships identified by Pauly (1980) and Hoenig (1983) to estimate M were refitted to the data from this study (separately for temperate stocks and for all stocks), and the resulting relationships compared to those of Pauly (1980) and Hoenig (1983). When temperature was not available for a species in a stock area for which a temperature was available for a different species, temperatures were assumed to be the same. When there were two or more different temperatures for given a stock area, the mean of those temperatures was used to specify missing values. When L_∞ and κ were available for each sex, but not for both sexes combined, the sex-specific values were averaged. In addition, Pauly's (1980) equation was re-fitted to his data where M was equal to or less than 0.5 for comparison with results from the current project.

Results and Discussion

The two parameters of the length-weight relationship are strongly correlated ($p<0.001$). However, there are several obvious outliers that fall well outside of the 95% CI for the regression line (Figure 1; Table 3). The relationship between a and b is uninformative because these parameters are estimated together, but this relationship is included to show that the relationship between parameters can become clearer by reversing the axes (Figure 2; Table 4). The parameters a and b are also significantly correlated with L_∞, while b is significantly correlated with L_m. Despite a low R^2, both a and b are also significantly correlated with M.

L_∞ is highly correlated with most of the other parameters (Figure 3; Table 5). This result highlights the importance of age data and perhaps that estimating growth parameters should be given priority when researching data-poor fish stocks. The correlation between L_m and L_∞ is particularly strong, with L_∞ explaining 54% of the variability in L_m. Frisk *et al* (2001) also found strong relationships between L_{max} and L_m (L_∞ was used for L_{max} in their study when available).

The other von Bertalanffy parameter examined, κ, did not correlate significantly with as many parameters as L_∞ (Figure 4; Table 6). Not surprisingly given the dependence of L_∞ on κ, κ is highly correlated with T_m, t_{max} and M. As with L_∞, Frisk *et al* (2001) also found strong relationships between κ and M for elasmobranchs. They, however, found that the slope of this relationship (0.42) differed significantly from that of teleosts (1.10). The results in Table 6 show that the slope for teleosts (0.454) in our study is nearly exactly the same as the value found by Frisk e*t al* (2001) for elasmobranches. This was initially thought to be due to the inclusion in the analyses of this chapter of some long-lived species which generally have a lower M/K ratio and hence should reduce the slope of the relationship between κ and M (Frisk *et al.*, 2001). However, removal of data for stocks with a t_{max} greater than 50 years resulted in no change to the slope of the relationship.

Length-at-maturity is highly correlated with age-at-maturity as expected, and also with t_{max} and several other parameters (Figures 5 and 6; Tables 7 and 8). Age-at-maturity is significantly correlated with t_{max}, and consequently, negatively correlated with M (Figures 7 and 8; Tables 9 and 10). The relationships between T_m, t_{max} and M illustrate the trade-off between growing faster and maturing early and dying at a greater rate, and growing and maturing slower and having lower rate of natural mortality.

t_{max} is strongly correlated with M ($R^2 = 0.60$) with very tight 95% confidence intervals (Figure 9; Table 11). Plots with M as the independent variable are shown in Figure 10 and Table 12 These results support the use of t_{max} in the estimation of M, showing that 60% of the variability in M can be explained by t_{max}.

Combinations of parameters were examined to determine if the estimation of M could be improved with the addition of extra parameters into the single parameter models. No improvements in R^2 were observed (Table 13). However, some large reductions in R^2 resulted from the reduction in the number of observations compared to the single parameter models. The cause of this was missing one of the parameters for a species when the other parameter was present (i.e. if L_∞ but not T_m was known for one species, it would have been included in the single parameter analysis based on L_∞, but not the multi-parameter analysis that used both L_∞ and T_m).

The estimates of the coefficients of the relationship between $\text{Log}_{10}M$ and $\text{Log}_{10}t_{\text{max}}$ from this study (all stocks and temperate stocks only) were very similar to those estimated by Hoenig (1983) (Table 14). The R^2 were high (0.64 and 0.61 respectively) for both analyses and the regression lines appear to fit the data reasonably well for the available range of values for $\text{Log}_{10}t_{\text{max}}$ (Figure 11). In contrast, the coefficients of the relationship between $\text{Log}_{10}M$ and $\text{Log}_{10}L_\infty$, $\text{Log}_{10}\kappa$ and $\text{Log}_{10}T$ based on the data in this study differ markedly from those reported by Pauly (1980) (Table 14); specifically, the coefficients were much smaller, particularly when all of the data were used. R^2s were also low indicating that the model does not explain much of the variability. The inability to capture much of the variability in $\text{Log}_{10}M$ is surprising given that Pauly (1980) reports an R^2 of 0.85 for his original relationship. Figure 12 plots estimates of M using Pauly's equation and those derived from the data in the current study. The estimates of M based on the regression model of this study are notably smaller than those based on Pauly's model, with the discrepancy increasing with M. In the most extreme case, M from our equation was 0.74yr^{-1} compared to $2.32\ \text{yr}^{-1}$ from Pauly's equation; the actual value of M for the stock in question the data set was 1yr^{-1}.

When Pauly's equation was re-fitted to the subset of his original data set for which $M \leq 0.5\text{yr}^{-1}$, the estimates for M were more similar to those estimated using our equation (Figure 13).

The relationships between T_m and t_{max},, and T_m and M for each family from which data were collected are presented in Table 15. Data for other species from previous studies are also included in Table 15 for comparison. The results from this study are comparable with those of the previous studies for all groups, particularly for T_m / t_{max}.

Although most of the correlations in Tables 3 - 13 are weak, there are nevertheless some apparently noteworthy relationships. Specifically, over 50% of the variability in the length-at-maturity (both sexes) can be explained by L_∞ and *vice versa* (Tables 5 and 7), although the evidence for strong correlation disappears when female length-at-maturity is used instead of the length-at-maturity for both sexes (Tables 5 and 8). There are also strong (and highly statistically significant) correlations between the age-at-maturity and the maximum age (Tables 9 and 11). This correlation is analogous to that between L_∞ and L_m. Somewhat surprisingly, there is only a weak correlation between the age-at-maturity and the length-at-maturity (Table 9).

The ability to predict M is possibly of greatest interest to those conducting assessments of 'data-poor' species. The results in Tables 3 - 13 provide some, but not much, encouragement. Many biological parameters are highly correlated with M (Table 12) although the relationships are generally rather weak. The best explanatory variable for M is the maximum age (Table 12; Figure 11) although considerable uncertainty remains about the relationship between M and t_{max}. A complication particular to predicting M is that independent estimates of this quantity are seldom available so that the values for M in Table 1 are likely guesses or values obtained from the relationships developed by Pauly (1980) or Hoenig (1983). As such, any correlations between M and biological parameters should be interpreted with caution. Nevertheless, the results in Tables 12 and 13 imply that if a way of estimating M based on biological data is needed, the best predictor is t_{max} (using, for example, Hoenig's (1983) formula or the alternative relationships in Table 14). The weak relationship between L_m and M (Table 12) suggests that some ageing data are needed to estimate M (either using t_{max} or the parameters of the growth curve).

The values for the coefficients estimated for the relationship between M and t_{max} were similar to those obtained by Hoenig (1983). This is not surprising given that some of the values of M had obviously been obtained using Hoenig's formula. The differences in coefficients observed (smaller constant and larger coefficient for t_{max}) are both likely to have resulted from the larger proportion of greater estimates of t_{max} in our data set (less than 60% of the Hoenig's samples had a t_{max} greater than 10 years compared to nearly 70% in our data set) and because Hoenig used mostly unexploited or lightly exploited stocks in his analyses. Our re-estimation of the coefficients of Pauly's (1980) equation for M revealed very different results, particularly at higher values of M. This appears to be caused largely by the high values of M in Pauly's data set. When the equation was re-fitted to his data set for values of M less than or equal to 0.5yr^{-1}, estimates of M were much more similar to those from our equation.

The results of this chapter provide defaults for estimating key biological parameters using estimates of parameters that are easier to determine. However, it is necessary to consider not just the estimates based on the relationships, but also the variability about those relationships. For example, the confidence intervals about the lines in Figures1 - 10 represent the uncertainty about the mean behaviour. The variability for an individual stock will be much larger than implied by these confidence intervals. Therefore, if relationships such as those estimated in this chapter are to be used in stock assessments, sensitivity tests based on the uncertainty of the estimates need to be conducted.

Table 1.Fish stocks examined and their population parameters.

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
Acipenseriformes																																	
	Acipenseridae																																
		Russian-sturgeon (Acipenser guldanstadti)	Danube-river										13									44.30		0.05									
		Starred-sturgeon (Acipenser stellatus)	Danube-river																			44.30											
Atheriniformes																																	
	Scophthalmidae																																
		Pacific-Saury (Cololabis saira)	Soledad-Basin,-Baja-California	30.4	-1.56	0.595									20				3	1	3	25.15	6.5	1.6									
		Pacific-Saury (Cololabis saira)	California	37.6	-1.19	0.340									20				3	1	3	34.15	6.5	1.6									
Aulopiformes																																	
	Synodontidae																																
		Bombay-duck (Harpodon nehereus)	Northwest-coast-of-India	27		1.1							1									19.30		1.1	1								
		Greater-lizardfish (Saurida tumbil)	East-China-Sea	69.5	-0.28	0.286							3		31		0.416		4	1	1	30.00	7	0.46		17				0.0025	3.426	0.0027	3.396
Beryciformes																																	
	Berycidae																																
		Alfonsino (Beryx splendens)	NZ				51.1	-3.56	0.11	57.5	-4.1	0.08		4		30		0.95		3	2		17	0.23									
	Trachichthyidae																																
		Orange-roughy (Hoplostethus atlanticus)	NZ-Challenger-Plateau				36.4	-0.4	0.07	38	-0.6	0.061					1.1	0.75	4	4	2		130	0.045									
Clupeiformes																																	
	Clupeidae																																
		Blueback-herring (Alosa aestivalis)	Chowan-River,-USA										3				0.792		3	1	3	36.01	8	1	0.307								
		Blueback-herring (Alosa aestivalis)	Connecticut-River,-USA										3				2.467		3			43.55	8	1	0.307								

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Blueback-herring (Alosa aestivalis)	Saint-John-River										4.5				1.182		3			45.55	8										
		Blueback-herring (Alosa aestivalis)	Saint-John-River										4.5				0.693		3			45.55	8	1	0.307								
		Black-Sea-shad (Alosa kessleri)	Black-Sea										3									44.30		0.7									
		Anadromous-alewife (Alosa pseudoharengus)	Annaquatucket-River,-USA										3									41.55	8	1	0.33								
		Anadromous-alewife (Alosa pseudoharengus)	Damariscotta-Lake,-Maine																			44.10	8										
		Anadromous-alewife (Alosa pseudoharengus)	Damariscotta-River										3									44.03	8	1	0.33								
		Anadromous-alewife (Alosa pseudoharengus)	Lamprey-River										3									42.05	8	1	0.33								
		Anadromous-alewife (Alosa pseudoharengus)	Long-Pond,-MA,-USA										4									44.29	8	1	1.581977								
		Anadromous-alewife (Alosa pseudoharengus)	Lake-Ontario											2		11	1.173		3	1		43.30	8										
		Anadromous-alewife (Alosa pseudoharengus)	Saint-John-River																			45.55	8										
		Anadromous-alewife (Alosa pseudoharengus)	Saint-John-River										3									45.55	8	1	0.33								
		Anadromous-american-shad (Alosa sapidissima)	Connecticut-River										4.5									43.55		0.33	3.55745								
		Gulf-Menhaden (Brevoortia patronus)	Gulf-of-Mexico	254.3	-1.054	0.354	24	-9999	0.37	24	-9999	0.37	2	1		15	0.43	0.57	1	1	3	28.00	6	1.1	0.02691043			-12.657	3.358				
		Atlantic-Menhaden (Brevoortia tyrannus)	U.S.-Atlantic				33.8	-9999	0.4	33.8	-9999	0.4	2.5	2		18	0.559	0.86	1	1	3	35.00	11	0.45	0.17			0.0099	3.216				
		Herring (Clupea harengus)	Baltic-areas-22-and-24	21	-1.16	0.380							2.5				0.350		1	1	3	55.00	10	0.3	0.38			0.0121	2.778				
		Herring (Clupea harengus)	Baltic-areas-25-29,-32-plus-Gulf-of-Riga	21	-1.16	0.380							2.5				0.375		1	1	3	57.00	10					0.0121	2.778				
		Herring (Clupea harengus)	Baltic-areas-28-and-29S	21	-1.16	0.380							2.5				0.495		1	1	3	58.00	10	0.3				0.0121	2.778				
		Herring (Clupea harengus)	Baltic-area-30	21	-1.16	0.380							2.5				0.734		1	1	3	62.00	10	0.2				0.0121	2.778				
		Herring (Clupea harengus)	NAFO-4-5	35.2		0.280							3.5				0.723		1	1	3	44.10	19	0.2	0.6			0.0026	3.328				
		Herring (Clupea harengus)	NAFO-4R-(Fall-spawners)	35.2		0.280							5				1.34		1	1	3	49.25	19					0.0026	3.328				
		Herring (Clupea harengus)	NAFO-4R-(Spring-spawners)	35.2		0.280							5				1.601		1	1	3	49.25	19					0.0026	3.328				
		Herring (Clupea harengus)	NAFO-4T-(Fall-spawners)	35.2		0.280							4				1.086		1	1	3	47.00	25					0.0026	3.328				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Herring (Clupea harengus)	NAFO-4T-(Spring-spawners)	35.2		0.280							4				0.956		1	1	3	47.00	23					0.0026	3.328				
		Herring (Clupea harengus)	NAFO-4WX	35.2		0.280							4				0.998		1	1	3	42.00	19					0.0026	3.328				
		Herring (Clupea harengus)	Newfoundland(AB)	35.2		0.280							5				3.564		1	1	3	50.00	19					0.0026	3.328				
		Herring (Clupea harengus)	Archipelago-and-Bothnian-Seas	21	-1.16	0.380							2.5				0.465		1	1	3	61.00	17	0.2				0.0121	2.778				
		Herring (Clupea harengus)	Bothnian-Bay	21	-1.16	0.380							2.5				0.685		1	1	3	65.00	17	0.15				0.0121	2.778				
		Herring (Clupea harengus)	Central-Coast-B.C.	35.2		0.280							4						1	1	3	52.30	19	0.373	0.25			0.0026	3.328				
		Herring (Clupea harengus)	Newfoundland(CD)	35.2		0.280							5				4.762		1	1	3	48.45	19					0.0026	3.328				
		Herring (Clupea harengus)	Craig,-Alaska	35.2		0.280							3						1	1	3	55.29	19	0.2				0.0026	3.328				
		Herring (Clupea harengus)	Downs-stock	29.2		0.48							3				2.033		1	1	3	52.00	13	0.2	0.79	9		0.005	3.1				
		Herring (Clupea harengus)	Gulf-of-Dvina,-White-Sea	21	-1.16	0.380							2.5				0.464		1	1	3	65.00	17					0.0121	2.778				
		Herring (Clupea harengus)	Eastern-Bering-Sea	21	-1.16	0.380							4						1	1	3	58.00	17		0.512			0.0121	2.778				
		Herring (Clupea harengus)	Newfoundland(EF)	35.2		0.280							5				4.272		1	1	3	47.30	19					0.0026	3.328				
		Herring (Clupea harengus)	Georges-Bank	35.2		0.280							3.5				1.948		1	1	3	41.30	19	0.2	0.91			0.0026	3.328				
		Herring (Clupea harengus)	Gulf-of-Finland	21	-1.16	0.380							2				0.683		1	1	3	61.00	17	0.2	0.2			0.0121	2.778				
		Herring (Clupea harengus)	Newfoundland(GH)	35.2		0.280							5				2.847		1	1	3	46.40	19					0.0026	3.328				
		Herring (Clupea harengus)	Gulf-of-Maine	35.2		0.280							3.5				0.993		1	1	3	43.00	22	0.2	0.68			0.0026	3.328				
		Herring (Clupea harengus)	Gulf-of-Riga	21	-1.16	0.380							2				0.556		1	1	3	57.30	17	0.2	0.14			0.0121	2.778				
		Herring (Clupea harengus)	Hokkaido														5.713		1	1	3	44.30											
		Herring (Clupea harengus)	Newfoundland(I)	35.2		0.280							5				3.145		1	1	3	47.25	19					0.0026	3.328				
		Herring (Clupea harengus)	Iceland-(Spring-spawners)	21	-1.16	0.380							4				13.55		1	1	3	63.00	19	0.1	2.88			0.0121	2.778				
		Herring (Clupea harengus)	Iceland-(Summer-spawners)	21	-1.16	0.380							3.5				1.141		1	1	3	63.00	18	0.1	2.13			0.0121	2.778				
		Herring (Clupea harengus)	Gulf-of-Kandalaksha,-White-Sea	21	-1.16	0.380							2.5				1.601		1	1	3	66.24	17					0.0121	2.778				
		Herring (Clupea harengus)	Northern-Irish-Sea	29.5		0.390							3				0.4		1	1	3	54.05	12	0.2	0.54	12		0.0050	3.192				
		Herring (Clupea harengus)	Norway-(Spring-spawners)	21	-1.16	0.380							4.5				13.77		1	1	3	65.00	23	0.13	1.62			0.0075	3.0				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Herring (Clupea harengus)	North-Sea	30.0		0.38							3				1.044		1	1	3	58.00	12	0.2	0.79			0.0075	3.0				
		Herring (Clupea harengus)	North-Strait-of-Georgia	35.2		0.280							4						1	1	3	49.30	19	0.692	0.15			0.0026	3.328				
		Herring (Clupea harengus)	North-West-Coast-Vancouver-Island	35.2		0.280							4						1	1	3	49.30	19	0.712	0.16			0.0026	3.328				
		Herring (Clupea harengus)	Gulf-of-Onega,-White-Sea	21	-1.16	0.380							2.5				0.925		1	1	3	64.20	17					0.0121	2.778				
		Herring (Clupea harengus)	Prince-Rupert-District	35.2		0.280							4						1	1	3	54.30	19	0.359	0.38			0.0026	3.328				
		Herring (Clupea harengus)	Queen-Charlotte-Islands	35.2		0.280							4						1	1	3	52.30	19	0.431	0.32			0.0026	3.328				
		Herring (Clupea harengus)	Revilla-Channel-(Kah-Shakes),-Alaska	21	-1.16	0.380							3						1	1	3	55.12	19	0.2				0.0026	3.328				
		Herring (Clupea harengus)	Southern-Central-Baltic	21	-1.16	0.380							2.5				0.754		1	1	3	54.30	17	0.2				0.0121	2.778				
		Herring (Clupea harengus)	S.E.-Alaska	35.2		0.280							4						1	1	3	56.00	19		0.169			0.0026	3.328				
		Herring (Clupea harengus)	Seymour-Canal,-Alaska	35.2		0.280							3						1	1	3	57.39	19	0.2				0.0026	3.328				
		Herring (Clupea harengus)	Sitka,-Alaska	35.2		0.280							3						1	1	3	57.00	19	0.2				0.0026	3.328				
		Herring (Clupea harengus)	Southern-Strait-of-Georgia	35.2		0.280							4						1	1	3	48.30	19	0.684	0.15			0.0026	3.328				
		Herring (Clupea harengus)	South-West-Coast-Vancouver-Island	35.2		0.280							4						1	1	3	49.00	19	0.292	0.51			0.0026	3.328				
		Herring (Clupea harengus)	ICES-VIa-(north)	29.5		0.390									24.5		0.767		1	1	3	57.00	12		1.91			0.0050	3.192				
		Herring (Clupea harengus)	ICES-VIa-(south)-and-VIIb,c	29.5		0.390									24.5		0.622		1	1	3	54.30	12		2.05			0.0050	3.192				
		Herring (Clupea harengus)	Yellow-Sea-or-Huanghai-Sea	30.8	0.54	0.59							2.5						1	1	3	35.00		0.11				0.0121	2.778				
		Round-herring (Etrumeus teres)	South-Africa-1.6	26.2		0.330									1.7		0.800		1	1	3	-34.00	5	0.65		16.7		0.00433	3.79				
		Spanish-sardine (Sardina pilchardus)	West-Iberian-(ICES-VIIIc-IXa)	24.3		0.430							1		15		0.849		1	1	3	43.00	15	0.33	0.116			0.0060	3.0				
		Brazilian-sardine (Sardinella brasiliensis)	South-Eastern-Brazil	27.1	-0.15	0.59							1		16.8		0.494		1	2	3	-25.00		1.2				0.0035	3.29				
		Sardine (Sardinops sagax)	South-Africa										1		9.5				1	2	3	-35.00		0.5	0.13								
		Sardine (Sardinops sagax)	South-Africa										1		9.5				1	2	3	-25.00		0.5									
		Sardine (Sardinops sagax)	California	29		0.45							2		21.5		2.458		1	1	3	36.45	13	0.4	0.41								
		Sardine (Sardinops sagax)	Gulf-of-California										1				1.024		1	1	3	29.00	13										
		Sardine (Sardinops sagax)	Japan-E.	218.6		0.263							2				3.130		1	1	3	35.00	9					0.526	3.615				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Sardine (Sardinops sagax)	Chile--Northern-zone	40	-0.91581	0.20495									24		0.64		1	1	3	-21.00		0.4									
		Sardine (Sardinops sagax)	Sea-of-Japan	218.6		0.263							2				1.038		1	1	3	40.00	9	0.57				0.526	3.615				
		Sprat (Sprattus sprattus)	Baltic-Areas-22-32	16.4		0.775							2				0.943		1	1	3	58.00	6	0.28	0.042			0.00211	3.475				
		Sprat (Sprattus sprattus)	Baltic-Areas-26-and-28	16.4		0.775							2				1.376		1	1	3	56.15	6	0.38	0.024			0.00211	3.475				
		Sprat (Sprattus sprattus)	Black-Sea	11.9	-0.83	0.310							1				0.953		1	1	3	44.00	6	0.64	0.0052			0.00211	3.475				
	Engraulidae																																
		Gold-spotted-grenadier-anchovy (Coilia dussumieri)	Northwest-coast-of-India	27		1.1							0.5				0.765		3	1	3	20.00		2.08	1								
		S.A.-Anchovy (Engraulis capensis)	South-Africa																			-35.00	4	0.8									
		S.A.-Anchovy (Engraulis capensis)	South-Africa																			-35.00	4	0.8									
		Anchovy (Engraulis encrasicolus)	Bay-of-Biscay	24.6		0.320							1		11		0.859		1	2	3	45.30	3	1.2	0.0087	14.5		0.0065	2.981				
		Anchovy (Engraulis encrasicolus)	Bay-of-Biscay	24.6		0.320							1		11		0.859		1	2	3	45.30	3	1.2	0.0087			0.0065	2.981				
		Anchovy (Engraulis encrasicolus)	Black-Sea	13.9		1.730							1				0.469		1	2	3	43.00	3	0.82	0.017	14.3				0.0021	3.454	0.0028	3.333
		Northern-anchovy (Engraulis mordax)	Soledad-Basin,-Baja-California				12.0	-1.83	0.551	12.8	-1.81	0.465							1	2	3	25.15	4			18	4000	0.0117	2.95				
		Northern-anchovy (Engraulis mordax)	California	21		0.45							2				0.991		1	2	3	34.00	7	0.6	0.015		4000						
		Northern-anchovy (Engraulis mordax)	California	21		0.45							2				0.991		1	2	3	34.15	7	0.6	0.015		4000						
		Northern-anchovy (Engraulis mordax)	California	21		0.45							2				0.991		1	2	3	34.15	7	0.6	0.015		4000						
		Northern-anchovy (Engraulis mordax)	Gulf-of-California														0.991		1	2	3	27.54	7				4000						
		Peruvian-anchoveta (Engraulis ringens)	Northern/Central-Stock-Peru	20.65		1.26							1		11		1.586		1	1	3	-9.00	3	1.2				0.0065	3				
		Peruvian-anchoveta (Engraulis ringens)	Peru	17.0		1.400									12		1.114		1	1	3	-12.00	3	1		18		0.0065	3				
Cypriniformes																																	
	Cyprinidae																																
		Bream (Abramis brama)	Lake-Tjeukemeer,-the-Netherlands	65.5		0.191								5.5			1.854		4	1	2	52.50	17	0.165		7		0.007	3.11				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
Gadiformes	Gadidae	Roach (Rutilus rutilus)	Klicava-Reservoir																														
		Roach (Rutilus rutilus)	River-Frome,-Dorset,-England										4									50.42											
		Roach (Rutilus rutilus)	River-Stour,-Dorset,-England										4									50.55											
		Pacific-cod (Gadus macrocephalus)	Eastern-Bering-Sea	105.0		0.157							3				2.429		4	3	1	58.00	25	0.29				0.0224	2.89				
		Pacific-cod (Gadus macrocephalus)	Hecate-Strait	94.0		0.270							3				0.491		4	3	1	52.30	25	0.91				0.0224	2.89				
		Pacific-cod (Gadus macrocephalus)	West-Vancouver-Island	108		0.2							3		49		0.669		4	3	1	49.15	25					0.0224	2.89				
		Cod (Gadus morhua)	West-Greenland-(NAFO-1)	92.3		0.218							6				7.059		4	1	2	63.00	25	0.2	18.3	5		0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-2J3KL	73.3		0.154							7				1.084		4	1	2	50.00	25	0.2	11.94	7		0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-3M	102	0.3	0.17							5	5		52	4.880		4	1	2	47.00	25	0.2				0.00812589	3.01788342				
		Cod (Gadus morhua)	Flemish-Cap-(NAFO-Div.-3M)	102	0.3	0.17							5	5		52	5.862		4	1	2	47.00	25	0.2				0.00812589	3.01788342				
		Cod (Gadus morhua)	Flemish-Cap-(NAFO-Div.-3M)	102	0.3	0.17							5	5		52			4	1	2	47.00	25	0.2	4.1			0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-3M	102	0.3	0.17							5	5		52	1.908		4	1	2		25	0.2				0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-3NO	116.0		0.114							6				1.194		4	1	2	44.30	25	0.2	21.79	2		0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-3Pn4RS	77.0		0.26							7				0.723		4	1	2	49.00	25	0.2	8.77			0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-3Pn4RS	77.0		0.26							7				1.1712		4	1	2	49.00	25	0.2	8.77			0.00812589	3.01788342				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Cod (Gadus morhua)	NAFO-3Ps	77.0		0.26							6				0.365		4	1	2	46.00	25	0.2	16.52			0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-4TVn	68.6		0.17							7				0.504		4	1	2	47.30	25	0.2	8.21			0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-4VsW	68.6		0.17							6				0.562		4	1	2	44.00	25	0.2	9.83			0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-4X	68.6		0.17							3.5				0.349		4	1	2	43.00	25	0.2	12.14			0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-5Y	148.0		0.121							3				0.417		4	1	2	43.30	25	0.2	27.82			0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-5Y	148.0		0.121							3				1.890		4	1	2	43.30	25	0.2		12		0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-5Z	148.0		0.121							2				0.681		4	1	2	41.00	25	0.2	27.13	12		0.00812589	3.01788342				
		Cod (Gadus morhua)	NAFO-5Z	148.0		0.121							2				1.344		4	1	2	41.00	25	0.2				0.00812589	3.01788342				
		Cod (Gadus morhua)	Baltic-Areas-22-and-24	105	0.5	0.15							3	3		33	0.59	0.84	4	1	2	55.00	25	0.2	18.34			0.0108	2.968				
		Cod (Gadus morhua)	Baltic-Areas-25-32	105	0.5	0.15							3				0.637		4	1	2	56.00	25	0.2	13.52			0.0099	2.965				
		Cod (Gadus morhua)	Celtic-Sea	105.0		0.2							3				0.948		4	1	2	51.00	25	0.2	37.9			0.0095	3.031				
		Cod (Gadus morhua)	Faroe-Plateau	115	-0.42	0.19							4				0.683		4	1	2	62.00	25	0.2	19.76			0.0104	3				
		Cod (Gadus morhua)	Greenland-offshore-component	92.3		0.218							7				7.101		4	1	2	59.00	25	0.3	5.9			0.0104	3				
		Cod (Gadus morhua)	Iceland	102	-0.35	0.234							7				0.470		4	1	2	63.00	25	0.2	23.99			0.0104	3				
		Cod (Gadus morhua)	Irish-Sea	105.0		0.2							3				0.577		4	1	2	54.00	10	0.2	22.1			0.0095	3.031				
		Cod (Gadus morhua)	Kattegat	126		0.219							3				0.649		4	1	2	57.00	25	0.2	16.7	9		0.0081	3.03				
		Cod (Gadus morhua)	North-East-Arctic	105.0		0.2							8				0.863		4	1	2	68.00	25	0.2	19			0.0081	3.03				
		Cod (Gadus morhua)	North-East-Arctic	105.0		0.2							7.5				0.808		4	1	2	70.00	25	0.2	19			0.0081	3.03				
		Cod (Gadus morhua)	North-East-Arctic	105.0		0.2							8				0.758		4	1	2	68.00	25	0.2	6.03			0.0081	3.03				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Cod (Gadus morhua)	North-East-Arctic	105.0		0.2							8				1.085		4	1	2	68.00	25	0.2				0.0081	3.03				
		Cod (Gadus morhua)	North-Sea	132		0.2								4		66	0.61	0.84	4	1	2	55.00	25	0.2	9.82			0.0081	3.03				
		Cod (Gadus morhua)	Skagerrak	106		0.177							3				0.352		4	1	2	58.00	25	0.2	27.5			0.0081	3.03				
		Cod (Gadus morhua)	ICES-VIa	119		0.269							2.5				0.496		4	1	2	58.30	25	0.2	21.16			0.0081	3.03				
		Cod (Gadus morhua)	ICES-VIId	105.0		0.2							3				1.275		4	1	2	50.30	25	0.1	9.762123			0.0095	3.031				
		Cod (Gadus morhua)	West-Greenland				92.3		0.218	92.3		0.218		6		70	1.39	0.84	4	1	2		25	0.2				0.00812589	3.01788342				
		Haddock (Melanogrammus aeglefinus)	NAFO-3NO1-(First-part-of-HAD3NO)	73		0.28							6				8.43		4	2	1	44.30	22					0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	NAFO-3NO2-(Second-part-of-HAD3NO)	73		0.28							6				2.212		4	2	1	44.30	22					0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	NAFO-3Ps1-(First-part-of-HAD3Ps)	73		0.28							6				8.332		4	2	1	45.10	22					0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	NAFO-3Ps2-(Second-part-of-HAD3Ps)	73		0.28							6				9.629		4	2	1	45.10	22					0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	NAFO-4TVW	73		0.28							4.5				1.065		4	2	1	44.10	22	0.2	8.13			0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	NAFO-4X	73		0.28							4				0.908		4	2	1	43.00	22	0.2	6.65			0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	NAFO-4X	73		0.28							4				0.901		4	2	1	43.00	22	0.2	6.65			0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	NAFO-5Y	73		0.28							3				0.274		4	2	1	43.30	22					0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	NAFO-5Z	73		0.28							2				3.058		4	2	1	41.00	22	0.2	9.67			0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	Faroe-Plateau	73		0.28							3.5				1.270		4	2	1	62.00	22	0.2	6.69			0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	Georges-Bank	73		0.28	73	-9999	0.28	73	-9999	0.28		2		39	1.38	0.74	4	2	1		22	0.2				0.0132	2.901				
		Haddock (Melanogrammus aeglefinus)	Iceland	81	-0.25	0.228							5.5				0.696		4	2	1	63.00	22	0.2	10.86			0.0052	3.155				
		Haddock (Melanogrammus aeglefinus)	ICES-Sub-Area-VII				64.33		0.374	64.33	0.08	0.374		2		33	1.27	0.74	4	2	1		22	0.2				0.0052	3.155				
		Haddock (Melanogrammus aeglefinus)	North-East-Arctic				64.33		0.374	64.33	0.08	0.374	6				3.122		4	2	1	70.00	22	0.2	7.5			0.0052	3.155				
		Haddock (Melanogrammus aeglefinus)	North-Sea	63.5		0.26							2.5				1.551		4	2	1	55.00	22	0.2	0.07			0.0052	3.155				
		Haddock (Melanogrammus aeglefinus)	North-Sea	63.5		0.26							2.5				1.482		4	2	1	55.00	22	0.2	0.07			0.0052	3.155				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Haddock (Melanogrammus aeglefinus)	Rockall-Bank	63.5		0.26							3				1.174		4	2	1	57.15	22	0.2	2.83			0.0052	3.155				
		Haddock (Melanogrammus aeglefinus)	ICES-VIa	63.5		0.26							3				1.416		4	2	1	57.00	22	0.2	2.03			0.0052	3.155				
		Whiting (Merlangius merlangus)	Eastern-Black-Sea	55.2	-1.46	0.158							1				0.717		4	1	2	43.00	20	0.7	0.029			0.0075	3.007				
		Whiting (Merlangius merlangus)	Western-Black-Sea	55.2	-1.46	0.158							1				0.651		4	1	2	43.00	20	0.7	0.022			0.0075	3.007				
		Whiting (Merlangius merlangus)	Celtic-Sea	55.2	-1.46	0.158							2				0.636		4	1	2	51.00	20	0.2	3.09			0.0075	3.007				
		Whiting (Merlangius merlangus)	Irish-Sea	55.2	-1.46	0.158							2				0.283		4	1	2	54.00	20	0.2	1.86			0.0075	3.007				
		Whiting (Merlangius merlangus)	North-Sea	55.2	-1.46	0.158							2				0.557		4	1	2	55.00	20	0.2	0.017			0.0075	3.007				
		Whiting (Merlangius merlangus)	North-Sea	55.2	-1.46	0.158							2				3.174		4	1	2	55.00	20	0.2	0.017			0.0075	3.007				
		Whiting (Merlangius merlangus)	ICES-VIa	55.2	-1.46	0.158							2				0.729		4	1	2	57.00	20	0.2	1.79			0.0075	3.007				
		Whiting (Merlangius merlangus)	ICES-VIId	55.2	-1.46	0.158							3				0.605		4	1	2	50.00	20	0.2	1.39			0.0075	3.007				
		Hake (Merluccius australis)	NZ,-HAK-1				92.5	-0.06	0.259	115.5	-10.2	0.185		8		90	1	0.9	4	3	2		30	0.21						0.016	3.36	0.0015	3.37
		Hake (Merluccius australis)	NZ,-HAK-4				88.8	0	0.294	116.1	-0.21	0.181		8		90	1	0.9	4	3	2		30	0.21						0.0051	3.11	0.0045	3.11
		Silver-hake (Merluccius bilinearis)	NAFO-4VWX										3									44.10		0.4	0.38								
		Silver-hake (Merluccius bilinearis)	NAFO-5Ze										2									40.40		0.4	0.48								
		Silver-hake (Merluccius bilinearis)	Mid-Atlantic-Bight										2									38.00		0.4	0.45								
		Silver-hake (Merluccius bilinearis)	North-Georges-Bank				52.67	0.14	0.229	52.67	0.14	0.229		2		23	0.54	0.47	4	1	1		11	0.4									
		Silver-hake (Merluccius bilinearis)	South-Georges-Bank				52.67	0.14	0.229	52.67	0.14	0.229		2		23	0.95	0.47	4	1	1		11	0.4									
		S.A.-Hake (Merluccius capensis)	South-Africa				144.6	-0.45	0.086	260.9	-0.71	0.041		4		47	0.4		4	2	1		12	0.3									
		S.A.-Hake (Merluccius capensis)	South-Africa-1.6	126.0		0.110							3				0.323		3	2	1	-30.00		0.3	2.29	15				0.0052	3.105	0.0050	3.116
		S.A.-Hake (Merluccius capensis)	South-Africa-South-Coast	126.0		0.110							3				0.209		3	2	1												
		Peruvian-hake (Merluccius gayi)	Peru				66.1	-0.84916	0.1885	103.9	-0.99623	0.0996							4	2	1	-12.00	13	0.3							0.014985	2.965	0.008369
		Peruvian-hake (Merluccius gayi)	Chile---South-Central-zone				55.7	-0.2275	0.30464	73.4	0.71238	0.17184	2		32				4	2	1	-38.00	13	0.43				2.966	0.00702				
		Hake (Merluccius hubbsi)	Argentina				54.4	-4.78	0.278	98	-4.58	0.191		3		51	0.25	0.82	4	1	2		15	0.23				0.161	2.7884				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Hake (Merluccius hubbsi)	Southwest-Atlantic-Ocean				54.4	-4.78	0.278	98	-4.58	0.191	2.5						4	1	2	-40.00	15	0.3	5.937658			0.161	2.7884				
		Hake (Merluccius merluccius)	Northern				114	-0.7	0.09	114	-0.7	0.09	4		40		0.22		4	2	1		12	0.2				3.159	0.00433				
		Hake (Merluccius merluccius)	Southern				100	-1.1	0.08	100	-1.1	0.08	4		40		0.60		4	2	1		12	0.2				3.159	0.00433				
		Hake (Merluccius merluccius)	Jabuka-Pit,-Adriatic-Sea	85		0.12									40	29			4	2	1	43.00	12	0.3				3.159	0.00433				
		Hake (Merluccius merluccius)	ICES-VIIIab-d-VIIb-k	60.8		0.255							4						4	2	1	54.00	12	0.2	3.998			3.07	0.0046				
		Hake (Merluccius merluccius)	ICES-VIIIc-and-IXa	60.8		0.255							4						4	2	1	43.00	12	0.2	3.3			3.07	0.0046				
		W.C.Hake (Merluccius productus)	US-West-Coast				56.29	-0.2	0.3	61.23	-0.01	0.3				35	1.55	0.32	4	1	3		13	0.237	1.216					2.556	0.0347	2.695	0.0204
		W.C.Hake (Merluccius productus)	US-West-Coast											5					4	1	3			0.23	1.205398								
		Southern-blue-whiting (Micromesistius australis)	Campbell-Island,-NZ				47.6	-0.93	0.35	51.5	-1.03	0.32	3.5			39	1.22		3	2	2	-51.30	25	0.2			.		0.00515	3.092	0.00407	3.152	
		Blue-whiting (Micromesistius poutassou)	Northern-ICES	33.4	0.23	-2.94							3	3		25	0.75	0.71	4	3	2	60.00	20	0.2	0.53	6		0.00745	3.027				
		Blue-whiting (Micromesistius poutassou)	Southern-ICES	33.4	0.23	-2.94							3				0.204		4	3	2	44.00	20	0.2	0.38	6		0.00745	3.027				
		Pollock-or-saithe (Pollachius virens)	NAFO-4VWX5	111		0.100							3				0.586		4	1	1	43.00	25	0.2				0.00771	3.048				
		Pollock-or-saithe (Pollachius virens)	Faroe	128.0	-0.9	0.13							5				0.533		4	1	1	62.00	25	0.2	20.27			0.00771	3.048				
		Pollock-or-saithe (Pollachius virens)	Iceland	128.0	-0.9	0.13							5				0.511		4	1	1	63.00	25	0.2	22.37			0.00771	3.048				
		Pollock-or-saithe (Pollachius virens)	North-East-Arctic	158.0		0.070							6				0.490		4	1	1	70.00	25	0.2	11.44			0.00771	3.048				
		Pollock-or-saithe (Pollachius virens)	North-Sea	177.0		0.070							4.5				0.574		4	1	1	55.00	25	0.2	6			0.00771	3.048				
		Pollock-or-saithe (Pollachius virens)	ICES-VI	177.0		0.070							5				0.323		4	1	1	54.00	25	0.2	8.13			0.00771	3.048				
		Walleye-pollock (Theragra chalcogramma)	Alaska				50.39		0.33	54.06		0.3					0.95	0.55	4	3	1		10										
		Walleye-pollock (Theragra chalcogramma)	Gulf-of-Alaska,-Alaska	58		0.274							5				1.447		4	2	2	58.00	28	0.3	1.24			0.0059	3.03				
		Walleye-pollock (Theragra chalcogramma)	Japan-Pacific-coast-of-Hokkaido	91		0.03							3.5				0.470		4	2	2	43.00	8	0.32				0.0059	3.03				
		Walleye-pollock (Theragra chalcogramma)	East-Kamchatka	74.5		0.047							3.5				0.587		4	2	2	53.30	8					0.0059	3.03				
		Walleye-pollock (Theragra chalcogramma)	West-Bering-Sea	74.5		0.047								4		39	0.581		4	2	2	61.00	8	0.4				0.0059	3.03				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Norway-pout (Trisopterus esmarkii)	North-Sea	21.29	-0.63	0.65							2			16.6	0.606		4	2	2	55.00	5	1.6				0.0068	3.0				
		Red-hake (Urophycis chuss)	NAFO-Gulf-of-Maine,-N.-Georges-Bank	60.2		0.190							2	1.8			0.518		4	1	1	41.25	12	0.2									
		Red-hake (Urophycis chuss)	NAFO-S.-New-England	60.2		0.190							2	1.7			1.022		4	1	1	40.00	12	0.2									
		White-hake (Urophycis tenuis)	NAFO-4T				84.0	0.126	0.218	136.0	-0.28	0.106	4				0.376		4	3	1	47.00	23	0.19		7				0.0040	3.172	0.0043	3.147
	Moridae																																
		Red-cod (Pseudophycis bachus)	NZ				68.5	0.06	0.47	76.5	-0.03	0.41				52	0.6	1		2	1		7	0.76									
Lophiiformes																																	
	Lophiidae																																
		Black-anglerfish (Lophius budegassa)	ICES-VIIb-k-and-VIIIa,b.				84.8		0.100	111.0		0.070	4	4	34		16.8		4	2	1	49.00	14	0.15	8.25	11		0.0111	3				
		Monkfish (Lophius piscatorius)	ICES-VIIb-k-and-VIIIa,b.				130.0		0.110	167.0		0.080			35		0.602		4	3	1	49.00	9					0.024	2.896				
		Monkfish (Lophius piscatorius)	ICES-VII-and-VIIIa,b.				130.0		0.110	167.0		0.080			35		0.735		4	3	1	49.00	9					0.024	2.896				
Ophidiiformes																																	
	Ophidiidae																																
		Ling (Genypterus blacodes)	NZ,-Bounty-Platform				123.2	0.28	0.128	158.4	-0.7	0.079					0.4	0.75	4	3	1		30	0.18									
		Ling (Genypterus blacodes)	NZ,-Chatham-Rise				119	-1.24	0.108	160.1	-1.05	0.076					0.4	0.75	4	3	1		30	0.18									
		Ling (Genypterus blacodes)	NZ,-Southern-Plateau				95.1	0.16	0.194	125.7	-0.67	0.113					0.4	0.75	4	3	1		30	0.18									
		Kingklip (Genypterus capensis)	South-Africa,-South-coast				136	0.22	0.142	136	0.22	0.142		5		66	0.58	0.5	4	3	1		24	0.2				0.0013	3.33				
		Kingklip (Genypterus capensis)	South-Africa,-West-coast				129.2	-0.32	0.141	129.2	-0.32	0.141		5		70	0.58	0.5	4	3	1		24	0.2				0.0013	3.33				
		Kingklip (Genypterus capensis)	South-Africa-1.3-1.4				136	0.22	0.142	136	0.22	0.142	5		70		3.160		4	2	1	-20.00	24	0.3				0.0013	3.33				
Perciformes																																	
	Ammodytidae																																
		Sandeel (Ammodytes marinus)	Northern-North-Sea	21.8		0.89							2				0.762		1	1	2	58.00	9	0.4						-6.45	3.43	-6.3	3.39
		Sandeel (Ammodytes marinus)	Shetland	21.8		0.89							2			110	0.877		1	1	2	60.30	9	0.843						-6.45	3.43	-6.3	3.39

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Sandeel (Ammodytes marinus)	Southern-North-Sea	21.8		0.89							2				0.926		1	1	2	52.30	9	0.4						-6.45	3.43	-6.3	3.39
		Sandeel (Ammodytes marinus)	ICES-VIa	15.0		0.334							2.5				0.550		1	1	2	57.15	9	0.4						-6.45	3.43	-6.3	3.39
	Branchiostegidae																																
		Branquillo (Branchiostegus japonicus)	Wakasa-Bay				34.9		0.298	33.2		0.330					0.0495		4	1	1	35.20	12			10				0.0288	3.049	0.0267	2.978
	Carangidae																																
		False-scad (Decapterus rhonchus)	N.W.-Africa-(CECAF-34.1.3-34.3.1)	55.69	-1.295	0.136									20		0.323		4	1	3	18.00						0.035	2.7313				
		Cape-horse-mackerel (Trachurus capensis)	South-Africa-1.3-1.5	62.9		0.109							3				1.004		3	2	3	-34.30		0.49				0.0078	3.001				
		Mediterranean-horse-mackerel (Trachurus mediterraneus)	Black-Sea	19.25	-0.59142	0.34806							2		20		1.153		4	2	3	43.00	12	0.45	0.026			0.0152	2.996				
		S.-pacific-horse-mackerel (Trachurus symetricus)	South-Pacific-Ocean	74.24	-0.8113	0.1109							4						4	2	3	-30.00		0.4									
		Horse-mackerel (Trachurus trachurus)	Western-ICES	22.4		0.299							4		25		2.113		4	2	3	49.00	11	0.15	0.733	14.3		0.0034	3.294				
		Horse-mackerel (Trachurus trachurus)	Southern-ICES	22.4		0.299							4		25		0.465		4	2	3	43.00	11	0.15	0.84546	14.3		0.0034	3.294				
		Horse-mackerel (Trachurus trecae)	N.W.-Africa-(CECAF-34.1.3-34.3.1)	38.98	-1.16	0.278								3		31			4	2	3	18.00	30	0.5				0.0139	2.9606				
	Centrarchidae																																
		Smallmouth-bass (Micropterus dolomieui)	Courtois-Creek,-Missouri																			37.52											
		Smallmouth-bass (Micropterus dolomieui)	Baie-du-Dore,-Lake-Huron,																			44.21											
		Smallmouth-bass (Micropterus dolomieui)	South-Bay,-Manitoulin-Island,-Canada																			45.50											
	Centrolophidae																																
		Blue-warehou (Seriolella brama)	NZ,-south-of-Banks-Peninsula				63.8	-0.46	0.241	66.3	-0.79	0.209		4		42	0.8	0.75	2	2	2			0.24									
	Channichthyidae																																
		Champsocephalus-gunnari (Champsocephalus gunnari)	South-Georgia,-Antarctic-Ocean	50.1	-0.09	0.136							2			29	0.93		3	2	1	-54.00	13	0.5		1.5		0.0017	3.363				
		Champsocephalus-gunnari (Champsocephalus gunnari)	South-Orkney-Islands,-Antarctic-Ocean	50.1	-0.09	0.136							2						3	2	1	-60.30	13	0.5		1.5		0.0006	3.655				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Pseudochaenichthys (Pseudochaenichthys georgianus)	South-Georgia,-Antarctic-Ocean	62.6		0.243										38.2			4	2	1	-54.00											
	Gempylidae																																
		Hoki (Macruronus novaezelandiae)	NZ,-Eastern-stock				89.5	-1.23	0.232	101.8	-2.18	0.161	3.5		60		1	0.9	4	3	2		25	0.28				0.004	2.95				
		Hoki (Macruronus novaezelandiae)	NZ,-Western-stock				92.6	-0.5	0.261	104	-0.6	0.213					1	0.9	4	3	2		25	0.28				0.006	2.85				
		Gemfish (Rexea solandri)	NZ,-Northern				87.4	-0.35	0.266	105	-0.55	0.194					1	0.9	4	3	2		17	0.25									
		Gemfish (Rexea solandri)	NZ,-Southern				88.5	-0.66	0.242	104.2	-0.88	0.178					1	0.75	4	3	2		17	0.23									
	Lactariidae																																
		False-trevally (Lactarius lactarius)	Gulf-of-Thailand	27.0		0.629									16		2.722		4	1	3	11.00			19.28366			0.0098	3.047				
	Latridae																																
		Blue-moki (Latridopsis ciliaris)	NZ				66.95	-0.029	0.208	66.95	-0.03	0.208				40	0.9		3	1	1		33	0.14									
	Lutjanidae																																
		Red-Snapper (Lutjanus campechanus)	U.S.-Gulf-of-Mexico				92	-9999	0.12	92	-9999	0.12	8			31	0.48	0.92	4	1	1	28.00	16	0.15	26230000			0.0169	2.99				
		Silk-Snapper (Lutjanus synagris)	Zone-B---Cuba	43.4	0.3	0.290								2		19	0.565		4	2	2	19.45	6	0.17569				0.0186	2.97				
	Moronidae																																
		Sea-bass (Dicentrarchus labrax)	English-Channel				75.1		0.090	72.0		0.090	4				5.378		4	1	1	50.50	15	0.1				0.0074	3.096				
		Sea-bass (Dicentrarchus labrax)	Hinkley-Point,-Somerset-UK				75.1		0.090	72.0		0.090	4				1.863		4	1	1	51.00	15	0.1				0.0074	3.096				
		Sea-bass (Dicentrarchus labrax)	Severn-Estuary-UK				75.1		0.090	72.0		0.090	4				1.428		4	1	1	51.50	15	0.1				0.0074	3.096				
		Sea-bass (Dicentrarchus labrax)	Southern-Irish-UK				75.1		0.090	72.0		0.090	4						4	1	1	56.30	15	0.1				0.0074	3.096				
		Sea-bass (Dicentrarchus labrax)	South-western-UK				75.1		0.090	72.0		0.090	4				1.131		4	1	1	50.30	15	0.1				0.0074	3.096				
		White-perch (Morone americana)	Western-Lake-Erie																			42.00											
		White-bass (Morone chrysops)	Western-Lake-Erie																			42.00											
		Striped-bass (Morone saxatilis)	Choptank-River,-Chesapeake-Bay				102.0		0.274	139.0		0.117	7				2.620		4	1	1	38.38	30	0.15						0.0047	3.224	0.0061	3.153

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Striped-bass (Morone saxatilis)	Head-of-Chesapeake-Bay				102.0		0.274	139.0		0.117	7				2.157		4	1	1	39.20	30	0.15						0.0047	3.224	0.0061	3.153
		Striped-bass (Morone saxatilis)	Nanticoke-River,-Chesapeake-Bay				102.0		0.274	139.0		0.117	7				1.543		4	1	1	38.14	30	0.15						0.0047	3.224	0.0061	3.153
		Striped-bass (Morone saxatilis)	Potomac-River,-Chesapeake-Bay				102.0		0.274	139.0		0.117	7				1.799		4	1	1	37.56	30	0.15						0.0047	3.224	0.0061	3.153
		Striped-bass (Morone saxatilis)	East-Coast,-USA				102.0		0.274	139.0		0.117	7				0.699		4	1	1	35.00	30	0.15	12.97					0.0047	3.224	0.0061	3.153
		Striped-bass (Morone saxatilis)	East-Coast,-USA				102.0		0.274	139.0		0.117	7				0.699		4	1	1	35.00	30	0.15	12.97					0.0047	3.224	0.0061	3.153
	Mugilidae																																
		Grey-mullet (Mugil cephalus)	Taiwan	59.3	-0.12	0.301							3		35.5		0.651		1	1	2	22.45	16	0.33				0.0117	3.064				
	Nototheiniidae																																
		Gobionotothen-gibberifrons (Gobionotothen gibberifrons)	South-Georgia,-Antarctic-Ocean	57.5	0.439	1.040								10		37.5			3	2	1	-54.00		0.8		3	500	0.0017	3.5				
		Lepidonotothen (Lepidonotothen squamifrons)	Lena-Bank,-Antarctic-Ocean	43		0.117								8.5		35			3	2	2	-53.00	19	0.23									
		Notothenia-rossii (Notothenia rossii)	South-Georgia,-Antarctic-Ocean	80.3	0.296	0.2							7				0.538		4	2	2	-54.00	16	0.29				0.0080	3.06				
		Notothenia-rossii (Notothenia rossii)	South-Orkney-Islands,-Antarctic-Ocean	80.3	0.296	0.2							7						4	2	2	-60.30	16	0.29				0.0080	3.06				
		Patagonotothen-guntheri (Patagonotothen guntheri)	South-Georgia,-Antarctic-Ocean														0.504			3	2	-54.00		0.8									
	Nototheniidae																																
		Lepidonotothen (Lepidonotothen squamifrons)	Kerguelen-Islands,-Antarctic-Ocean	67		0.078								8.5		35			3	2	2	-50.00	19	0.23									
		Lepidonotothen (Lepidonotothen squamifrons)	Ob-Bank,-Antarctic-Ocean	43		0.117								8.5		35			3	2	2	-52.30	19	0.23									
		Notothenia-rossii (Notothenia rossii)	Kerguelen-Islands,-Antarctic-Ocean	80.3	0.296	0.2							7						4	2	2	69.30	16	0.31						0.0231	2.85	0.0213	2.88
	Pentacerotidae																																
		Pelagic-armourhead (Pseudopentaceros wheeleri)	Southeast-Hancock-Seamount,-Hawaii										2				4.53		3	2	3	29.48		0.54									
	Percidae																																
		Yellow-perch (Perca flavescens)	Western-Erie-Lake																			42.00											

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Yellow-perch (Perca flavescens)	Green-Bay,-Lake-Michigan																			45.00											
		Yellow-perch (Perca flavescens)	Leech-Lake,-Minnesota																			47.09											
		Yellow-perch (Perca flavescens)	Oneida-Lake,-New-York																			43.13											
		Yellow-perch (Perca flavescens)	Rainy-Lake,-Minnesota																			48.37											
		Yellow-perch (Perca flavescens)	Red-Lakes,-Minnesota										4									48.10											
		Yellow-perch (Perca flavescens)	Savanne-Lake,-Ontario																			46.04											
		Yellow-perch (Perca flavescens)	South-Bay,-Lake-Huron										4									45.45											
		Yellow-perch (Perca flavescens)	Western-Lake-Erie																			41.40											
		Sauger (Stizostedion canadense)	Lake-Kabetogama,-Minnesota																			48.28											
		Sauger (Stizostedion canadense)	Lake-Pepin,-Minnesota																			44.22											
		Sauger (Stizostedion canadense)	Rainy-Lake,-Minnesota																			48.37											
		Sauger (Stizostedion canadense)	Lake-of-the-Woods,-Minnesota																			49.15											
		Pikeperch (Stizostedion lucioperca)	Lake-Ijssel,-the-Netherlands										3									52.23											
		Pikeperch (Stizostedion lucioperca)	Lake-Tjeukemeer,-the-Netherlands										3									52.50											
		Walleye (Stizostedion vitreum)	Balsam-Lake																			44.35		0.4255									
		Walleye (Stizostedion vitreum)	Buckhorn-Lake																			44.29		0.3632									
		Walleye (Stizostedion vitreum)	Cass-Lake,-Minnesota										5									47.25											
		Walleye (Stizostedion vitreum)	Lake-Erie,-New-York										5									42.50											
		Walleye (Stizostedion vitreum)	Lake-Erie,-Michigan										5									41.55											
		Walleye (Stizostedion vitreum)	Lake-Erie										5									42.15		0.32	1.4								
		Walleye (Stizostedion vitreum)	Erie-Lake																			42.00		0.35									
		Walleye (Stizostedion vitreum)	Escanaba-Lake,-Wisconsin																			46.04											
		Walleye (Stizostedion vitreum)	Mille-Lacs-Lake,-Minnesota										5									46.15		0.23	0.778								
		Walleye (Stizostedion vitreum)	Namakan-River																					0.2974									

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Walleye (Stizostedion vitreum)	Nipissing-Lake																			46.17		0.3667									
		Walleye (Stizostedion vitreum)	Rainy-Lake,-Minnesota																			48.42											
		Walleye (Stizostedion vitreum)	Rainy-Lake																			48.42		0.5									
		Walleye (Stizostedion vitreum)	Rice-Lake																			44.10		0.34									
		Walleye (Stizostedion vitreum)	Savanne-Lake																			48.49		0.29									
		Walleye (Stizostedion vitreum)	Scugog-Lake																			44.10		0.5									
		Walleye (Stizostedion vitreum)	Woods-Lake																					0.42									
		Blue-pike (Stizostedion vitreum-glaucum)	Eastern-Lake-Erie																			42.50											
	Pomatomidae																																
		Bluefish (Pomatomus saltatrix)	East-Coast,-USA	87.2	-0.93	0.26								1.1		33.9			4	1	3	34.00	12	0.25	9.0145		1000000	0.0103	2.77				
	Sciaenidae																																
		Weakfish (Cynoscion guatucupa)	East-Coast,-USA										2		29.6							34.00		0.15	4.36								
	Scianidae																																
		White-croaker (Argyrosomus argentatus)	East-China-Sea	35.3		0.760							3				0.208		4	1	2	41.00		0.29	1	22							
		Black-croaker (Argyrosomus nibe)	East-China-Sea	45		0.25							3		14.5		0.677			1	1	29.00				20		0.0030	3.213				
		Yellow-croaker (Pseudociaena polyactis)	East-China-Sea	34.8		0.370							3				0.743				2	33.00											
	Scombridae																																
		Chub-mackerel (Scomber japonicus)	Soledad-Basin,-Baja-California	41		0.22							2						4	2	1	25.15	12					0.0014	3.394				
		Chub-mackerel (Scomber japonicus)	Southern-California	41		0.22							2				2.119		4	2	1	35.30	12	0.5	0.67			0.0014	3.394				
		Chub-mackerel (Scomber japonicus)	Gulf-of-California	41		0.22							2						4	2	1	27.54	12					0.0014	3.394				
		Chub-mackerel (Scomber japonicus)	Pacific-Coast-of-Japan	38.1		0.63							2.5				2.078		4	2	1	36.00	13	0.15		17		0.00389	3.3619				
		Chub-mackerel (Scomber japonicus)	Pacific-Coast-of-Japan	38.1		0.63							2.5				1.163		4	2	1	34.00	13	0.15	1	17		0.00389	3.3619				
		Mackerel (Scomber scombrus)	NAFO-2-to-6	44.5	-1.57	0.269							1.9		26		1.824		4	1	3	48.00	20	0.2	1.96	10		0.0046	3.18				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Mackerel (Scomber scombrus)	Black-Sea	41.0		0.4							2		26		1.850		4	1	3	40.30	17	1.17				0.0046	3.18				
		Mackerel (Scomber scombrus)	Western-ICES	33.6	-0.18	0.837							3		32		0.71		4	1	3	49.00	17	0.15	1.87	9		0.0046	3.18				
		King-mackerel (Scomberomorus cavalla)	W.-Gulf-of-Mexico	115	0.256	0.1658										47	2.879		4	1	3	21.00	14	0.1658				0.0150	2.893				
		Albacore-tuna (Thunnus alalunga)	South-Pacific-Ocean	127.0	-2.31	0.12								5	80		0.467		4	3	3	-17.00	10	0.22			2000000	0.0453	2.79				
		Yellowfin-tuna (Thunnus albacares)	Eastern-Pacific-Ocean	191.0	-1.02	0.327							2				0.293		4	1	3	10.00	8	0.8	8.5	22		0.0216	2.981				
		Yellowfin-tuna (Thunnus albacares)	Indian-Ocean	194.0		0.163							2				0.846		4	1	3	-10.00	8	0.4		25		0.0514	2.858				
		Southern-bluefin-tuna (Thunnus maccoyii)	Southern-Pacific	220		0.140							8		125		0.238		4	1	3	-15.00	20	0.08	180			0.0265	2.94				
		Southern-bluefin-tuna (Thunnus maccoyii)	Southern-Pacific	220		0.140							8		125		0.473					-15.00	20	0.08	180			0.0265	2.94				
		Bigeye-Tuna (Thunnus obesus)	West-Atlantic	219.0		0.23							4		100		0.201		4	4	3	-20.00	11	0.4	15.5	20		0.0125	3.121				
		Bigeye-Tuna (Thunnus obesus)	East-Pacific	187.0		0.380							3				0.104		4	4	3	-10.00	11	0.6	22	23		0.0178	2.902				
		Bigeye-Tuna (Thunnus obesus)	East-Pacific	187.0		0.380							3				0.104		4	4	3	-10.00	11	0.4	4.25373	23		0.0178	2.902				
		Atlantic-bluefin-tuna (Thunnus thynnus)	West-Atlantic				278		0.170	266.0		0.170	8				0.966		4	1	3	20.00	15	0.14	940.702	15		0.0404	2.837				
	Sparidae																																
		Sea-bream (Chrysophrys major)	Yellow-Sea	70.8		0.117							3				1.392		4	1	1	35.00	20	0.357				0.0199	3				
		Snapper (Pagrus auratus)	New-Zealand,-SNA-8	66.7	-0.11	0.16							4		25		0.805		4	2	2	-37.00	35	0.06	50.956			0.04467	2.793				
		Snapper (Pagrus auratus)	Hauraki-Gulf/Bay-of-Plenty	58.8	-1.11	0.102							4.5		25		0.749		4	2	2	-36.00	35	0.06	26.574			0.04467	2.793				
		Snapper (Pagrus auratus)	NZ,-SNA-1				58.8	-1.11	0.102	58.8	-1.11	0.102		4		24		0.94	3	1	1		60	0.075									
		Snapper (Pagrus auratus)	NZ,-SNA-8				66.7	-0.11	0.16	66.7	-0.11	0.16		4		24	0.62	0.94	3	1	1		60	0.075									
		Red-porgy (Pagrus pagrus)	North-Carolina				76.3	-9999	0.096	76.3	-9999	0.096		4		23	0.4		4	1	2	35.00	17	0.28	0.5979445			0.0102	3.06				
		Scup (Stenotomus chrysops)	Cape-Cod---Cape-Hatteras-USA	42.4		0.17							2			16	0.32		3	1	1	39.00	15	0.2	2.5439								
		Yellow-sea-bream (Taius tumifrons)	Central-East-China-Sea	47.4	-0.3	0.249							3				0.532		4	1	2	30.00											
		Yellow-sea-bream (Taius tumifrons)	East-China-Sea	47.4	-0.3	0.249							3				0.222		4	1	2	30.00		0.2									

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Yellow-sea-bream (Taius tumifrons)	Japan-Coast	34.3	-0.37	0.373							3				0.576		4	1	2	32.00											
		Yellow-sea-bream (Taius tumifrons)	South-East-China-Sea	30.6		0.25							3				0.882		4	1	2	27.00											
		Yellow-sea-bream (Taius tumifrons)	South-East-China-Sea	30.6		0.25							3				1.524		4	1	2	27.00											
	Stromateidae																																
		Butterfish (Peprilus triacanthus)	NAFO-5-and-6	18.3	0.12	0.800							2		16		0.76		2	1	2	39.00	4	0.8		15		0.0065	3.26				
	Trichiuridae																																
		Hairtail (Trichiurus haumela)	East-China-Sea	55.3	-0.681	0.293							2	2	30		0.322		4	2	2	30.00	15	0.29		21		0.00015	3.427				
	Xiphiidae																																
		Swordfish (Xiphias gladius)	North-Atlantic	365.0		0.230							5				0.146		4	2	3	20.00	9	0.2	288.3039	12		0.0027	3.3				
Pleuronectiformes																																	
	Bothidae																																
		Summer-flounder (Paralichthys dentatus)	Middle-Atlantic-Bight											2		32						38.00		0.2									
		Black-Sea-turbot (Psetta maeotica)	Black-Sea				66.2	-0.14	0.310	81.5	-0.48	0.210	4				6.053		4	1	1	43.30	26	0.19				0.0110	3.104				
	Pleuronectidae																																
		Petrale-sole (Eopsetta jordani)	Southern-B.C.,-Canada				49	-2.6	0.16	58.6	-0.27	0.167	8	8		44	0.675		4	2	1	50.00	25	0.25				0.00606	3.21749	0.00272	3.135		
		Flathead-flounder (Hippoglossoides elassodon)	West-Kamchatka-Shelf				37.6	-0.3536	0.1731	47.2	-0.2102	0.1322		1.5			0.319		3	3	1	55.00	27	0.2									
		American-plaice (Hippoglossoides platessoides)	NAFO-3LNO	65.9		0.1								8		30	0.218		3	2	1	44.30	30	0.2				0.0011	3.345				
		American-plaice (Hippoglossoides platessoides)	Flemish-Cap-(NAFO-Div.-3M)	65.9		0.1							5				5.061		3	2	1	47.00	30					0.0011	3.345				
		American-plaice (Hippoglossoides platessoides)	NAFO-3Ps	65.9		0.1								8		30	0.251		3	2	1	46.00	30					0.0011	3.345				
		American-plaice (Hippoglossoides platessoides)	NAFO-4V	65.9		0.1								8		30	2.342		3	2	1	43.25	30					0.0011	3.345				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		American-plaice (Hippoglossoides platessoides)	NAFO-5YZ	65.9		0.1							3.5				0.461		3	2	1	41.10	30					0.0011	3.345				
		American-plaice (Hippoglossoides platessoides)	West-Greenland	72.52	-0.74	0.049							8	8		26	0.393		3	2	1	61.30	30	0.2									
		Pacific-halibut (Hippoglossus stenolepis)	North-Pacific	184		0.14								20			0.377		4	3	1	50.00	55	0.19	62.13			0.0031	3.24				
		Rock-sole (Lepidopsetta bilineata)	Hecate-Strait,-B.C.				40.2	-1.56	0.26	51.6	-2.5	0.146	4			30			4	2	1	52.00	22	0.26				0.00552	3.23131	0.00008792	3.0626	0.00001145	3.410
		Yellowfin-sole (Limanda aspera)	E.-Bering-Sea				42.97	-0.85	0.08	43.06	-0.26	0.1	10	9		21.4	0.520		3	2	1	58.00	26	0.25									
		Yellowfin-sole (Limanda aspera)	West-Kamchatka-Shelf				42.97	-0.85	0.08	43.06	-0.26	0.1	10	9		21.4	0.721		3	2	1	55.00	26	0.25									
		Common-dab (Limanda limanda)	Belt-Sea	33.0		0.3							2				0.302		4	1	1		12	0.35		9	50000	0.00495	3.14				
		Longhead-dab (Limanda proboscidea)	West-Kamchatka-Shelf																			55.00											
		Sakalin-flounder (Limanda sakhalinensis)	West-Kamchatka-Shelf														0.674					55.00											
		English-sole (Parophrys vetulus)	Hecate-Strait				31.22	-0.8272	0.366494	43.22	-0.6754	0.25318	3	4		29.5	0.382		3	2	1	53.00	17	0.294			150000	0.0000147	2.916				
		Flounder (Platichthys flesus)	Baltic-Areas-24-and-25				32.6	-0.49	0.322	38.5	-0.64	0.250	3	5		22	0.266		4	1	1	57.00	15	0.2	1.2	9				0.220	2.83	0.0158	2.956
		Alaska-plaice (Pleuronectes auadrituberculatus)	West-Kamchatka-Shelf	57.0		0.099									30.0		0.285		3	2	1	55.00	31			3-9							
		Yellowtail-flounder (Pleuronectes ferrugineus)	NAFO-3LNO	50		0.335							6				0.609		4	1	1	44.30	12	0.2									
		Yellowtail-flounder (Pleuronectes ferrugineus)	NAFO-5Z	50		0.335							2				0.776		4	1	1	41.00	12	0.2	2.153								
		Yellowtail-flounder (Pleuronectes ferrugineus)	Southern-New-England	50		0.335							2						4	1	1	40.00	12	0.2	2.153								
		Plaice (Pleuronectes platessa)	ICES-VIId	73.2	-2.07	0.095							3				0.335		3	1	1	50.00	30	0.12	3.4			0.0103	3.017				
		Plaice (Pleuronectes platessa)	ICES-VIIe	73.2	-2.07	0.095							3				0.534		3	1	1	49.30	30	0.12	3.91			0.0103	3.017				
		Plaice (Pleuronectes platessa)	Celtic-Sea	73.2	-2.07	0.095							3				0.542		3	1	1	51.00	30	0.12	3.39			0.0103	3.017				
		Plaice (Pleuronectes platessa)	ICES-IIIa	73.2	-2.07	0.095							3				0.439		3	1	1	58.00	30	0.1	3.94			0.0103	3.017				
		Plaice (Pleuronectes platessa)	Irish-Sea	73.2	-2.07	0.095							3				0.338		3	1	1	54.00	30	0.12	2.83			0.0103	3.017				
		Plaice (Pleuronectes platessa)	Kattegat				45.0		0.15	70		0.08	3				1.122		3	1	1	57.00	30	0.1	4.03			0.0103	3.017				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Plaice (Pleuronectes platessa)	North-Sea				45.0		0.15	70		0.08	3				0.429		3	1	1	55.00	30	0.1	3.66			0.0103	3.017				
		Plaice (Pleuronectes platessa)	Skagerrak				45.0		0.15	70		0.08	3				0.462		3	1	1	58.00	30	0.1	3.12			0.0103	3.017				
		Greenland-halibut (Reinhardtius hippoglossoides)	E.-Bering-Sea-and-Aleutian-Islands	138		0.056								9		60	1.348		1	4	2	56.00	30	0.18		2	60000			0.0039	3.206	0.0025	3.328
		Greenland-halibut (Reinhardtius hippoglossoides)	North-East-Arctic	112		0.1							9	10		70	0.694		1	4	2	70.00	30	0.15	10.46091	5	60000			0.0039	3.206	0.0025	3.328
		Greenland-halibut (Reinhardtius hippoglossoides)	Northwest-Atlantic	112		0.1							14	10.8			0.231		1	4	2	65.00	30	0.1	23.319		60000			0.0039	3.206	0.0025	3.328
		Greenland-halibut (Reinhardtius hippoglossoides)	ICES-V-and-XIV	112		0.1							10.5	9		60	0.321		1	4	2	65.00	30	0.15	13.05833		60000			0.0039	3.206	0.0025	3.328
	Scophthalmidae																																
		Megrim (Lepidorhombus whiffiagonis)	ICES-VII-and-VIII				59.4		0.13	97.5		0.076		3		25.3			4	2	1	49.00						0.0029	3.26				
		Megrim (Lepidorhombus whiffiagonis)	ICES-VII-and-VIIIa,b				59.4		0.13	97.5		0.076		3		25.3			4	2	1	49.00						0.0029	3.26				
		Megrim (Lepidorhombus whiffiagonis)	ICES-VIIIc-and-IXa				59.4		0.13	97.5		0.076		3		25.3			4	2	1	43.00		0.2				0.0029	3.26				
	Soleidae																																
		Sole (Solea vulgaris)	Celtic-Sea	39.0		0.400							3				0.60		3	1	1	51.00	26	0.1	3.54			0.0036	3.313				
		Sole (Solea vulgaris)	ICES-IIIa	39.0		0.400							3						3	1	1	58.00	26	0.1	2.18			0.0036	3.313				
		Sole (Solea vulgaris)	Irish-Sea	39.0		0.400							3				0.659		3	1	1	54.00	26	0.1	2.68			0.0036	3.313				
		Sole (Solea vulgaris)	North-Sea	39.0		0.400							3				0.948		3	1	1	55.00	26	0.1	2.74			0.0036	3.313				
		Sole (Solea vulgaris)	ICES-VIId				42.4	0.093	0.397	48.3	0.075	0.329	3				0.764		3	1	1	50.00	26	0.1	2.59			0.0048	3.175				
		Sole (Solea vulgaris)	ICES-VIIe				42.4	0.093	0.397	48.3	0.075	0.329	3				0.480		3	1	1	49.30	26	0.1	2.81			0.0048	3.175				
		Sole (Solea vulgaris)	Bay-of-Biscay-(VIII)				42.4	0.093	0.397	48.3	0.075	0.329	3				0.166		3	1	1	45.30	26	0.1	2.68			0.0048	3.175				
Salmoniformes																																	
	Argentinidae																																
		Atlantic-argentine (Argentina silus)	NAFO-4VWX	43.8	-1.74	0.139							7				5.737		4	4	1	44.10	35			7.5		0.039	3.203				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
	Esocidae																																
		Pike (Esox lucius)	Lake-Kabetogama,-Minnesota																			48.28											
		Pike (Esox lucius)	Bay-of-Quinte,-Ontario																														
		Pike (Esox lucius)	Rainy-Lake,-Minnesota																			48.37											
		Pike (Esox lucius)	River-Frome,-Dorset,-England																			50.42											
		Pike (Esox lucius)	North-Basin,-Windermere-Lake										2									54.18		0.3	6.76								
		Pike (Esox lucius)	South-Basin,-Windermere-Lake										2		2							54.12		0.35	5.17								
		Pike (Esox lucius)	Lake-of-the-Woods,-Minnesota																			49.15											
		Maskinonge (Esox masquinongy)	Nogies-Creek-Sanctuary,-Ontario																			44.30											
	Osmeridae																																
		Capelin (Mallotus villosus)	Iceland										3				0.48		4	2	3	63.00	5							0.0015	3.41	0.0022	3.25
		Capelin (Mallotus villosus)	Iceland										3				0.725		4	2	3	63.00	5							0.0015	3.41	0.0022	3.25
		Capelin (Mallotus villosus)	Northern-Newfoundland				20		0.480	19		0.480	3				0.652		4	2	3	49.15	5	1.3		4.6				0.0015	3.41	0.0022	3.25
		Capelin (Mallotus villosus)	Northern-Newfoundland				20		0.480	19		0.480	3				0.723		4	2	3	49.15	5	1.3		4.6				0.0015	3.41	0.0022	3.25
		Capelin (Mallotus villosus)	Barents-Sea				27.8	-0.83	0.259	19.8	-0.53	0.454	3				4.083		4	2	3	71.00	5		0.0063	4				0.0015	3.41	0.0022	3.25
		Capelin (Mallotus villosus)	Barents-Sea				27.8	-0.83	0.259	19.8	-0.53	0.454	3				4.905		4	2	3	71.00	5		0.0063	4				0.0015	3.41	0.0022	3.25
		Capelin (Mallotus villosus)	Barents-Sea				27.8	-0.83	0.259	19.8	-0.53	0.454	3				1.517		4	2	3	71.00	5			4				0.0015	3.41	0.0022	3.25
		Rainbow-smelt (Osmerus mordax)	Western-Lake-Erie																			42.00											
Scorpaeniformes																																	
	Anoplopomatidae																																
		Sablefish (Anoplopoma fimbria)	W.-Canada	74		0.27							5			60						51.30		0.1									
		Sablefish (Anoplopoma fimbria)	West-Coast-USA	74		0.27				66.2		0.246	5	5								46.00		0.07	11.15								
		Sablefish (Anoplopoma fimbria)	West-Coast-USA-(alternative-model)	74		0.27				66.2		0.246	5	5								46.00		0.07	18.14691								

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Sablefish (Anoplopoma fimbria)	US,-West-Coast				66.7	-1.07	0.29	81.4	-0.77	0.249		5		62		0.95	4	4	1		62	0.08									
	Hexagrammidae																																
		Atka-mackerel (Pleurogrammus monopterygius)	Eastern-Bering-Sea-and-Aleutian-Islands	41.4	-0.13	0.439							4	3.6		31	0.853		4	2	1	52.00	15	0.3	0.71	5							
	Scorpaenidae																																
		Pacific-ocean-perch (Sebastes alutus)	Aleutian-Is.	39.6		0.167							8				0.874		4	3	1	52.00	98	0.05	3.094705			0.0122	3.030				
		Pacific-ocean-perch (Sebastes alutus)	British-Colombia				44.1		0.130	50.6		0.090					0.653		4	3	1	52.00	98					0.0149	2.999				
		Pacific-ocean-perch (Sebastes alutus)	Gulf-of-Alaska	40.0		0.142							8		10.5		1.535		4	3	1	58.00	98	0.05	3.49867			0.0154	2.96				
		Pacific-ocean-perch (Sebastes alutus)	Goose-Island-Gully,-B.C.				44.1		0.130	50.6		0.090	9	9			0.853		4	3	1	51.17	98	0.05	16.29					1.49E-02	2.99892	4.98E-03	3.18058
		Pacific-ocean-perch (Sebastes alutus)	US-West-Coast				40.3	-0.71	0.142	43.2	1.109	0.180	6.5				1.424		4	3	1	45.30	98	0.05	322908								
		Widow-rockfish (Sebastes entomelas)	US,-West-Coast				62.2	-0.07	0.17	62.2	-0.07	0.17		4		32	1.003	0.81	4	2	3		58	0.071									
		Widow-rockfish (Sebastes entomelas)	W.-U.S.-+-Canada			0.14			0.15			0.13	5	5		37	1.003		4	2	3	29.30	59	0.15									
		Yellowtail-rockfish (Sebastes flavidus)	Columbia	47.884	-3.935	0.245	47.25	-5.487	0.2	52.225	-4.074	0.199	7	7		36	0.286		4	1	1	46.15	56	0.11									
		Yellowtail-rockfish (Sebastes flavidus)	Vancouver	48.778	-5.861	0.181	48.546	-6.864	0.154	51.78	-5.048	0.182	7	7		36	0.465		4	1	1	48.30	56	0.11									
		Chilipepper-rockfish (Sebastes goodei)	West-U.S.A.				39	-0.15	0.3	53	-0.43	0.18	4	4		30	0.61	0.35	4	2	1	38.10	35	0.223	1.29982								
		Redfish (Sebastes marinus)	ICES-V-and-XIV				49	-2.47	0.06	49	-2.47	0.06				40.5	1.494		4	4	2	68.00	48	0.1									
		Redfish (Sebastes marinus)	Iceland				49	-2.47	0.06	49	-2.47	0.06				30	0.221		4	4	2	63.00	48										
		Redfish (Sebastes mentela-and-fasciatus)	NAFO-3M				32.7		0.151	52.5		0.058	16			43.1			4	3	1	44.00		0.1	1.8								
		Redfish (Sebastes mentella)	NE-Atlantic				49	-2.47	0.06	49	-2.47	0.06				39	0.73	0.47	4	4	2		48	0.1									
		Redfish (Sebastes mentella)	North-East-Arctic				32.7		0.151	52.5		0.058	16			43.1	0.793		4	3	1	70.00		0.1	3.3								
		Canary-rockfish (Sebastes pinniger)	US,-West-Coast				53.23	-1	0.193	57.53	-0.83	0.165		9		44	0.59		4	1	1		19	0.06		5							
		Canary-rockfish (Sebastes pinniger)	W.-U.S.(Columbia-region)				53.23	-0.995	0.193	57.53	-0.827	0.165	7	9		44	0.642		4	2	2	45.00	84	0.06		5.4							
		Redfish (Sebastes sp.)	NAFO-3NO				32.7		0.151	52.5		0.058				43.1			4	3	1	43.00											

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
		Redfish (Sebastes sp.)	NAFO-3Ps				32.7		0.151	52.5		0.058				43.1			4	3	1	46.00											
		Redfish (Sebastes sp.)	NAFO-4VWX				32.7		0.151	52.5		0.058				43.1			4	3	1	44.10											
		Redfish (Sebastes sp.)	NAFO-5YZ				32.7		0.151	52.5		0.058				43.1			4	3	1	41.10											
		Shortspine-thornyhead (Sebastolobus alaskanus)	Gulf-of-Alaska	48.36	-6.94	0.025							11	11		22			4	2	1	50.00	56	0.07				0.00000265	3.264				
Unknown																																	
	Hexagrammidae																																
		Lingcod (Ophiodon elongatus)	US-West-Coast-(South)											5		69								0.18	11.6109								
		Lingcod (Ophiodon elongatus)	US-West-Coast-(North)											5		69								0.18	16.2291								
Zeiformes																																	
	Oreosomatidae																																
		Black-oreo (Allocyttus niger)	NZ				37.2	16.4	0.056	39.9	-17.6	0.043		27		34	0.65	0.75	2	4	2		153	0.044									
		Smooth-oreo (Pseudocyttus maculatus)	NZ				43.6	-1.6	0.067	50.8	-2.9	0.047		31		40	0.65	0.75	2	4	2		86	0.063									
	Zeidae																																
		John-dory (Zeus faber)	NZ,-tmax=4				63.8	0.02	0.39	68.9	0.14	0.4		2		36	0.6	0.95	4	1	1		4	1.15									
		John-dory (Zeus faber)	NZ,-tmax=8				50.4	0.18	0.62	54.4	0.27	0.63		2		36	0.6	0.95	4	1	1		8	0.57									

Table 2. Population parameters for SESSF species.

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
Beryciformes																																	
	Berycidae																																
		Centroberyx affinis	SEF				23.9	-0.52	0.26	26.5	-0.47	0.24		4		20			4	2	2		40	0.12						0.0626	2.7233	0.0477	2.8213
	Trachichthyidae																																
		Hoplostethus atlanticus	SEF				39.06	-3.2	0.06	39.06	-3.2	0.06		25					4	4	2		150	0.04						0.0383	2.942	0.0351	2.970
Gadiformes																																	
	Merlucciidae																																
		Macruronus novaezelandiae	SEF				95.5	-0.86	0.2	101	-0.58	0.18		7		73			4	3	2		25	0.2						2.84E-6	2.89	3.93E-6	2.95
Ophidiiformes																																	
	Ophidiidae																																
		Genypterus blacodes	SEF				135.5		0.095	135.5		0.095		3		60			4	3	1		28	0.16				2.93E-3	3.1390				
Perciformes																																	
	Carangidae																																
		Pseudocaranx dentex	SEF				44.9	-1.4	0.29	44.5	-1.4	0.3		4		32			3	1	2		46	0.1									
	Centrolophidae																																
		Hyperoglyphe antarctica	SEF				85	-14	0.05	130	-12	0.03		6		61			2	3	1		42	0.28									
		Seriolella brama	SEF				59.8	-1.37	0.19	59.8	-1.37	0.19		3		40			2	2	2		12	0.58				0.03	2.90				
		Seriolella punctata	SEF				55	-0.2	0.36	55	-0.2	0.36		3		40			2	2	2		23	0.33				1.53E-5	3				
	Cheilodactylida																																
		Nemadactylus macropterus	SEF				45.5		0.17	51.3		0.13		3		20			3	1	1		38	0.45				4.29E-5	3				
	Gempylidae																																
		Rexea solandri	SEF				97.5	-0.52	0.21	109.4	-0.61	0.18		5		70			4	3	2		17	0.27				0.00143	3.3900				

Order	Family	Name	stock	Both sexes-L_∞	Both sexes-t_0	Both sexes-K	Male-L_∞	Male-t_0	Male-K	Female-L_∞	Female-t_0	Female-K	Both sexes-T_m	Female-T_m	Both sexes-L_m	Female-L_m	z	σ_r	Diet	Depth	Habitat	Latitude	t_{max}	M	KG/recF=O	Temperature	Fecundity	Both sexes-a	Both sexes-b	Males-a	Males-b	Females-a	Females-b
	Sillaginidae																																
		Sillago flindersi	SEF				23.9	-0.5	0.46	23.9	-0.5	0.46		2		16			3	1	1		8	0.9				1.32E-5	2.93				
Scorpaeniformes																																	
	Platycephalidae																																
		Neoplatycephalus richardsoni	SEF				48.2	-1.69	0.16	58.8	-1.22	0.19		4		36			4	1	1		17	0.27				2.49E-6	3.31				
Sebastinae																																	
	Sebastidae																																
		Helicolenus percoides	SEF				43.7		0.11	43.7		0.11		11		31			4	3	1		47	0.1								0.0181	2.997
Zeiformes																																	
	Zeidae																																
		Zenopsis nebulosus	SEF				60.9	0.18	0.2	60.9	0.18	0.2		5		38				2	1		12	0.38									
		Zeus faber	SEF				53.2	-1	0.15	53.2	-1	0.15		4		28			4	1	1		12	0.38									

Table 3. Regression statistics of relationships between biological parameters with a as the independent variable.

Model	R^2_{adj}	$p_{overall}$	RMSE	n
$\text{Log}_{10}\, b$=-0.036 (0.004) x $\text{Log}_{10}\, a$+0.412 (0.009)	$\underline{\underline{0.3263}}$	$\underline{\underline{\leq .0001}}$	0.0231	169
$\text{Log}_{10}\, L_\infty$=0.112 (0.058) x $\text{Log}_{10}\, a$+1.978 (0.126)	$\underline{0.0190}$	$\underline{0.0550}$	0.3007	142
$\text{Log}_{10}\, \kappa$=-0.062 (0.051) x $\text{Log}_{10}\, a$-0.756 (0.112)	0.0032	0.2294	0.2657	142
$\text{Log}_{10}\, L_m$=0.098 (0.124) x $\text{Log}_{10}\, a$+1.616 (0.272)	-0.0119	0.4355	0.3466	32
$\text{Log}_{10}\, L_{m}$_f=-0.022 (0.077) x $\text{Log}_{10}\, a$+1.492 (0.172)	-0.0367	0.7805	0.1789	26
$\text{Log}_{10}\, T_m$=0.029 (0.039) x $\text{Log}_{10}\, a$+0.589 (0.085)	-0.0032	0.4585	0.2042	139
$\text{Log}_{10}\, T_{m}$_f=-0.094 (0.093) x $\text{Log}_{10}\, a$+0.378 (0.212)	0.0009	0.3219	0.2660	25
$\text{Log}_{10}\, t_{max}$=-0.007 (0.043) x $\text{Log}_{10}\, a$+1.226 (0.094)	-0.0061	0.8743	0.2466	160
$\text{Log}_{10}\, M$=-0.112 (0.053) x $\text{Log}_{10}\, a$-0.845 (0.115)	$\underline{\underline{0.0231}}$	$\underline{\underline{0.0361}}$	0.2698	147

All analyses used $\log_{10}$ transformed data. Regression coefficients are shown as ±1 SE in parenthesis; R^2_{adj} = correlation coeficient; *p* = probablility level; RMSE = root mean square error from regression model, and *n* = number of stocks (_f after parameter indicates that parameter was estimated for females only). Results for which p<0.1 are indicated by underlines and those for which p<0.05 by double-underlines.

Table 4. Regression statistics of relationships between biological parameters with *b* as the independent variable.

Model	R^2_{adj}	$p_{overall}$	RMSE	n
$\text{Log}_{10}\, a$=-9.173 (1.008) x $\text{Log}_{10}\, b$+2.349 (0.493)	$\underline{\underline{0.3263}}$	$\underline{\underline{\leq 0.0001}}$	0.3680	169
$\text{Log}_{10}\, L_\infty$=-2.505 (0.854) x $\text{Log}_{10}\, b$+2.960 (0.418)	$\underline{\underline{0.0504}}$	$\underline{\underline{0.0039}}$	0.2960	143
$\text{Log}_{10}\, \kappa$=1.071 (0.764) x $\text{Log}_{10}\, b$-1.147 (0.374)	0.0067	0.1630	0.2647	143
$\text{Log}_{10}\, L_m$=-4.318 (1.949) x $\text{Log}_{10}\, b$+3.516 (0.954)	$\underline{\underline{0.1088}}$	$\underline{\underline{0.0342}}$	0.3253	32
$\text{Log}_{10}\, L_{m}$_f=-0.832 (1.380) x $\text{Log}_{10}\, b$+1.937 (0.680)	-0.0241	0.5515	0.1879	27
$\text{Log}_{10}\, T_m$=-0.809 (0.630) x $\text{Log}_{10}\, b$+0.921 (0.308)	0.0046	0.2012	0.2036	140
$\text{Log}_{10}\, T_{m}$_f=2.780 (1.967) x $\text{Log}_{10}\, b$-0.805 (0.970)	0.0370	0.1699	0.2790	26
$\text{Log}_{10}\, t_{max}$=-1.190 (0.698) x $\text{Log}_{10}\, b$+1.819 (0.342)	$\underline{0.0117}$	$\underline{0.0904}$	0.2463	161
$\text{Log}_{10}\, M$=3.162 (0.792) x $\text{Log}_{10}\, b$-2.146 (0.387)	$\underline{\underline{0.0916}}$	$\underline{\underline{0.0001}}$	0.2641	148

All analyses used $\log_{10}$ transformed data. Regression coefficients are shown as ±1 SE in parenthesis; R^2_{adj} = correlation coeficient; *p* = probablility level; RMSE = root mean square error from regression model, and *n* = number of stocks (_f after parameter indicates that parameter was estimated for females only). Results for which p<0.1 are indicated by underlines and those for which p<0.05 by double-underlines.

Table 5. Regression statistics of relationships between biological parameters with L_{∞} as the independent variable.

Model	R^2_{adj}	$p_{overall}$	RMSE	n
$\mathrm{Log}_{10}\ a$=0.231 (0.120) x $\mathrm{Log}_{10}\ L_{\infty}$-2.530 (0.210)	0.0190	0.0550	0.4314	142
$\mathrm{Log}_{10}\ b$=-0.023 (0.008) x $\mathrm{Log}_{10}\ L_{\infty}$+0.528 (0.014)	0.0504	0.0039	0.0282	143
$\mathrm{Log}_{10}\ \kappa$=-0.618 (0.061) x $\mathrm{Log}_{10}\ L_{\infty}$+0.444 (0.106)	0.3634	≤.0001	0.2380	181
$\mathrm{Log}_{10}\ L_m$=0.836 (0.135) x $\mathrm{Log}_{10}\ L_{\infty}$+0.001 (0.223)	0.5382	≤.0001	0.2201	32
$\mathrm{Log}_{10}\ L_m$_f=0.439 (0.149) x $\mathrm{Log}_{10}\ L_{\infty}$+0.766 (0.267)	0.2097	0.0064	0.1778	29
$\mathrm{Log}_{10}\ T_m$=0.343 (0.057) x $\mathrm{Log}_{10}\ L_{\infty}$-0.070 (0.099)	0.1874	≤.0001	0.2101	155
$\mathrm{Log}_{10}\ T_m$_f=0.670 (0.270) x $\mathrm{Log}_{10}\ L_{\infty}$-0.550 (0.501)	0.1554	0.0197	0.2963	28
$\mathrm{Log}_{10}\ t_{max}$=0.343 (0.063) x $\mathrm{Log}_{10}\ L_{\infty f}$+0.636 (0.111)	0.1507	≤.0001	0.2412	161
$\mathrm{Log}_{10}\ M$=-0.297 (0.079) x $\mathrm{Log}_{10}\ L_{\infty}$-0.064 (0.139)	0.0764	0.0002	0.2996	158

All analyses used log$_{10}$ transformed data. Regression coefficients are shown as ±1 SE in parenthesis; R^2_{adj} = correlation coeficient; p = probablility level; RMSE = root mean square error from regression model, and n = number of stocks (_f after parameter indicates that parameter was estimated for females only). Results for which p<0.1 are indicated by underlines and those for which p<0.05 by double-underlines.

Table 6. Regression statistics of relationships between biological parameters with κ as the independent variable.

Model	R^2_{adj}	$p_{overall}$	RMSE	n
$\mathrm{Log}_{10}\ a$=-0.166 (0.137) x $\mathrm{Log}_{10}\ \kappa$-2.24 (0.093)	0.0032	0.2294	0.4348	142
$\mathrm{Log}_{10}\ b$=0.013 (0.009) x $\mathrm{Log}_{10}\ \kappa$+0.497 (0.006)	0.0067	0.1630	0.0289	143
$\mathrm{Log}_{10}\ L_{\infty}$=-0.593 (0.058) x $\mathrm{Log}_{10}\ \kappa$+1.355 (0.040)	0.3634	≤.0001	0.2332	181
$\mathrm{Log}_{10}\ L_m$=-0.428 (0.179) x $\mathrm{Log}_{10}\ \kappa$+1.139 (0.107)	0.1282	0.0232	0.3024	32
$\mathrm{Log}_{10}\ L_m$_f=0.012 (0.101) x $\mathrm{Log}_{10}\ \kappa$+1.558 (0.084)	-0.0340	0.9042	0.2000	30
$\mathrm{Log}_{10}\ T_m$=-0.429 (0.055) x $\mathrm{Log}_{10}\ \kappa$+0.257 (0.037)	0.2752	≤.0001	0.1982	156
$\mathrm{Log}_{10}\ T_m$_f=-0.449 (0.162) x $\mathrm{Log}_{10}\ \kappa$+0.327 (0.139)	0.1881	0.0096	0.2855	29
$\mathrm{Log}_{10}\ t_{max}$=-0.482 (0.061) x $\mathrm{Log}_{10}\ \kappa$+0.924 (0.043)	0.2751	≤.0001	0.2250	162
$\mathrm{Log}_{10}\ M$=0.454 (0.073) x $\mathrm{Log}_{10}\ \kappa$-0.300 (0.050)	0.1913	≤.0001	0.2800	159

All analyses used log$_{10}$ transformed data. Regression coefficients are shown as ±1 SE in parenthesis; R^2_{adj} = correlation coeficient; p = probablility level; RMSE = root mean square error from regression model, and n = number of stocks (_f after parameter indicates that parameter was estimated for females only). Results for which p<0.1 are indicated by underlines and those for which p<0.05 by double-underlines.

Table 7. Regression statistics of relationships between biological parameters with Lm (sexes combined) as the independent variable.

Model	R^2_{adj}	$p_{overall}$	RMSE	n
Log$_{10}$ a=0.201 (0.254) x Log$_{10}$ L_m-2.414 (0.368)	-0.0119	0.4355	0.4956	32
Log$_{10}$ b=-0.032 (0.014) x Log$_{10}$ L_m+0.533 (0.021)	0.1088	0.0342	0.0279	32
Log$_{10}$ L_∞=0.661 (0.107) x Log$_{10}$ L_m+0.727 (0.149)	0.5382	<.0001	0.1958	32
Log$_{10}$ κ=-0.363 (0.152) x Log$_{10}$ L_m-0.023 (0.212)	0.1282	0.0232	0.2783	32
Log$_{10}$ T_m=0.386 (0.119) x Log$_{10}$ L_m-0.124 (0.171)	0.2461	0.0031	0.2189	29
Log$_{10}$ t_{max}=0.359 (0.162) x Log$_{10}$ L_m+0.587 (0.238)	0.1050	0.0346	0.3118	33
Log$_{10}$ M=-0.334 (0.176) x Log$_{10}$ L_m-0.022 (0.249)	0.0711	0.0665	0.3921	34

All analyses used log$_{10}$ transformed data. Regression coefficients are shown as ±1 SE in parenthesis; R^2_{adj} = correlation coeficient; p = probablility level; RMSE = root mean square error from regression model, and n = number of stocks. Results for which p<0.1 are indicated by underlines and those for which p<0.05 by double-underlines.

Table 8. Regression statistics of relationships between biological parameters with L_m (females only) as the independent variable.

Model	R^2_{adj}	$p_{overall}$	RMSE	n
Log$_{10}$ a=-0.146 (0.518) x Log$_{10}$ L_m_f-1.963 (0.802)	-0.0367	0.7805	0.4639	26
Log$_{10}$ b=-0.017 (0.028) x Log$_{10}$ L_m_f+0.518 (0.042)	-0.0241	0.5515	0.0265	27
Log$_{10}$ L_∞=0.540 (0.183) x Log$_{10}$ L_m_f+0.945 (0.286)	0.2097	<0.0001	0.1973	29
Log$_{10}$ κ=0.041 (0.341) x Log$_{10}$ L_m_f-0.820 (0.532)	-0.0340	0.9042	0.3671	30
Log$_{10}$ T_m_f=0.560 (0.169) x Log$_{10}$ L_m_f-0.216 (0.264)	0.1297	<0.0001	0.2615	67
Log$_{10}$ t_{max}=0.365 (0.182) x Log$_{10}$ L_m_f+0.774 (0.284)	0.0383	<0.0001	0.3051	76
Log$_{10}$ M=-0.321 (0.186) x Log$_{10}$ L_m_f-0.161 (0.293)	0.0234	0.0891	0.3068	82

All analyses used log$_{10}$ transformed data. Regression coefficients are shown as ±1 SE in parenthesis; R^2_{adj} = correlation coeficient; p = probablility level; RMSE = root mean square error from regression model, and n = number of stocks (_f after parameter indicates that parameter was estimated for females only). Results for which p<0.1 are indicated by underlines and those for which p<0.05 by double-underlines.

Table 9. Regression statistics of relationships between biological parameters with T_m (sexes combined) as the independent variable.

Model	R^2_{adj}	$p_{overall}$	RMSE	n
Log$_{10}$ a=0.137 (0.185) x Log$_{10}$ T_m-2.206 (0.104)	-0.0032	0.4585	0.4444	139
Log$_{10}$ b=-0.015 (0.011) x Log$_{10}$ T_m+0.497 (0.006)	0.0046	0.2012	0.0273	140
Log$_{10}$ L_∞=0.562 (0.093) x Log$_{10}$ T_m+1.426 (0.053)	0.1874	<0.0001	0.2689	155
Log$_{10}$ κ=-0.652 (0.084) x Log$_{10}$ T_m-0.275 (0.048)	0.2752	<0.0001	0.2444	156
Log$_{10}$ L_m=0.705 (0.218) x Log$_{10}$ T_m+1.100 (0.105)	0.2461	<0.0001	0.2959	29
Log$_{10}$ t_{max}=0.740 (0.070) x Log$_{10}$ T_m+0.846 (0.042)	0.3891	<0.0001	0.2072	172
Log$_{10}$ M=-0.772 (0.075) x Log$_{10}$ T_m-0.188 (0.044)	0.3685	<0.0001	0.2517	181

All analyses used log$_{10}$ transformed data. Regression coefficients are shown as ±1 SE in parenthesis; R^2_{adj} = correlation coeficient; p = probablility level; RMSE = root mean square error from regression model, and n = number of stocks. Results for which p<0.1 are indicated by underlines and those for which p<0.05 by double-underlines.

Table 10.Regression statistics of relationships between biological parameters with T_m (females only) as the independent variable.

Model	R^2_{adj}	$p_{overall}$	RMSE	n
$\mathrm{Log}_{10}\ a$=-0.436 (0.431) x $\mathrm{Log}_{10}\ \mathrm{T_m}$_f-1.964 (0.277)	0.0009	0.3219	0.5738	25
$\mathrm{Log}_{10}\ b$=0.027 (0.019) x $\mathrm{Log}_{10}\ \mathrm{T_m}$_f+0.477 (0.012)	0.0370	0.1699	0.0273	26
$\mathrm{Log}_{10}\ L_\infty$=0.277 (0.112) x $\mathrm{Log}_{10}\ \mathrm{T_m}$_f+1.652 (0.084)	0.1554	<0.0001	0.1904	28
$\mathrm{Log}_{10}\ \kappa$=-0.481 (0.173) x $\mathrm{Log}_{10}\ \mathrm{T_m}$_f-0.470 (0.130)	0.1881	<0.0001	0.2956	29
$\mathrm{Log}_{10}\ L_m$_f=0.255 (0.077) x $\mathrm{Log}_{10}\ \mathrm{T_m}$_f+1.386 (0.055)	0.1297	<0.0001	0.1764	67
$\mathrm{Log}_{10}\ t_{max}$=0.735 (0.090) x $\mathrm{Log}_{10}\ \mathrm{T_m}$_f+0.882 (0.067)	0.4785	<0.0001	0.2331	71
$\mathrm{Log}_{10}\ M$=-0.587 (0.094) x $\mathrm{Log}_{10}\ T_m$_f-0.304 (0.069)	0.3285	<0.0001	0.2464	77

All analyses used $\log_{10}$ transformed data. Regression coefficients are shown as $\underline{+}1$ SE in parenthesis; R^2_{adj} = correlation coeficient; *p* = probablility level; RMSE = root mean square error from regression model, and *n* = number of stocks (_f after parameter indicates that parameter was estimated for females only). Results for which $p<0.1$ are indicated by underlines and those for which $p<0.05$ by double-underlines.

Table 11.Regression statistics of relationships between biological parameters with t_{max} as the independent variable.

Model	R^2_{adj}	$p_{overall}$	RMSE	n
$\mathrm{Log}_{10}\ a$=-0.023 (0.145) x $\mathrm{Log}_{10}\ t_{max}$-2.096 (0.184)	-0.0061	0.8743	0.4517	160
$\mathrm{Log}_{10}\ b$=-0.015 (0.009) x $\mathrm{Log}_{10}\ t_{max}$+0.507 (0.011)	0.0117	0.0904	0.0276	161
$\mathrm{Log}_{10}\ L_\infty$=0.455 (0.084) x $\mathrm{Log}_{10}\ t_{max}$+1.173 (0.105)	0.1507	<0.0001	0.2780	161
$\mathrm{Log}_{10}\ \kappa$=-0.579 (0.073) x $\mathrm{Log}_{10}\ t_{max}$+0.074 (0.092)	0.2751	<0.0001	0.2466	162
$\mathrm{Log}_{10}\ L_m$=0.368 (0.167) x $\mathrm{Log}_{10}\ t_{max}$+1.020 (0.191)	0.1050	<0.0001	0.3160	33
$\mathrm{Log}_{10}\ L_m$_f=0.140 (0.070) x $\mathrm{Log}_{10}\ t_{max}$+1.363 (0.096)	0.0383	<0.0001	0.1886	76
$\mathrm{Log}_{10}\ T_m$=0.531 (0.051) x $\mathrm{Log}_{10}\ t_{max}$-0.116 (0.065)	0.3891	<0.0001	0.1756	172
$\mathrm{Log}_{10}\ T_m$_f=0.661 (0.081) x $\mathrm{Log}_{10}\ t_{max}$-0.238 (0.115)	0.4785	<0.0001	0.2212	71
$\mathrm{Log}_{10}\ M$=-0.816 (0.045) x $\mathrm{Log}_{10}\ t_{max}$+0.414 (0.059)	0.5980	<0.0001	0.2014	221

All analyses used $\log_{10}$ transformed data. Regression coefficients are shown as $\underline{+}1$ SE in parenthesis; R^2_{adj} = correlation coeficient; *p* = probablility level; RMSE = root mean square error from regression model, and *n* = number of stocks (_f after parameter indicates that parameter was estimated for females only). Results for which $p<0.1$ are indicated by underlines and those for which $p<0.05$ by double-underlines.

Table 12. Regression statistics of relationships between biological parameters with *M* as the independent variable

Model	R^2_{adj}	$p_{overall}$	RMSE	n
$Log_{10}\ a$=-0.266 (0.126) x $Log_{10}\ M$-2.301 (0.087)	0.0231	0.0361	0.4168	147
$Log_{10}\ b$=0.031 (0.008) x $Log_{10}\ M$+0.507 (0.005)	0.0916	0.0001	0.0261	148
$Log_{10}\ L_\infty$=-0.277 (0.074) x $Log_{10}\ M$+1.577 (0.049)	0.0764	0.0002	0.2898	158
$Log_{10}\ \kappa$=0.433 (0.070) x $Log_{10}\ M$-0.369 (0.046)	0.1913	$\leq$.0001	0.2734	159
$Log_{10}\ L_m$=-0.295 (0.155) x $Log_{10}\ M$+1.222 (0.097)	0.0711	0.0665	0.3683	34
$Log_{10}\ L_m$_f=-0.110 (0.064) x $Log_{10}\ M$+1.491 (0.047)	0.0234	0.0891	0.1796	82
$Log_{10}\ T_m$=-0.482 (0.047) x $Log_{10}\ M$+0.248 (0.032)	0.3685	$\leq$.0001	0.1988	181
$Log_{10}\ T_m$_f=-0.574 (0.092) x $Log_{10}\ M$+0.272 (0.070)	0.3285	$\leq$.0001	0.2438	77
$Log_{10}\ t_{max}$=-0.735 (0.040) x $Log_{10}\ M$+0.812 (0.028)	0.5980	$\leq$.0001	0.1912	221

All analyses used log_{10} transformed data. Regression coefficients are shown as ±1 SE in parenthesis; R^2_{adj} = correlation coeficient; p = probablility level; RMSE = root mean square error from regression model, and n = number of stocks (_f after parameter indicates that parameter was estimated for females only). Results for which $p<0.1$ are indicated by underlines and those for which $p<0.05$ by double-underlines.

Table 13. Multiple regression statistics for relationships between biological parameters and *M*.

Model	F	R^2
$Log_{10}\ M$= $Log_{10}\ L_\infty$ x –0.027 (0.094) + $Log_{10}\ \kappa$ x 0.436 (0.093) - 0.264 (0.138)	18.89	0.19
$Log_{10}\ M$= $Log_{10} t_{max}$ x –0.773 (0.073) + $Log_{10}\ L_\infty$ x 0.014 (0.063) + 0.327 (0.111)	66.96	0.48
$Log_{10}\ M$= $Log_{10}\ L_\infty$ x 0.043 (0.077) + $Log_{10}\ T_m$ x -0.806 (0.097) - 0.257 (0.200)	41.46	0.38
$Log_{10}\ M$= $Log_{10}\ t_{max}$ x- 0.728 (0.079) + $Log_{10}\ T_m$ x -0.182 (0.093) + 0.395 (0.079)	94.27	0.55

All analyses used Log_{10} transformed data. Regression coefficients are shown as ±1 SE in parenthesis; R^2 = correlation coeficient; F=F-ratio.

Table 14. Comparison of relationships between biological parameters and *M* derived based on data from the current study and those derived by Hoenig (1983) and Pauly (1980). R^2 = correlation coeficient; F=F-ratio.

Model		F	R^2
Hoenig (1983)	$Log_{10}M$ = 1.44 - 0.982 x $Log_{10}t_{max}$		
Current study –temperate	$Log_{10}\ M$ = 1.09 - 0.858 x $Log_{10}t_{max}$	60.44	0.64
Current study –all data	$Log_{10}\ M$ = 0.97 - 0.822 x $Log_{10}t_{max}$	327.29	0.61
Pauly (1980)	$Log_{10}M$ = -0.0152 - 0.2790 x $Log_{10}L_\infty$ + 0.6543 x $Log_{10}\kappa$ + 0.4634 x $Log_{10}T$		
Current study –temperate	$Log_{10}M$ = -0.8803 - 0.0431 x $Log_{10}L_\infty$ + 0.3730 x $Log_{10}\kappa$ - 0.0823 x $Log_{10}T$	5.69	0.18
Current study –all data	$Log_{10}M$ = -1.3519 + 0.0431 x $Log_{10}L_\infty$ + 0.4778 x $Log_{10}\kappa$ + 0.2202 x $Log_{10}T$	12.54	0.27

Table 15. Comparison of reproductive parameters among different families of fish. Data for other species from previous studies are included for comparison at the bottom of the table.

	Both sexes		Females only	
Family	$T_{\mathrm{m}}/t_{\mathrm{max}}$	$T_{\mathrm{m}}*M$	$T_{\mathrm{m}}/t_{\mathrm{max}}$	$T_{\mathrm{m}}*M$
Acipenseridae		0.65		
Ammodytidae	0.24	1.07		
Anoplopomatidae		0.40	0.08	0.37
Argentinidae	0.20			
Berycidae			0.17	0.69
Bothidae		0.76		0.40
Branchiostegidae				
Carangidae	0.30	1.03	0.09	0.95
Centrolophidae			0.17	1.34
Channichthyidae	0.15	1.00		
Cheilodactylida			0.07895	1.35
Clupeidae	0.24		0.20	1.00
Cyprinidae			0.32	0.91
Engraulidae	0.31	1.13		
Esocidae		0.65		
Gadidae	0.20	0.90	0.20	0.92
Gempylidae	0.14	0.98	0.29	1.35
Hexagrammidae	0.27	0.40	0.24	0.96
Lophiidae	0.29	0.60	0.29	0.60
Lutjanidae	0.50	1.20	0.33	0.35
Merlucciidae			0.28	1.40
Moronidae	0.25	0.75		
Mugilidae	0.19	0.99		
Nototheiniidae	0.44	2.03	0.45	4.98
Nototheniidae	0.44	2.17	0.45	1.96
Ophidiidae	0.21	1.50	0.17	0.83
Oreosomatidae			0.27	1.57
Osmeridae	0.60	3.90		
Pentacerotidae		1.08		
Percidae		1.38		
Platycephalidae			0.24	1.08
Pleuronectidae	0.21	0.94	0.29	1.66
Pomatomidae			0.09	0.28
Sciaenidae		0.30		
Scianidae		0.87		
Scombridae	0.25	1.02	0.50	1.10
Scophthalmidae				0.60
Scorpaenidae	0.11	0.76	0.15	0.64
Sebastidae			0.23	1.10
Sillaginidae			0.25	1.80
Soleidae	0.12	0.3		
Sparidae	0.13	0.52	0.12	0.57
Stromateidae	0.50	1.60		
Synodontidae	0.43	1.24		
Trachichthyidae			0.17	1.00
Trichiuridae	0.13	0.58	0.13	0.58
Xiphiidae	0.56	1.00		
Zeidae			0.38	1.72
Previous studies				
Genus *Sebastes*			0.16	0.4
Pacific species			0.16	0.4
Atlantic species			0.23	0.7

Clupeidae	0.24	0.7
Gadiformes	0.23	1.5
Pleuronectiformes	0.39	1.6
Elasmobranchs	0.38	1.7
Birds		0.4
Mammals		0.7
Lizards and snakes		1.4

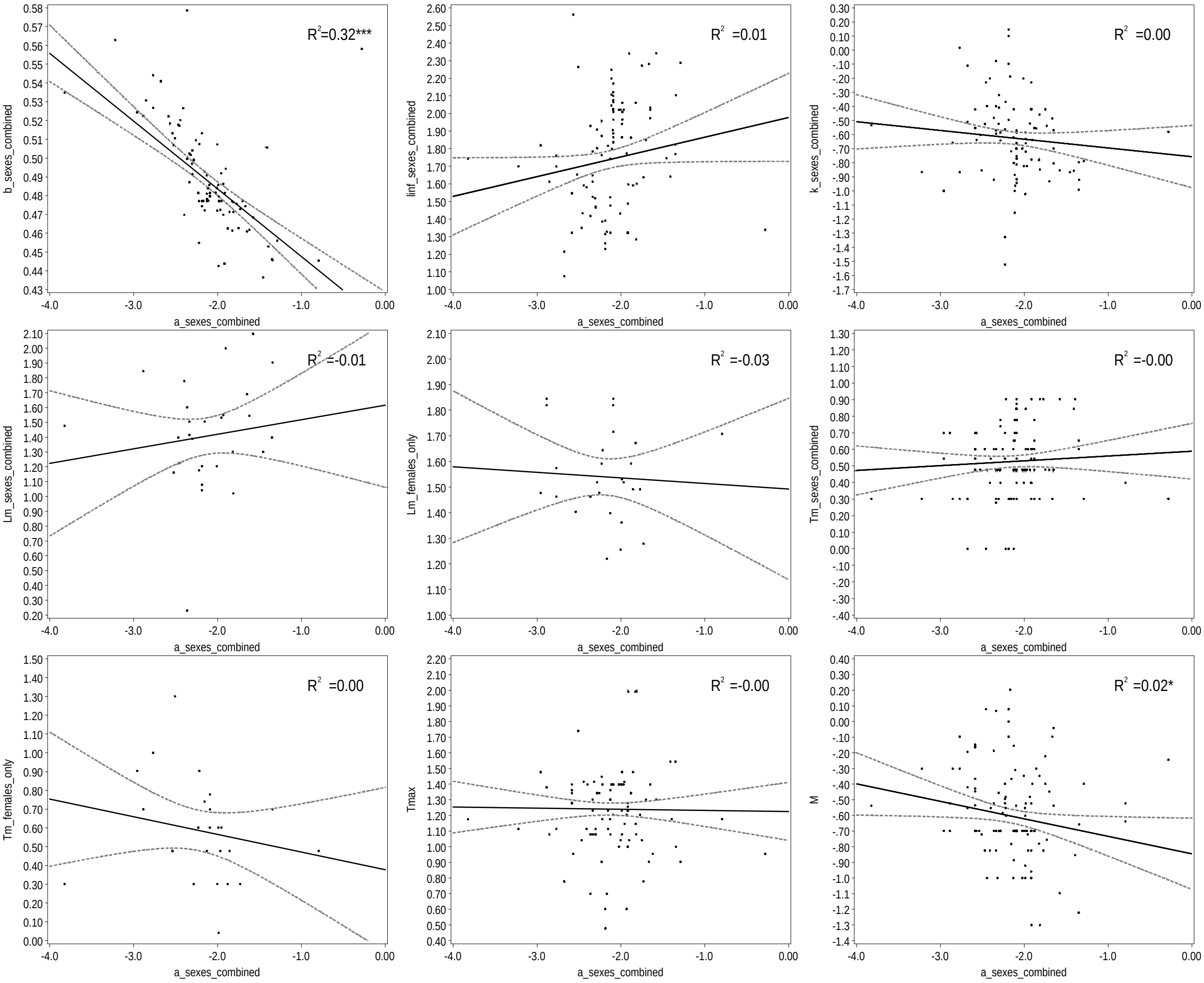

Figure 1. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of *a*, with regression line, 95% confidence intervals and adjusted R^2 values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

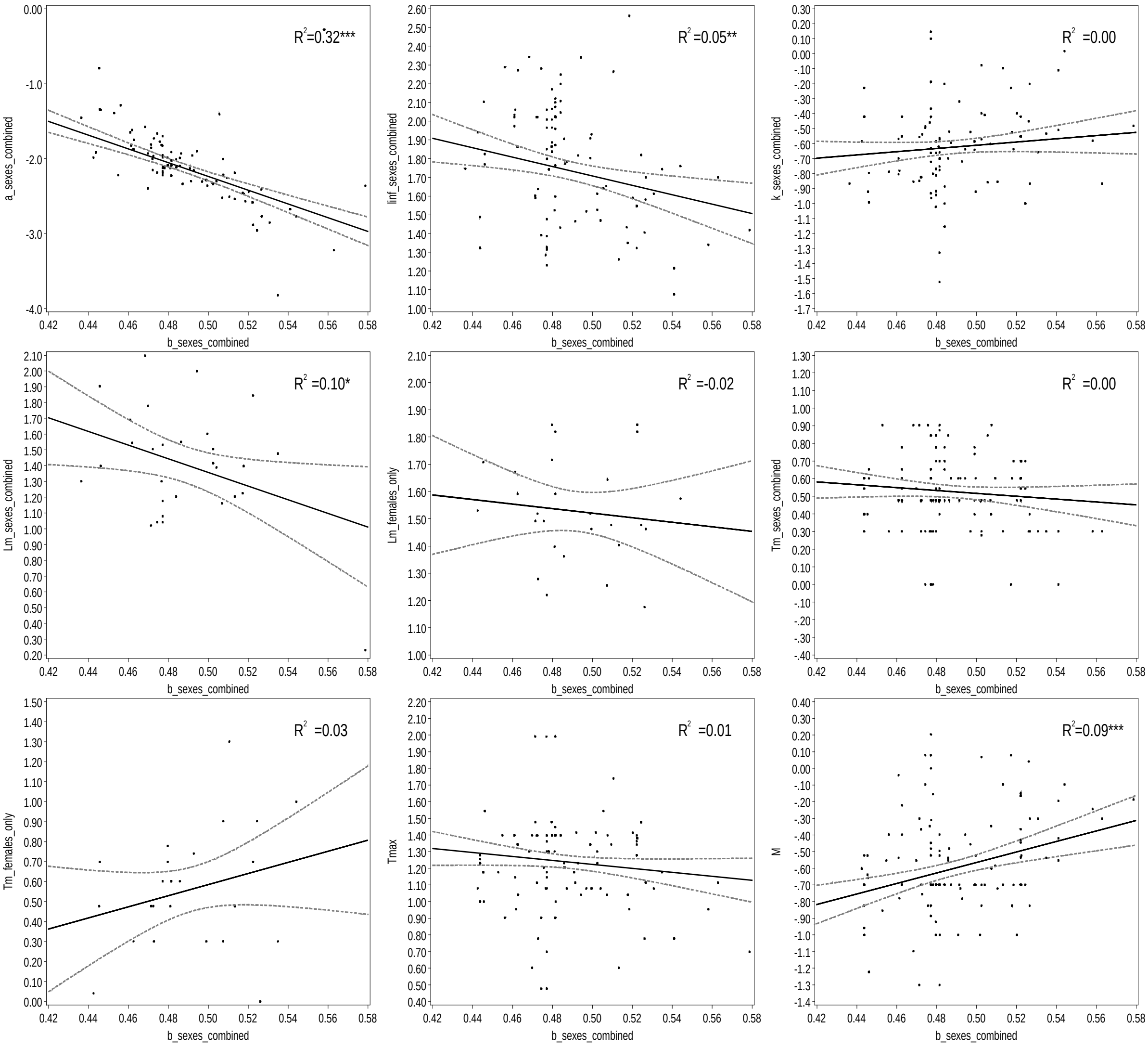

Figure 2. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of *b*, with regression line, 95% confidence intervals and adjusted R^2 values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

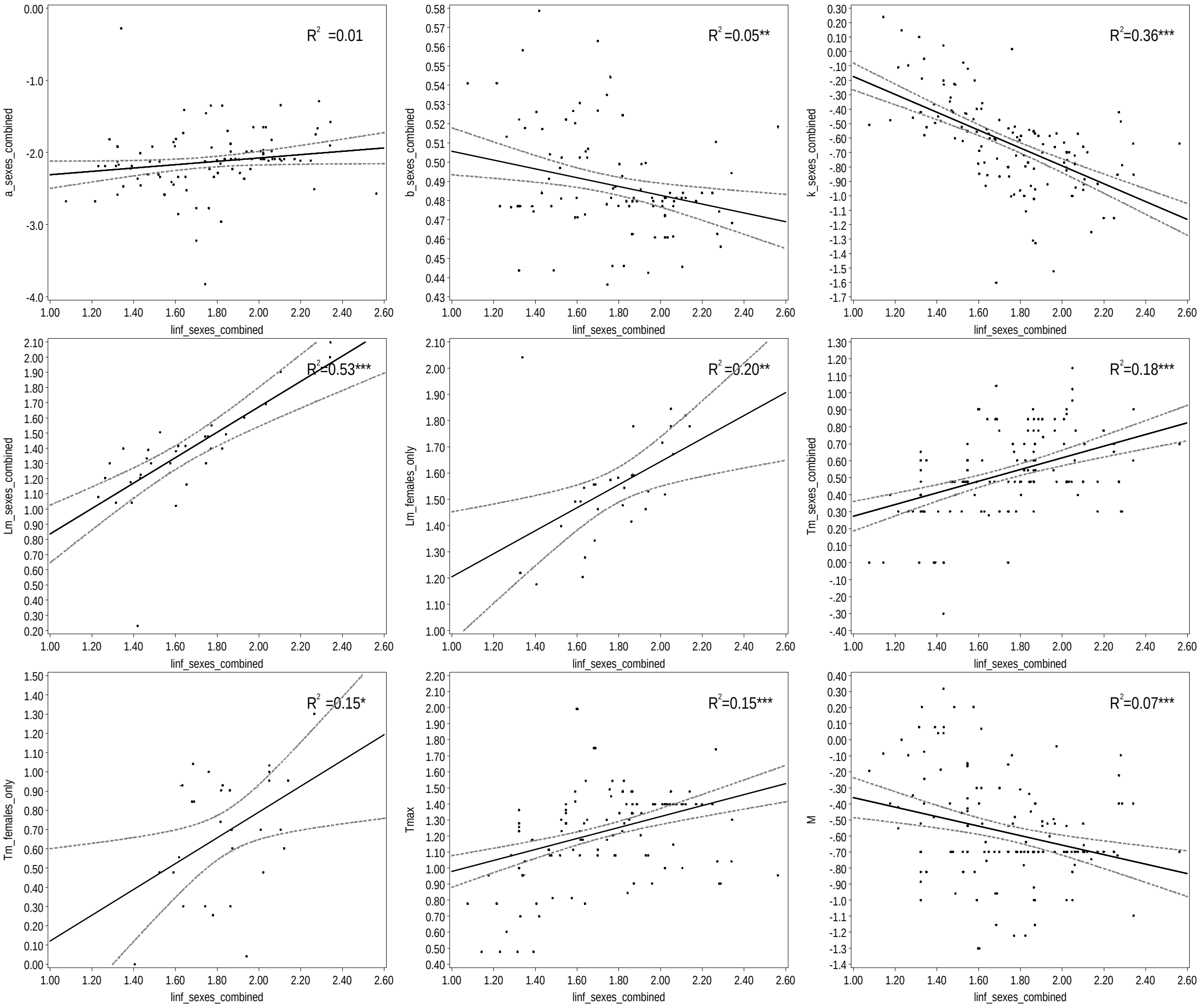

Figure 3. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of L_∞, with regression line, 95% confidence intervals and adjusted R^2 values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

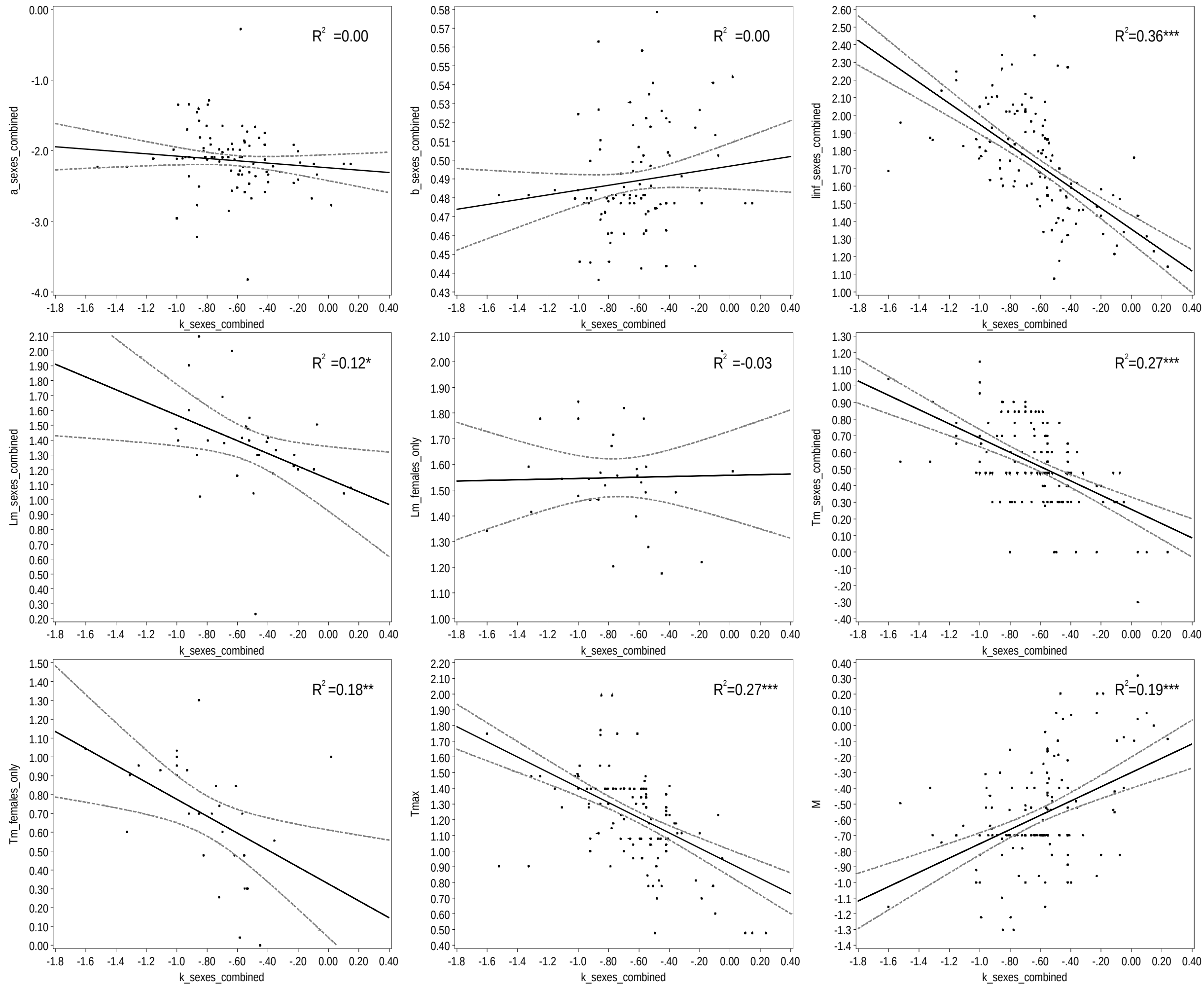

Figure 4. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of *κ*, with regression line, 95% confidence intervals and adjusted *R*^{2} values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

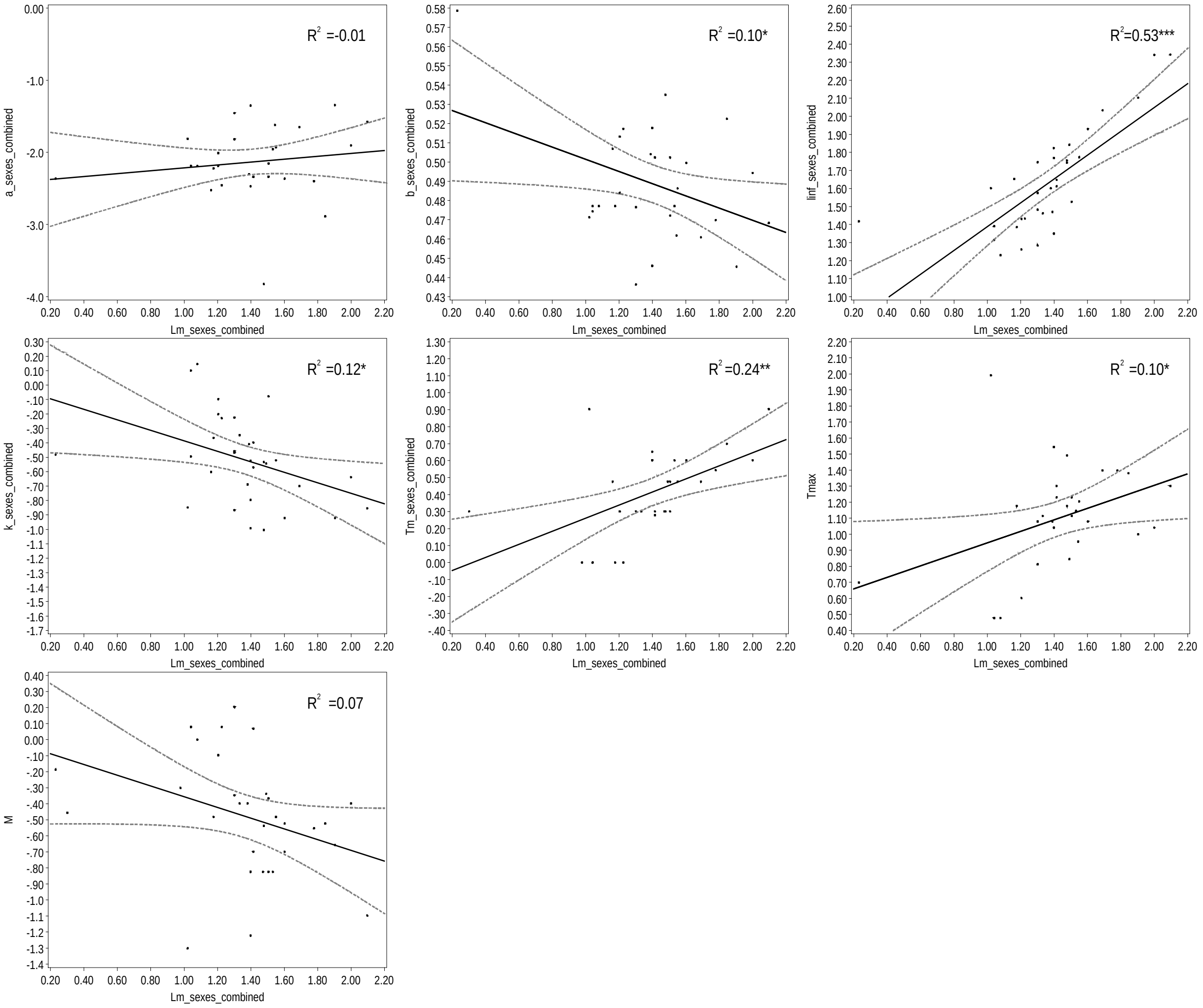

Figure 5. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of L_m, with regression line, 95% confidence intervals and adjusted R^2 values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

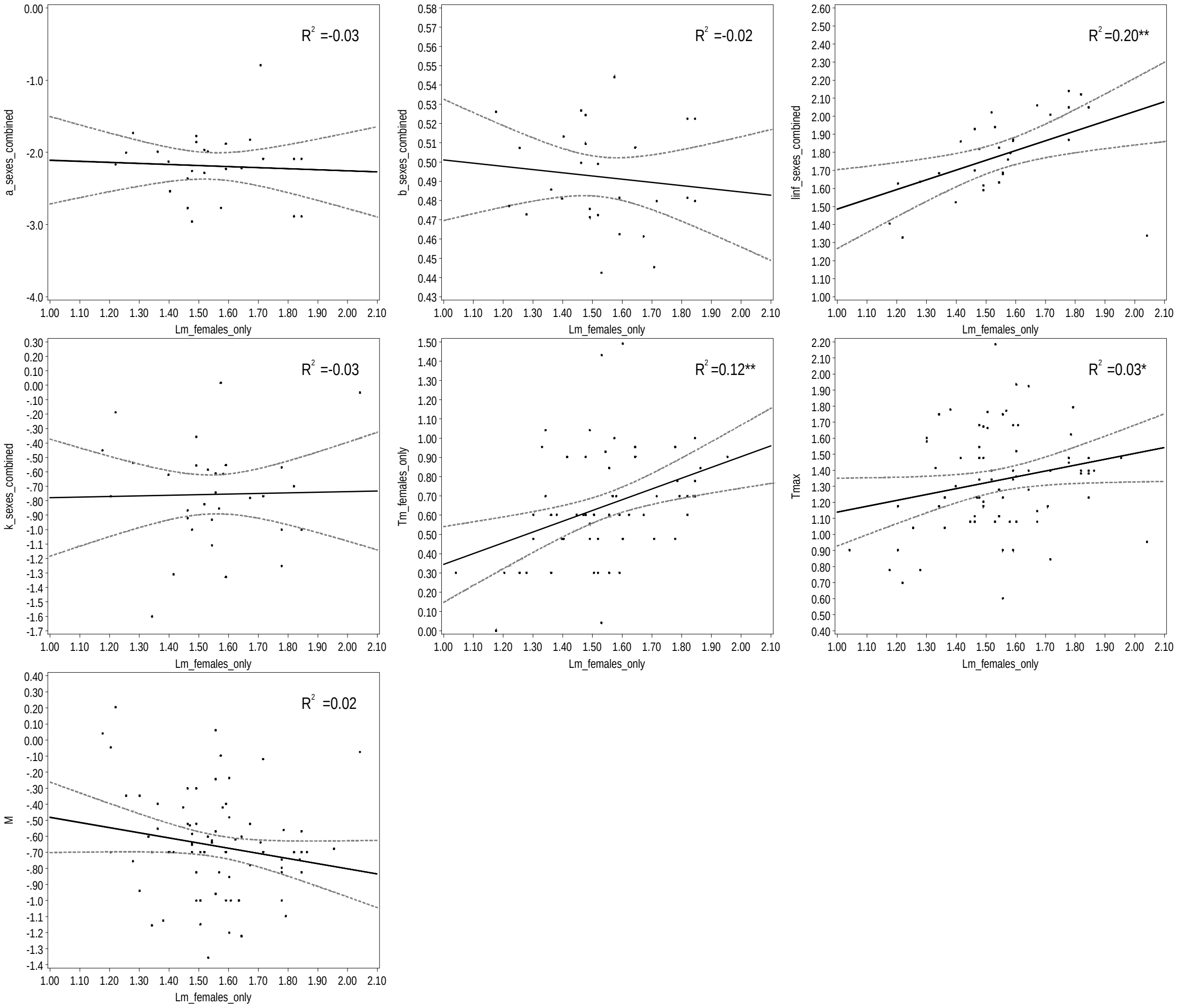

Figure 6. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of female L_m, with regression line, 95% confidence intervals and adjusted R^2 values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

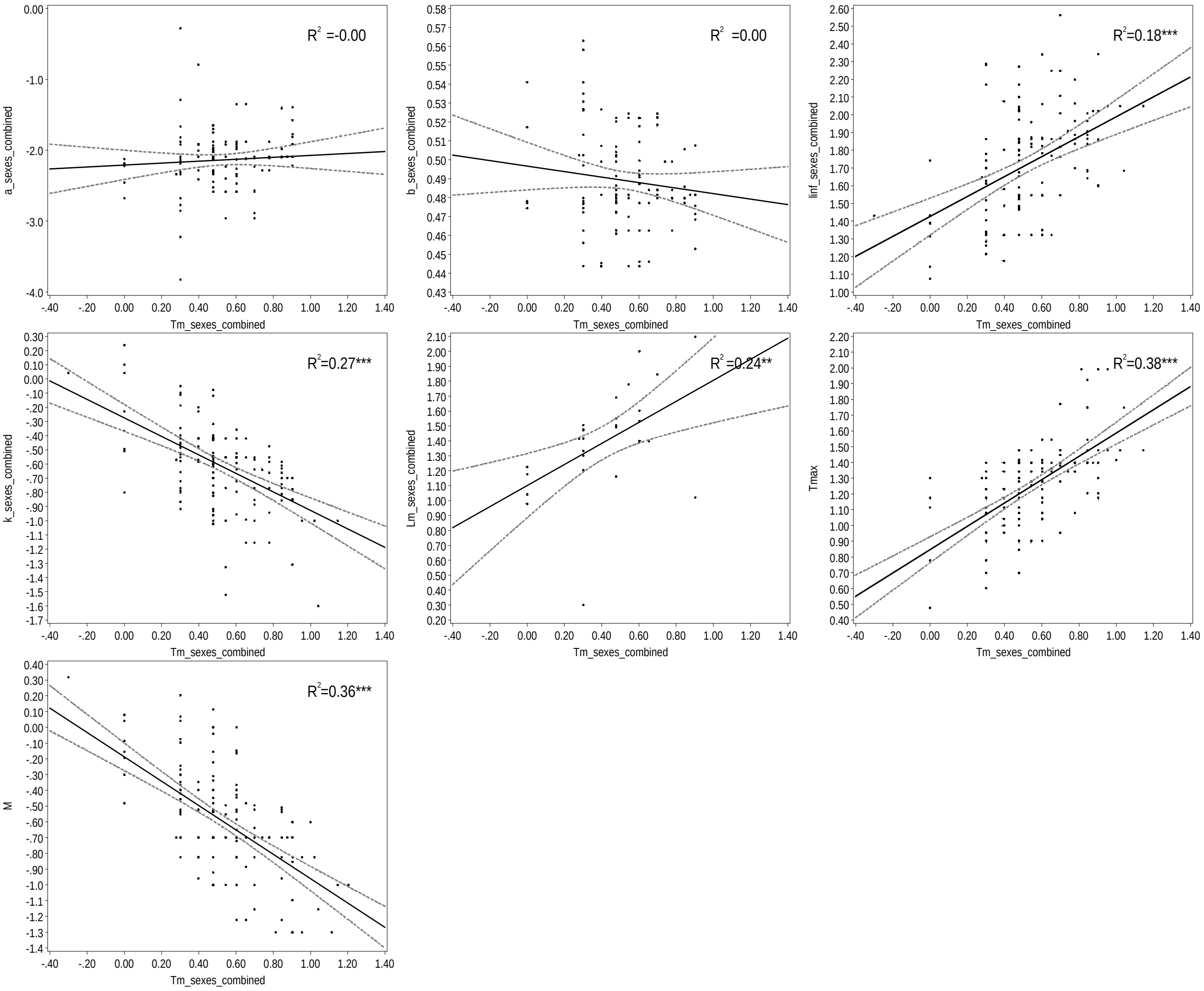

Figure 7. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of T_m, with regression line, 95% confidence intervals and adjusted R^2 values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

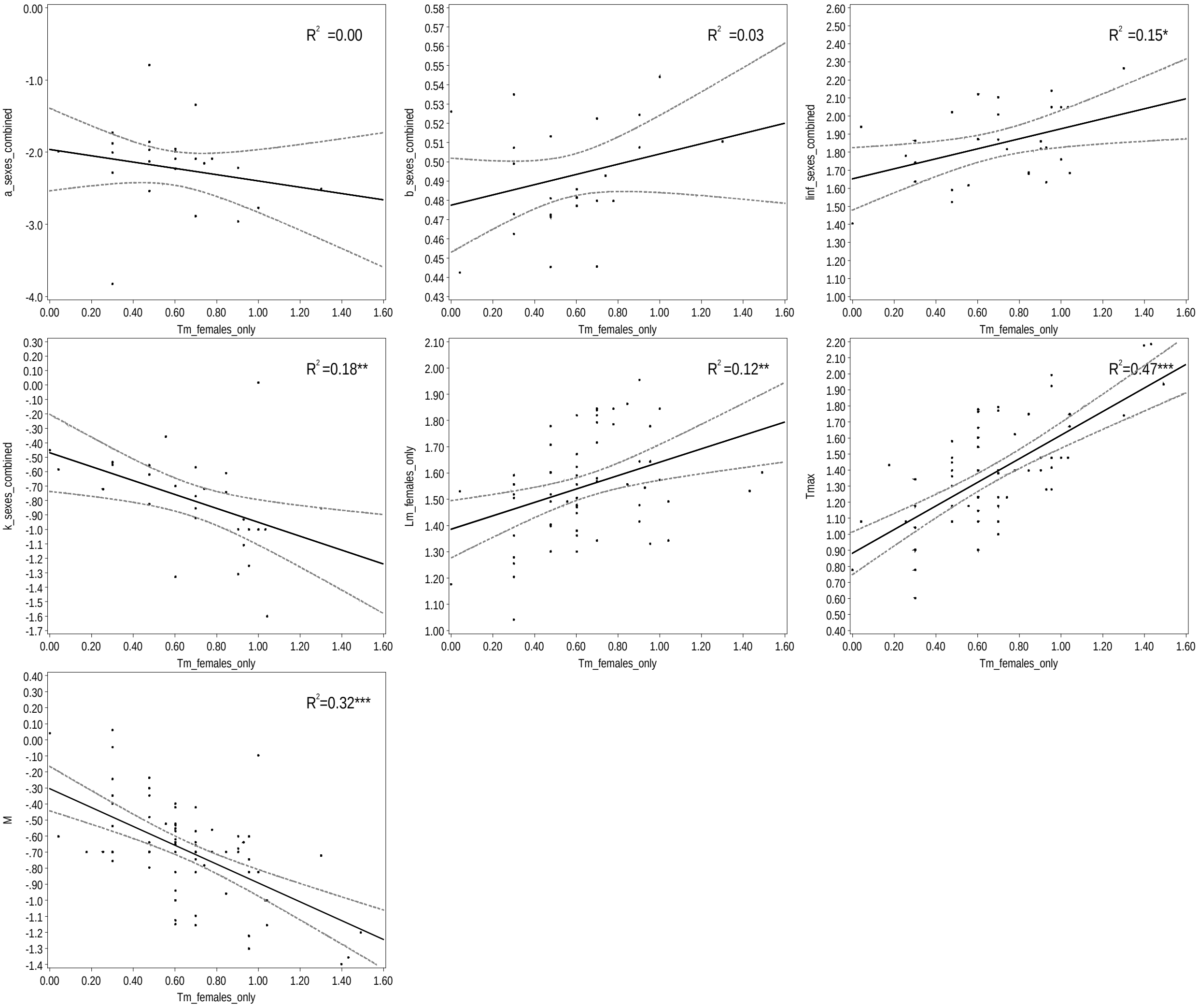

Figure 8. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of female T_m, with regression line, 95% confidence intervals and adjusted R^2 values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

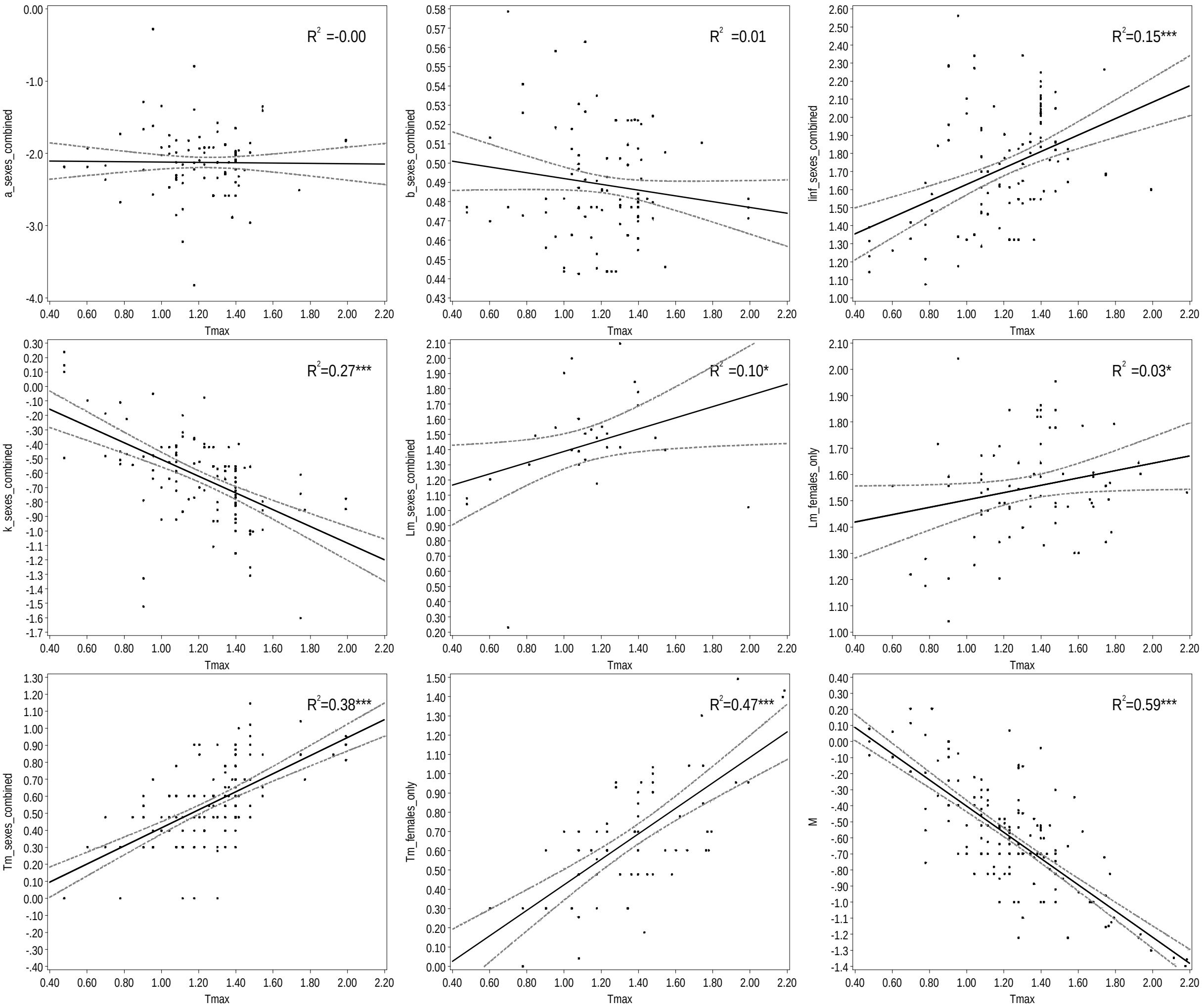

Figure 9. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of t_{max}, with regression line, 95% confidence intervals and adjusted R^2 values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

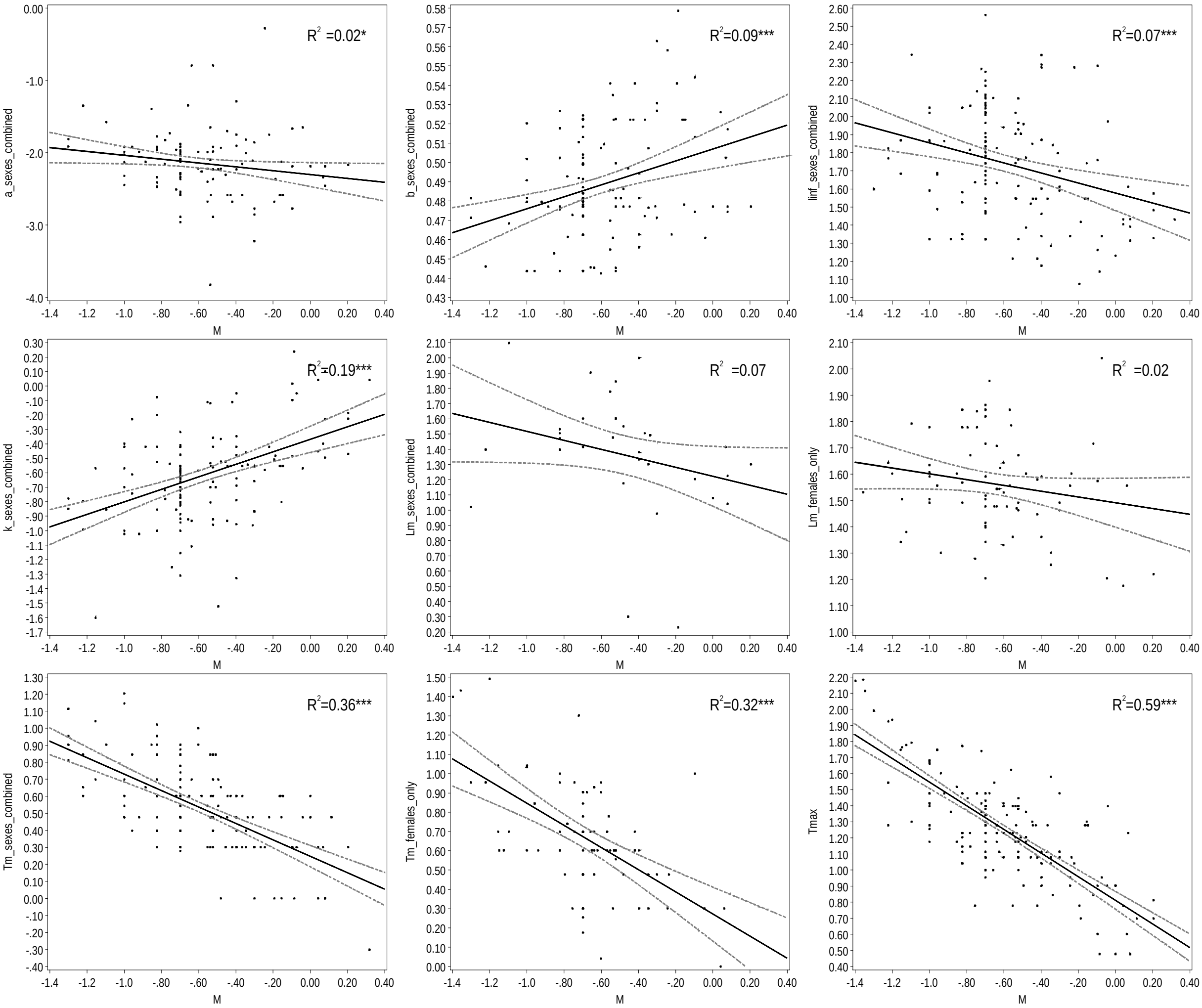

Figure 10. X-Y plots of various biological parameters (log-transformed) against the independent variable the logarithm of *M*, with regression line, 95% confidence intervals and adjusted R^2 values

(* 0.05 >P>0.01; ** 0.01 >P>0.001; * 0.001 >P>0.0001).**

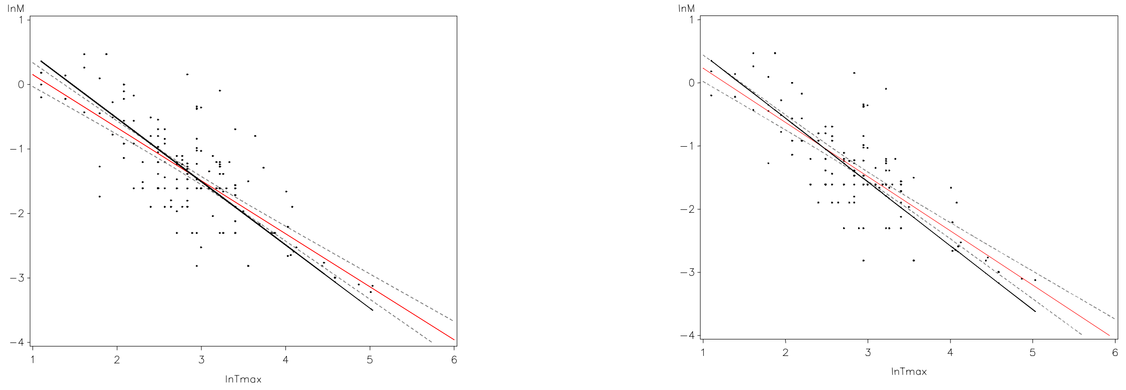

Figure 11. X-Y plot of $\ell n t_{\max}$ against $\ell n M$, overlayed with the relationship between these variables as estimated by Hoenig (1983) (dark solid line) and the relationships derived using data from this study (light solid line) for all stocks (left panel) and for temperate stocks (right panel).

95% confidence intervals about the relationships derived using data from this study are shown as broken grey lines.

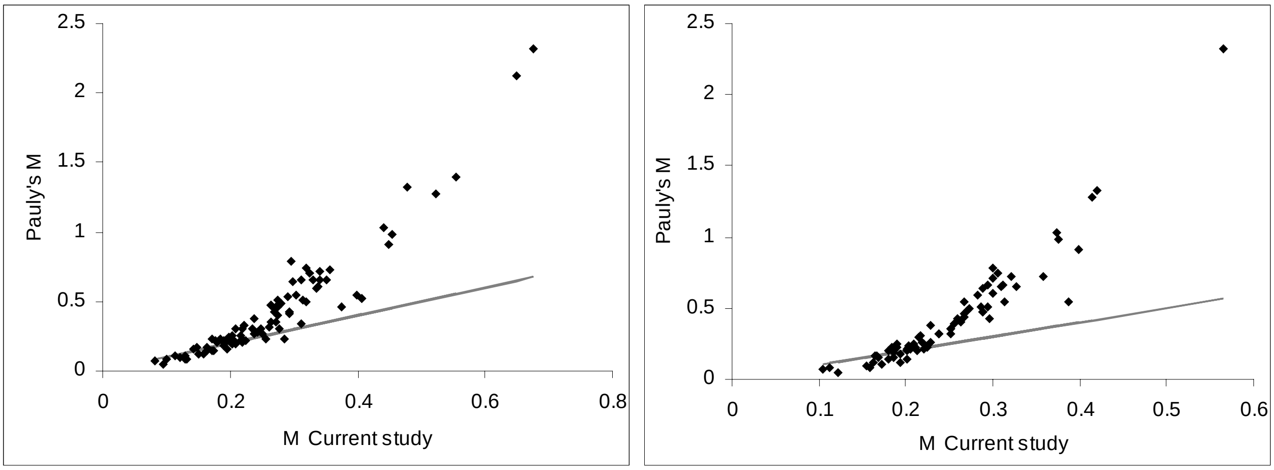

Figure 12.X-Y plot of *M* estimated from the multiple regression based *L*∞, *κ* and *T* for a) all stocks (left panel) and b) temperate stocks (right panel), versus *M* estimated using Pauly's (1980).

The line indicates the 1:1 relationship.

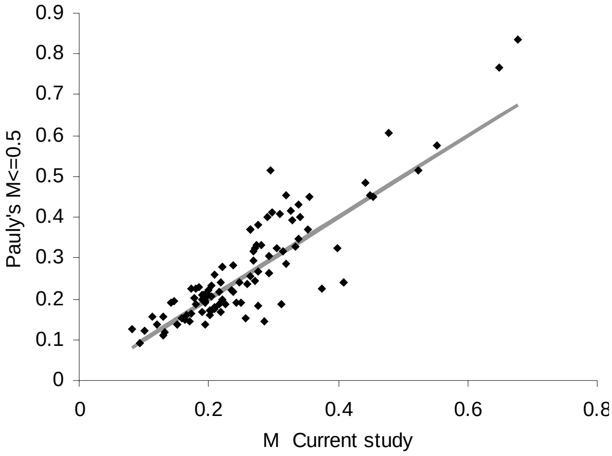

Figure 13. X-Y plot of *M* estimated from the multiple regression based *L*∞, *κ* and *T* for all stocks versus *M* estimated from an equation parameterized by fitting Pauly's (1980) equation to the subset of his data for which $M \leq 0.5 yr^{-1}$.

The line indicates the 1:1 relationship.

Chapter 3: Bayesian Analysis of Stock and Recruitment Data

Introduction

The use of Bayesian techniques when conducting fisheries stock assessments is desirable because *inter alia*, Bayesian methods provide a single framework within which various sources of uncertainty can be represented (in particular, both parameter and model-structure uncertainty), and because the results from a Bayesian analysis (the probabilities associated with alternative hypotheses) are exactly the information needed when providing scientific management advice to decision makers (Punt and Hilborn, 1997; McAllister and Kirkwood, 1998). However, the primary reason that most stock assessment scientists choose Bayesian over classical approaches is probably because it becomes possible to formally include knowledge from previous assessments (of species / stocks other than that of current interest) in a new assessment. Hilborn and Liermann (1998) argue that using data for well-studied species to inform data-poor species can be considered to be 'standing on the shoulders of giants'.

The frequency with which Bayesian approaches have been used when conducting fisheries stock assessments has increased markedly in recent years (e.g. Hilborn *et al.*, 1994; McAllister *et al.*, 1994; Walters and Ludwig, 1994; Raftery *et al.*, 1995; McAllister and Ianelli, 1997; Punt and Kennedy, 1997; Smith and Punt, 1998; Punt and Butterworth, 1999; Ianelli *et al.*, 2000; Punt *et al.*, 2001a). The main reason for this is the availability of algorithms to numerically evaluate the integrals needed when conducting Bayesian analyses. The two most common methods used to draw samples from the posterior distribution are the Sample-Importance-Resample (SIR) method (Rubin, 1987; Van Dijk *et al.*, 1987) and the Markov-Chain-Monte Carlo (MCMC) algorithm (Hastings, 1970; Gelman *et al.*, 1995).

It is necessary to specify prior distributions for all of the parameters of a model when applying Bayesian techniques (Punt and Hilborn, 1997). Unfortunately, the specification of prior distributions is often the most difficult step of any Bayesian analysis. Priors can either be informative or uninformative. Three types of priors have been used when conducting fisheries stock assessments.

1. Uninformative priors are assigned to parameters for which the data for other species cannot be used to derive an informative prior (e.g. the virgin biomass, B_0, and fishery catchability).
2. Uniform priors are assigned to parameters for which plausible lower and upper bounds are available (e.g. natural mortality, the parameters that define fishery and survey selectivity).
3. Informative priors are assigned to parameters for which the data for other species can be used to develop a prior for the stock under consideration (e.g. steepness, *h*, survey catchability, and the extent of variation in recruitment, σ_R).

This chapter addresses the question of how best to specify priors for *h* and σ_R based on data for other stocks /species. Steepness, *h*, is defined as the fraction of virgin recruitment to be expected when the spawning biomass is reduced to 20% of its virgin level (Francis, 1992). Steepness can be calculated when the relationship between spawning biomass and recruitment is assumed to be governed by the Beverton-Holt or Ricker formulations, i.e.:

$$\hat{R} = \begin{cases} \dfrac{\alpha_1 S}{\beta_1 + S} & \text{Beverton-Holt} \\ \alpha_2\, S e^{-\beta_2 S} & \text{Ricker} \end{cases} \tag{3.1}$$

where $\hat{R}$ is the model-predicted recruitment,

S is the spawning biomass,

α_1, β_1 are the parameters of the Beverton-Holt stock-recruitment relationship, and

α_2, β_2 are the parameters of the Ricker stock-recruitment relationship.

Steepness is constrained to lie between 0.2 and 1 for the Beverton-Holt stock-recruitment relationship while steepness must be larger than 0.2 for the Ricker stock-recruitment relationship. The analyses of this chapter place an upper bound of 5 on steepness when the stock-recruitment relationship is assumed to be of the Ricker form. The limit of 5 is imposed to avoid high posterior probability being assigned to stock-recruitment relationships which exhibit severe over-compensation.

Equation (3.1) can be reparametersized in terms of the steepness of the stock-recruitment relationship, the virgin recruitment, R_0, and the spawner-biomass-per-recruit in the absence of exploitation, $\tilde{S}$, i.e.:

$$\hat{R} = \begin{cases} \dfrac{4hR_0S}{R_0\tilde{S}(1-h)+(5h-1)S} & \text{Beverton-Holt} \\ (5h)^{1.25}S/\tilde{S}\,e^{-1.25\ell n(5h)S/(\tilde{S}R_0)} & \text{Ricker} \end{cases} \tag{3.2}$$

The value of S is computed from information on natural mortality-at-age and fecundity-at-age using the standard spawning biomass-per-recruit equations. Dorn (2002) notes that an implicit assumption associated with calculating $\tilde{S}$ this way is that all compensation is assumed to occur in the relationship between spawning biomass and subsequent recruitment. There are usually too few data to allow a quantitative evaluation of whether other population dynamics processes (such as growth, natural mortality, fecundity) are, in fact, density-dependent. However, for some species, there is evidence that this is the case (Patterson *et al.*, 2001). For example, in the context of the SESS, the growth of blue grenadier (*Macruronus novaezelandiae*) off Australia appears to be density-dependent (Punt and Smith, 2001)

At present, when conducting assessments of SESSF species, the values for *h* and σ_R are generally pre-specified (e.g. Punt *et al.*, 2001a) based on the list of values for *h* and σ_R for a range of stocks assembled by McAllister *et al.* (1994). The estimates of *h* and σ_R considered by McAllister *et al.* (1994) were based on a subset of the data in Myers *et al.* (1995). Sensitivity is then explored to alternative plausible values. The approach applied by McAllister *et al.* (1994) is tantamount to applying an Empirical Bayes approach to developing priors for *h* and σ_R. However, this approach can be criticized because each stock is given equal weight, even though the estimates of *h* and σ_R for some of the stocks would be highly imprecise.

Liermann and Hilborn (1997) introduced hierarchical meta-analysis to fisheries assessment by conducting a meta-analysis of the impact of depensation at low stock size. In common with tabling estimates of quantities of interest, hierarchical modeling is a Bayesian technique that can be used to combine data from several independent sources (species / stocks) and represent the outcome in the form of a probability distribution for the quantity of interest. The basic idea is that each species / stock for which data are available has a different value for the quantity of interest but that species / stocks are interchangeable in the sense that the value of the quantity of interest for any given stock can be considered to be a random selection from an underlying distribution (which is the same for all species). These assumptions are displayed graphically in Figure 14 (modified from Liermann and Hilborn (1997)).

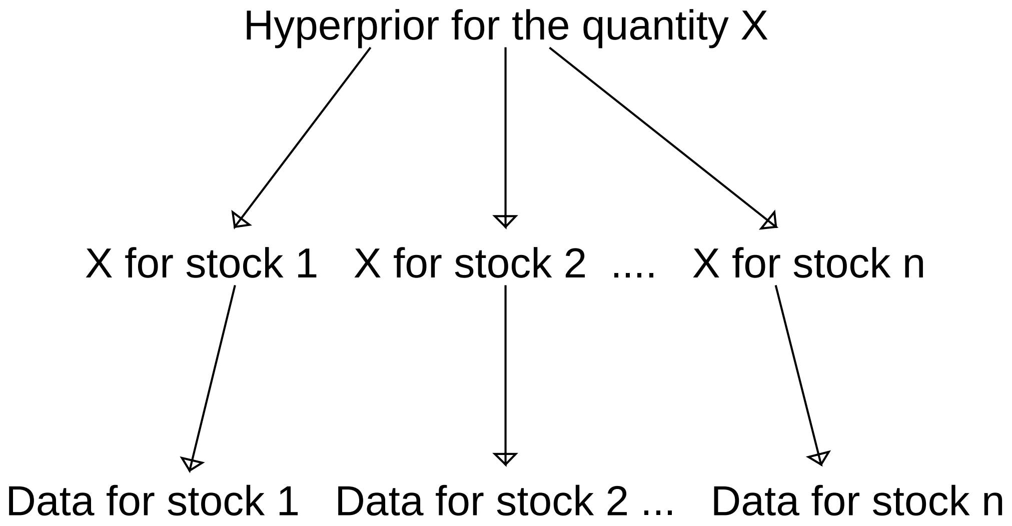

Figure 14. Overview of the structure of a hierarchical model illustrating the relationship between the value of some quantity of interest *X* for a set of stocks, the data for those stocks, and the underlying distribution for *X*.

Hierarchical meta-analysis has been used in the past to examine the steepness of the stock-recruitment relationship (Myers *et al*., 1999; Dorn, 2002), the relationship between catch rate and abundance (Harley *et al*., 2001), survey catchability and selectivity (Harley and Myers, 2001; Millar and Methot, 2002), and carrying capacity (Myers *et al*., 2001).

In order to conduct a hierarchical meta-analysis, it is therefore necessary to:

1. select a set of species / stocks that can be considered be to interchangeable in terms of the quantity (quantities) of interest,
2. select a distribution from which the values for the quantity of interest for each stock is selected,
3. select a model of the data for each stock,
4. specify prior distributions (for the parameters of the prior for the quantity of interest (the hyperprior) and for all of the parameters of the model of the data, except that for the quantity of interest), and
5. sample from the posterior distribution implied by the choices made at steps 2) - 4).

Methods

Selection of stocks

Information is available for a total of 443 stocks (Table 1). However, not all of these stocks can be included in the meta-analysis. The reasons for excluding stocks from inclusion in the meta-analysis are.

a) There are fewer than 10 spawning biomass – recruitment pairs[1].

b) No estimate of spawning biomass-per-recruit is available.

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[1] Although reference is made here to 'spawning biomass and recruitment', the data for some of the species are in terms of other units (e.g. biomass of females, egg production). This is, however, not a concern as long as spawning biomass-per-recruit is defined in the correct units.

c) The species is oviviporous – species with this life history strategy appear to have lower steepness than viviparous species (Myers *et al.*, 2002).

Table 16 lists the 128 stocks that remain after the exclusions imposed through constraints a) – c) are applied. The stocks are grouped by order, family, genus and species. Table 16 indicates the number of stocks for each species and for how many stocks of each species is information on each of maximum age, natural mortality rate, age-at-maturity (t_m), length-at-maturity (l_m), asymptotic length (ℓ_∞), average latitude, diet, habitat, and depth available.

Priors and likelihoods

The basic approach taken is virtually identical to that applied by Dorn (2002).

The model of the data

The available data are estimates of spawning biomass and recruitment. The relationship between these estimates is assumed to be either the Ricker form or the Beverton-Holt form, and the error structure is assumed to be log-normal. For a single species, the contribution of the data to the likelihood function is given by:

$$L(D\,|\,h,R_0,\sigma_R)=\prod_i \frac{1}{\sqrt{2\pi}\sigma_R\,R_i}\exp\left[-\frac{\left(\ell\text{n}R_i-\ell\text{n}\hat{R}(S_i)+\sigma_R^2/2\right)^2}{2\sigma_R^2}\right] \tag{3.3}$$

where R_i is the ith recruitment,

S_i is the ith spawning biomass, and

$\hat{R}(S)$ is the model-predicted recruitment corresponding to a spawning biomass of S (note that $\hat{R}(S)$ depends on h and R_0)

Note that, as in Dorn (2002), the likelihood formulation is based on the recruitment from the stock-recruitment relationship being the mean of the distribution rather than the more convention assumption that it is the median of the distribution.

The likelihood of the total (across all species) data set is given by:

$$L(D\,|\,\underline{h},\underline{R}_0,\underline{\sigma}_R)=\prod_k\prod_i \frac{1}{\sqrt{2\pi}\sigma_R^k R_i^k}\exp\left[-\frac{(\ell\text{n}R_i^k-\ell\text{n}\hat{R}^k(S_i^k)+(\sigma_R^k)^2/2)^2}{2(\sigma_R^k)^2}\right] \tag{3.4}$$

or

$$-\ell\text{n}L(D\,|\,\underline{h},\underline{R}_0,\underline{\sigma}_R)\propto\sum_k\sum_i \ell\text{n}(\sigma_R^k)+\sum_k\frac{1}{2(\sigma_R^k)^2}\sum_i(\ell\text{n}R_i^k-\ell\text{n}\hat{R}^k(S_i^k)+(\sigma_R^k)^2/2)^2 \tag{3.5}$$

where R_i^k is the ith recruitment for stock k,

S_i^k is the i^th spawning biomass for stock *k*,

$\hat{R}^k(S)$ is, for stock *k*, the model-predicted recruitment corresponding to a spawning biomass of *S*,

h^k is the steepness of the stock-recruitment relationship for stock *k*,

R_0^k is the virgin recruitment for stock *k*, and

σ_R^k is the standard deviation of the fluctuations about the stock recruitment relationship for stock *k*.

The prior and hyperprior distributions

The prior for steepness is defined in terms of the logit of steepness. This prior is normal with mean μ and variance τ, i.e.:

$$P(\underline{h}\,|\,\mu,\tau)=\prod_k \frac{1}{\sqrt{2\pi\tau}}\exp\left[-\frac{(\tilde{h}^k-\mu)^2}{2\tau}\right] \tag{3.6}$$

where $\tilde{h}^k$ is the logit-transformed steepness, i.e.:

$$\tilde{h}^k=\begin{cases}\ell\text{n}\left(\dfrac{h^k-0.2}{1-h^k}\right) & \text{Beverton-Holt}\\ \ell\text{n}\left(\dfrac{h^k-0.2}{1-0.2\,h^k}\right) & \text{Ricker}\end{cases} \tag{3.7}$$

The remaining two parameters of the model are virgin recruitment and the standard deviation of the fluctuations about the stock-recruitment relationship, σ_R. The prior distribution for the logarithm of σ_R is assumed to be uniform over the interval U[-∞, ∞] while a relatively uninformative prior is placed on virgin recruitment. This prior, following Dorn (2002), is a normal distribution with mean for stock *k* given by the average of the observed recruitments for stock *k* when the observed spawning biomass exceeds the median observed spawning biomass for stock *k*, and a coefficient of variance of 3, i.e.:

$$P(\underline{R}_0)=\prod_k \frac{1}{\sqrt{2\pi}(3\bar{R}_0^k)}\exp\left[-\frac{(R_0^k-\bar{R}_0^k)^2}{2(3\bar{R}_0^k)^2}\right] \tag{3.8}$$

where $\bar{R}_0^k$ is the observed average recruitment when the observed spawning biomass exceeds the median observed spawning biomass.

This prior imposes a weak constraint on the extent to which the virgin recruitment can differ from the observed mean recruitment at 'high' spawning biomass. This prior is not totally ideal because it is based on the data for species *k*. However, in the absence of a prior of this type, the estimate of *h* can be very close to 0.2 and R_0 essentially infinite for some stocks.

It is necessary to place a hyperprior on the parameters of the prior for the logit of steepness to finalize the specification of the prior. Following Dorn (2002) again, the hyperprior is chosen to be relatively uninformative so that the posteriors for h are driven primarily by the data rather than by the choice of the prior distribution. In particular, the prior for μ is assumed to be uniform over a wide interval [-1000,1000] while the prior for τ is taken to be a scaled inverse chi-squared distribution, i.e.:

$$P(\tau)=\frac{\left(\frac{v}{2}\right)^{(v/2)} s^{v}\exp\left(-\frac{vs^{2}}{2\tau}\right)}{\Gamma\left(\frac{v}{2}\right)\tau^{(v/2+1)}} \qquad (3.9)$$

where v and s are the parameters of the hyperprior.

Gelman *et al*. (1995) and Dorn (2002) note that this prior is equivalent to basing the prior information for τ on v observations from $N(\mu,\tau)$ with a mean squared deviation of s^2. It is necessary to select v and s^2 to force the prior for τ away from zero. Dorn (2002) notes that a prior with v=10 and s^2=0.5 is sufficient to achieve this. Given the priors for h^K (Equation 3.6), the uniform prior for μ, and the scaled inverse chi-squared prior with v=10 and s^2=0.5 for τ (Equation 3.9), the prior for h^K has high weight at its bounds (0.2 and 1 for the Beverton-Holt model and 0.2 and 5 for the Ricker model) and is locally flat for values between these bounds.

Computational aspects

The posterior distribution for the parameters of the hierarchical model is computed using Bayes rule, i.e.:

$$P(\underline{h},\underline{R}_0,\underline{\sigma}_R,\mu,\tau\mid D)=\frac{L(D\mid \underline{h},\underline{R}_0,\underline{\sigma}_R)P(\underline{R}_0)P(\underline{h}\mid\mu,\tau)P(\tau)}{\iiint L(D\mid \underline{h},\underline{R}_0,\underline{\sigma}_R)P(\underline{R}_0)P(\underline{h}\mid\mu,\tau)P(\tau)} \qquad (3.10)$$

The denominator of Equation (3.10) cannot be evaluated numerically so it is necessary to rely on numerical methods to represent the posterior distribution. For the purposes of this study, samples are drawn from the posterior distribution using the Markov Chain Monte Carlo algorithm as implemented in the AD Model Builder package[2]. A total of 20,000,000 cycles were carried out of which the first 10% were discarded as a burn-in and the chain was thinned further by sub-sampling every 5,000th element.

A potentially major problem with the use of the Markov Chain Monte Carlo algorithm is how to assess whether it has been run long enough so that convergence to the posterior distribution has been achieved satisfactorily. In this study, this assessment has been achieved in four ways.

a Visually examining the traces for several of the key model outputs.

b Computing the diagnostic statistics developed by Raftery and Lewis (1992), Geweke (1992), and Heidelberger and Welsh (1983).

c Computing the so-called 'single chain Gelman statistic'. This statistic involves comparing the variability of the means in 50 segments of the chain with the variability within each such segment.

d Examining the partial auto-correlation function to assess whether the amount of thinning is sufficient to ensure that sequential points are essentially uncorrelated.

Numerical representations of the posteriors for the parameters of the model (in particular the values for the steepness parameter for each of the 128 stocks) can be constructed from the samples from the posterior

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[2] © Otter Software.

distribution. A key output from a meta-analysis is the value for the parameter of interest (in this case steepness) for an unknown stock. A numerical representation of the posterior for this quantity is constructed by sampling 100 values from normal distributions defined by each of the (μ, τ) pairs in the sample from the posterior distribution and transforming from logit-space to normal space.

Allowing for covariates

The analysis outlined above is predicated on the assumption that the stocks are interchangeable. However, it may well be that steepness depends on some of the biological characteristics of a stock. For example, Myers *et al.* (2002) note that steepness depends on the reproductive longevity of a stock. If a relationship between the value of steepness and some biological characteristics is considered plausible, the hyperprior can be extended so that the expected steepness for a stock depends on a vector of covariates that capture these biological characteristics.

In order to assess which (if any) covariates may explain steepness, loess plots of the posterior median for steepness for each stock is plotted against the values for a variety of basic covariates (maximum age, rate of natural mortality, asymptotic length (ℓ_∞), age-at-maturity (t_m), length-at-maturity (l_m), mean latitude, diet, depth and habitat; see Table 16 for a summary of which covariates are available for which stocks). Given the results of Myers *et al.* (2002), the values for steepness are also plotted against two measures of reproductive longevity (the difference between the maximum age and the age-at-maturity, and the sum of the age-at-maturity and $1/M$).

Results and discussion

Evaluation of convergence

Prior to examining the results, it is necessary to evaluate whether the Markov Chain Monte Carlo algorithm has been run for sufficiently long that adequate convergence to the posterior distribution has been achieved. Appendices 3.1 and 3.2 list the posterior medians and 95% probability intervals for steepness for each stock and for the parameters of the hyperprior (μ, τ) and whether convergence has been achieved according to the four convergence statistics. Results are shown in Appendix 3.1 for the two alternative stock-recruitment relationships when the values of the parameters of the hyperprior are assumed to be same for all stocks (abbreviations "Beverton-Holt form" and "Ricker form") and in Appendix 3.2 for the Beverton-Holt form when the values of the parameters of the hyperprior are assumed to be same for all stocks (abbreviation "Beverton-Holt-1") and when the values for these parameters are estimated separately for a group of species consisting of the Clupeiformes, Pleuronectiformes, and Gadiformes and a group consisting of all other species / stocks (i.e. two groups of species) (abbreviation "Beverton-Holt-2").

Figures 15 to 20 show diagnostic plots for μ, τ, and the model deviance (twice the negative of the logarithm of the likelihood function) based on the fits of the Beverton-Holt-1 and Beveton-Holt-2 analyses. The panels show the trace, the posterior density function (estimated using a normal kernel density), the correlation at different lags, the 50-point moving average against cycle number (dotted line in the rightmost panels), and the running mean and running 95% probability intervals (solid lines in the rightmost panels). Evidence for lack of convergence would be trends with cycle number in the values for the parameters in the upper left and lower right panels, high auto-correlations in the bottom left panel and a posterior density function which is not smooth.

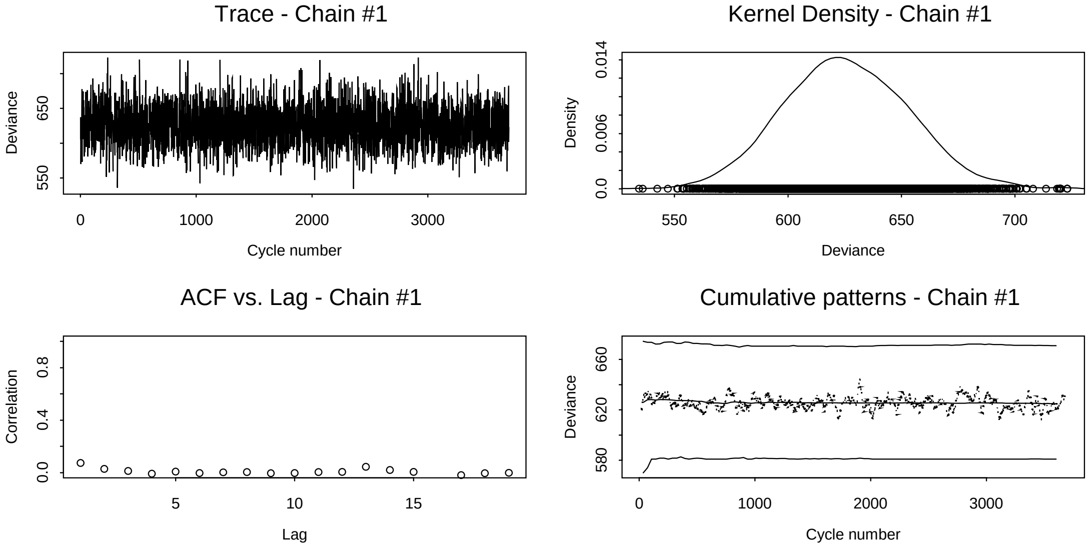


Figure 15. Diagnostic statistics (see text for details) for the model deviance.

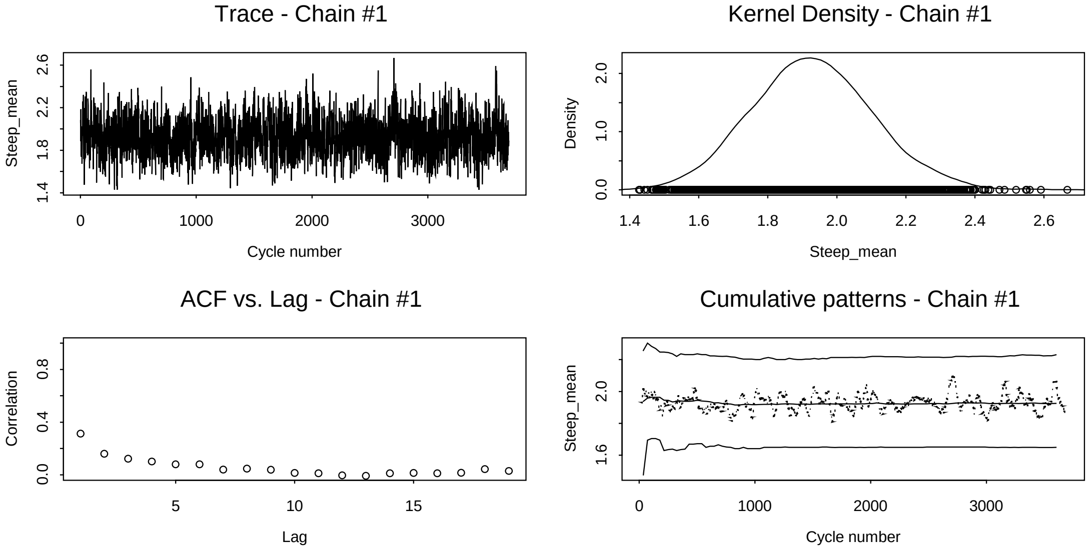


Figure 16.Diagnostic statistics (see text for details) for the mean of the hyperprior for steepness.

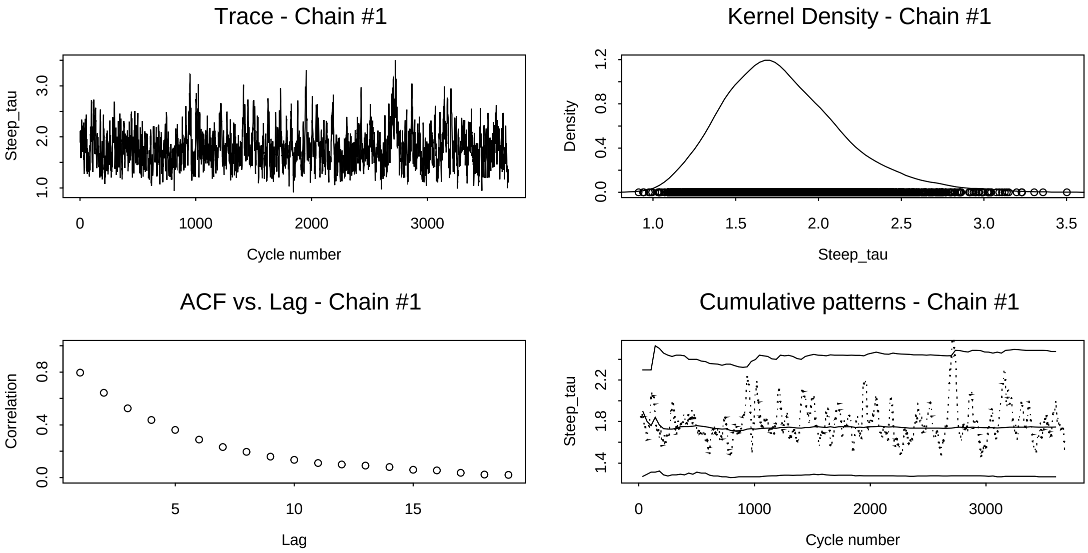


Figure 17. Diagnostic statistics (see text for details) for the variance of the hyperprior for steepness.

Considering the results in Figures 15 - 17 first, there is no evidence for convergence problems for the deviance and for μ. The sample from the posterior for τ exhibits high lag-1 autocorrelation. However, τ does not fail any of the four tests (see Appendix 3.1). The results in Figures 18 - 20 are more indicative of convergence problems because of the higher auto-correlations and the length of time it takes for the upper and lower 95 percentiles for the posterior to stabilise. This is also evident in Appendix 3.2 where a greater number of parameters fail the tests for lack of convergence. However, visually there are no obvious problems in Figures 15 - 20.

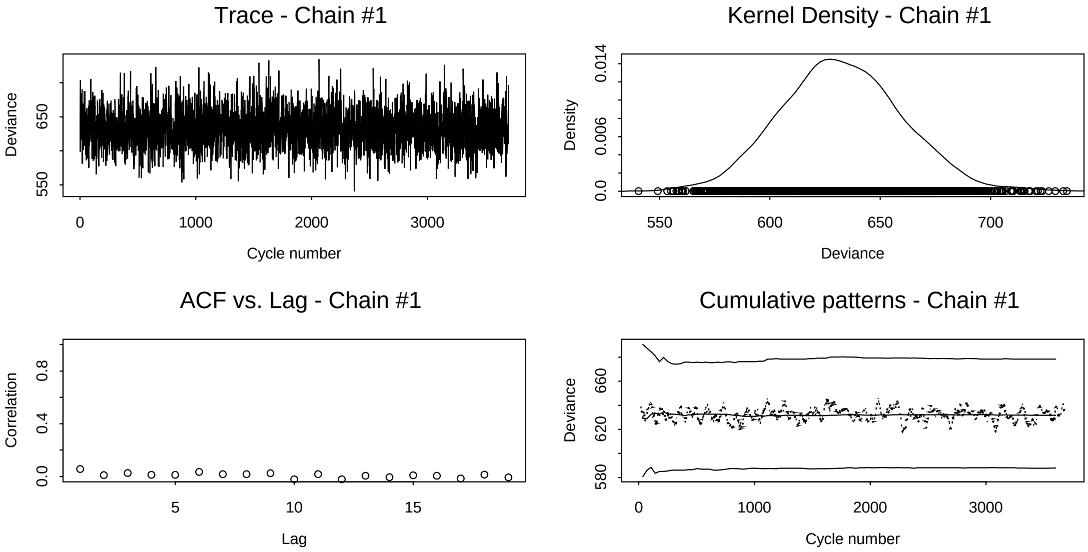


Figure 18. Diagnostic statistics (see text for details) for the model deviance.

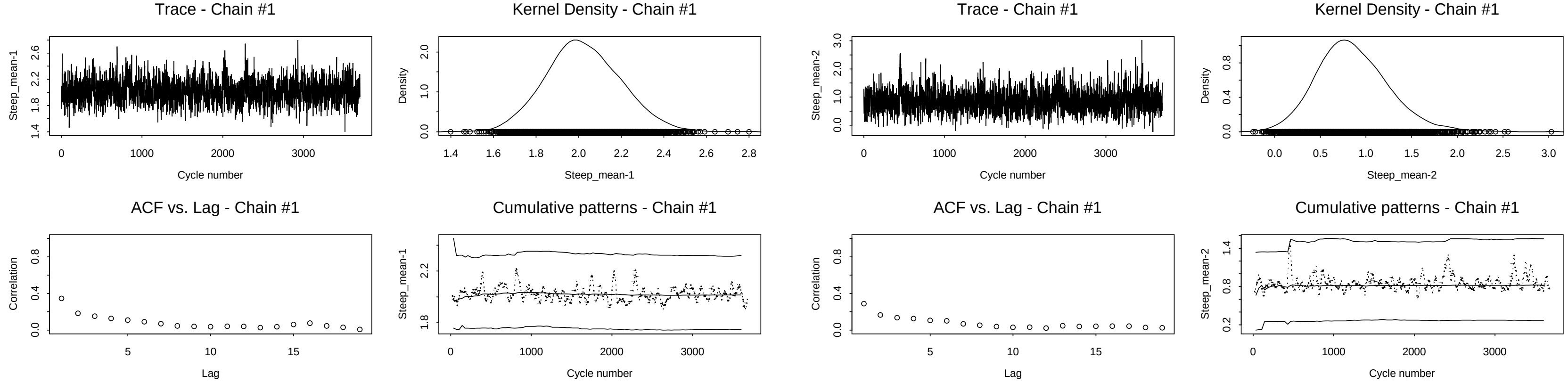


Figure 19. Diagnostic statistics (see text for details) for the means of the hyperpriors for steepness.

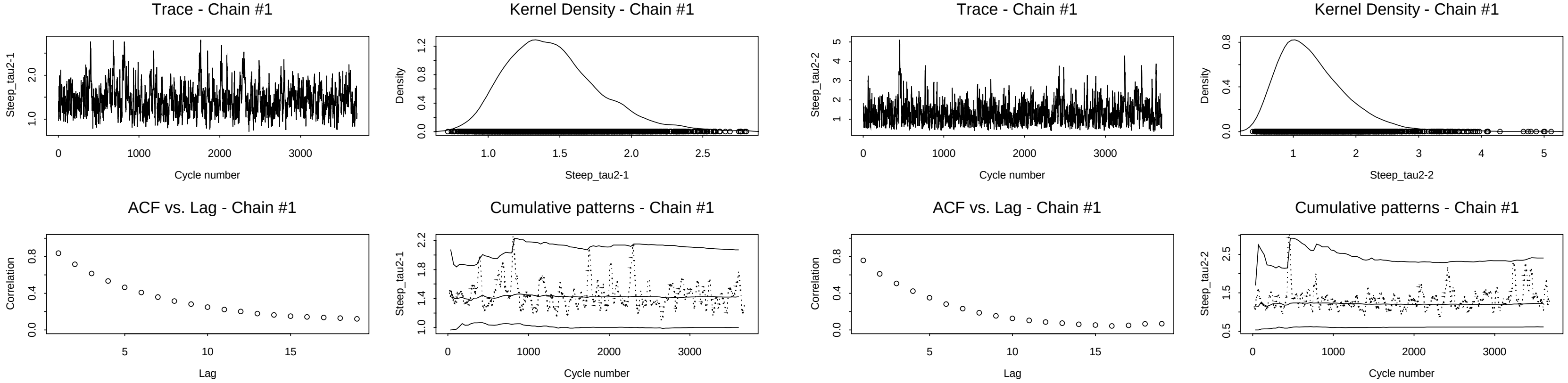


Figure 20. Diagnostic statistics (see text for details) for the variances of the hyperpriors for steepness.

Figures 21 - 26 summarize the values for six diagnostic statistics (the ratio of the batch standard deviation to the naive standard deviation, the extent of lag-1 auto-correlation, the value of the Raftery-Lewis statistic, the p-value computed from the Geweke statistic, whether the Heidelberger and Welch test is passed or not, and the value of the single-chain Gelman statistic) for the estimates of (a) steepness, (b) the logarithm of B_0 and (c) the logarithm of σ_R from the Beverton-Holt-1 and Beverton-Holt-2 analyses. Ideally, the value of the first statistic should be close to 1, the value of the second statistic should be close to zero, the value of the third statistic should be less than 5, the value of the fourth statistic should be greater than 0.05, and the value of the last statistic should be less than 1.05. The p-value for the Geweke statistic is less than 0.05 reasonably often (more so for the Beveton-Holt-2 analysis than for the Beverton-Holt-1 analysis). However, this is not a particularly major concern because this statistic can be triggered at random, and the other statistics suggest that convergence has been achieved very successfully.

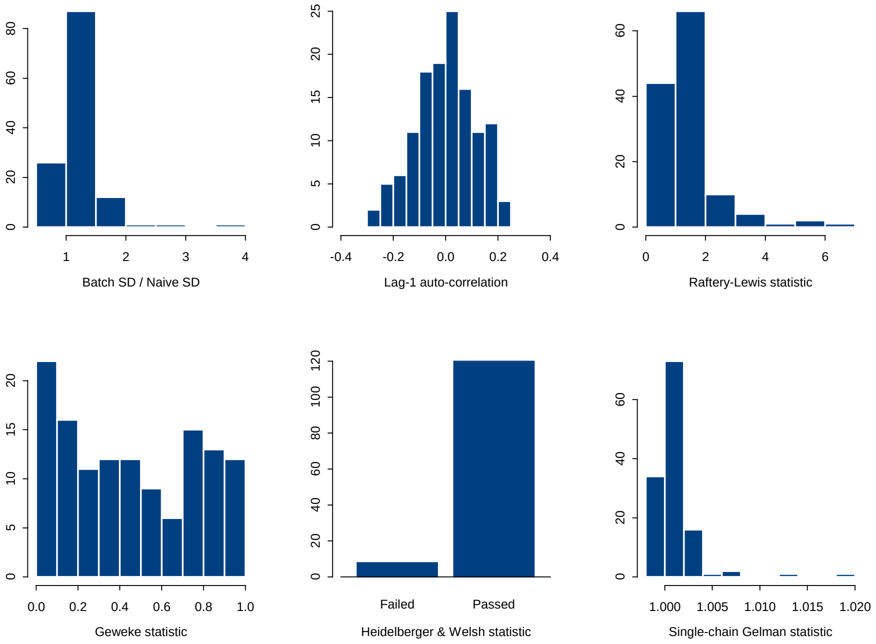


Figure 21. Summary of six diagnostic statistics for the 128 steepnesses from the Beverton-Holt-1 analysis.

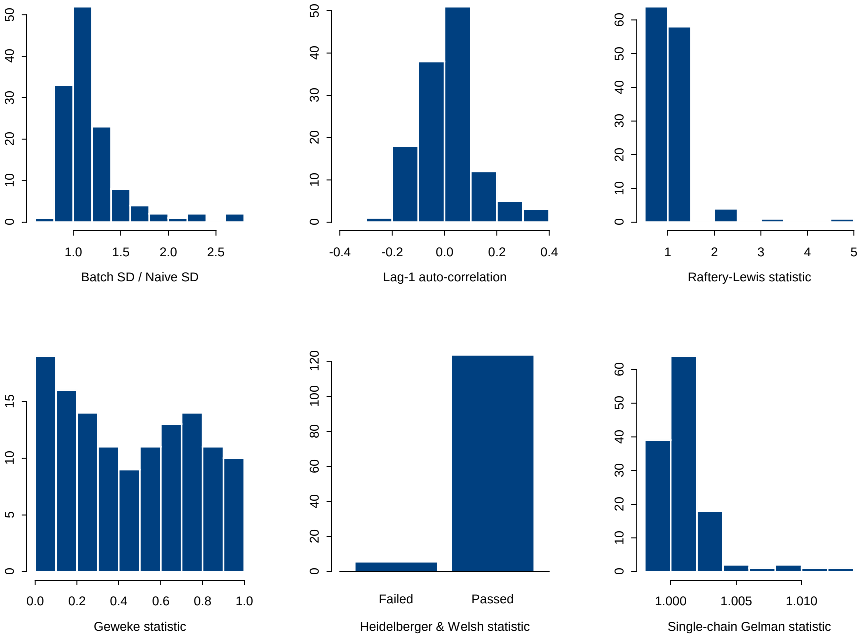


Figure 22. Summary of six diagnostic statistics for the 128 logarithms of B_0 from the Beverton-Holt-1 analysis.

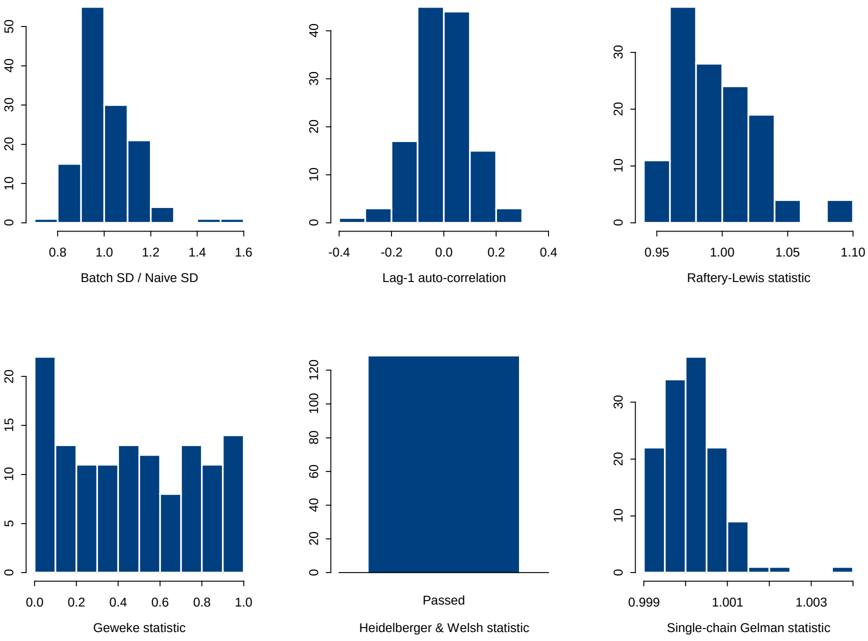


Figure 23. Summary of six diagnostic statistics for the 128 logarithms of σ_R from the Beverton-Holt-1 analysis.

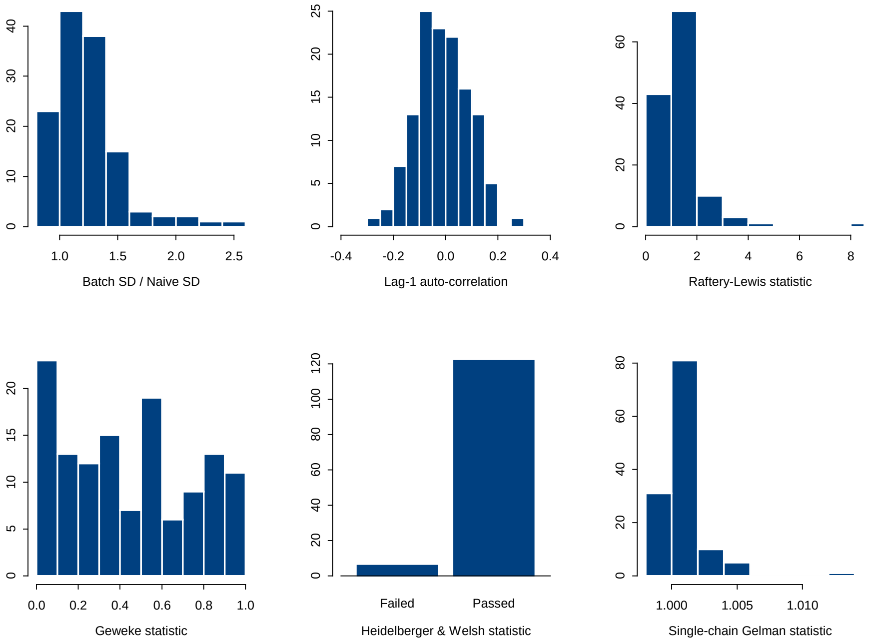


Figure 24. Summary of six diagnostic statistics for the 128 steepnesses from the Beverton-Holt-2 analysis.

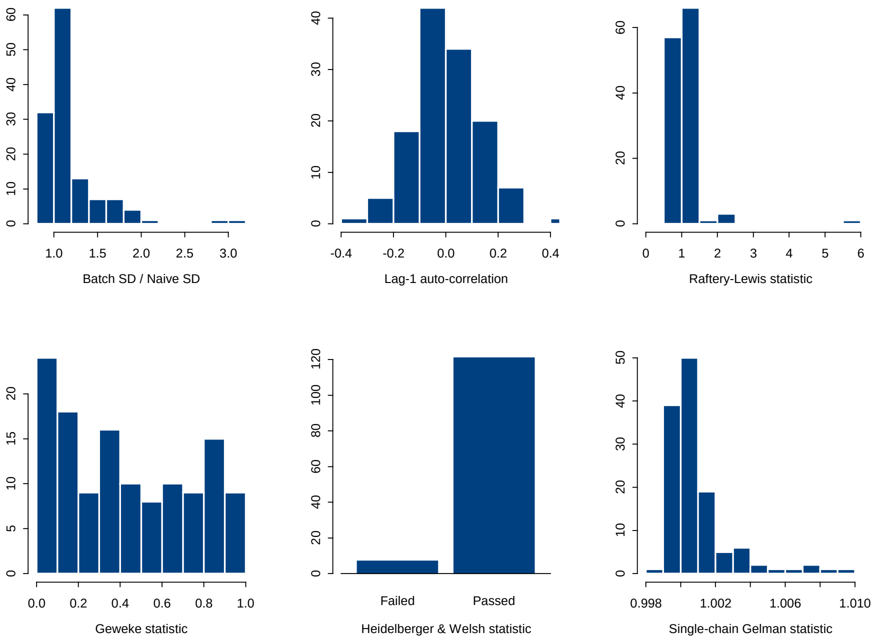


Figure 25. Summary of six diagnostic statistics for the 128 logarithms of B_0 from the Beverton-Holt-2 analysis.

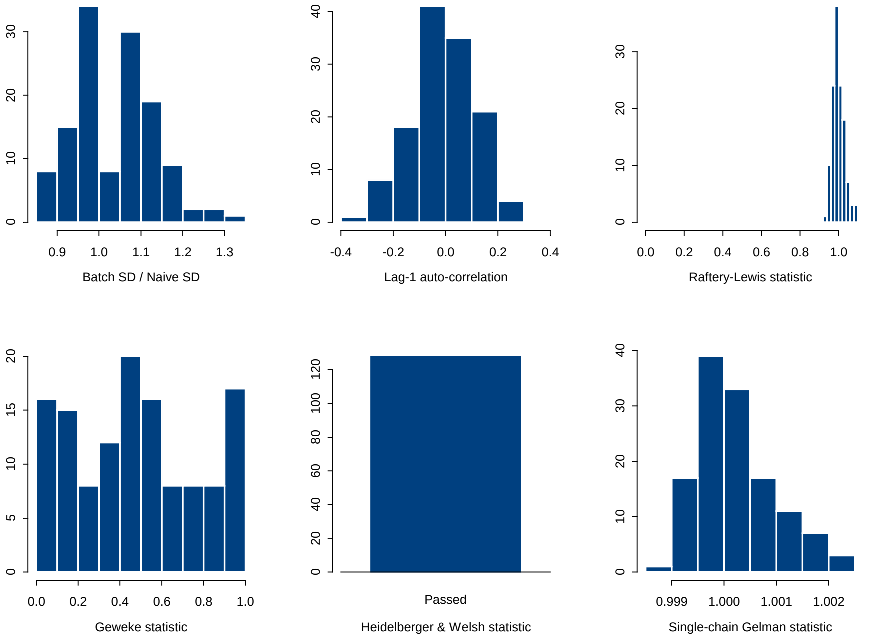


Figure 26. Summary of six diagnostic statistics for the 128 logarithms of σ_R from the Beverton-Holt-2 analysis.

Ricker or Beverton-Holt stock-recruitment relationship

The modes of the posterior distributions for the steepness of an unknown stock are essentially 1, i.e. recruitment at 20% of the virgin level equals the recruitment at the virgin level (Figure 27). The posterior for the steepness of the Ricker model assigns high probability to steepness values greater than 1 (Figure 27). A comparison can be made between the Ricker and Beverton-Holt forms for the stock-recruitment relationship using the Deviance Information Criterion (DIC; Spiegelhalter *et al.*, 2002).

$$DIC = \overline{\text{Deviance}} + p_D \tag{3.11}$$

where $\overline{\text{Deviance}}$ is the deviance (averaged over all of the samples from the posterior distribution), and

p_D is the 'effective number of parameters'.

The effective number of parameters, p_D, is defined as the difference between $\overline{\text{Deviance}}$ and the deviance at the maximum of the posterior density function (Deviance_{MPD}). Table 17 reports the statistics needed to calculate DIC. Perhaps not expectedly given that a hyperprior is placed on steepness, the effective number of parameters for both forms of the stock-recruitment relationship is notably less than the actual number of parameters (386). The effective number of parameters is greater for the Ricker model than for the Beverton-Holt model. This is probably because the hyperprior for steepness included in the Beverton-Holt model constrains the value for steepness more than the hyperprior for steepness included in the Ricker model because the range for *h* for the Beverton-Holt model is narrower than that for the Ricker model.

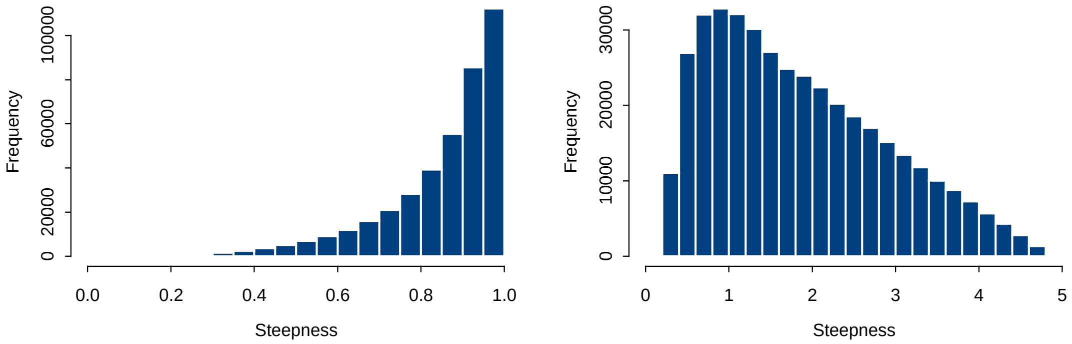


Figure 27. Posterior distributions for the steepness of the stock-recruitment relationship based on the Beverton-Holt (left panel) and Ricker (right panel) stock-recruitment relationship.

DIC clearly favours the Beverton-Holt over the Ricker model; the DIC for the Beverton-Holt model is 888.24 while that for the Ricker model is 1073.67. The very large difference in DIC between these two forms for the stock-recruitment relationship is indicative of the possibility that more complicated models of this relationship (e.g. forms with depensation or the impacts of climate change on productivity) may be supported by the data. However, consideration of such models is beyond the scope of the current project.

Figure 28 shows the posterior distributions for the steepness of an unknown Clupeiform, Pleuronectiform, Gadiform and 'other' stock. The posterior distribution for the first group is essentially identical to that for all stocks in Figure 27. In contrast, the posterior distribution for the steepness for 'other' stocks provides support for lower values of steepness than Figure 27. The difference between the Beverton-Holt-1 and Beverton-Holt-2 analyses is explored further in Figure 29 which plots the posterior medians for steepness for the 128 stocks from these two analyses. The points for the 'other' species are frequently smaller for the Beverton-Holt-2 analysis than for the Beverton-Holt-1 analysis. This suggests that the Beverton-Holt-1 analysis 'shrunk' the values of steepness for some of the 'other' species towards those for the clupeiformes, gadiformes and pleuronectiformes. As might be expected, Table 17 indicates that the model in which there are two groups provides a better representation of the data than that which assumes that the steepness for all species / stocks are drawn for a single underlying distribution.

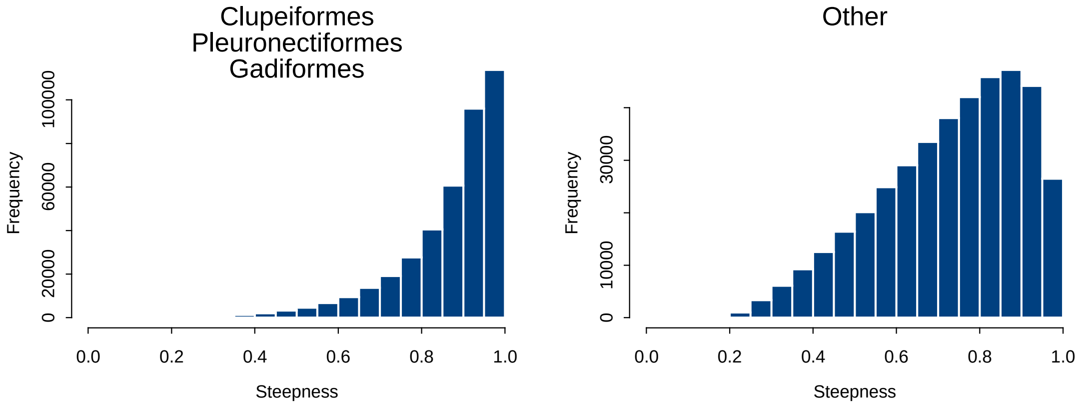


Figure 28. Posterior distributions for the steepness of the stock-recruitment relationship for two species / stock groups based on the Beverton-Holt-2 analysis.

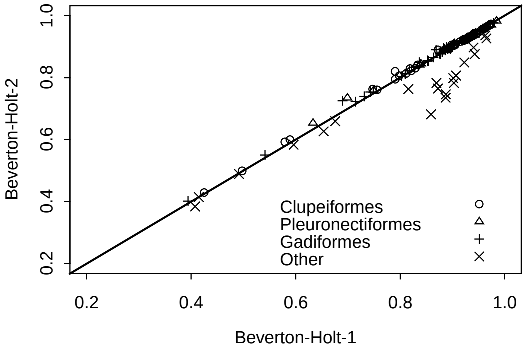


Figure 29. Posterior medians for the steepnesses of the 128 stocks from the analysis that assumes the same hypeprior for all stocks versus the posterior medians for the steepnesses of these stocks from the analysis that assumes different hyperpriors for two groups of stocks.

The posterior for steepness for the clupeiformes, gadiformes and pleuronectiformes can be summarized by its mean, median, and 95% probability intervals (0.866, 0.907, and [0.606, 0.986] respectively) while the posterior for the remaining species can be summarized by its mean, median, and 95% probability intervals (0.729, 0.757, and [0.402, 0.959] respectively). These posteriors can be summarized adequately by $N(-2.00, 1.198^2)$ and $N(-0.853, 1.216^2)$ distributions on $\ell n\left(\frac{1-h}{h-0.2}\right)$ (Figure 30).

Appendix 3.3 provides the posterior distributions for Beverton-Holt steepness for each of the 128 stocks considered in the Beverton-Holt-2 analysis. For ease of presentation, two representations of these posteriors are provided: one for the entire [0.2, 1] range for steepness and another constrained to the range where the posterior density is non-negligible. The distributions in Appendix 3.3 show that the posteriors for individual stocks (e.g. blue whiting and cod off west Greenland) can differ quite substantially from that for the unknown stock (Figure 28); in particular they can have the bulk of their mass at values for steepness much less than 0.8.

An analysis was conducted in which the clupeiformes, gadiformes and pleuronectiformes were treated as separate groups. However, the results of this analysis are not shown because it failed to exhibit convergence and because it forced the posterior distribution for the steepness for pleuronectiformes to be a delta function at 1.

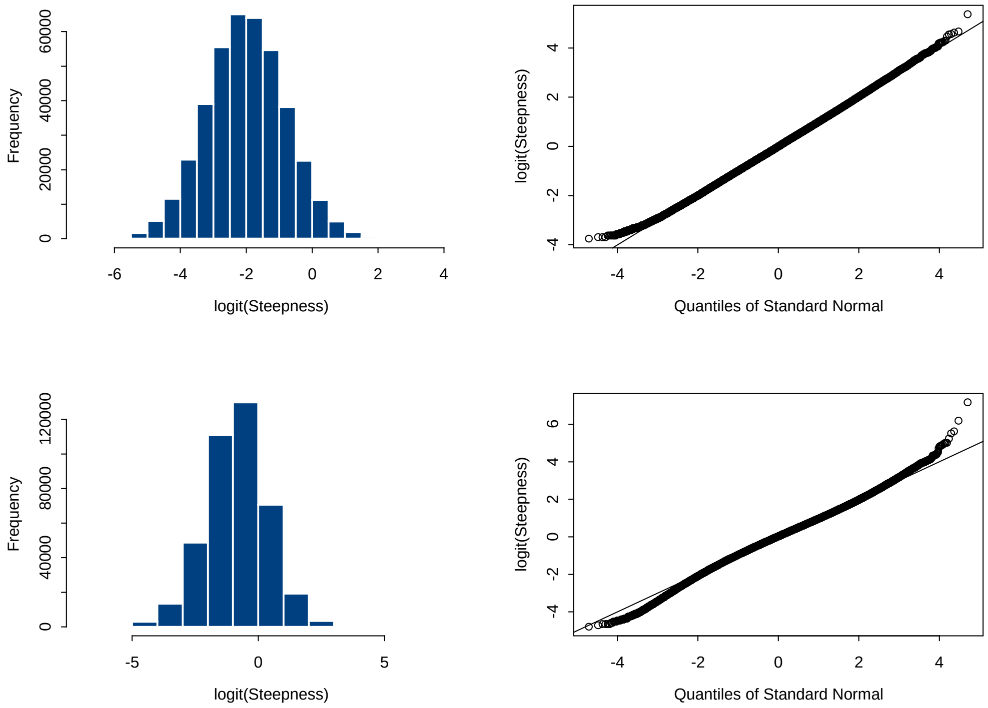


Figure 30. Posterior distributions for the logit of (*h*-0.2)/0.8 (left panels) and q-q plots of the data in the left panels standardized by their means and variances (right panels).

Results are shown for Clupeiformes, Pleuronectiformes, and Gadiformes in the upper panels and for 'other' species in the lower panels.

Impact of covariates

B_0 and σ_R

A key question is whether, as assumed by most Bayesian stock assessments, steepness is independent of other model parameters (in particular the virgin biomass, B_0, and the extent of variation about the stock-recruitment relationship, σ_R). This question is examined in Figure 31 which plots the posterior medians for steepness against those for B_0 and the posterior medians for σ_R against those for steepness. There is no evidence in Figure 31 for a relationship between B_0 and steepness (i.e. there is no evidence that large stocks have higher resilience to exploitation and *vice versa*). There is a very slight increasing trend in σ_R with steepness (i.e. more resilient stocks have very slightly higher variation in recruitment). However, overall, there is no evidence that the common assumption made when conducting Bayesian assessments that steepness is independent of B_0 and σ_R is violated.

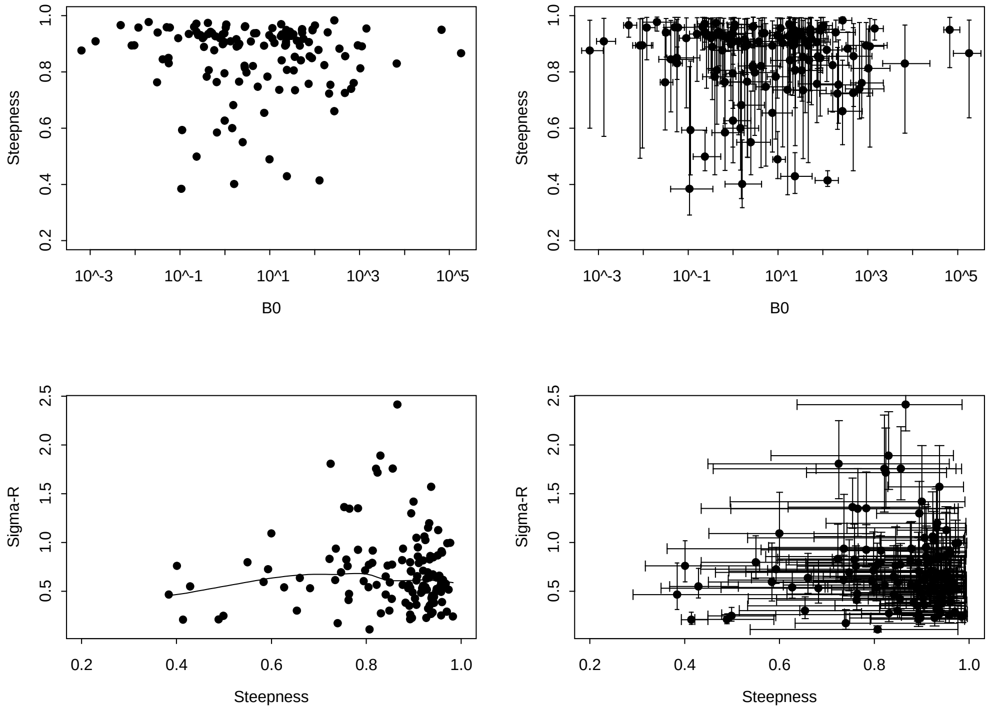


Figure 31. Posterior medians for steepness for the 128 stocks versus the corresponding posterior medians for B_0 (upper panels) and posterior medians for σ_R versus the corresponding posterior medians for steepness (lower panels). The right panels plot the 90% probability intervals for each data point in the left panels.

The mean, median and 90% intervals of the posterior medians for σ_R are 0.702, 0.615, and [0.232, 1.525] respectively. Although these summary statistics are not calculated from a distribution for an unknown stock, they nevertheless provide an effective summary of the information about σ_R, and we recommend that account of these values be taken when stock assessments in which recruitment anomalies are estimated are conducted.

Figure 32 summarizes the fits corresponding to the maximum of the posterior density function in terms of the extent of correlation among the residuals about the fit of the stock-recruitment relationship. In general, there is correlation among the residuals, which is primarily positive (mean and median across stocks of 0.307 and 0.326 with 90% intervals [-0.230, 0.767]).

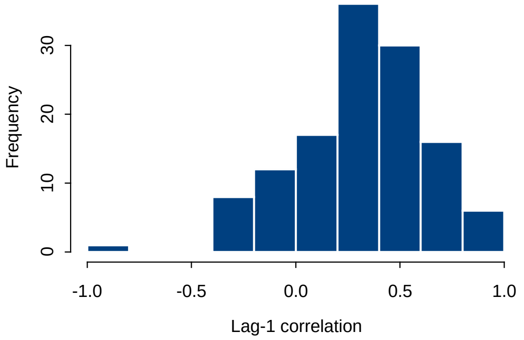


Figure 32. Lag-1 correlations among the residuals of the fits of the Beverton-Holt stock-recruitment relationship to the data for the 128 stocks.

The results in this figure are based on the maximum posterior density (MPD) estimates.

Biological covariates

Figure 33 plots the posterior medians for steepness against reproductive length for two definitions for reproductive length (the age-at-maturity plus $1/M$ and the difference between the maximum age and the age-at-maturity) and the posterior medians for steepness versus reproductive length (first definition) when the data are divided into categories according to the family (Clupeiformes, Pleuronectiformes, Gadiformes and 'other'), diet preference, depth preference, and habitat preference (see Chapter 2: Species Characteristics for details of the various diet, depth and habitat categories).

There is no obvious relationship between steepness and reproductive length. This is somewhat surprising because Myers *et al.* (2002) found such a relationship. However, Myers *et al.* (2002) based their analyses on the Ricker form of the stock-recruitment relationship (which, according to DIC, does not fit the data as well as the Beverton-Holt form) and defined steepness for the Ricker model as $\frac{\alpha_2}{4\tilde{SSB}+\alpha_2}$ where $\tilde{SSB}$ is the spawner biomass-per-recruit in the absence of exploitation. This is, however, only an approximation to the steepness of the Ricker stock-recruitment relationship (see Equation 3.2) and may be inaccurate for high steepness.

The evidence for different relationships between steepness and reproductive length for different species, habitat preferences, diet preferences, and depth preferences is not clear (Figure 33). The only exceptions to this appear to be that 'other' species with reproductive lengths of 10–15 years have lower steepnesses, and the stocks with diet type 1 (phytoplankton or zooplankton) have lower steepness at low reproductive length.

Figure 34 plots the posterior medians for steepness against various (continuous) biological characteristics of the stocks under consideration. In general, there is no evidence that steepness depends on any of these characteristics. The results for length-at-maturity should be interpreted with some caution because length-at-maturity is available for only a small subset of the stocks (21 of 128).

There are no major differences in the relationship between steepness and reproductive length among the factors considered. However, steepness does appear to differ among these factors in absolute terms (Figure 35). In particular, and as expected from the results in Figure 28, 'other' species appear to be less resilient than Clupeiformes, Pleuronectiformes, and Gadiformes.

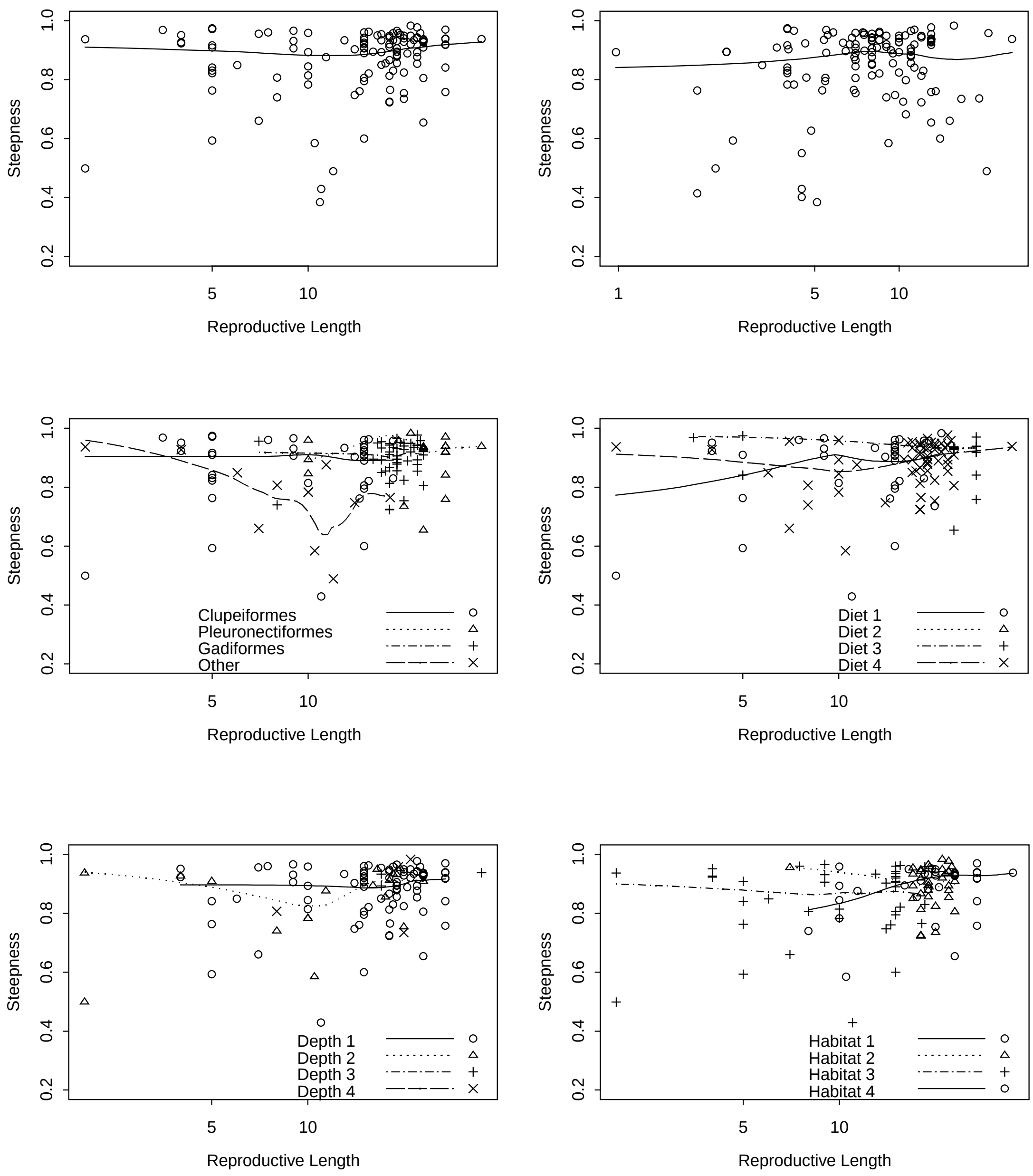


Figure 33. Posterior medians for steepness *versus* reproductive length for two alternative definitions for reproductive length (upper panels), and steepness versus reproductive length when the data are divided into various discrete categories.

The lines are loess curves.

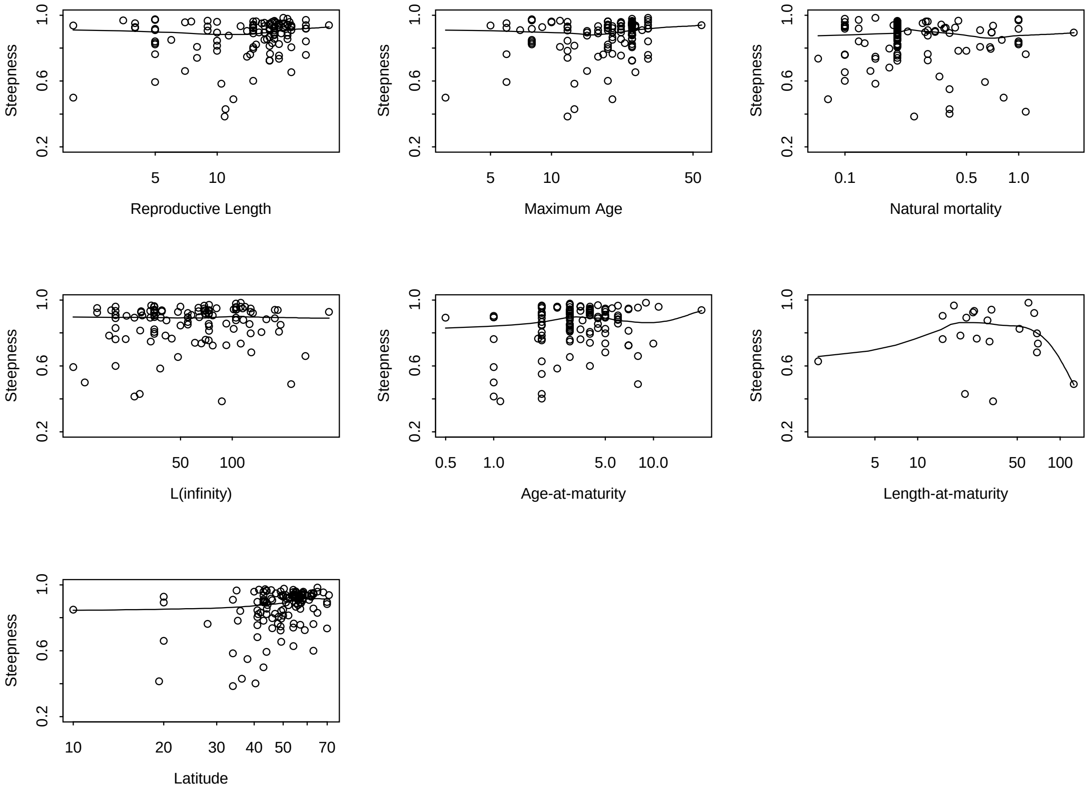


Figure 34. Posterior medians for steepness *versus* various biological variables. The solid lines are loess curves.

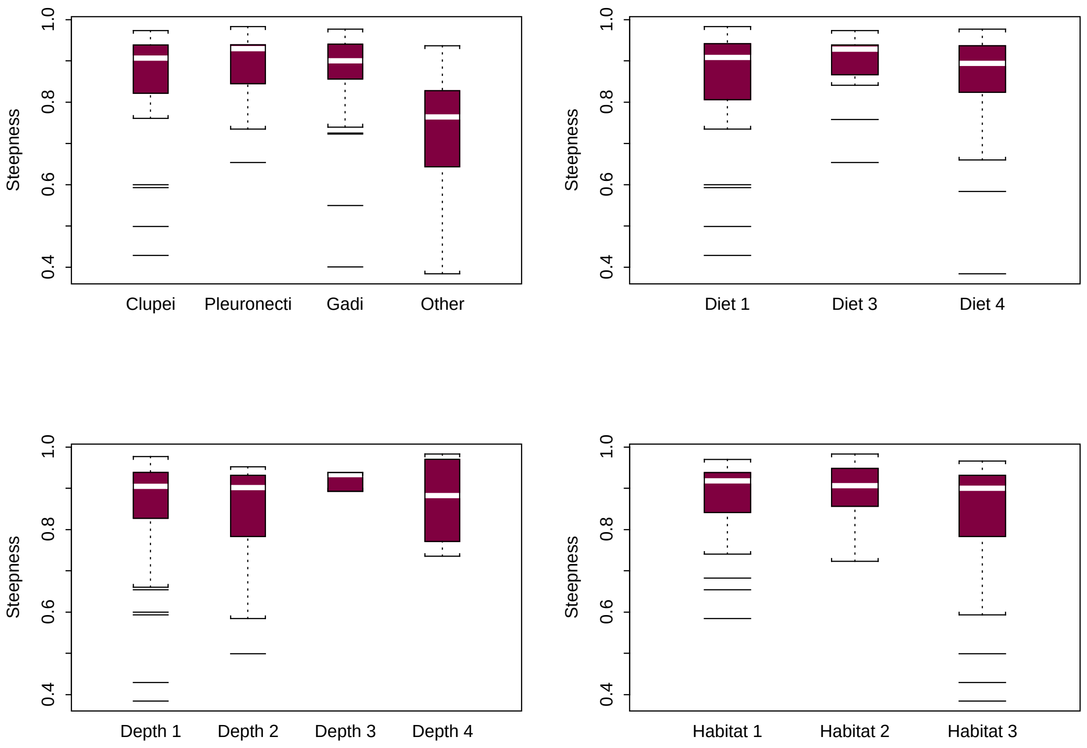


Figure 35. Box plots of the posterior medians for steepness *versus* various discrete characteristics.

Figure 36 plots the posterior medians for steepness against various (continuous) biological characteristics of the 'other' stocks. Unfortunately, the number of stocks represented in Figure 36 is low so that it is not straightforward to draw definite conclusions. However, Figure 36 is indicative of lower steepness with higher maximum age and longer reproductive length.

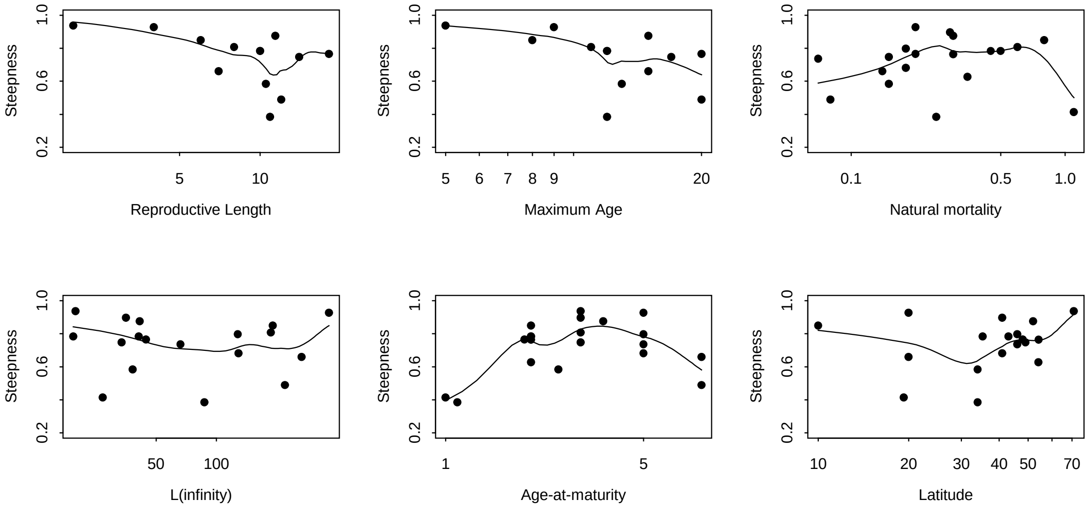


Figure 36. Posterior medians for steepness *versus* various biological variables for species that are not Clupeiformes, Pleuronectiformes, Gadiformes. The solid lines are loess curves.

General discussion

Meta-analysis is being used increasingly to improve fisheries stock assessment. For example, in recent years, meta-analysis (based on Bayesian techniques or mixed effects modeling) has been used to examine the steepness of the stock-recruitment relationship (Myers *et al.*, 2002; Dorn, 2002), the maximum rate of increase at low population size (Myers *et al.*, 1999), depensation (Liermann and Hilborn, 1997), trawl survey catchability (Millar and Methot, 2002), survey selectivity (Harley and Myers, 2001), carrying capacity (Myers *et al.*, 2001), and whether catch-rate is likely to be related linearly to abundance (Harley *et al.*, 2001).

Meta-analysis is, however, not without its problems. The major problems as they relate to this study are:

1. Are the stocks truly interchangeable even after the impact of known covariates is removed?
2. Are the data sets representative of the populations to which the results are likely to be applied. This is a particularly important issue for the present study. The stocks for which data on stock and recruitment are available tend to be commercially important species from three genus' (*Gadidae*, *Clupeidae*, and *Pleuronectidae*); three species within these families (*Clupea harengus*, *Gadus morhua*, and *Melanogrammus aeglefinus*) make up 53 of the 128 stocks in Table 16. In contrast, the species to which the results are likely to be applied (Table 18) do not generally come from these families. Furthermore, the stocks in Table 16 tend to be those that are likely to be fairly productive, if only because they have been fished for several decades and are still sufficiently large that quantitative stock assessment methods can be applied to them.
3. Are all the estimates of spawning biomass and recruitment equally reliable? Although some 'quality control' was applied when selecting the 128 species in Table 16, the stock assessments on which the estimates of spawning biomass and recruitment (and spawning biomass-per-recruit) are based are not all likely to be equally reliable.
4. The 'data' are in fact model outputs. One of the implications of this is that the recruitment estimates for the earliest and most recent years are likely to be the least reliable. However, the analysis technique, as currently formulated, gives equal weight to each data point.

5. The results may be influenced by the 'uninformative' priors placed on parameters other than the parameter of interest (in this case the normal prior on κ_0 and the log-uniform prior on σ_R), the choice for the form of the prior for steepness (which in this case places high prior weight on very low and very high values for steepness), and the choice for the priors for the parameters of the hyperprior.

Other concerns with meta-analysis which are likely to be less of a concern for this study are:

a 'Publication bias' (studies are only published if the results confirm some *apriori* hypothesis); stock assessment results are usually reported irrespective of the outcomes.

b Numerical problems conducting the analyses – the application of several different types of diagnostic statistics suggests that this is not likely to be a very major problem in this case.

Recommendations

1) The data available on stock and recruitment support the Beverton-Holt over the Ricker stock-recruitment relationship, although there are indications that other (more complicated) forms may provide better representations of the existing data.

2) If a single default point estimate for steepness is to be used in a stock assessment based on the Beverton-Holt stock-recruitment relationship, that default should be 0.907 for clupeiformes, gadiformes and pleuronectiformes and 0.757 for 'other' species (the medians of the posteriors for steepness – see Figure 28) while, if a default prior on $\ell n\left(\frac{1-h}{h-0.2}\right)$ is required, it should be $N(-2.00, 1.198^2)$ or $N(-0.853, 1.216^2)$ depending on whether or not the species is a clupeiform, gadiform or pleuronectiform.

3) The use of a prior for steepness that is independent of the other model parameters is supported by this study because steepness does not appear to be related to the virgin biomass nor to the extent of variation about the stock-recruitment relationship.

4) The median and 90% intervals for the posterior medians among stocks for σ_R are 0.615 and [0.232, 1.525] respectively. These values provide a default value for σ_R and an appropriate range when conducting tests of sensitivity.

Table 16.Stocks included in the meta-analysis.

Species	No Stocks	Max Age	M	ℓ_∞	t_m	l_m	Latitude	Diet	Depth	Habitat
Aulopiformes										
Synodontidae										
Harpodon nehereus (bombay duck)	1	0	1	1	1	0	1	0	0	0
Clupeiformes										
Clupeidae										
Alosa aestivalis (blueback herring)	3	3	3	0	3	0	3	3	1	1
Alosa pseudoharengus (anadromous alewife)	4	4	4	0	4	0	4	0	0	0
Alosa sapidissima (anadromous American shad)	1	0	1	0	1	0	1	0	0	0
Brevoortia patronus (Gulf menhaden)	1	1	1	1	1	1	1	1	1	1
Brevoortia tyrannus (Atlantic menhaden)	1	1	1	1	1	1	1	1	1	1
Clupea harengus (herring)	22	22	19	22	21	1	22	22	22	22
Sardina pilchardus (Spanish sardine)	1	1	1	1	1	1	1	1	1	1
Sardinops sagax (sardine)	1	1	1	1	1	1	1	1	1	1
Sprattus sprattus (sprat)	3	3	3	3	3	0	1	1	1	1
Engraulidae										
Coilia dussumieri (gold-potted grenadier anchovy)	1	0	1	1	1	0	1	1	1	1
Engraulis encrasicolus (anchovy)	1	1	1	1	1	0	1	1	1	1
Engraulis mordax (northern anchovy)	1	1	1	1	1	0	1	1	1	1
Gadiformes										
Gadidae										
Gadus morhua (cod)	23	23	23	23	23	3	23	23	23	23
Melanogrammus aeglefinus (haddock)	8	8	8	8	8	0	8	8	8	8
Merlangius merlangus (whiting)	3	3	3	3	3	0	3	3	3	3
Merluccius bilinearis (silver hake)	3	0	3	0	3	0	3	0	0	0
Merluccius merluccius (hake)	1	1	1	1	1	0	1	1	1	1
Merluccius productus (Pacific hake)	1	0	1	0	1	0	0	1	1	1
Micromesistius poutassou (blue whiting)	2	2	2	2	2	1	2	2	2	2
Pollachius virens (saithe)	5	5	5	5	5	0	5	5	5	5
Theragra chalcogramma (walleye pollock)	1	1	1	1	1	0	1	1	1	1
Perciformes										
Carangidae										
Trachurus mediterraneus (Mediterranean horse mackerel)	1	1	1	1	1	1	1	1	1	1

Species	No Stocks	Max Age	M	ℓ_∞	t_m	l_m	Latitude	Diet	Depth	Habitat
Pomatomidae										
Pomatomus saltatrix (bluefish)	1	1	1	1	1	1	1	1	1	1
Scianidae										
Argyrosomus argentatus (white croaker)	1	0	1	1	1	0	1	1	1	1
Scombridae										
Scomber japonicus (chub mackerel)	2	2	2	2	2	0	2	2	2	2
Scomber scombrus (mackerel)	2	2	2	2	2	2	2	2	2	2
Thunnus albacares (yellowfin tuna)	1	1	1	1	1	0	1	1	1	1
Thunnus maccoyii (southern bluefin tuna)	1	1	1	1	1	1	0	0	0	0
Thunnus obesus (bigeye tuna)	1	1	1	1	1	0	0	1	1	1
Thunnus thynnus (Atlantic bluefin tuna)	1	1	1	1	1	0	1	1	1	1
Xiphias gladius (swordfish)	1	1	1	1	1	0	1	1	1	1
Pleuronectiformes										
Pleuronectidae										
Hippoglossus stenolepis (Pacific halibut)	1	1	1	1	1	0	1	1	1	1
Platichthys flesus (flounder)	1	1	1	1	1	1	1	1	1	1
Pleuronectes ferrugineus (yellowtail flounder)	2	2	2	2	2	0	2	2	2	2
Pleuronectes platessa (plaice)	7	7	7	7	7	0	7	7	7	7
Reinhardtius hippoglossoides (Greenland halibut)	3	3	3	3	3	2	3	3	3	3
Soleidae										
Solea vulgaris (sole)	5	5	5	5	5	0	5	5	5	5
Salmoniformes										
Esocidae										
Esox lucius (pike)	2	0	2	0	2	1	2	0	0	0
Osmeridae										
Mallotus villosus (capelin)	1	1	0	1	1	0	1	1	1	1
Scorpaeniformes										
Anoplopomatidae										
Anoplopoma fimbria (sablefish)	1	0	1	1	1	0	1	0	0	0
Hexagrammidae										
Ophiodon-elongatus (lingcod)	2	0	2	2	2	2	2	2	2	2
Pleurogrammus-monopterygius (atka-mackerel)	1	1	1	1	1	1	1	1	1	1
Total	***128***	***113***	***122***	***112***	***125***	***21***	***121***	***111***	***109***	***109***

Table 17. Comparison of the Ricker and Beverton-Holt stock-recruitment models using the Deviance Information Criterion.

Model	$\overline{\text{Deviance}}$	Deviance_{MPD}	p_D	DIC
Beverton-Holt-1	625.58	362.93	262.65	888.24
Beverton-Holt-2	632.54	388.95	243.59	876.13
Ricker	721.60	369.52	352.08	1073.67

Results are shown for the Beverton-Holt form for analyses in which the parameters of the hyperprior are assumed to be the same for all stocks (Beverton-Holt-1) and in which these parameters differ among two groups of species (Beverton-Holt-2).

Table 18. The taxonomy of 15 of the 16 SESSF quota species.

Species	Species
Beryciformes	*Gempylidae*
Berycidae	*Rexea solandri* (gemfish)
Centroberyx affinis (Redfish)	*Macruronus novaezelandiae* (Blue grenadier)
Trachichthyidae	*Sillaginidae*
Hoplostethus atlanticus (orange roughy)	*Sillago flindersi (*Eastern school whiting)
Ophidiiformes	**Pleuronectiformes**
Ophidiidae	*Pleuronectidae*
Genypterus blacodes (ling)	*Neoplatycephalus richardsoni* (tiger flathead)
Perciformes	**Sebastinae**
Carangidae	*Sebastidae*
Pseudocaranx dentex (Silver trevally)	*Helicolenus* sp. (ocean perch)
Centrolophidae	**Zeiformes**
Hyperoglyphe Antarctica (blue-eye trevalla)	*Zeidae*
Seriolella brama (blue warehou)	*Zeus faber* (John dory)
Seriolella punctata (spotted warehou)	*Zenopsis nebulosus* (Mirror dory)
Cheilodactylida	
Nemadactylus macropterus (jackass morwong)	

Appendix 3.1. Medians and 95% probability intervals for steepness and whether four diagnostic tests are failed (indicated by asterisks – 1: Raftery & Lewis, 2: Geweke, 3: Heidelberger & Welsh, 4: Single-chain Gelman). The results in this Appendix are based on the Beverton-Holt-1 and Ricker analyses.

Quantity	Beverton-Holt form							Ricker form						
	2.5%	Medn	97.5%	1	2	3	4	2.5%	Medn	97.5%	1	2	3	4
Deviance	573.44	624.87	680.24					666.95	720.70	781.69			*	
Hyperprior mean, μ	1.589	1.925	2.287					0.55	0.78	1.02				
Hyperprior variance, τ	1.197	1.744	2.648					1.02	1.30	1.96				
Alosa pseudoharengus (Annaquatucket River, USA)	0.909	0.973	0.996					1.351	2.142	3.526			*	
Alosa pseudoharengus (Damariscotta River, USA)	0.756	0.821	0.886					1.349	1.712	2.207				
Alosa pseudoharengus (Lamprey River, USA)	0.771	0.829	0.886					1.189	1.497	1.965				
Alosa pseudoharengus (Saint John River, USA)	0.752	0.914	0.987					0.600	0.996	1.922				
Engraulis encrasicolus (Black Sea)	0.448	0.498	0.581		*			0.493	0.563	0.693				
Engraulis mordax (California, USA)	0.531	0.904	0.993					0.369	0.708	1.590				
Alosa sapidissima (Connecticut River, USA)	0.745	0.896	0.990					1.183	1.985	3.345				
Pleurogrammus monopterygius (Eastern Bering Sea / Aeultian Islands)	0.745	0.943	0.994					0.800	1.764	3.635				
Harpodon nehereus (Northwest coast of India)	0.392	0.415	0.446					0.421	0.450	0.490				
Alosa aestivalis (Chowan River, USA)	0.690	0.834	0.973					0.981	1.511	2.654				
Alosa aestivalis (Connecticut River, USA)	0.959	0.974	0.984					3.283	4.266	4.832				
Alosa aestivalis (Saint John River, USA)	0.916	0.970	0.993					2.015	3.237	4.498				
Thunnus obesus (East Pacific)	0.609	0.907	0.993					0.465	0.614	0.826				
Pomatomus saltatrix (East Coast, USA)	0.297	0.408	0.958					0.295	0.373	0.613				
Thunnus thynnus (West Atlantic)	0.548	0.676	0.882					0.639	0.869	1.340				
Micromesistius poutassou (Northern ICES)	0.697	0.933	0.993		*			0.806	1.431	2.577				
Micromesistius poutassou (Southern ICES)	0.790	0.897	0.990			*		1.517	1.847	3.522		*	*	
Mallotus villosus (Barents Sea)	0.875	0.963	0.995					1.825	3.169	4.521				
Scomber japonicus (Southern California, USA)	0.522	0.903	0.992					0.318	0.558	1.227				
Scomber japonicus (Pacific Coast, Japan)	0.453	0.596	0.861		*			0.472	0.670	1.132				
Gadus morhua (West Greenland (NAFO)	0.674	0.853	0.969					0.946	1.834	3.732				
Gadus morhua (NAFO 2J3KL)	0.709	0.810	0.953					1.099	1.465	2.209				
Gadus morhua (NAFO 3M)	0.648	0.818	0.952					0.952	1.873	3.747				
Gadus morhua (NAFO 3NO)	0.759	0.876	0.982					1.327	1.918	3.390				
Gadus morhua (NAFO 3Pn4RS)	0.592	0.714	0.879					0.758	1.090	1.995				

Quantity	Beverton-Holt form							Ricker form						
	2.5%	**Medn**	**97.5%**	**1**	**2**	**3**	**4**	**2.5%**	**Medn**	**97.5%**	**1**	**2**	**3**	**4**
Gadus morhua (NAFO 3Ps)	0.807	0.903	0.985					1.599	2.315	3.265	*			
Gadus morhua (NAFO 4TVn)	0.803	0.951	0.994					0.823	1.184	1.721				
Gadus morhua (NAFO 4VsW)	0.897	0.967	0.996					2.340	3.553	4.571	*			
Gadus morhua (NAFO 4X)	0.710	0.934	0.994					0.804	1.433	2.278	*			
Gadus morhua (NAFO 5Z)	0.692	0.803	0.966					1.028	1.410	2.323				
Gadus morhua (Baltic Areas 22 and 24)	0.907	0.942	0.986					3.121	3.859	4.624				
Gadus morhua (Baltic Areas 25 - 32)	0.778	0.877	0.976					1.385	2.002	3.096				
Gadus morhua (Celtic Sea)	0.806	0.891	0.983					1.647	2.287	3.611				
Gadus morhua (Faroe Plateau)	0.839	0.952	0.995					1.680	2.591	3.897	*			
Gadus morhua (Greenland)	0.433	0.690	0.940					0.420	0.857	2.351				
Gadus morhua (Iceland)	0.883	0.944	0.991					1.830	2.165	2.604				
Gadus morhua (Irish Sea)	0.900	0.959	0.994					2.655	3.711	4.678				
Gadus morhua (Kattegat)	0.788	0.852	0.925					1.526	2.004	2.759				
Gadus morhua (North East Arctic)	0.915	0.954	0.989					3.093	3.788	4.527				
Gadus morhua (North Sea)	0.871	0.920	0.973					2.421	3.174	4.377				
Gadus morhua (Skagerrak)	0.869	0.947	0.994					2.245	2.942	4.378				
Gadus morhua (ICES VIa)	0.840	0.960	0.996					1.778	2.861	4.225				
Gadus morhua (ICES VIId)	0.945	0.978	0.996					3.414	4.274	4.804				
Platichthys flesus (Baltic Areas 24 and 25)	0.499	0.890	0.993	*	*	*		0.426	0.773	1.628	*		*	
Reinhardtius hippoglossoides (North East Arctic)	0.487	0.699	0.980			*		0.516	0.708	1.120				
Reinhardtius hippoglossoides (Northwest Atlantic)	0.854	0.961	0.995					2.148	2.963	3.976				
Reinhardtius hippoglossoides (ICES V and XIV)	0.952	0.985	0.997					3.437	4.149	4.800				
Coilia dussumieri (Northwest coast of India)	0.817	0.894	0.963					1.608	2.143	3.001				
Melanogrammus aeglefinus (NAFO 4TVW)	0.760	0.854	0.947					1.307	1.806	2.706		*		
Melanogrammus aeglefinus (NAFO 4X)	0.635	0.905	0.992					0.717	1.421	3.658				
Melanogrammus aeglefinus (NAFO 5Z)	0.615	0.743	0.898					0.826	1.228	2.105				
Melanogrammus aeglefinus (Faroe Plateau)	0.685	0.937	0.995					1.714	3.242	4.545				
Melanogrammus aeglefinus (Iceland)	0.826	0.954	0.995					1.152	1.746	2.789				
Melanogrammus aeglefinus (North East Arctic)	0.802	0.895	0.977					1.660	2.513	4.002				
Melanogrammus aeglefinus (North Sea)	0.842	0.953	0.995					1.617	2.478	3.817				
Melanogrammus aeglefinus (ICES VIa)	0.729	0.935	0.994					0.959	1.929	3.925				
Merluccius merluccius (ICES VIIIab-d, VIIb k)	0.633	0.731	0.978			*		0.864	0.994	1.602				
Clupea harengus (Baltic areas 22 and 24)	0.840	0.962	0.995					2.124	3.363	4.450				

Quantity	Beverton-Holt form							Ricker form						
	2.5%	Medn	97.5%	1	2	3	4	2.5%	Medn	97.5%	1	2	3	4
Clupea harengus (NAFO 4-5)	0.900	0.963	0.994					1.897	2.756	3.974				
Clupea harengus (Central Coast B.C., Canada)	0.774	0.921	0.993					1.241	1.780	2.637				
Clupea harengus (Downs stock)	0.731	0.812	0.886					1.081	1.451	2.003				
Clupea harengus (Eastern Bering Sea)	0.691	0.934	0.993					0.482	0.948	2.422				
Clupea harengus (Georges Bank)	0.419	0.791	0.985					0.416	1.117	3.469		*		
Clupea harengus (Gulf of Finland)	0.671	0.906	0.993					0.835	1.627	4.007				
Clupea harengus (Gulf of Maine)	0.861	0.961	0.995					1.888	2.868	4.157				
Clupea harengus (Gulf of Riga)	0.578	0.873	0.991			*		0.646	1.031	2.842				
Clupea harengus (Iceland, Spring-spawning)	0.439	0.589	0.793					0.482	0.765	1.558				
Clupea harengus (Iceland, Summer-spawning)	0.635	0.756	0.902					0.811	1.086	1.679				
Clupea harengus (Northern- rish Sea)	0.806	0.931	0.990					1.265	1.876	2.768				
Clupea harengus (Norway, Spring-spawning)	0.559	0.819	0.969		*			0.545	1.179	3.101		*		
Clupea harengus (North Sea)	0.863	0.905	0.942					2.163	2.744	3.526				
Clupea harengus (North Srait of Georgia, Canada)	0.657	0.791	0.936					0.877	1.177	1.580				
Clupea harengus (North West Coast Vancouver Island, Canada)	0.750	0.939	0.994					0.625	0.983	1.594		*		
Clupea harengus (Prince Rupert District, USA)	0.817	0.941	0.992					1.539	2.469	3.885				
Clupea harengus (Queen Charlotte Islands, Canada)	0.811	0.926	0.990					1.402	2.139	3.387				
Clupea harengus (S.E. Alaska, USA)	0.486	0.899	0.991					0.276	0.503	1.169				
Clupea harengus (Southern Strait of Georgia, Canada)	0.600	0.799	0.981					0.705	1.065	1.751				
Clupea harengus (South West Coast Vancouver, Canada)	0.882	0.962	0.995					1.647	2.342	3.533				
Clupea harengus (ICES VIa (south) and VIIIb,c)	0.703	0.929	0.993		*			0.869	2.061	3.860	*	*	*	
Scomber scombrus (NAFO 2 to 6)	0.557	0.873	0.991					0.582	1.159	2.793				
Trachurus mediterraneus (Black Sea)	0.610	0.870	0.990					0.541	0.783	1.204				
Scomber scombrus (Western ICES)	0.526	0.888	0.992					0.494	0.988	3.030				
Brevoortia tyrannus (U.S. Atlantic)	0.924	0.966	0.994					2.557	3.195	4.020				
Brevoortia patronus (Gulf of Mexico)	0.582	0.748	0.950					0.594	0.793	1.084				
Hippoglossus stenolepis (North Pacific)	0.803	0.942	0.994					1.215	1.628	2.182				
Esox lucius (North Basin, Lake Windermere, USA)	0.631	0.816	0.982					0.801	1.077	1.463				
Esox lucius (South Basin, Lake Windermere, USA)	0.483	0.654	0.951		*			0.523	0.732	1.084				
Pleuronectes platessa (ICES VIIe)	0.759	0.837	0.960			*		1.397	1.771	2.851				
Pleuronectes platessa (Celtic Sea)	0.815	0.922	0.991					1.626	2.342	3.849				

Quantity	Beverton-Holt form							Ricker form						
	2.5%	Medn	97.5%	1	2	3	4	2.5%	Medn	97.5%	1	2	3	4
Pleuronectes platessa (ICES IIIa)	0.713	0.939	0.994					1.231	2.806	4.337	*			
Pleuronectes platessa (Irish Sea)	0.897	0.974	0.997					2.031	2.790	3.747				
Pleuronectes platessa (Kattegat)	0.615	0.749	0.952					0.815	1.179	2.206				
Pleuronectes platessa (North Sea)	0.730	0.938	0.995					1.455	2.757	4.288				
Pleuronectes platessa (Skagerrak)	0.661	0.920	0.993					0.807	1.798	3.777				
Pollachius virens (Faroe)	0.708	0.930	0.994					1.171	2.509	4.249				
Pollachius virens (Iceland)	0.803	0.951	0.995					1.450	2.167	3.304				
Pollachius virens (North East Arctic)	0.821	0.881	0.941					1.848	2.318	2.943				
Pollachius virens (North Sea)	0.795	0.887	0.978					1.503	2.016	2.777				
Pollachius virens (ICES VI)	0.849	0.941	0.992					1.554	1.949	2.456				
Anoplopoma fimbria (West Coast USA)	0.454	0.887	0.992					0.376	1.169	3.775				
Sardinops sagax (California)	0.365	0.425	0.507					0.382	0.462	0.585				
Sardina pilchardus (West Iberian (ICES V)	0.514	0.902	0.992					0.503	1.702	4.075	*	*	*	
Thunnus maccoyii (Southern Pacific)	0.422	0.492	0.587		*			0.447	0.522	0.613		*		
Merluccius bilinearis (NAFO 4VWX)	0.489	0.869	0.990	*				0.476	0.827	2.079				
Merluccius bilinearis (NAFO 5Ze)	0.313	0.394	0.536					0.315	0.405	0.572				
Merluccius bilinearis (Mid Atlantic Bight)	0.431	0.542	0.716					0.454	0.605	0.890				
Solea vulgaris (Celtic Sea)	0.747	0.940	0.995					1.248	2.271	3.832	*	*		
Solea vulgaris (Irish Sea)	0.683	0.930	0.994					0.989	2.850	4.517				
Solea vulgaris (North Sea)	0.751	0.936	0.994					1.050	1.855	3.221				
Solea vulgaris (ICES VIId)	0.735	0.930	0.994					1.253	1.814	2.772				
Solea vulgaris (ICES VIIe)	0.510	0.634	0.933					0.569	0.716	1.033				
Sprattus sprattus (Baltic Areas 22 - 32)	0.797	0.954	0.995		*			1.368	2.802	4.379		*		
Sprattus sprattus (Baltic Areas 26 and 28)	0.643	0.921	0.993					0.548	1.143	2.859				
Sprattus sprattus (Black Sea)	0.428	0.579	0.818					0.420	0.572	0.840				
Xiphias gladius (North Atlantic)	0.824	0.965	0.996	*				2.872	3.533	4.131				
Argyrosomus argentatus (East China Sea)	0.812	0.940	0.993					1.520	2.419	3.793	*		*	
Merlangius merlangus (Eastern Black Sea)	0.458	0.883	0.991			*		0.269	0.472	1.145				
Merlangius merlangus (Western Black Sea)	0.418	0.886	0.991					0.281	0.664	2.218			*	
Merlangius merlangus (North Sea)	0.624	0.864	0.987					0.888	2.070	4.077				
Merlangius merlangus (ICES VIa)	0.653	0.920	0.993		*			0.796	1.817	3.658		*		
Merlangius merlangus (ICES VIId)	0.573	0.837	0.989					0.640	1.009	2.297				
Theragra chalcogramma (Gulf of Alaska)	0.537	0.903	0.992			*		0.416	0.866	2.213				

Quantity	Beverton-Holt form							Ricker form						
	2.5%	Medn	97.5%	1	2	3	4	2.5%	Medn	97.5%	1	2	3	4
Pleuronectes ferrugineus (NAFO 5Z)	0.649	0.840	0.984					0.826	1.304	2.641				
Pleuronectes ferrugineus (Southern New England)	0.852	0.958	0.995					1.752	3.120	4.464				
Thunnus albacares (Eastern Pacific Ocea)	0.709	0.923	0.993					0.733	1.140	1.781				
Ophiodon elongatus (US West Coast (South)	0.625	0.902	0.991					0.707	1.436	3.700				
Ophiodon elongatus (US West Coast (North)	0.394	0.859	0.990					0.332	0.572	1.617				
Merluccius productus (US West Coast)	0.440	0.889	0.992					0.300	0.795	3.037		*		

Appendix 3.2. Medians and 95% probability intervals for steepness and whether four diagnostic tests are failed (indicated by asterisks – 1: Raftery & Lewis, 2: Geweke, 3: Heidelberger & Welsh, 4: Single-chain Gelman). The results in this Appendix are based on the Beverton-Holt-1 and Beverton-Holt-2 analyses.

Quantity	**Beverton-Holt-1**							**Beveton-Holt-2**						
	2.5%	**Medn**	**97.5%**	**1**	**2**	**3**	**4**	**2.5%**	**Medn**	**97.5%**	**1**	**2**	**3**	**4**
Deviance	573.44	624.87	680.24					581.399	631.764	686.873				
Hyperprior mean, μ (group-1)	1.589	1.925	2.287					1.702	2.015	2.382				
Hyperprior variance, τ (group-1)	1.197	1.744	2.648					0.166	0.822	1.711			*	
Hyperprior mean, μ (group-2)								0.938	1.421	2.244		*		
Hyperprior variance, τ (group-2)								0.548	1.223	2.788		*	*	
Alosa pseudoharengus (Annaquatucket River, USA)	0.909	0.973	0.996					0.906	0.971	0.994				
Alosa pseudoharengus (Damariscotta River, USA)	0.756	0.821	0.886					0.757	0.822	0.887				
Alosa pseudoharengus (Lamprey River, USA)	0.771	0.829	0.886					0.773	0.831	0.889				
Alosa pseudoharengus (Saint John River, USA)	0.752	0.914	0.987					0.762	0.916	0.988				
Engraulis encrasicolus (Black Sea)	0.448	0.498	0.581		*			0.449	0.499	0.592				
Engraulis mordax (California, USA)	0.531	0.904	0.993					0.571	0.909	0.991				
Alosa sapidissima (Connecticut River, USA)	0.745	0.896	0.990					0.751	0.898	0.988				
Pleurogrammus monopterygius (Eastern Bering Sea / Aeultian Islands)	0.745	0.943	0.994					0.600	0.876	0.984				
Harpodon nehereus (Northwest coast of India)	0.392	0.415	0.446					0.393	0.414	0.449				
Alosa aestivalis (Chowan River, USA)	0.690	0.834	0.973					0.692	0.841	0.975				
Alosa aestivalis (Connecticut River, USA)	0.959	0.974	0.984					0.959	0.974	0.984				
Alosa aestivalis (Saint John River, USA)	0.916	0.970	0.993					0.911	0.968	0.992				
Thunnus obesus (East Pacific)	0.609	0.907	0.993					0.538	0.807	0.976				
Pomatomus saltatrix (East Coast, USA)	0.297	0.408	0.958					0.291	0.384	0.819		*		
Thunnus thynnus (West Atlantic)	0.548	0.676	0.882					0.541	0.660	0.842				
Micromesistius poutassou (Northern ICES)	0.697	0.933	0.993		*			0.719	0.933	0.992				
Micromesistius poutassou (Southern ICES)	0.790	0.897	0.990			*		0.791	0.893	0.990		*	*	
Mallotus villosus (Barents Sea)	0.875	0.963	0.995					0.828	0.937	0.988				
Scomber japonicus (Southern California, USA)	0.522	0.903	0.992					0.435	0.783	0.977				
Scomber japonicus (Pacific Coast, Japan)	0.453	0.596	0.861		*			0.450	0.584	0.790				
Gadus morhua (West Greenland (NAFO)	0.674	0.853	0.969					0.677	0.856	0.972				
Gadus morhua (NAFO 2J3KL)	0.709	0.810	0.953					0.714	0.813	0.953				
Gadus morhua (NAFO 3M)	0.648	0.818	0.952					0.657	0.824	0.952				

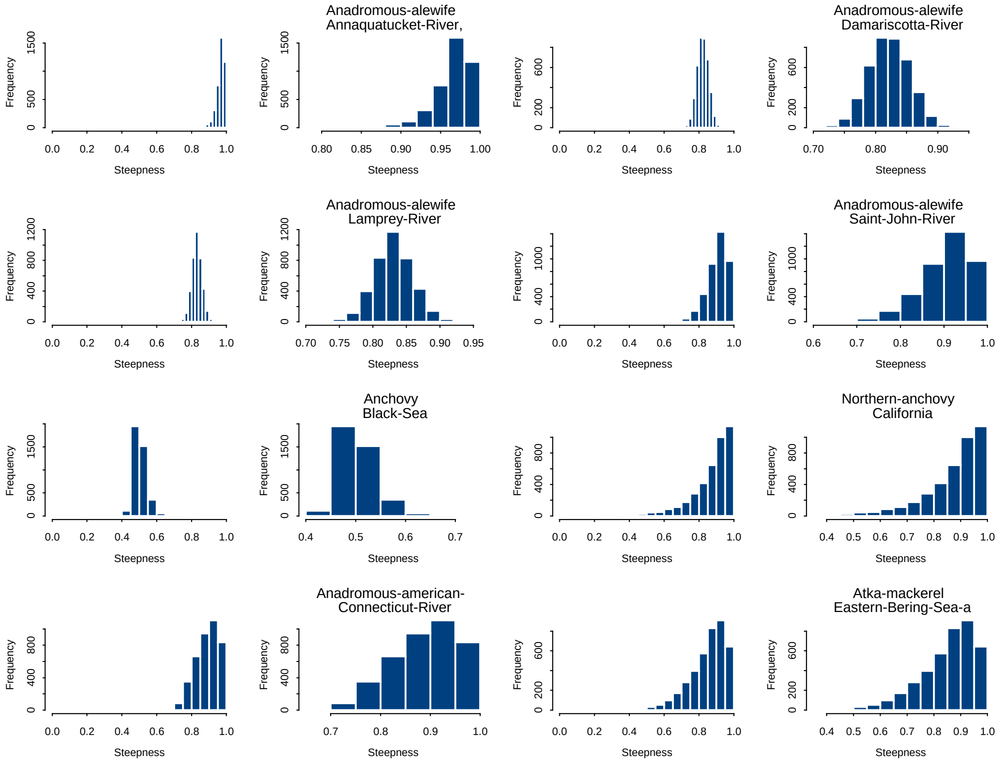
Quantity	**Beverton-Holt-1**							**Beveton-Holt-2**						
	2.5%	**Medn**	**97.5%**	**1**	**2**	**3**	**4**	**2.5%**	**Medn**	**97.5%**	**1**	**2**	**3**	**4**
Gadus morhua (NAFO 3NO)	0.759	0.876	0.982					0.766	0.878	0.979				
Gadus morhua (NAFO 3Pn4RS)	0.592	0.714	0.879					0.596	0.723	0.887				
Gadus morhua (NAFO 3Ps)	0.807	0.903	0.985					0.812	0.906	0.983		*		
Gadus morhua (NAFO 4TVn)	0.803	0.951	0.994					0.799	0.948	0.994				
Gadus morhua (NAFO 4VsW)	0.897	0.967	0.996					0.893	0.965	0.994				
Gadus morhua (NAFO 4X)	0.710	0.934	0.994					0.717	0.934	0.992				
Gadus morhua (NAFO 5Z)	0.692	0.803	0.966					0.696	0.805	0.955				
Gadus morhua (Baltic Areas 22 and 24)	0.907	0.942	0.986					0.907	0.941	0.985				
Gadus morhua (Baltic Areas 25 - 32)	0.778	0.877	0.976					0.778	0.877	0.972				
Gadus morhua (Celtic Sea)	0.806	0.891	0.983					0.804	0.893	0.982				
Gadus morhua (Faroe Plateau)	0.839	0.952	0.995					0.837	0.949	0.993		*		
Gadus morhua (Greenland)	0.433	0.690	0.940					0.449	0.725	0.958				
Gadus morhua (Iceland)	0.883	0.944	0.991					0.883	0.943	0.990				
Gadus morhua (Irish Sea)	0.900	0.959	0.994					0.898	0.956	0.992				
Gadus morhua (Kattegat)	0.788	0.852	0.925					0.787	0.854	0.928				
Gadus morhua (North East Arctic)	0.915	0.954	0.989					0.913	0.954	0.986		*		
Gadus morhua (North Sea)	0.871	0.920	0.973					0.873	0.920	0.974				
Gadus morhua (Skagerrak)	0.869	0.947	0.994					0.867	0.943	0.992				
Gadus morhua (ICES VIa)	0.840	0.960	0.996					0.843	0.958	0.994				
Gadus morhua (ICES VIId)	0.945	0.978	0.996					0.945	0.977	0.995				
Platichthys flesus (Baltic Areas 24 and 25)	0.499	0.890	0.993	*	*	*		0.478	0.893	0.989	*			
Reinhardtius hippoglossoides (North East Arctic)	0.487	0.699	0.980			*		0.492	0.735	0.983		*		
Reinhardtius hippoglossoides (Northwest Atlantic)	0.854	0.961	0.995					0.857	0.958	0.994				
Reinhardtius hippoglossoides (ICES V and XIV)	0.952	0.985	0.997					0.950	0.983	0.996				
Coilia dussumieri (Northwest coast of India)	0.817	0.894	0.963					0.812	0.893	0.960				
Melanogrammus aeglefinus (NAFO 4TVW)	0.760	0.854	0.947					0.761	0.855	0.946				
Melanogrammus aeglefinus (NAFO 4X)	0.635	0.905	0.992					0.655	0.911	0.991				
Melanogrammus aeglefinus (NAFO 5Z)	0.615	0.743	0.898					0.618	0.754	0.914				
Melanogrammus aeglefinus (Faroe Plateau)	0.685	0.937	0.995					0.711	0.934	0.993				
Melanogrammus aeglefinus (Iceland)	0.826	0.954	0.995					0.816	0.950	0.994		*		
Melanogrammus aeglefinus (North East Arctic)	0.802	0.895	0.977					0.805	0.895	0.976				
Melanogrammus aeglefinus (North Sea)	0.842	0.953	0.995					0.848	0.952	0.994		*		
Melanogrammus aeglefinus (ICES VIa)	0.729	0.935	0.994					0.742	0.931	0.992				

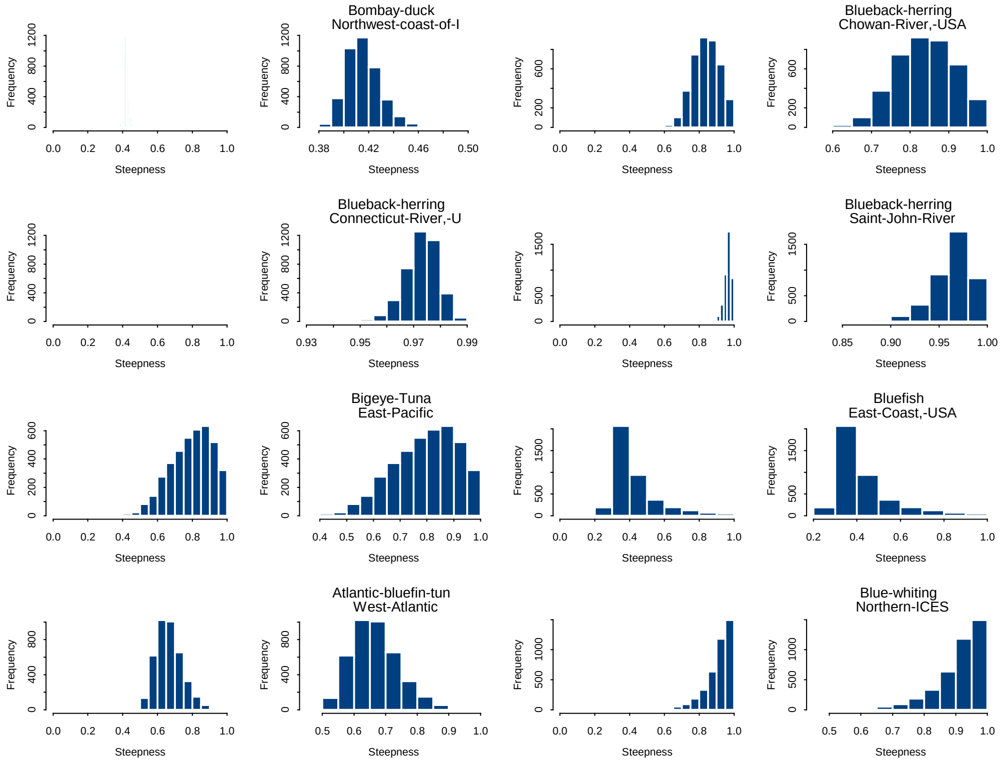
Quantity	Beverton-Holt-1							Beveton-Holt-2						
	2.5%	Medn	97.5%	1	2	3	4	2.5%	Medn	97.5%	1	2	3	4
Merluccius merluccius (ICES VIIIab-d, VIIb k)	0.633	0.731	0.978			*		0.633	0.740	0.976		*	*	
Clupea harengus (Baltic areas 22 and 24)	0.840	0.962	0.995					0.838	0.960	0.995				
Clupea harengus (NAFO 4-5)	0.900	0.963	0.994					0.896	0.962	0.994				
Clupea harengus (Central Coast B.C., Canada)	0.774	0.921	0.993					0.778	0.920	0.989				
Clupea harengus (Downs stock)	0.731	0.812	0.886					0.732	0.814	0.886		*		
Clupea harengus (Eastern Bering Sea)	0.691	0.934	0.993					0.698	0.933	0.993				
Clupea harengus (Georges Bank)	0.419	0.791	0.985					0.460	0.821	0.984				
Clupea harengus (Gulf of Finland)	0.671	0.906	0.993					0.667	0.908	0.991				
Clupea harengus (Gulf of Maine)	0.861	0.961	0.995					0.859	0.958	0.994				
Clupea harengus (Gulf of Riga)	0.578	0.873	0.991			*		0.608	0.890	0.989		*	*	
Clupea harengus (Iceland, Spring-spawning)	0.439	0.589	0.793					0.451	0.600	0.801				
Clupea harengus (Iceland, Summer-spawning)	0.635	0.756	0.902					0.637	0.761	0.909				
Clupea harengus (Northern- rish Sea)	0.806	0.931	0.990					0.811	0.931	0.991		*		
Clupea harengus (Norway, Spring-spawning)	0.559	0.819	0.969		*			0.582	0.830	0.967				
Clupea harengus (North Sea)	0.863	0.905	0.942					0.863	0.906	0.943		*		
Clupea harengus (North Srait of Georgia, Canada)	0.657	0.791	0.936					0.671	0.795	0.934				
Clupea harengus (North West Coast Vancouver Island, Canada)	0.750	0.939	0.994					0.751	0.935	0.992				
Clupea harengus (Prince Rupert District, USA)	0.817	0.941	0.992					0.822	0.942	0.992				
Clupea harengus (Queen Charlotte Islands, Canada)	0.811	0.926	0.990					0.812	0.925	0.988				
Clupea harengus (S.E. Alaska, USA)	0.486	0.899	0.991					0.533	0.906	0.990				
Clupea harengus (Southern Strait of Georgia, Canada)	0.600	0.799	0.981					0.614	0.806	0.979				
Clupea harengus (South West Coast Vancouver, Canada)	0.882	0.962	0.995					0.878	0.960	0.994				
Clupea harengus (ICES VIa (south) and VIIIb,c)	0.703	0.929	0.993		*			0.702	0.925	0.992				
Scomber scombrus (NAFO 2 to 6)	0.557	0.873	0.991					0.497	0.765	0.969		*		
Trachurus mediterraneus (Black Sea)	0.610	0.870	0.990					0.561	0.783	0.967				
Scomber scombrus (Western ICES)	0.526	0.888	0.992					0.465	0.747	0.972				
Brevoortia tyrannus (U.S. Atlantic)	0.924	0.966	0.994					0.924	0.966	0.992				
Brevoortia patronus (Gulf of Mexico)	0.582	0.748	0.950					0.594	0.763	0.958		*		
Hippoglossus stenolepis (North Pacific)	0.803	0.942	0.994					0.813	0.938	0.992				
Esox lucius (North Basin, Lake Windermere, USA)	0.631	0.816	0.982					0.616	0.764	0.950				
Esox lucius (South Basin, Lake Windermere, USA)	0.483	0.654	0.951		*			0.477	0.627	0.864				
Pleuronectes platessa (ICES VIIe)	0.759	0.837	0.960			*		0.764	0.841	0.962				

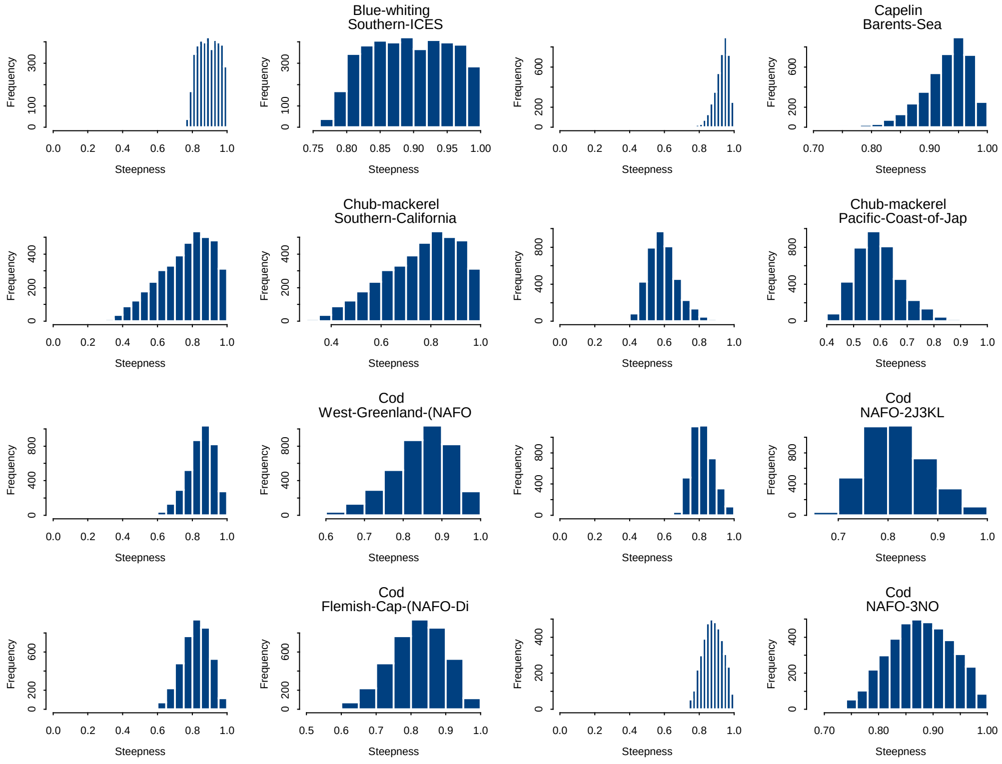
Quantity	Beverton-Holt-1							Beveton-Holt-2						
	2.5%	Medn	97.5%	1	2	3	4	2.5%	Medn	97.5%	1	2	3	4
Pleuronectes platessa (Celtic Sea)	0.815	0.922	0.991					0.818	0.919	0.989				
Pleuronectes platessa (ICES IIIa)	0.713	0.939	0.994					0.733	0.939	0.992				
Pleuronectes platessa (Irish Sea)	0.897	0.974	0.997					0.895	0.970	0.996				
Pleuronectes platessa (Kattegat)	0.615	0.749	0.952					0.620	0.758	0.956				
Pleuronectes platessa (North Sea)	0.730	0.938	0.995					0.758	0.938	0.993				
Pleuronectes platessa (Skagerrak)	0.661	0.920	0.993					0.683	0.918	0.992				
Pollachius virens (Faroe)	0.708	0.930	0.994					0.710	0.928	0.992				
Pollachius virens (Iceland)	0.803	0.951	0.995					0.810	0.949	0.994				
Pollachius virens (North East Arctic)	0.821	0.881	0.941					0.823	0.883	0.942				
Pollachius virens (North Sea)	0.795	0.887	0.978					0.797	0.889	0.973				
Pollachius virens (ICES VI)	0.849	0.941	0.992					0.853	0.940	0.990				
Anoplopoma fimbria (West Coast USA)	0.454	0.887	0.992					0.363	0.736	0.972				
Sardinops sagax (California)	0.365	0.425	0.507					0.368	0.429	0.513		*		
Sardina pilchardus (West Iberian (ICES V)	0.514	0.902	0.992					0.534	0.903	0.991				
Thunnus maccoyii (Southern Pacific)	0.422	0.492	0.587		*			0.421	0.489	0.588				
Merluccius bilinearis (NAFO 4VWX)	0.489	0.869	0.990	*				0.533	0.891	0.990				
Merluccius bilinearis (NAFO 5Ze)	0.313	0.394	0.536					0.317	0.401	0.558				
Merluccius bilinearis (Mid Atlantic Bight)	0.431	0.542	0.716					0.435	0.550	0.732				
Solea vulgaris (Celtic Sea)	0.747	0.940	0.995					0.737	0.937	0.993			*	
Solea vulgaris (Irish Sea)	0.683	0.930	0.994					0.707	0.930	0.992				
Solea vulgaris (North Sea)	0.751	0.936	0.994					0.767	0.935	0.993				
Solea vulgaris (ICES VIId)	0.735	0.930	0.994					0.737	0.927	0.991				
Solea vulgaris (ICES VIIe)	0.510	0.634	0.933					0.515	0.654	0.941				
Sprattus sprattus (Baltic Areas 22 - 32)	0.797	0.954	0.995		*			0.814	0.951	0.993		*		
Sprattus sprattus (Baltic Areas 26 and 28)	0.643	0.921	0.993					0.673	0.923	0.991				
Sprattus sprattus (Black Sea)	0.428	0.579	0.818					0.434	0.593	0.839				
Xiphias gladius (North Atlantic)	0.824	0.965	0.996	*				0.748	0.927	0.991		*	*	
Argyrosomus argentatus (East China Sea)	0.812	0.940	0.993					0.793	0.897	0.986		*	*	
Merlangius merlangus (Eastern Black Sea)	0.458	0.883	0.991			*		0.529	0.895	0.991				
Merlangius merlangus (Western Black Sea)	0.418	0.886	0.991					0.493	0.894	0.989		*		
Merlangius merlangus (North Sea)	0.624	0.864	0.987					0.637	0.866	0.985				
Merlangius merlangus (ICES VIa)	0.653	0.920	0.993		*			0.672	0.920	0.992		*		
Merlangius merlangus (ICES VIId)	0.573	0.837	0.989					0.587	0.850	0.987				

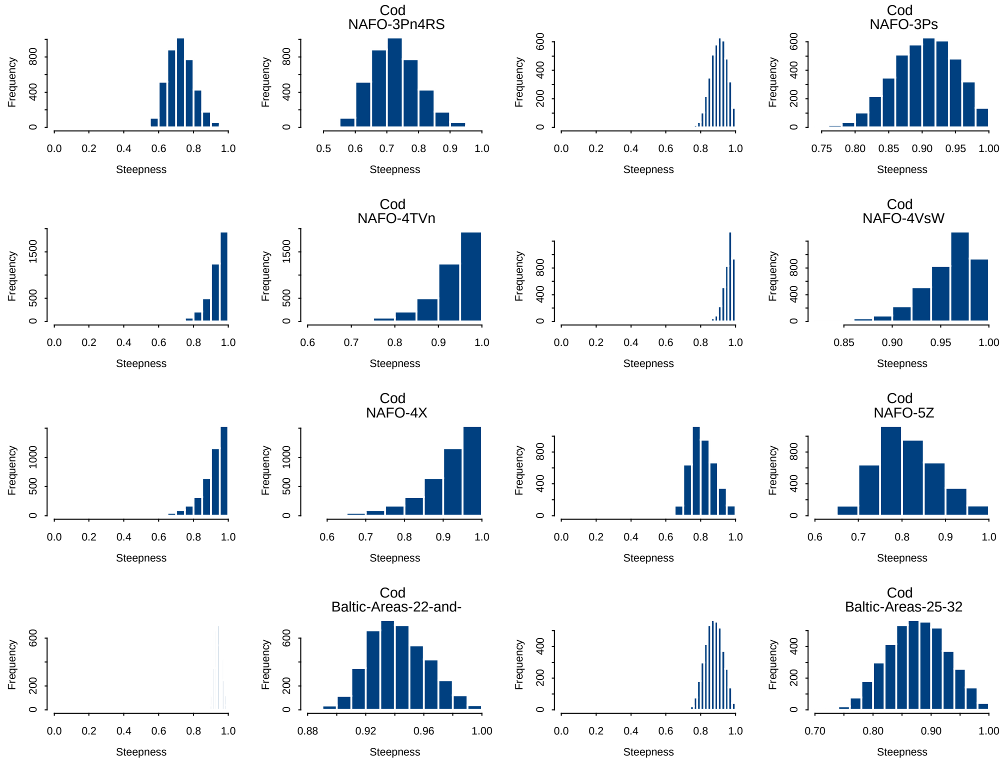
Quantity	Beverton-Holt-1							Beveton-Holt-2						
	2.5%	Medn	97.5%	1	2	3	4	2.5%	Medn	97.5%	1	2	3	4
Theragra chalcogramma (Gulf of Alaska)	0.537	0.903	0.992			*		0.577	0.909	0.991				
Pleuronectes ferrugineus (NAFO 5Z)	0.649	0.840	0.984					0.658	0.845	0.983				
Pleuronectes ferrugineus (Southern New England)	0.852	0.958	0.995					0.847	0.959	0.994		*		
Thunnus albacares (Eastern Pacific Ocea)	0.709	0.923	0.993					0.643	0.849	0.976				
Ophiodon elongatus (US West Coast (South)	0.625	0.902	0.991					0.575	0.798	0.976				
Ophiodon elongatus (US West Coast (North)	0.394	0.859	0.990					0.350	0.682	0.970				
Merluccius productus (US West Coast)	0.440	0.889	0.992					0.496	0.900	0.991				

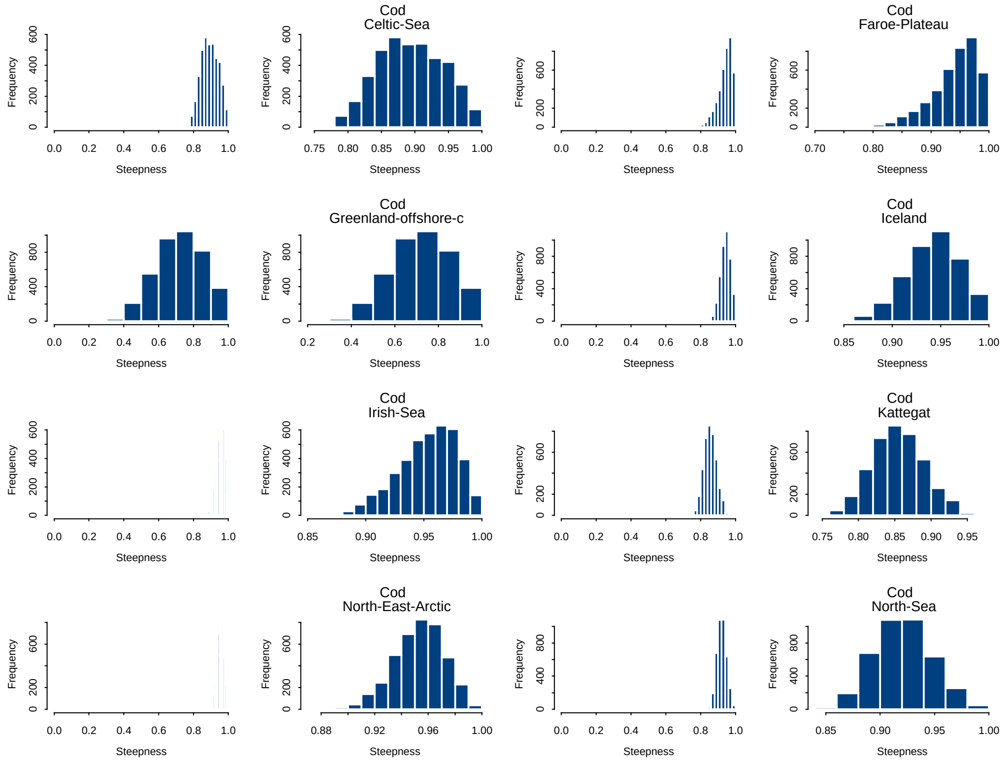
Appendix 3.3. Posterior distributions for the steepness of the Beverton-Holt stock-recruitment relationship for the 128 stocks.

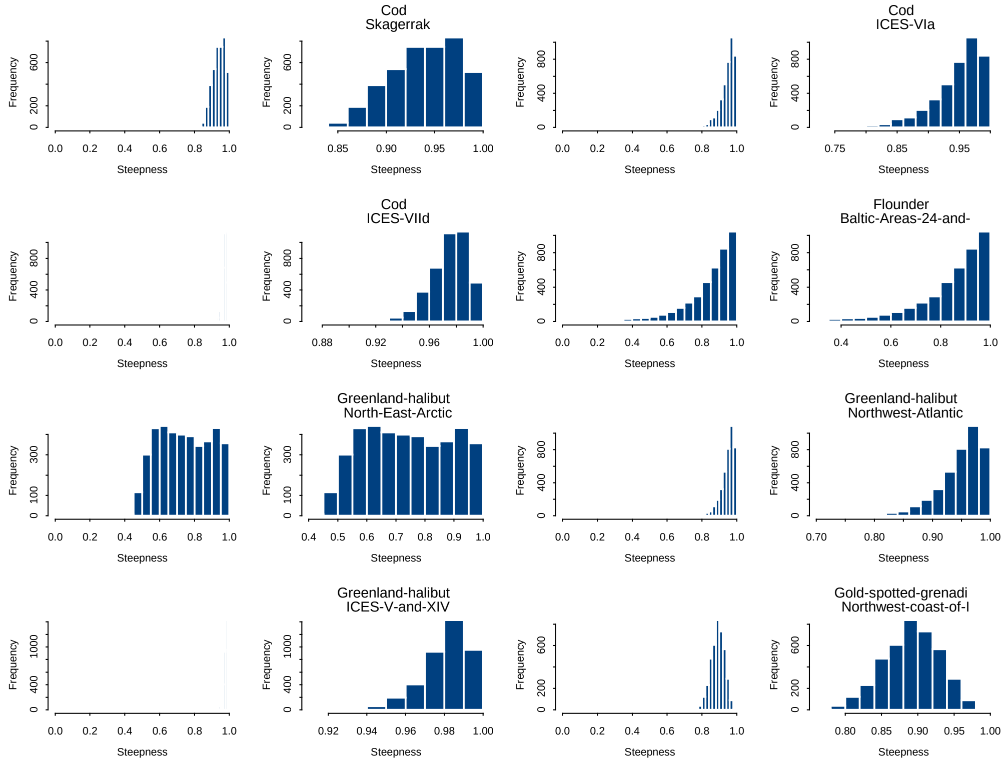


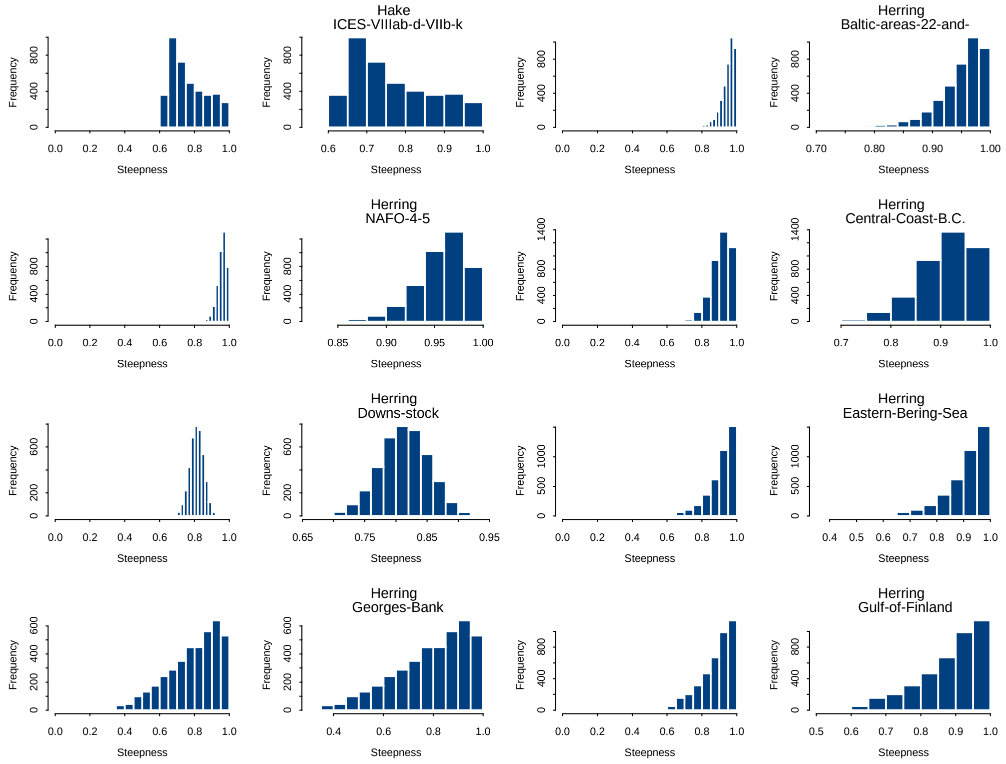

Bombay-duck
Northwest-coast-of-I
Blueback-herring
Chowan-River,-USA
Blueback-herring
Connecticut-River,-U
Blueback-herring
Saint-John-River
Bigeye-Tuna
East-Pacific
Bluefish
East-Coast,-USA
Atlantic-bluefin-tun
West-Atlantic
Blue-whiting
Northern-ICES
Frequency
Steepness
0 400 800 1200
0.0 0.2 0.4 0.6 0.8 1.0
0.38 0.42 0.46 0.50
0 200 600
0.6 0.7 0.8 0.9 1.0
0.93 0.95 0.97 0.99
0 500 1500
0.85 0.90 0.95 1.00
0 200 400 600
0.4 0.5 0.6 0.7 0.8 0.9 1.0
0.2 0.4 0.6 0.8 1.0
0 400 800
0.5 0.6 0.7 0.8 0.9 1.0
0 500 1000

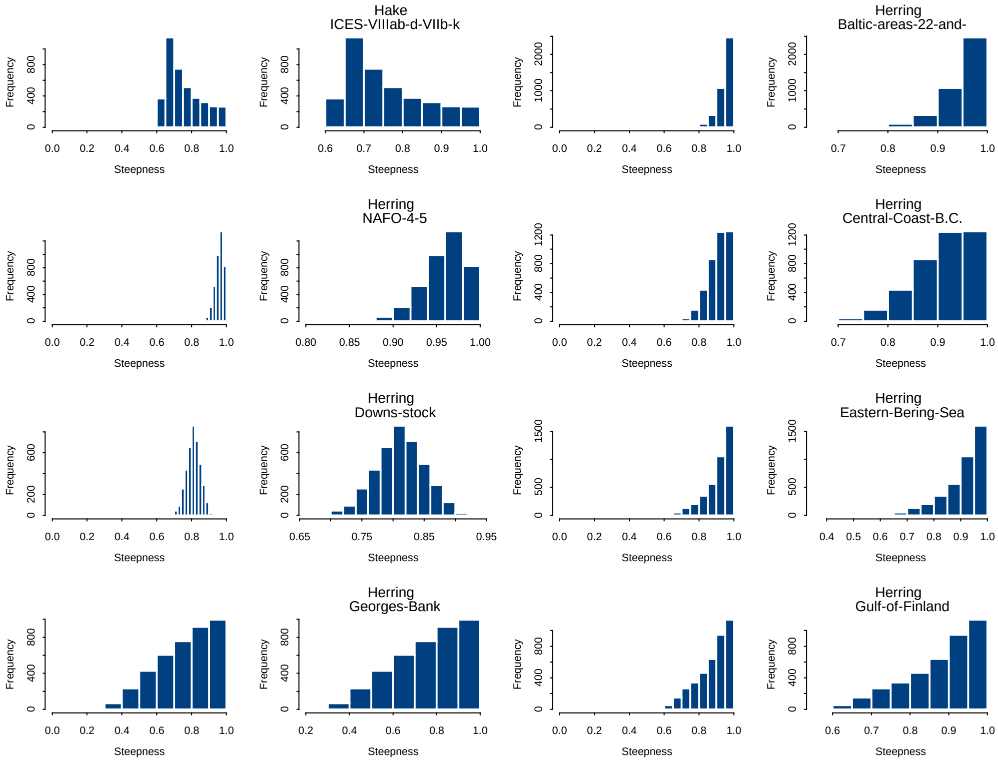

Blue-whiting
Southern-ICES
Capelin
Barents-Sea
Chub-mackerel
Southern-California
Chub-mackerel
Pacific-Coast-of-Jap
Cod
West-Greenland-(NAFO
Cod
NAFO-2J3KL
Cod
Flemish-Cap-(NAFO-Di
Cod
NAFO-3NO
Frequency
Steepness
0 100 300
0.0 0.2 0.4 0.6 0.8 1.0
0.75 0.80 0.85 0.90 0.95 1.00
0 200 600
0.70 0.80 0.90 1.00
0 200 400
0.4 0.6 0.8 1.0
0 400 800
0.4 0.5 0.6 0.7 0.8 0.9 1.0
0.6 0.7 0.8 0.9 1.0
0.7 0.8 0.9 1.0
0 200 600
0.5 0.6 0.7 0.8 0.9 1.0
0 200 400
0.70 0.80 0.90 1.00

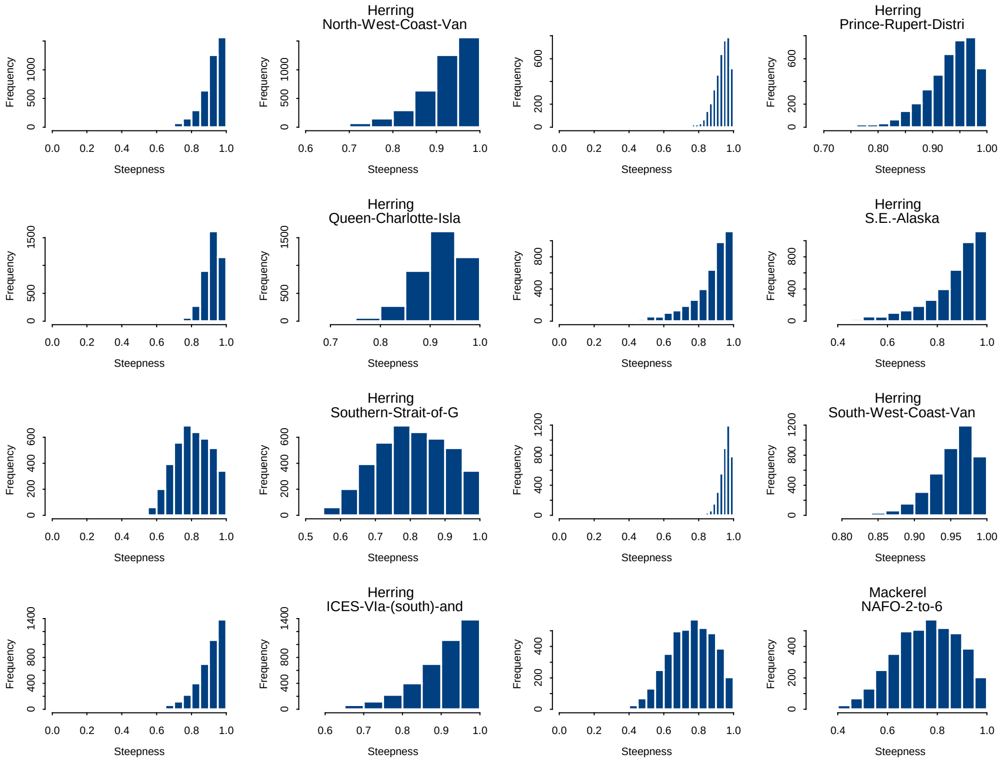

Cod
NAFO-3Pn4RS
Cod
NAFO-3Ps
Cod
NAFO-4TVn
Cod
NAFO-4VsW
Cod
NAFO-4X
Cod
NAFO-5Z
Cod
Baltic-Areas-22-and-
Cod
Baltic-Areas-25-32
Frequency
Steepness
0.0
0.2
0.4
0.6
0.8
1.0
0.5
0.7
0.9
0.75
0.80
0.85
0.90
0.95
1.00
0.88
0.92
0.96
0.70
0
200
400
500
600
800
1000
1500

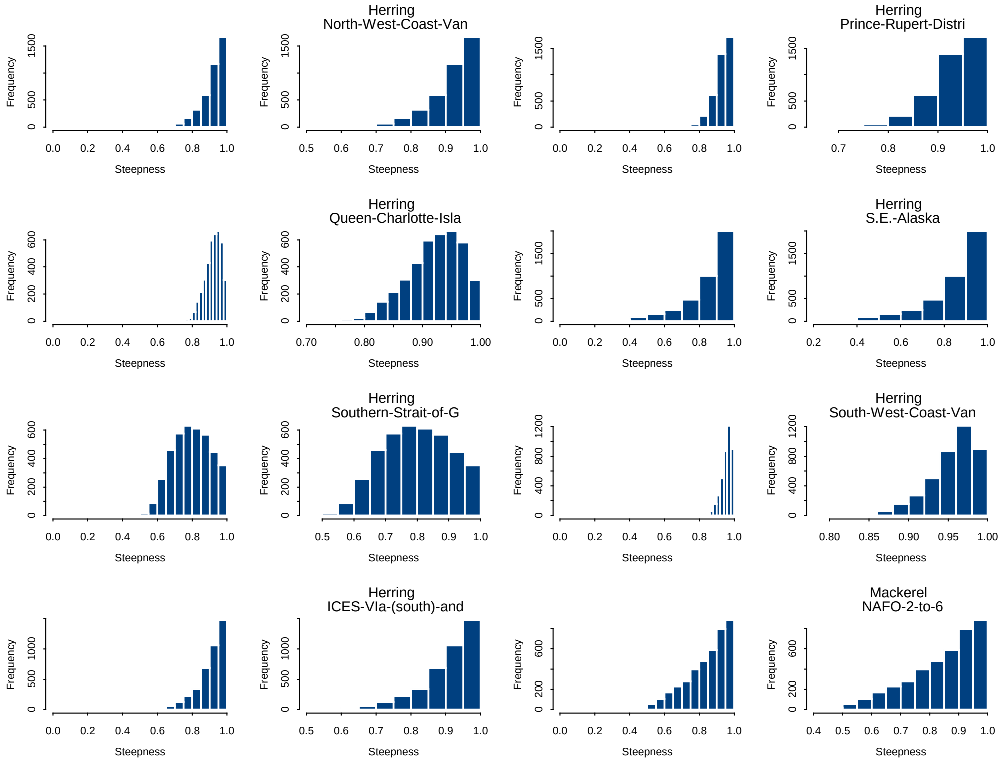

Cod
Celtic-Sea
Cod
Faroe-Plateau
Cod
Greenland-offshore-c
Cod
Iceland
Cod
Irish-Sea
Cod
Kattegat
Cod
North-East-Arctic
Cod
North-Sea
Frequency
Steepness
0.0
0.2
0.4
0.6
0.8
1.0
0.70
0.75
0.80
0.85
0.88
0.90
0.92
0.95
0.96
1.00
0
200
400
600
800

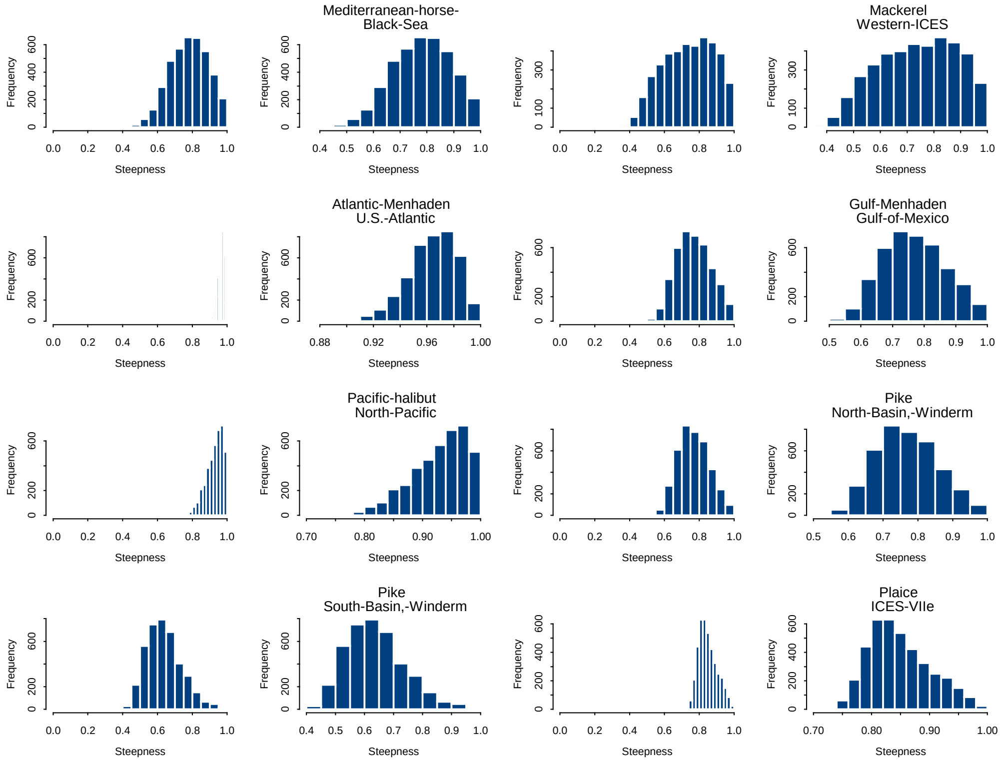

Cod
Skagerrak
Cod
ICES-VIa
Cod
ICES-VIId
Flounder
Baltic-Areas-24-and-
Greenland-halibut
North-East-Arctic
Greenland-halibut
Northwest-Atlantic
Greenland-halibut
ICES-V-and-XIV
Gold-spotted-grenadi
Northwest-coast-of-I
Frequency
Steepness

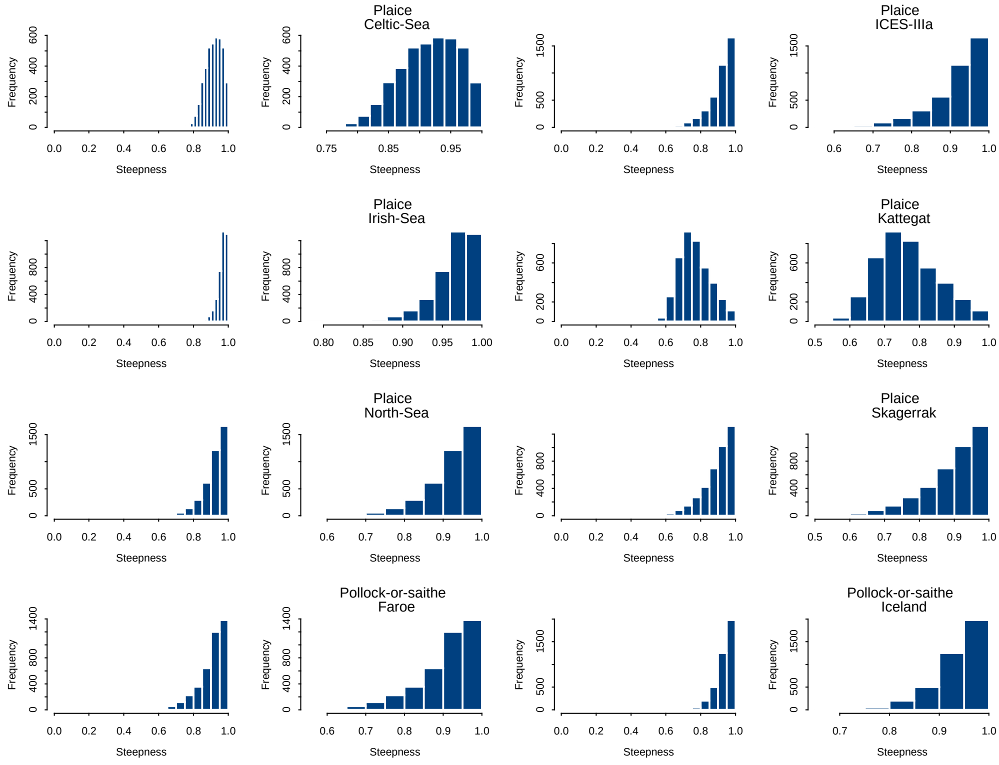

Hake
ICES-VIIIab-d-VIIb-k
Herring
Baltic-areas-22-and-
Herring
NAFO-4-5
Herring
Central-Coast-B.C.
Herring
Downs-stock
Herring
Eastern-Bering-Sea
Herring
Georges-Bank
Herring
Gulf-of-Finland
Frequency
Steepness

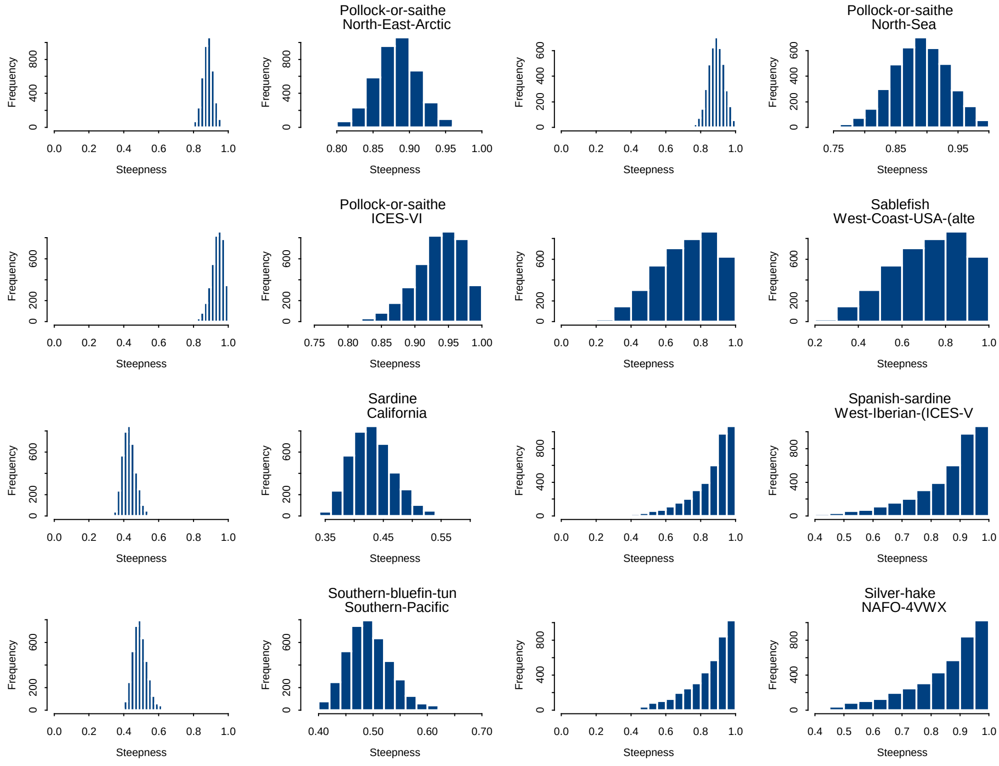

Hake
ICES-VIIIab-d-VIIb-k
Herring
Baltic-areas-22-and-
Herring
NAFO-4-5
Herring
Central-Coast-B.C.
Herring
Downs-stock
Herring
Eastern-Bering-Sea
Herring
Georges-Bank
Herring
Gulf-of-Finland
Frequency
Steepness

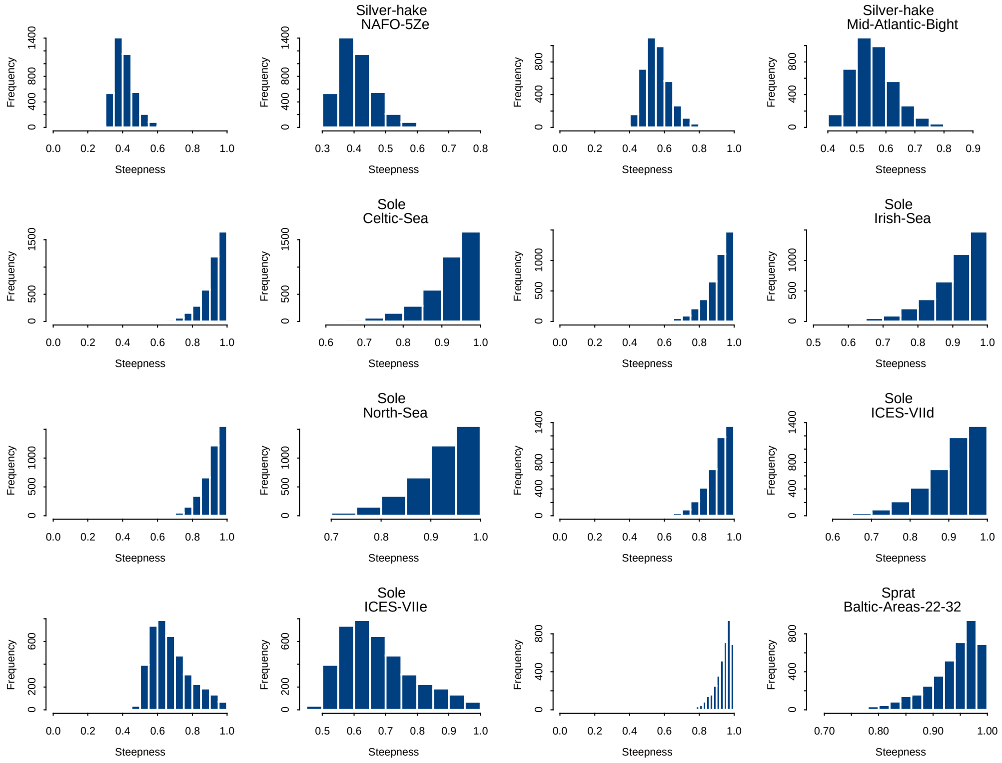

Herring
North-West-Coast-Van
Herring
Prince-Rupert-Distri
Herring
Queen-Charlotte-Isla
Herring
S.E.-Alaska
Herring
Southern-Strait-of-G
Herring
South-West-Coast-Van
Herring
ICES-VIa-(south)-and
Mackerel
NAFO-2-to-6
Frequency
Steepness

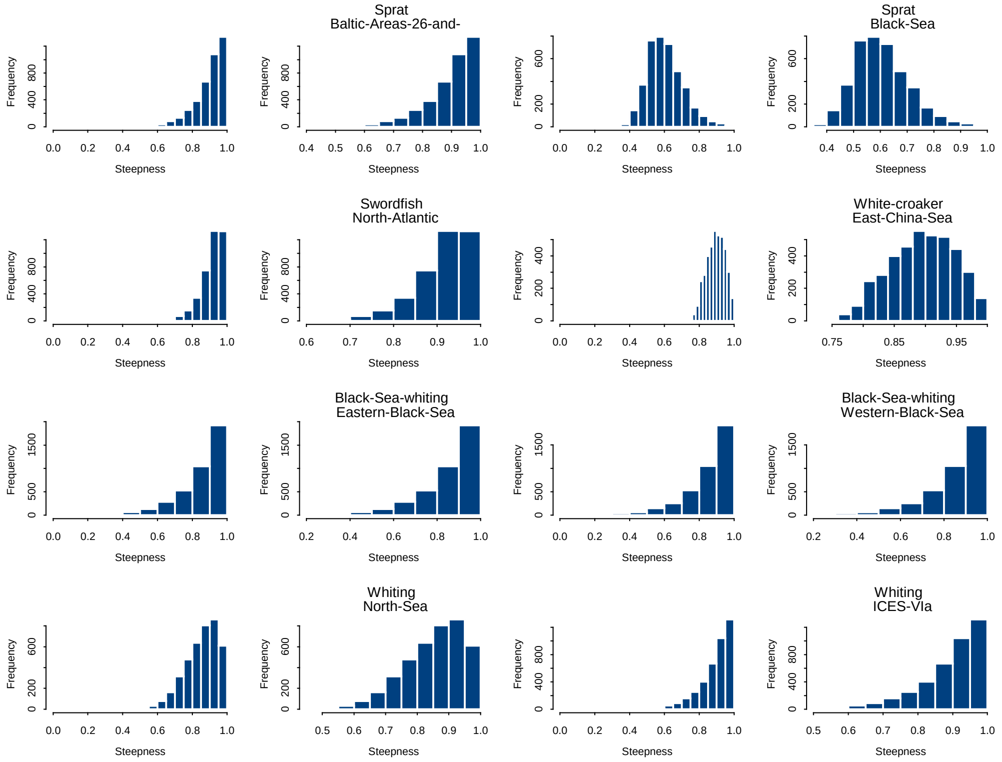

Herring
North-West-Coast-Van
Herring
Prince-Rupert-Distri
Herring
Queen-Charlotte-Isla
Herring
S.E.-Alaska
Herring
Southern-Strait-of-G
Herring
South-West-Coast-Van
Herring
ICES-VIa-(south)-and
Mackerel
NAFO-2-to-6
Frequency
Steepness

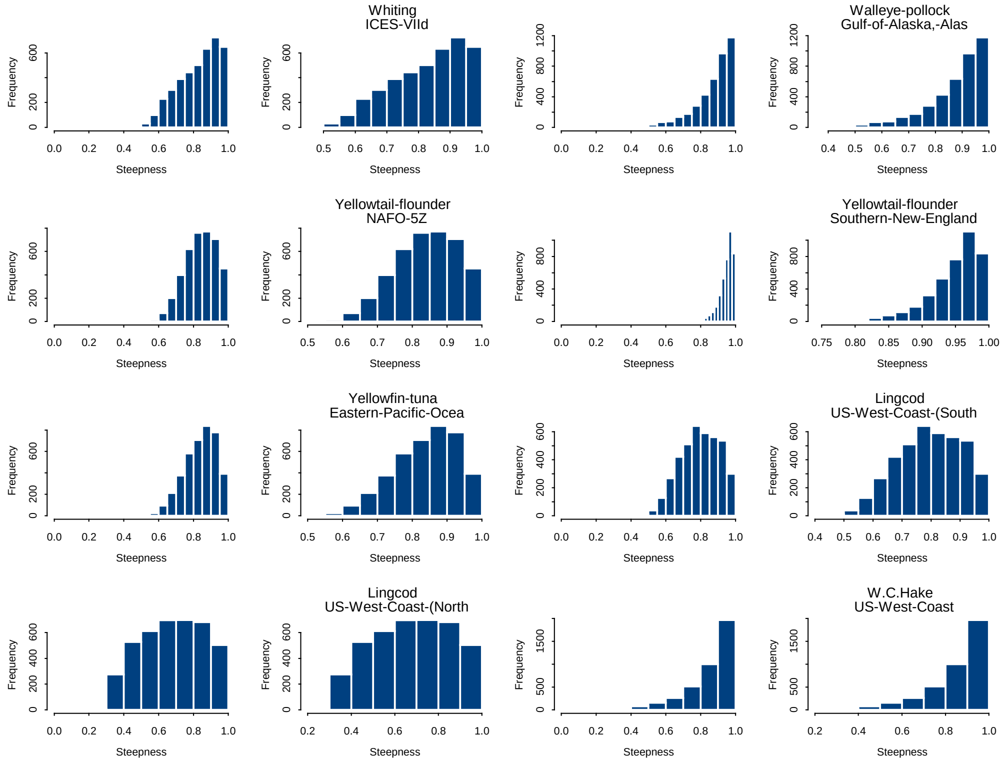

Mediterranean-horse-
Black-Sea
Mackerel
Western-ICES
Atlantic-Menhaden
U.S.-Atlantic
Gulf-Menhaden
Gulf-of-Mexico
Pacific-halibut
North-Pacific
Pike
North-Basin,-Winderm
Pike
South-Basin,-Winderm
Plaice
ICES-VIIe
Frequency
Steepness


Plaice
Celtic-Sea
Plaice
ICES-IIIa
Plaice
Irish-Sea
Plaice
Kattegat
Plaice
North-Sea
Plaice
Skagerrak
Pollock-or-saithe
Faroe
Pollock-or-saithe
Iceland
Frequency
Steepness
0.0
0.2
0.4
0.6
0.8
1.0
0.75
0.85
0.95
0.80
0.90
0.5
0.7
0.9
0
200
400
600
800
500
1400
1500


Pollock-or-saithe
North-East-Arctic
Pollock-or-saithe
North-Sea
Pollock-or-saithe
ICES-VI
Sablefish
West-Coast-USA-(alte
Sardine
California
Spanish-sardine
West-Iberian-(ICES-V
Southern-bluefin-tun
Southern-Pacific
Silver-hake
NAFO-4VWX
Frequency
Steepness
0.0
0.2
0.4
0.6
0.8
1.0
0.75
0.80
0.85
0.90
0.95
1.00
0.35
0.45
0.55
0.40
0.50
0.60
0.70
0
200
400
600
800


Silver-hake NAFO-5Ze
Silver-hake Mid-Atlantic-Bight
Sole Celtic-Sea
Sole Irish-Sea
Sole North-Sea
Sole ICES-VIId
Sole ICES-VIIe
Sprat Baltic-Areas-22-32
Frequency
Steepness


Sprat Baltic-Areas-26-and-
Sprat Black-Sea
Swordfish North-Atlantic
White-croaker East-China-Sea
Black-Sea-whiting Eastern-Black-Sea
Black-Sea-whiting Western-Black-Sea
Whiting North-Sea
Whiting ICES-VIa
Frequency
Steepness


Whiting
ICES-VIId
Walleye-pollock
Gulf-of-Alaska,-Alas
Yellowtail-flounder
NAFO-5Z
Yellowtail-flounder
Southern-New-England
Yellowfin-tuna
Eastern-Pacific-Ocea
Lingcod
US-West-Coast-(South
Lingcod
US-West-Coast-(North
W.C.Hake
US-West-Coast
Frequency
Steepness

Chapter 4: Data for the Example Application of the Model

Introduction

The example application of the approach to stock assessment that allows 'data-poor' species to obtain information from 'data-rich' species is based on seven species (blue grenadier, gemfish, pink ling, spotted warehou, mirror dory, king dory, and offshore ocean perch). Gemfish has been divided into two stocks (eastern and western) for assessment and management purposes (Rowling, 1994) so the example application is based on a total of eight stocks.

The data available for assessment purposes for these eight stocks include catches, discard rates, length-frequencies and age-compositions by fleet and stock, values for biological parameters, and survey estimates of the spawning biomass of blue grenadier in 1994 and 1995. The following sections outline the details of each source of data.

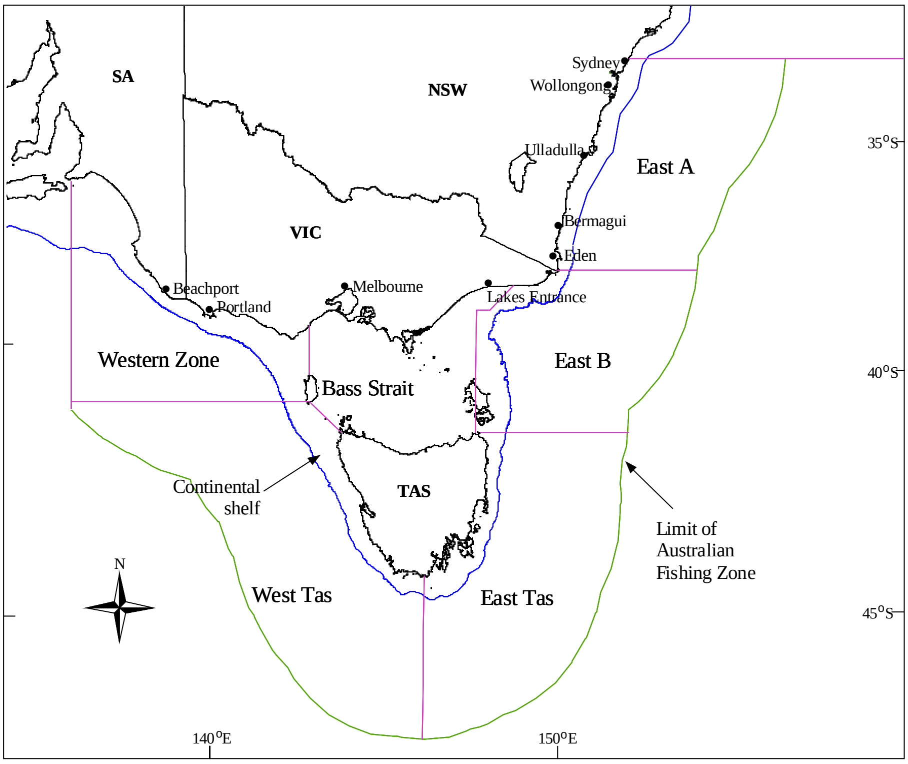


Figure 37. Map of southern Australia highlighting the various zones considered in the analyses of this chapter.

Selection of fleets

The process of selecting 'fleets' when conducting assessments involves a balance between selecting a large number of 'fleets' to adequately capture the behaviour of fishers and a small number of 'fleets' to avoid having very few data for each of the fleets. The fleets considered in the example application include one non-trawl fleet and four trawl fleets. The four trawl fleets are based on dividing the fishery into eastern and western sectors (East A, East B, East Tas, zones 10, 20 and 30, and West Tas, Western Zone, zones 40 and 50 of the SESSF (Figure 37) respectively). This split is needed to separate the fisheries for eastern and western gemfish. The fishery is then further divided into winter (June-August) and non-winter fisheries in the eastern sector, the winter fishery off western Tasmania, and the remainder of the fishery in the western sector. The split of the fishery in the eastern sector is needed to separate out the fishery that targeted primarily eastern gemfish during their winter spawning migration from the fishery that targeted non-spawning gemfish. This split is needed because the length-composition of the catches during the spawning and non-spawning fisheries differ markedly (Punt *et al*., 2000). The split of the fishery in the western sector allows the winter fishery for spawning blue grenadier to be treated as a separate fishery. The trawl fleets are assigned numbers as follows:

1) eastern sector; non-winter fishery;
2) eastern sector; winter (June-August) fishery;
3) western sector; all catches in zone 50 and non-winter catches in zone 40; and
4) western sector; winter (June-August) fishery in zone 40.

Table 19 lists the catches (aggregated over the years 1986–2002) for 13 ‘major stocks’ and fleets (values in italics) and the fraction of the catch of each stock / fleet by each of these 13 ‘major stocks’ / fleets. ‘Major stocks’ / fleets are defined here to be those combinations of stock and fleet for which sufficient data are likely to be available on which to base a catch-rate index of relative abundance. The ‘27.5’ under gemfish in the row for ‘blue grenadier / fleet 1’ implies that 27.5% of the gemfish catch in the eastern sector in the non-winter period was caught in shots that also caught blue grenadier. There are several large numbers in Table 19. For example:

- King dory is caught predominantly in shots that also caught blue grenadier and pink ling.
- Ocean perch off western Tasmania is caught in winter predominantly in shots that also caught blue grenadier while in the eastern sector, they are caught in shots that also caught pink ling.
- Spotted warehou off western Tasmania is caught in winter predominantly in shots that also caught blue grenadier.
- Blue grenadier is caught predominantly with pink ling in the eastern sector in winter.

Catches

Information on catches is available from the SEF1 and GNO1 databases (which provide the raw logbook information for the trawl and non-trawl sectors), the SEF2 and SAN2 databases (which contain the vertified landings records for the trawl and non-trawl sectors), and from historical records (for the years prior to 1986 (trawl) and 1997 (non-trawl) – data are available for 1985 in the SEF1 database but these data are incomplete).

Total annual catches

The total catches for the trawl and non-trawl sectors are based on a variety of data sources. The time-series of trawl catches by species are constructed as follows:

a Blue grenadier:

1979–83: The catches reported by Smith (1994) multiplied the ratio of the total SEF2 catch over 1993–98 to the total SEF1 catch over 1993–98 (1.05).

1984–2001: The estimated total catch within the SEF area based on the Fishery Assessment Report (1984–89: Verified catch history; 1990–91: SEF1 data; 1992–2001: SEF2 data).

2002: The SEF2 catch extracted from the SEF2 database.

b Eastern Gemfish

1968–2000: The values agreed to by the Eastern Gemfish Assessment Group (Punt *et al*., 2000).

2001: The estimated total catch within the SEF area based on the Fishery Assessment Report (SEF2 data).

2002: The 2002 SEF2 catch for all gemfish (195.9t) split between eastern and western gemfish based on the SEF1 catches.

c Western Gemfish

1979–84: The catches recorded in Victorian logbooks as having been taken from South Australia, western Bass Strait and western Tasmania during 1978–85 rescaled so that the catch for 1985 equals that for 1986.

1985: Assumed equal to the catch for 1986.

1986–91: The SEF1 catches multiplied by the ratio of the SEF2 catch for 1993–98 to the SEF1 catch for 1993–98 (1.44 – this is, as expected, slightly larger than the loss rate due to heading and gutting of 1.3).

1992–2001: The estimated total catch within the SEF area based on the Fishery Assessment Report (SEF2 data).

2002: The 2002 SEF2 catch for all gemfish (195.9t) split between eastern and western gemfish based on the SEF1 catches.

d Pink Ling

1976–83: The catches reported by Tilzey (1994) multiplied the ratio of the total SEF2 catch over 1993–98 to the total SEF1 catch over 1993–98 (1.49).

1984–2001: The estimated total catch within the SEF area based on the Fishery Assessment Report (1984–89: Verified catch history; 1990–91: SEF1 data; 1992–2001: SEF2 data).

2002: The SEF2 catch extracted from the SEF2 database.

e Spotted warehou

1979–85: Linear increase in catch from 0 in 1979 to the 1986 catch in 1986.

1986–2001: The estimated total catch within the SEF area based on the Fishery Assessment Report (1986–89: Verified catch history; 1990–91: SEF1 data; 1992–2001: SEF2 data).

2002: The SEF2 catch extracted from the SEF2 database.

f Mirror Dory

1971–2001: The estimated total catch within the SEF area based on the Fishery Assessment Report (1971–83: NSW State catches; 1984–89: Verified catch history; 1990–91: SEF1 data; 1992–2001: SEF2 data).

2002: The SEF2 catch extracted from the SEF2 database.

g Offshore Ocean Perch

1977–2001: The estimated total catch within the SEF area based on the Fishery Assessment Report (1977–83: NSW State catches; 1984–89: Verified catch history; 1990–91: SEF1 data; 1992–2001: SEF2 data).

2002: The SEF2 catch extracted from the SEF2 database.

h King dory

1979–84: the catches of king dory recorded in Victorian logbooks as having been taken from South Australia, western Bass Strait and western Tasmania during 1978–85 rescaled so that the catch for 1985 equals that for 1986. The estimates of the annual catch of king dory from 1979–84 was estimated by the sum of the catches recorded as king dory, silver dory and unspecified dory less 12t. The reason for estimating king dory catches this way is that silver dory is an inshore species with low catches in recent years (an average of 12t over 1986–93) but fairly substantial catches of silver dory are recorded in Victorian logbooks (e.g. 63t in 1981). It is assumed here that some king dory catches were mis-recorded as silver dory and the subtraction of 12t is to account for the 'real' catch of silver dory.

1985: Assumed equal to the catch for 1986.

1986–2002: the SEF1 catches extracted from the SEF1 database (the SEF2 catches for king dory appear unreliable – in some years the reported SEF2 catch is less than 1% of the SEF1 catch).

The time-series of non-trawl catches by species are constructed as follows:

a Pink ling

1977–96: Thomson *et al*. (2001).

1997–2002: GN01 logbooks.

b Spotted warehou

1986–96: Blue Warehou Assessment Group (pers. commn).

1997–2002: GN01 logbooks.

It is necessary to split the trawl catches among each of the four trawl fleets. For the years after 1985, the split is based on the records in the SEF1 database except for blue grenadier. For blue grenadier, the SEF1 catches are reported as processed rather than as whole weight (the SEF2 catches are in whole weight). Therefore, when splitting the total trawl catches of blue grenadier to fleet, the SEF1 catches are first multiplied by conversion factors. These conversion factors are 1.4 for fleets 1–3 (all years), 1.2 for fleet 4 (1986–98), and 1.1 for fleet 4 (1999–2002) (Chesson and Staples, 1995; D.C. Smith, MAFRI, pers. commn). The lower factors for fleet 4 reflect a higher proportion of the catch landed whole (particularly in recent years). The catches prior to 1986 are split to fleets based on the split of the total catch over 1993–98.

Table 20 and Figure 38 list the total catches (trawl and non-trawl) by year while Table 21 lists the trawl catches by fleet and year.

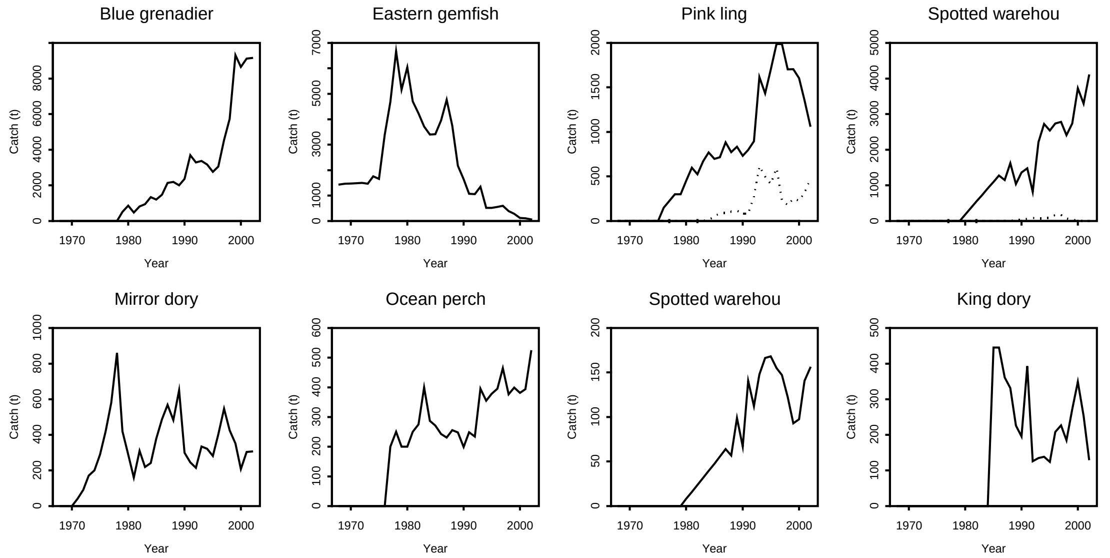


Figure 38. Total catches (trawl – solid lines and non-trawl – dotted lines) by year for the eight stocks considered in the analyses of this report.

Discard rates

Information on the fraction of the catch (in weight) of each species by each trawl fleet which is discarded annually is available from onboard observers (discards by the non-trawl fleet are assumed to be negligible). Two observer programmes, the SMP (Liggins *et al.*, 1997) and the ISMP (Knuckey *et al.*, 1999) have collected onboard data which can be used to estimate discard rates. The data collected by observers are estimates by shot of the weight retained and the weight discarded. The discard rate is simply the ratio of the weight discarded (summed over all shots by a given fleet in a given year) to the total weight (retained and discarded). The data were validated by excluding any records for which the gear code was not bottom or midwater trawl, and in which the catch did not occur in one of SESSF zones 10, 20, 30, 40 and 50. Discard rates for combinations of fleet and year for which there are not at least 20 data points are ignored when fitting the model. The discard rates used when fitting the model are listed (by year, stock and fleet) in Table 22(a). The precision of the discard rate estimates, expressed as coefficients of variation (Table 22b) were obtained by bootstrapping. For each combination of fleet, year and stock, 1,000 pseudo data sets were generated by resampling shots at random, and with replacement, from the actual observer data for the fleet, year and stock under consideration. The sample size for each pseudo data set is assumed to be the same as the actual sample size.

The discard rate estimates for fleet 4 and for the years 1993–95 tend to be very imprecise. This is due primarily to low sample sizes.

Catch-rates

Catch-rate data constitute the primary source of information to determine trends in population size for the species in the SESS. However, the catch and effort data need to be standardized to (attempt to) eliminate the impact of factors other than changes in abundance on trends in catch-rates (Gavaris, 1980; Kimura, 1981; Vignaux, 1994). Catch-rate indices were developed for a total of fourteen fleets (two series for one fleet for eastern gemfish, two fleets for blue grenadier, four fleets for spotted warehou, four fleets for pink ling, one fleet for western gemfish, and one fleet for mirror dory – see Table 23). One of the standardized catch-rate series for eastern gemfish was that used by the Eastern Gemfish Assessment Group (EGAG) (Punt *et al.*, 2000) and is not discussed further here. Ideally, catch-rate series should be developed for each combination of species and fleet. However, lack of data for some of these combinations (see, for example, the criteria used to select vessels) precludes this.

The catch-effort standardization exercise involved fitting a linear model (with normal error structure) to relate log-transformed catch-rate data to the factors that influence catch-rates. This approach has been used widely to standardize catch and effort data for SESSF species (e.g. Klaer, 1994, 2004; Punt *et al.*, 2001a; Haddon, 2002a, 2002b). Any shots in which the catch was zero were excluded as were any shots not in SESSF zones 10–50, shots for which the recorded effort is zero, and shots for which depth or zone were missing. Prior to fitting the linear models for each fleet and stock, subsets of the catch and effort data were extracted so that the analysis was based on data for those vessels which are likely to have been targeting the stock concerned. The criteria applied to define the vessels that ‘target’ each stock are:

- Blue grenadier: catch and effort data for at least three years and a median annual catch (over all years for which catch data are reported) of at least 5t.
- Spotted warehou: catch and effort data for at least three years and a median annual catch of at least 4t.
- Pink ling: catch and effort data for at least three years and a median annual catch of at least 4t.
- Eastern and western gemfish: catch and effort data for at least two years and a median annual catch of at least 2t.
- Mirror dory: catch and effort data for at least three years and a median annual catch of at least 4t.

These criteria were applied by fleet (rather than for all fleets combined). Table 24 lists the number of records by fleet and stock for which zone is 10–50 and the number of records selected for use in the various catch-effort standardizations. The difference between the total number of records for a year and the number actually used relate to records with zero catch or effort, records for which depth is missing and records for vessels that do not satisfy the criteria listed above.

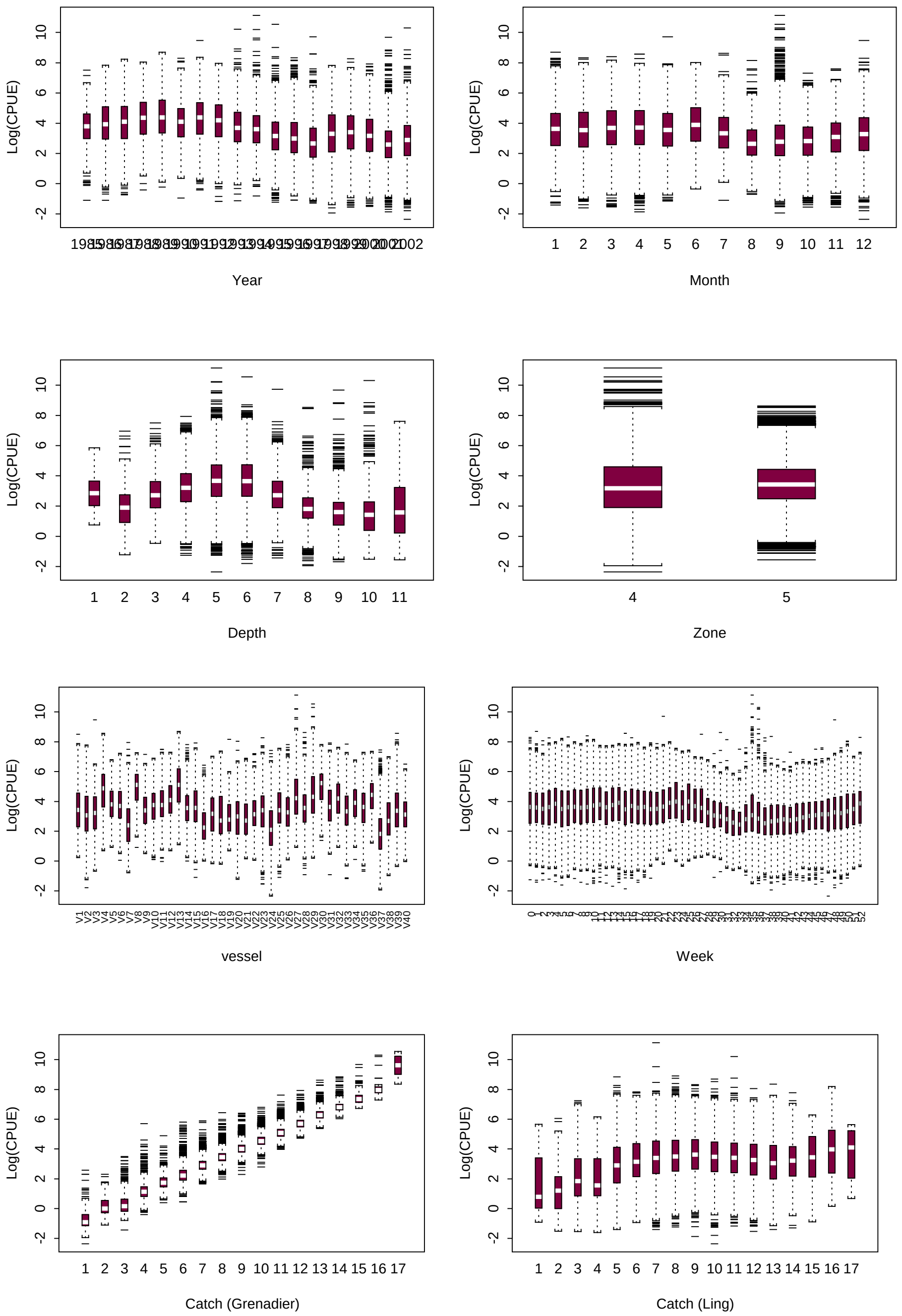


Figure 39. Box and whisker plots examining the relationship between the catch-rate of blue grenadier in zone 50 and zone 40 in September-May (fleet 3) and various potential explanatory variables.

The proportion of zero shots for the vessels selected using the above criteria and for which depth is available ranges from 28% (blue grenadier in winter in zone 40) to >70% (the two summer fisheries for spotted warehou). There are trends in the proportion of zero shots for several of the fleet / species combinations. The most marked of these is for the spawning season fishery for blue grenadier where the proportion of zero shots by the selected vessels declines from ~45% in 1985-7 to 15% in 2000-2. It is difficult to interpret changes in the proportion of zero shots as vessels in the SESSF exhibit complex targeting strategies which cannot be resolved from the data collected in logbooks.

The linear models fitted to the catch and effort data include the following factors:

- Year.
- Month.
- Zone.
- Depth: The depth recorded for the trawl assigned to categories based on 100m depth intervals from 0-1000m and categories for 1000-2000m and 2000m+.
- Vessel: An individual factor for each vessel. Vessel was defined by a unique callsign in the SEF1 database.
- Week. Week is defined as the integer part of the Julian day of the year (ignoring leap years) divided by seven. Week cannot be included in models in which month is treated as a factor.
- Covariate species catch. The catch of species (other than that of interest) can be included as a covariate in the analysis. Rather than attempting to develop a functional relationship between the catch-rate of the species of interest and that of each covariate species, the catch of the covariate species is divided into 20 intervals based on the logarithm of the catch (and these intervals form the basis for a categorical variable).

Separate factors are estimated for each vessel rather than characterizing vessels by means of physical characteristics such as length, breadth and horsepower, because these physical factors do not account for differences among vessels in fishing practices (and other factors such as skipper and quota holdings).

The models chosen for each species and fleet are:

- Blue grenadier (abbreviation BG); fleet 3:
    - Year+Week+Zone+Depth+Vessel+Pink ling + Jackass morwong + Zone*Week
- Blue grenadier; fleet 4:
    - Year+Week+Depth+Vessel+Pink ling+Jackass morwong
- Spotted warehou (abbreviation SW); fleets 1-3:
    - Year+Week+Zone+Depth+Vessel + Pink ling + Jackass morwong + Zone*Week
- Spotted warehou; fleet 4:
    - Year+Week+Depth+Vessel+Pink ling+Jackass morwong
- Pink ling (abbreviation PL); fleets 1-3:
    - Year+Month+Depth+Vessel+Zone*Vessel+Month*Depth
- Pink ling: fleet 4:
    - Year+Month+Depth+Vessel+ Month*Depth
- Eastern gemfish (abbreviation GF); fleet 2:
    - Year+Month+Depth+Vessel+Zone
- Western gemfish; fleet 3:
    - Year+Month+Depth+Vessel+Zone
- Mirror dory (abbreviation MD); fleet 2:
    - Year+Month+Depth+Vessel+Zone + Eastern gemfish

The choice of factors to include in each model was based on previous analyses by SEFAG (e.g. Haddon, 2002a, 2000b).

It is beyond the scope of this project to conduct a detailed analysis including model selection and regression diagnostics for each of the thirteen catch-effort standardizations. However, diagnostic plots (e.g. Figures 39 and 40) were developed to allow practioners to examine the relationship between catch-rate and a variety of potential explanatory variables and whether the specific regression model provides an adequate fit to the data (in the sense of lack of model mis-specification and homoscedascity).

The standardized catch-rate indices used in the analyses are listed in Table 23 and displayed in Figure 41. Figure 41 provides the geometric mean catch rates (dotted lines) as well as the standardized catch-rate indices (solid lines) to allow the impact of standardizing the catch and effort data to be examined. The trend in standardized catch-rate will differ from that of the geometric mean catch-rate if some of the factors in the analysis have changed over time (e.g. changes in the composition of the fleet), while the average absolute value of the standardized catch-rate series may differ from that of the geometric mean catch-rate series depending on the vessel, week, etc. chosen as the standard factors for the analysis. Catch-rates are treated as relative indices of abundance in assessments, so their scale is irrelevant from the viewpoint of the results of an assessment.

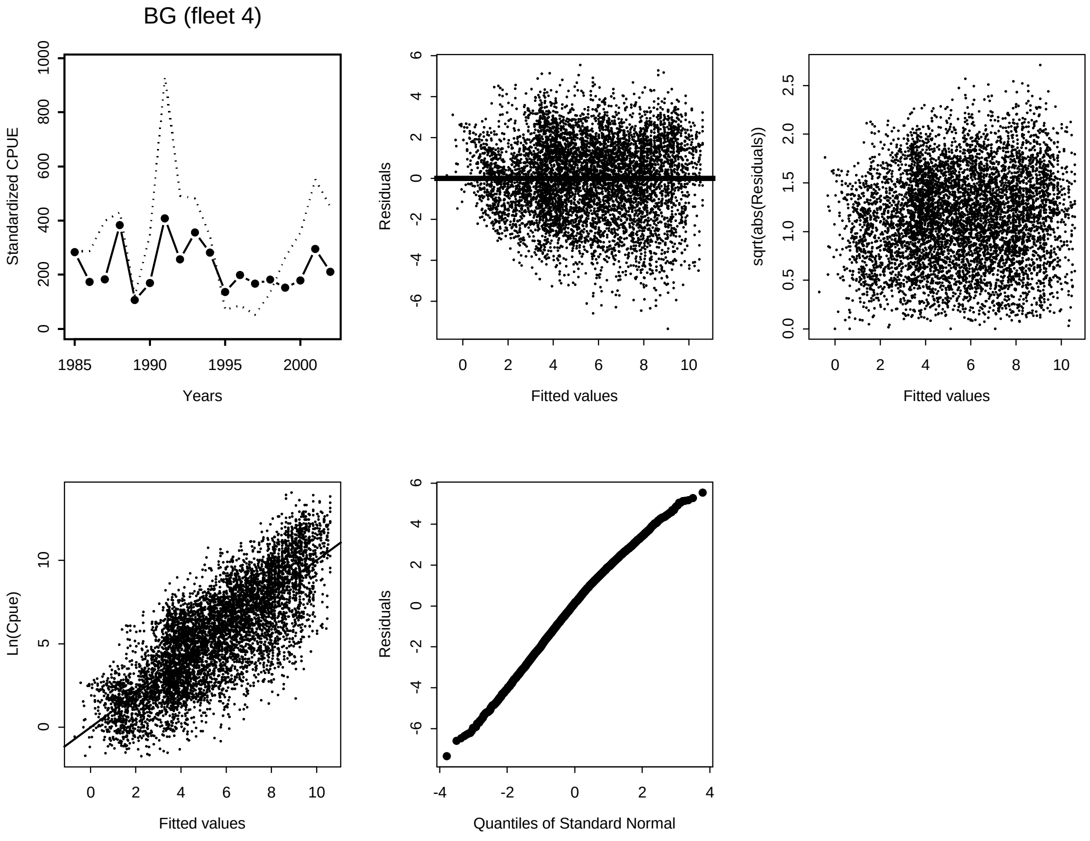


Figure 40. Diagnostic plots for the standardization of the catch and effort data for blue grenadier off the west coast of Tasmania (zone 40) in winter (fleet 4).

The solid line in the upper left panel is the standardized catch-rate index and the dotted line is the geometric mean catch rate.

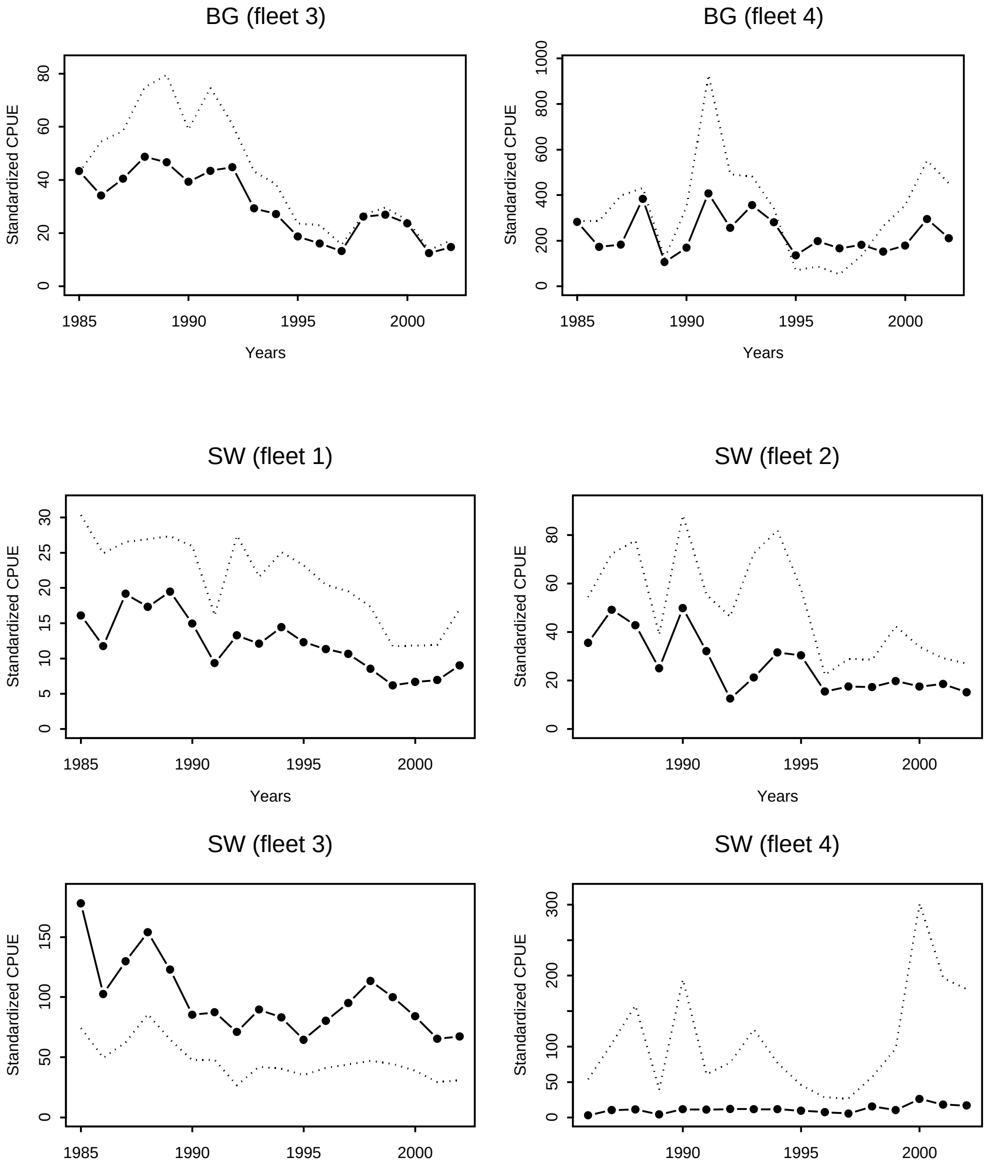


Figure 41. Time-trajectories of standardized catch-rate.

The solid lines are the standardized catch-rate indices and the dotted lines are the geometric mean catch rates.

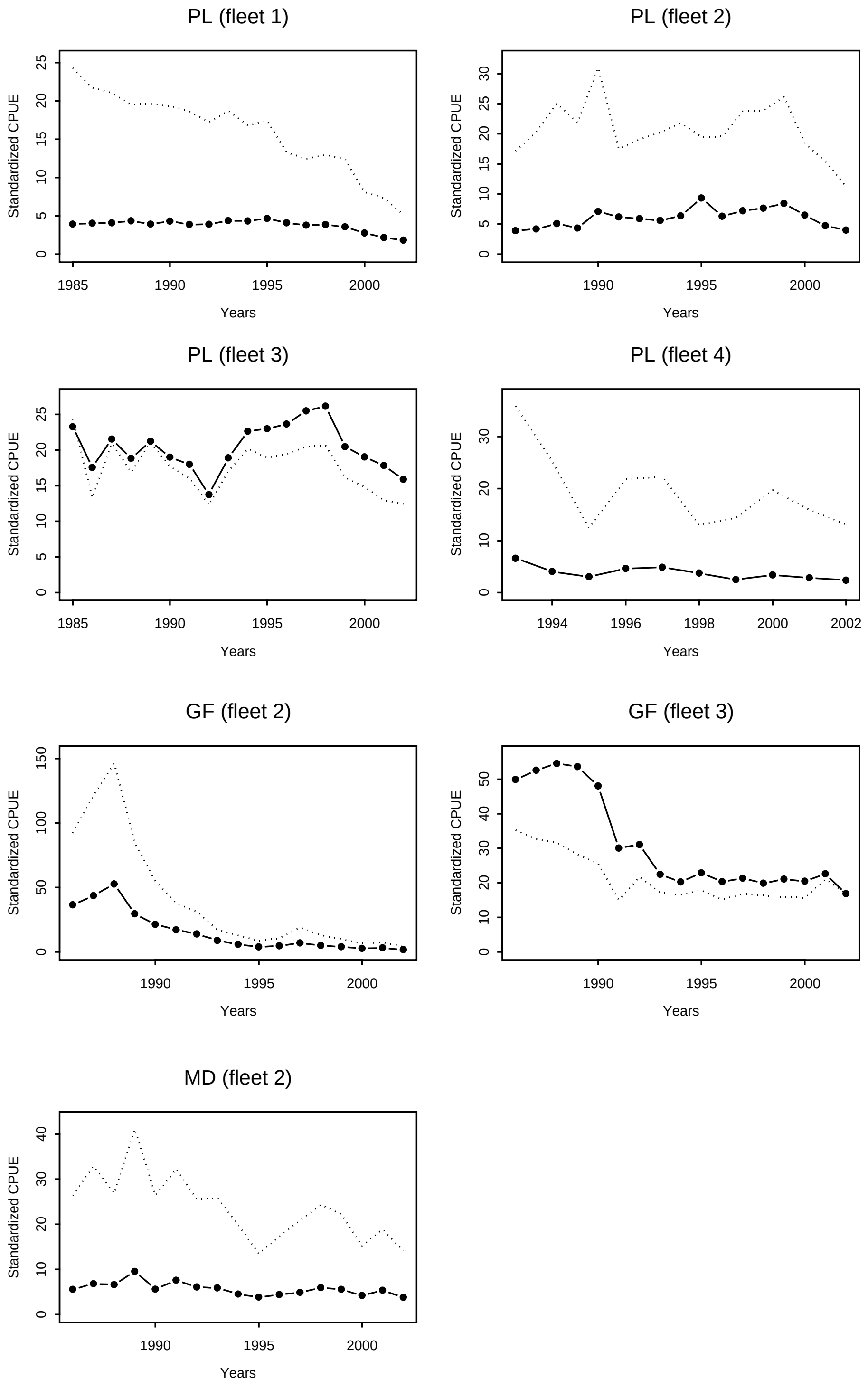


Figure 42 (continued)Time-trajectories of standardized catch-rate.

The solid lines are the standardized catch-rate indices and the dotted lines are the geometric mean catch rates.

Length-frequency information

Length frequency data are available from port measurers and from onboard sampling. The former generally involve much larger sample sizes than the latter so the length-frequencies used when fitting the model and when constructing catch age-compositions are based on the port length measurements only. The onboard sampling programmes provide information on the length-frequencies of the discarded as well as the landed catch and so are used to determine the probability of fish being discarded as a function of size (by fleet and stock).

Port-based length-frequencies

The data available to construct port-based length-frequencies can be divided into two types: (a) data available at the level of individual landings and (b) data already processed into length-frequencies for the entire catch from a particular area (i.e. cases in which the raw data appear to be no longer available). The sample sizes for the catch length-frequencies are listed in Table 25.

Length data are expressed using a variety of length measurements. Anne Gason and Sonia Talman (MAFRI) were consulted regarding valid length codes, and the equations to convert length measures used to report the catch length-frequencies to the standard length measurement for each species. Data recorded using length measurements that appeared invalid were discarded as were records for which zone was not 10–50 and gear-type was not otter trawl.

Given information on individual landings, the port length-frequencies for a given stock and fleet are constructed from the raw data collected by the measurers using the equation:

$$N_{y,L}^{s,f} = \sum_{v} \tilde{N}_{y,L}^{s,f,v} / R_{y}^{s,f,v} \tag{4.1}$$

where $N_{y,L}^{s,f}$ is the number of animals in the component of the landed catch of stock *s* by fleet *f* during year *y* that was measured that are in length-class *L*,

$\tilde{N}_{y,L}^{s,f,v}$ is the number of animals in the *v*th sample collected from the landed catch of stock *s* by fleet *f* during year *y* that are in length-class *L*, and

$R_{y}^{s,f,v}$ is the fraction of the catch of the *v*th sample collected from the landed catch of stock *s* by fleet *f* during year *y* that was measured.

This approach to constructing catch length-frequencies is based on the assumption that the samples for a given fleet and stock are a simple random sample of the catch of that fleet and stock. In principle, this approach to constructing length-frequencies could be generalized so that, for example, port-specific length-frequencies are constructed and these then weighted by the port-specific contribution to the overall catch. The data for the Sydney Fish Market and those collected during the SMP and ISMP are available as individual length measurements.

In the absence of the raw data, Equation 4.1 was not used to construct length-frequencies for:

1) Eastern gemfish (1975–2000) – the length-frequencies collected by port measurers in New South Wales (K. Rowling, pers. commn) were used instead.
2) Blue grenadier in the winter spawning fishery off Tasmania (1999–2002) – the length-frequencies collected by Sarah Russell on trawlers operating in the winter fishery off western Tasmania were used instead.
3) Blue grenadier (1987–89), pink ling (1987–88), king dory (1987–89), western gemfish (1987–88) – the length-frequencies collected by port measures at Beachport and Portland were combined to construct these length-frequencies (Smith *et al.*, 1995).
4) Blue grenadier (1984–85) – the length-frequencies were based on sampling off western Tasmania.

The data used when fitting the model were restricted to those combinations of year, fleet and species for which the number of fish measured was at least 200.

Discard length-frequencies

The proportion of the trawl catch that is discarded by length-class can be determined from the onboard length-frequency data. Equation 4.1 can be used to compute the numbers retained and discarded by length-class, species and fleet. The ratio of the numbers discarded to the numbers discarded and retained empirically defines the probability of discarding by length-class.

The discard length-frequencies were used to determine the values of the parameters of the function that relates the probability of a fish being discarded to length. This function was estimated by fitting a logistic curve to the empirical discard estimates by minimizing the function:

$$SS = \sum_f \sum_L \left(P_L^f - \left[1 + \exp\left\{ -\ell n 19 \frac{\bar{L}_L - \phi_{50}}{\phi_{95} - \phi_{50}} \right\} \right]^{-1} \right)^2 \qquad (4.2)$$

where $\bar{L}_L$ is the length corresponding to length-class *L*,

P_L^f is the empirical probability of fleet *f* discarding a fish of length *L*,

ϕ_{50} is the length-at-50%-retention, and

ϕ_{95} is the length-at-95%- retention.

The resultant fits are shown in Figure 42. The values for the parameters φ_{50} and φ_{95} for each stock are listed in Table 26. The fits are generally very good although there are some notable mis-fits (for example, spotted warehou for fleets 3 and 4). These mis-fits suggest that larger (generally marketable) fish are occasionally discarded.

Age-composition data

Age-length keys (generally sex-specific) are available for six of the seven species. The age-data are generally obtained from samples from the retained component of the catch. Table 27 lists the sample sizes for each stock and year. A total of 303 king dory otoliths have been aged but these data have not been used to construct age-length keys. The age-length keys were provided by the Central Aging Facility, except those for 1980–90 for eastern gemfish, which were provided by K. Rowling (NSW Fisheries).

Validation of the technique used for age determination has been achieved using the bomb radiocarbon method for blue grenadier (Kalish *et al.* 1997), pink ling (Kalish *et al.*, 2002a), and king dory (Kalish *et al.*, 2002b). Modal progression in the catch age-compostion data has been used to infer that the ageing techniques used for blue grenadier (Punt *et al.*, 2001a), eastern gemfish (this study) and spotted warehou (Thomson, 2003; Taylor and Smith, 2004) are able to determine the primary ages in the catch fairly reliably. Smith *et al.* (1995) were able to use modal progression to validate the ageing of western gemfish for ages 1-3. The ageing techniques for Ocean perch and mirror dory have not been validated.

Age-composition data (by stock, fleet and year) can be constructed by multiplying the (port) length-frequencies by the stock- and year-specific age-length keys (length-at-age is assumed to be independent of fleet). The assumption that length-at-age is independent of fleet will be invalid to some extent if selectivity is strongly size-dependent (Walker *et al.*, 1998) or if there is density-dependent growth (e.g. Punt and Smith, 2001).

There are cases in which length-frequency data exist for some length-classes for which age data are not available. When this happened, the length-classes adjacent to that for which age data were required were investigated and the age data for these length-classes averaged to obtain age data for the length-class for which this was needed. This process of searching adjacent length-classes was repeated if the length-classes adjacent to that for which age data were needed also had no age data and this process of an expanding search repeated until ageing data were obtained. Ages greater than 40 were pooled into a plus-group at age 40.

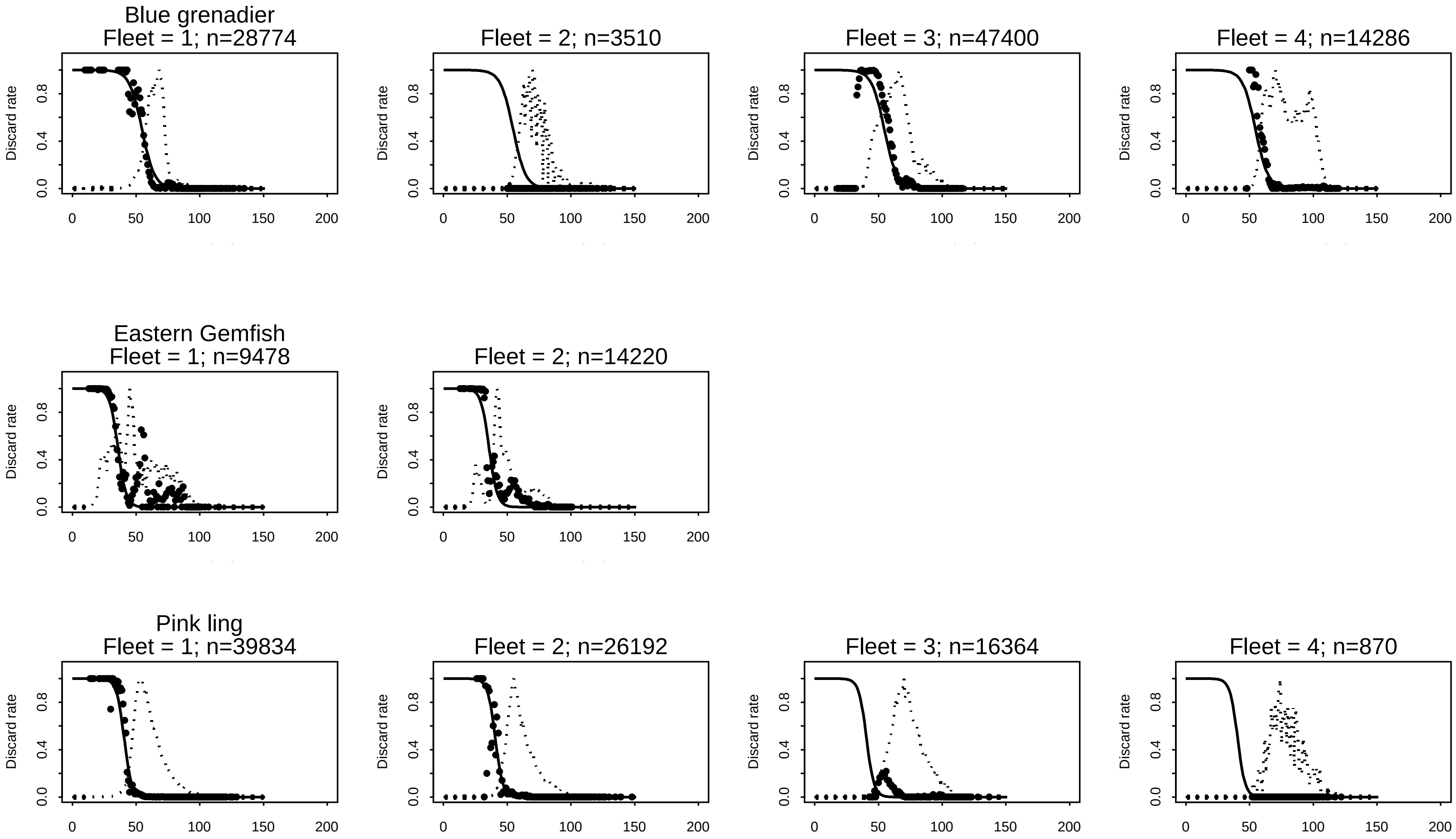


Figure 42. Fits of the logistic curve to the fraction of the catch discarded by fleet and stock.

The dotted line indicates the sample size for each length-class (relative to the sample size for the length-class with the largest sample).

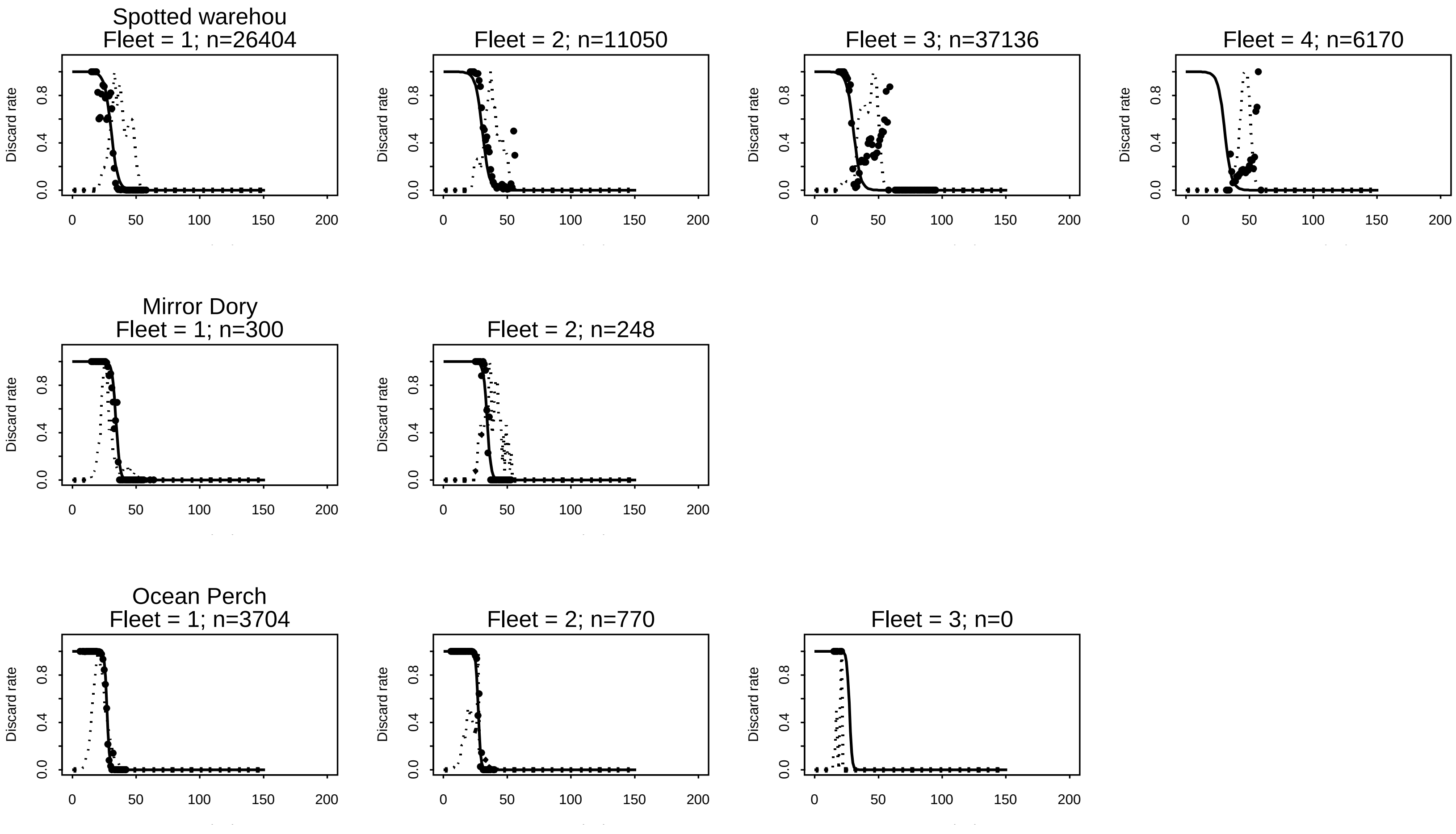


Figure 42 (Continued). **Fits of the logistic curve to the fraction of the catch discarded by fleet and stock.**

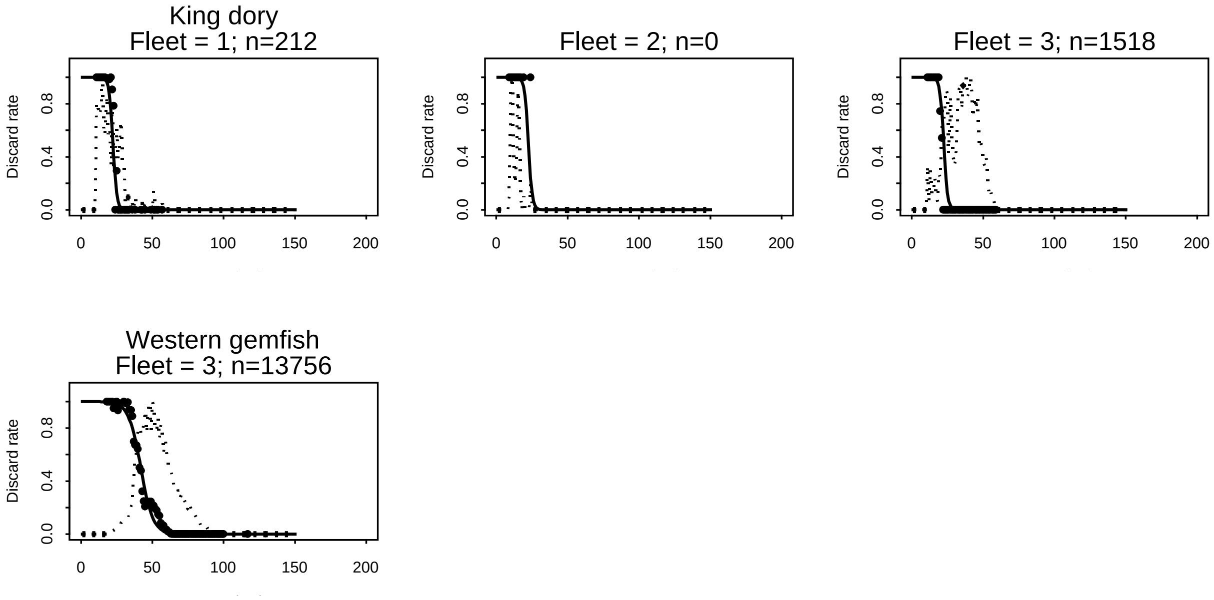


Figure 42 (continued) Fits of the logistic curve to the fraction of the catch discarded by fleet and stock.

The data included in the analyses of this report are restricted to combinations of year and stock for which the sample size on which the age-length key is based is at least 100 animals.

Age-reading error

Account needs to be taken when fitting population dynamics models of age-reading error. One reason for this is that age-reading error can lead to strong year-classes being 'smeared' across several year-classes, reducing the apparent extent of variation in recruitment. An ageing error matrix can be estimated which determines the probability that an animal of (true) age a is estimated to be age a'. The data available to estimate the entries in this matrix are the results of inter-reader calibration experiments (i.e. from the age-estimates for otoliths that were read by more than one reader or twice by the same age-reader; see Table 28 for sample sizes for the stocks considered in the analyses of this report). The model on which the estimation of the entries in the ageing error matrix is based assumes that readers are correct on average and that age-reading error is normally distributed about the true age, i.e.:

$$P(a'|a) = \frac{\exp[-(a-a')^2/(2SD_a^2)]}{\sum_{a''}\exp[-(a-a'')^2/(2SD_a^2)]} \tag{4.3}$$

where $P(a'|a)$ is the probability that an animal of (true) age a is aged to be a', and

SD_a is the standard deviation of the age-reading error for animals whose true age is a.

The parameters of this model are those which define SD_a. The coefficient of variation of the age-reading error for ages 1+ is assumed to be related quadratically to age for the analyses of this report, i.e.:

$$CV_a = CV_0 + \alpha a + \beta a^2 \tag{4.4}$$

where α, β are estimable parameters, and

CV_0 is the coefficient of variation for the limit $a \rightarrow 0$.

To avoid zero values for SD_a, SD_0 is assumed to be equal to SD_1.

The data from which the parameters of Equation 4.4 can be estimated are pairs of ages (a^1, a^2) for each otolith, summarized in the form of triples (a_i^1, a_i^2, n_i) where n_i is the number of otoliths for which the first age-reader estimated the age to a_i^1 and the second age-reader estimated the age to be a_i^2. By definition, the total sample size equals $\sum_i$. The likelihood function maximized to find the estimates for the parameters of the model is therefore:

$$L = \prod_i \tilde{P}(a_i^1, a_i^2)^{n_i} \tag{4.5}$$

where $\tilde{P}(a^1, a^2)$ is the probability that the first age-reader ages a randomly sampled animal to be a^1 when the second age-reader ages it to be a^2. Assuming that age-reading error for the two age-readers is independent, this probability depends on how age-reading error changes with age (see Equation 4.3) and the frequency of each (true) age-class in the sample, i.e.:

$$\tilde{P}(a^1, a^2) \propto \sum_a R(a)\, P(a^1|a)\, P(a^2|a) \tag{4.6}$$

where $R(a)$ is the relative frequency of animals of (true) age *a* in the sample, and $P(a^1 \mid a)$ and $P(a^2 \mid a)$ are calculated from Equation 4.3. Equation 4.6 implies, for example, that age-readers may agree on an age for a given animal because: (a) they both age it correctly, (b) they both under-estimate its age by 1 year, (c) they both over-estimate its age by 1 year, etc.

The values for $R(a)$ cannot be determined directly from the sample information (because the true ages for the animals are unknown) and are therefore treated as nuisance parameters that need to be estimated along with CV_0, α, and β. Note that if the ages in the data set range from 0 to *n*, it is only necessary to estimate *n* values for $R(a)$ because $R(a)$ is the relative frequency of age-class *a* in the sample.

Simulation evaluation

The approach described above involves estimating *n*+3 parameters from the data. The performance of this estimator as the total sample size is changed is evaluated by simulation in the ideal situation in which its key assumptions: (a) the coefficient of variation of ageing error changes quadratically with age, and (b) the probability of the first age-reader making an error is independent of the second age-reader making an error, are valid. The true age-structure of the sample is assumed to be based on a data set for spotted warehou (Figure 43) – although the estimator is unaware of this – for the purposes of these simulations.

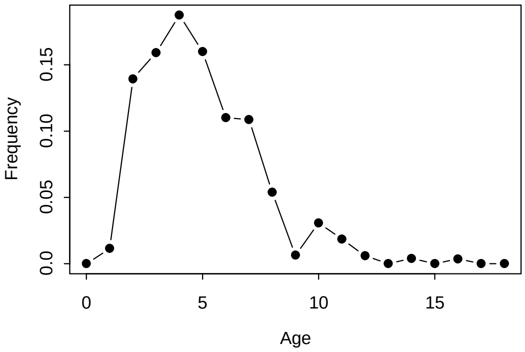


Figure 43. Relative frequency of different ages in the population for the simulations used to evaluate the performance of the estimator of age-reading error.

Figure 44 shows histograms (based on 500 simulations for each sample size) of the estimate of the parameter CV_0 and the coefficient of variation for ages 9 and 18 (the midpoint and upper end of the age-range in Figure 43). The true values for these quantities are 0.2, 0.1 and 0.15 (i.e. the ability to estimate age is best for intermediate ages). This is not an unreasonable assumption because it is often difficult to identify the annulus for the first year (which leads to a larger percentage error for young animals) and because the annuli become more difficult to distinguish as the number of annuli increase. As expected, performance improves as a function of sample size. The estimates for a total sample size of 100 are both biased and imprecise. Performance in terms of estimating CV_0 and the coefficient of variation for age 9 improve dramatically when the sample size is increased from 100 to 1,000. However, the estimate of the coefficient of variation for age 18 remains slightly (~5%) biased and fairly imprecise. The results for sample sizes of 10,000 and 100,000 are qualitatively identical to those for a sample size of 1,000.

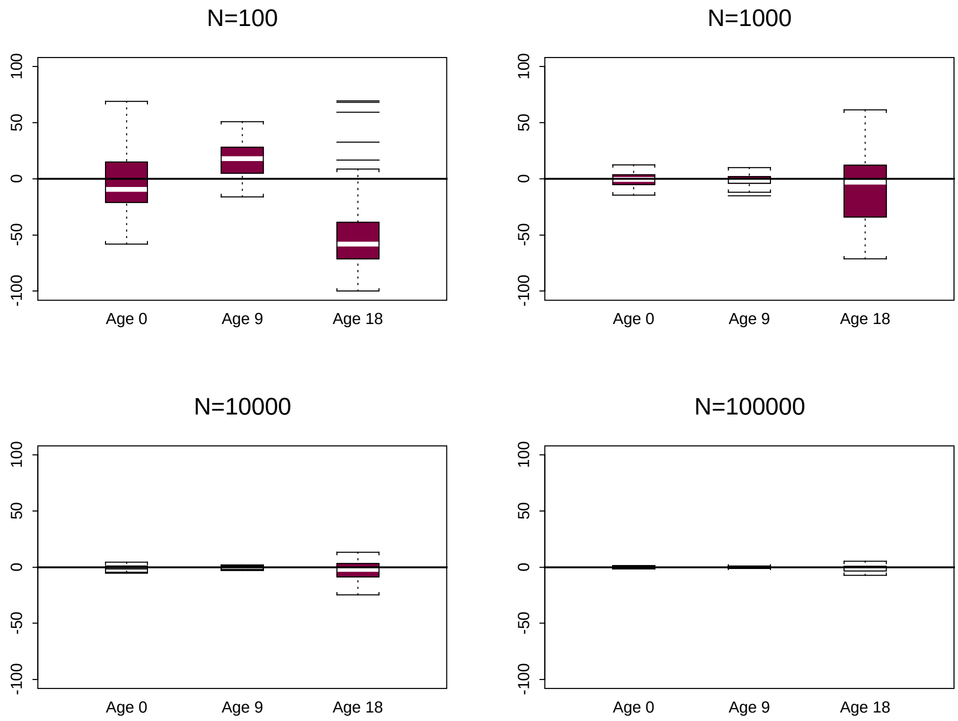


Figure 44. Distributions of the relative error associated with estimates of the coefficients of variation of age-reading error for three ages (0, 9 and 18).

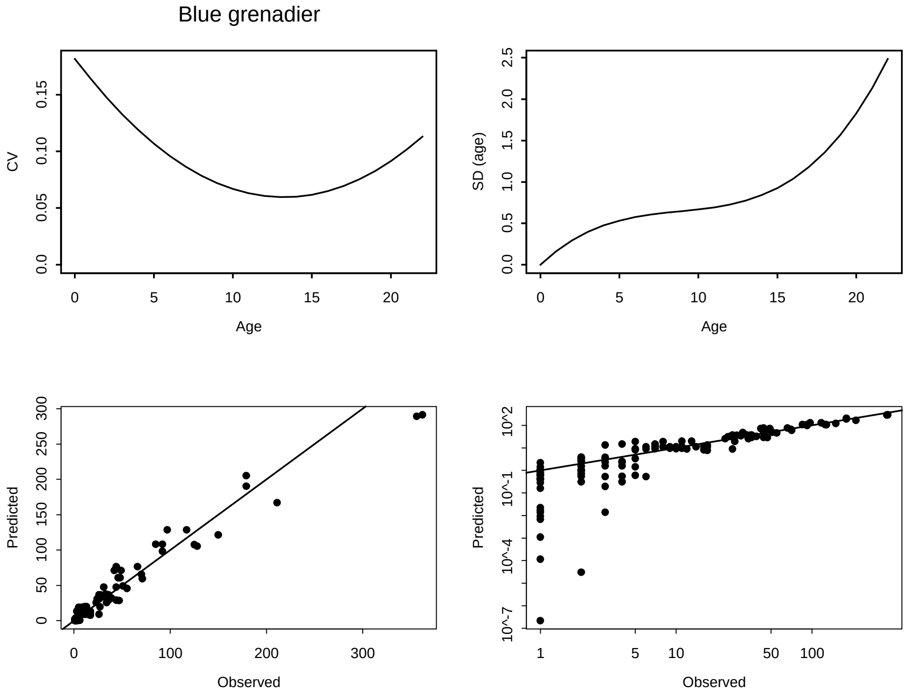
Results are shown for four sample sizes.

The results of the simulations suggest that the precision of the method outlined above is unlikely to produce particularly accurate and precise estimates for sample sizes of ~100 but that performance is likely to be adequate for sample sizes of ~1,000.

Application to actual data

The upper panels of Figures 45 (a)-(g) show the model-predictions of the coefficients of variation and standard deviations as a function of true age for seven of the eight stocks (the data set for king dory being too small to warrant application of the method). The number of data points for each stock are 3789, 1401, 1114, 401, 372, 217, 119 for blue grenadier, pink ling, spotted warehou, western gemfish, eastern gemfish, ocean perch, and mirror dory respectively.

The quality of the fits is examined in the lower panels of these figures which plot the observed number of animals for each combination of age by the first age-reader and age by the second age-reader with the model prediction based on Equation 4.6 (i.e. n_i in Equation 4.5 *versus* $P(a^1,a^2)$ in Equation 4.6). The fits are generally adequate (the observed and model-predicted values lie close to the 1:1 line). However, there are two noteworthy exceptions. First, the model for blue grenadier is unable to mimic the ability to correctly age animals of age 6 as age 6 and animals of age 7 as age 7. The exact reasons for this are unclear but may be related to the fact that two very strong year-classes have passed through the blue grenadier stock recently. The second exception is that the fit for mirror dory appears very imprecise (although the sample size for this stock is the lowest of all those in Figure 45).



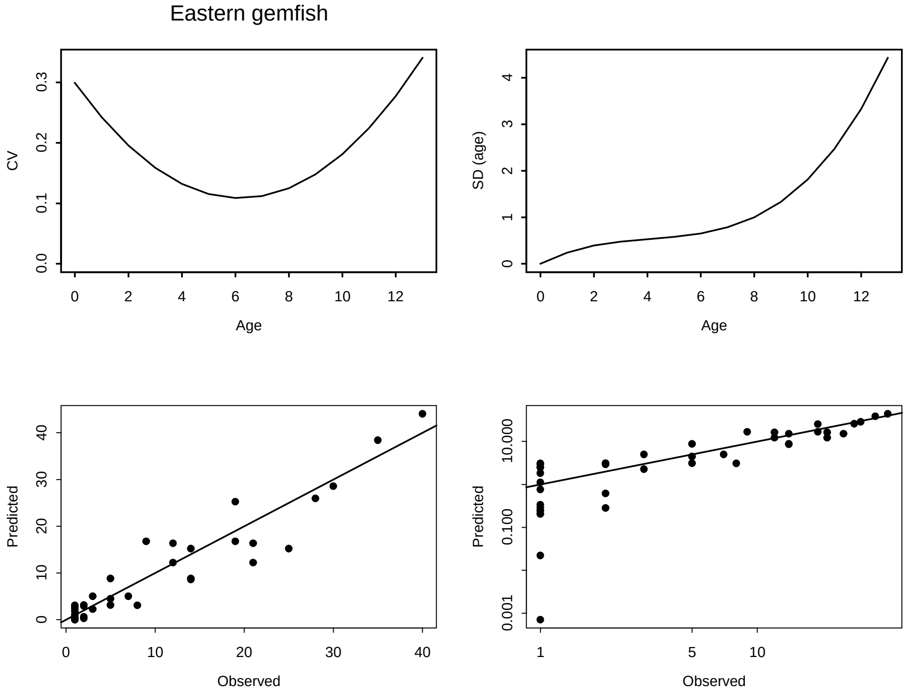
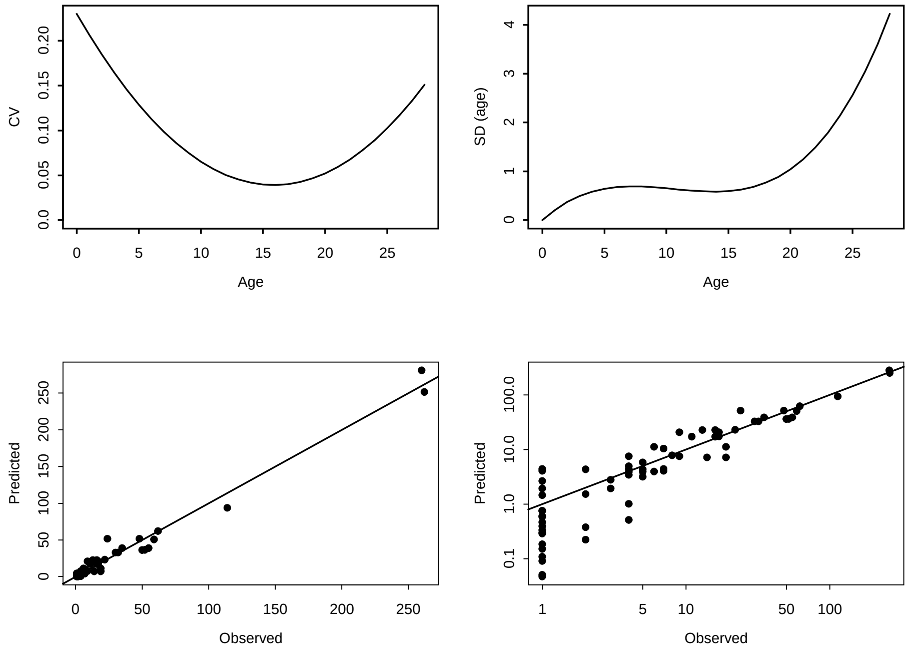


Figure 45. Diagnostic plots for the fits of the age-reading error model to the data for the seven of the eight stocks.

Pink ling



Spotted warehou

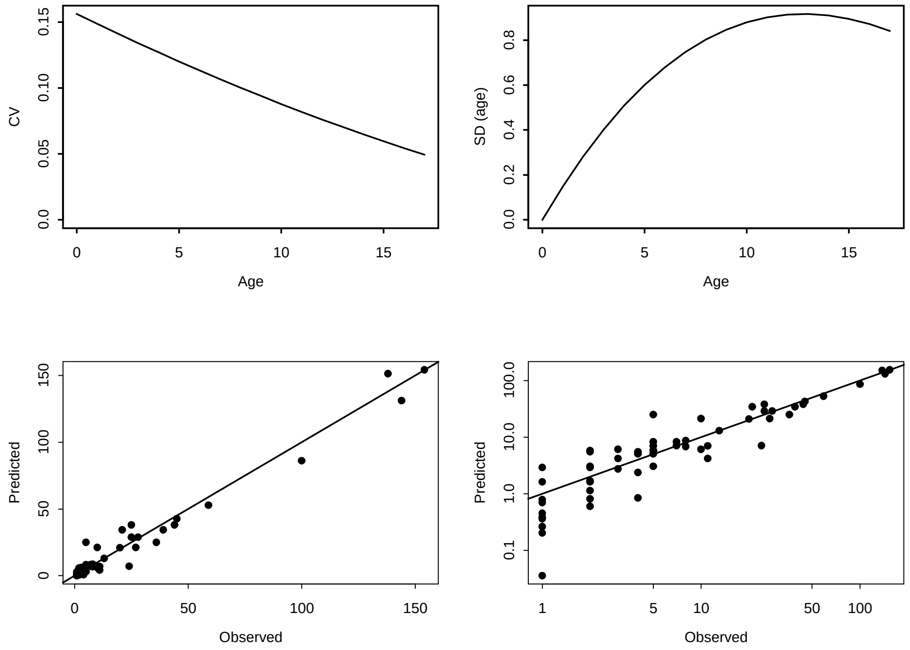
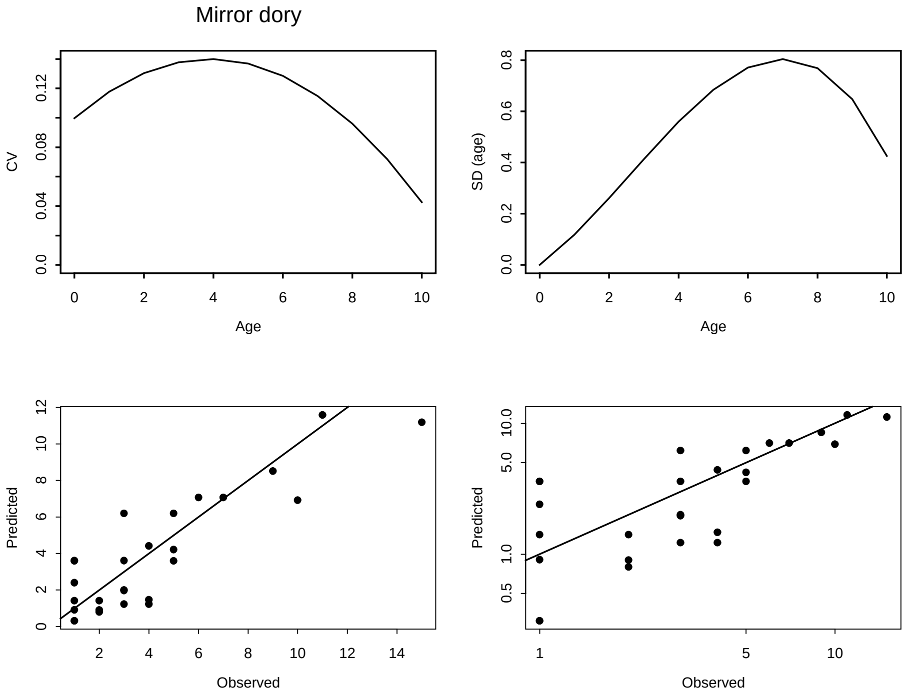
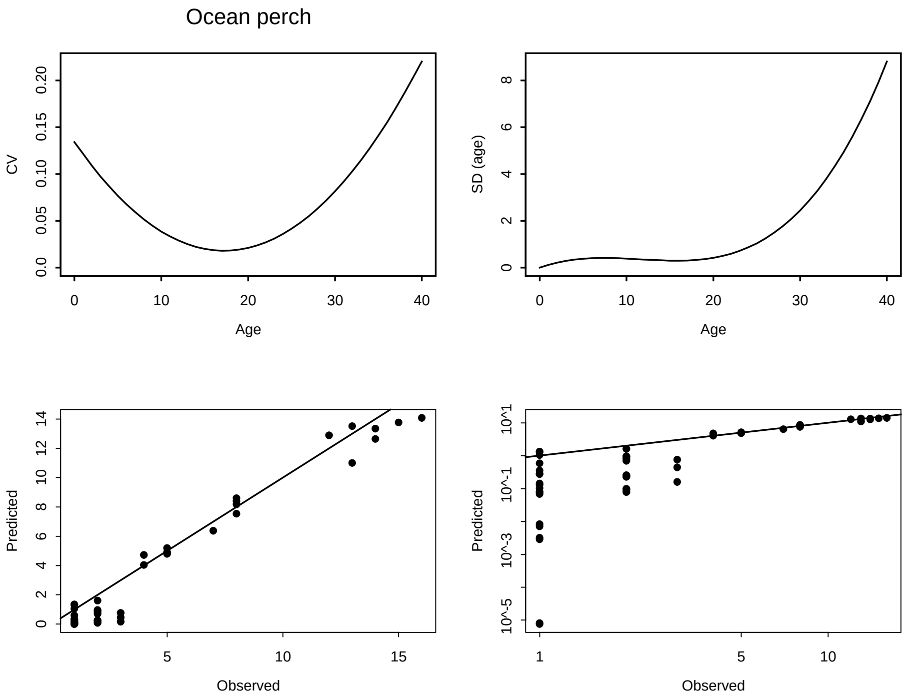


Figure 45 (continued) Diagnostic plots for the fits of the age-reading error model to the data for the seven of the eight stocks.



Mirror dory



Ocean perch

Figure 45 (continued) Diagnostic plots for the fits of the age-reading error model to the data for the seven of the eight stocks.

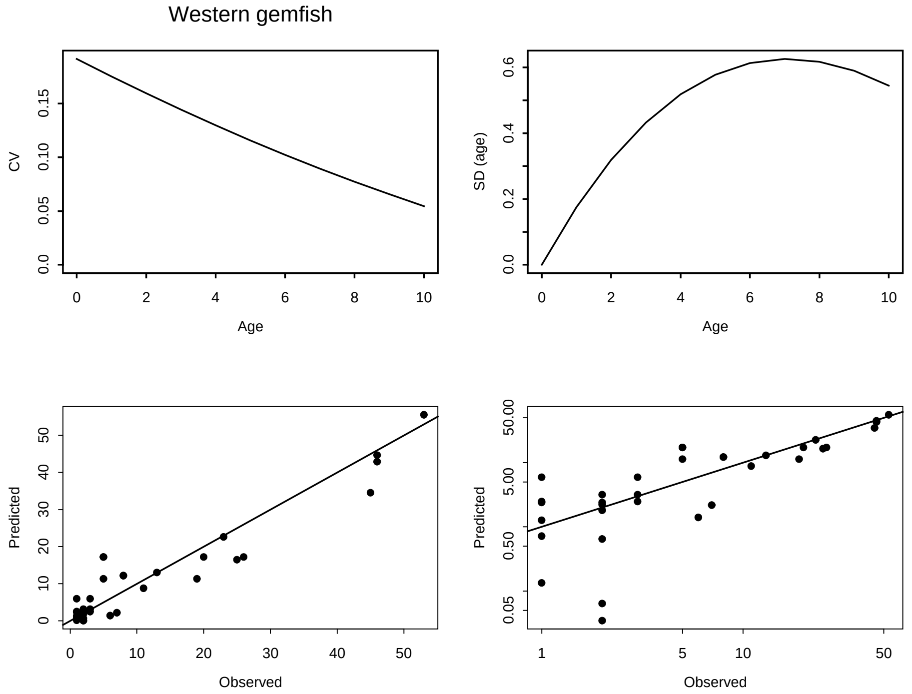


Figure 45 (continued) Diagnostic plots for the fits of the age-reading error model to the data for the seven of the eight stocks.

Figure 46 show the relationships for each of the seven stocks between the coefficient of variation of age-reading error and age, with asymptotic 95% confidence intervals. Three patterns are evident in Figure 46 a) quadratic with a minimum at intermediate ages (blue grenadier, eastern gemfish, pink ling, and ocean perch), b) linear decreasing (spotted warehou and western gemfish), and c) quadratic with a maximum at intermediate ages (mirror dory). The results for mirror dory should, however, treated with some caution as they are fairly imprecise. The precision of the estimates of the coefficients of variation are greatest for intermediate ages (Figure 46) and lowest at high age (the results for mirror dory being an exception to this). This is, however, not particularly surprising because the number of data points is greatest for the youngest and intermediate ages.

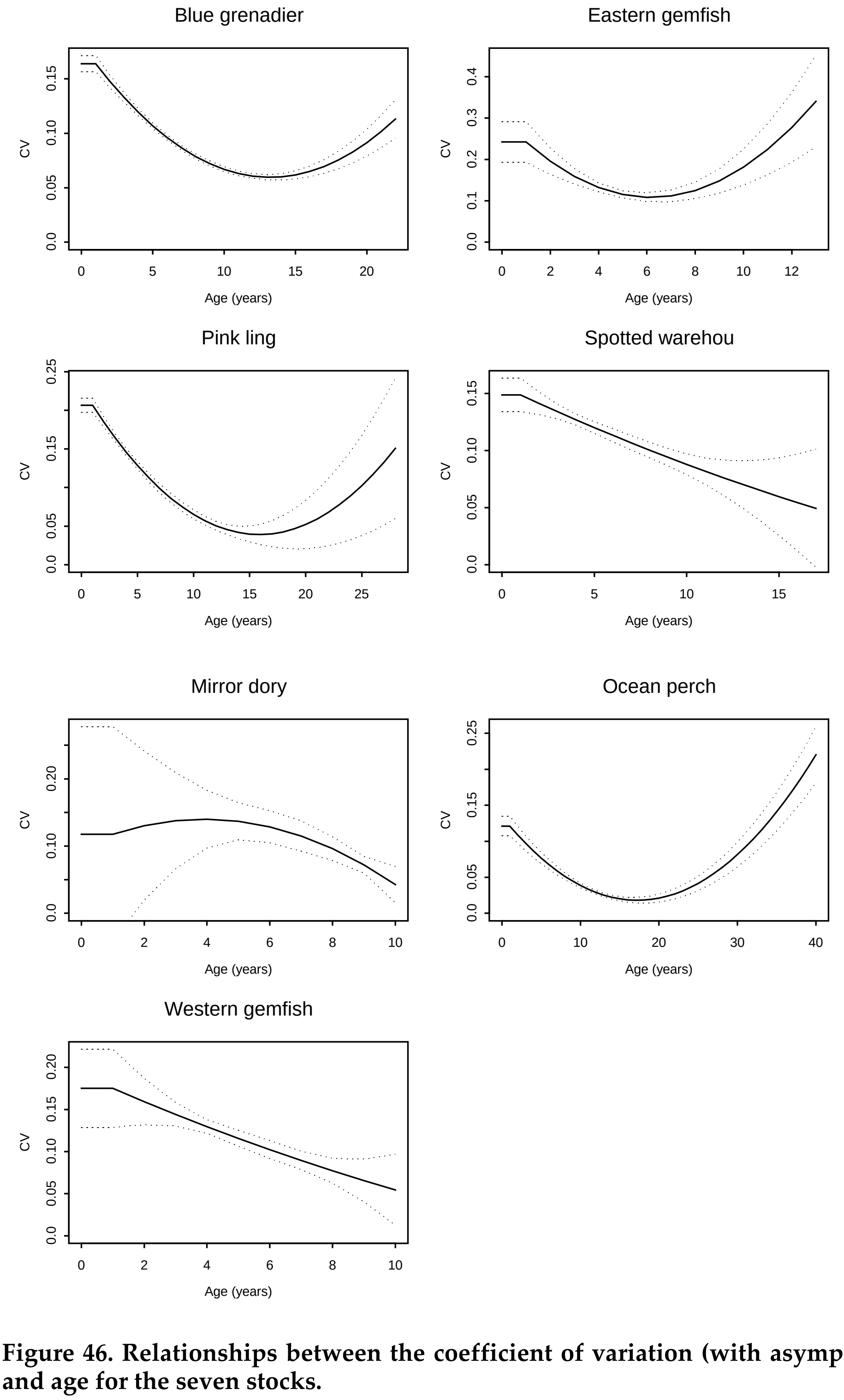


Figure 46. Relationships between the coefficient of variation (with asymptotic 95% confidence intervals) and age for the seven stocks.

Survey estimates of spawning biomass

Two estimates of the abundance of the spawning stock of blue grenadier are available based on the annual egg production method (59,080*t* (CV 0.189) and 44,195*t* (CV 0.287) for 1994 and 1995 respectively; Bulman *et al.*, 1999). These estimates relate to only the female component of the spawning stock because of uncertainties surrounding the sex ratios of spawning blue grenadier (Smith, 1998).

Biological parameters

Table 26 lists the values for the pre-specified parameters of the model. For the purposes of the example application, growth is assumed to be governed by the von Bertalanffy growth equation and weight related to length by means of a power relationship, i.e.:

$$\begin{aligned} L_a^{g,s} &= \ell_\infty^{g,s}(1-e^{-\kappa^{g,s}(a-t_0^{g,s})}) \\ w_a^{g,s} &= a^{g,s}\,(L_a^{g,s})^{b^{g,s}} \end{aligned} \tag{4.7}$$

where $\ell_\infty^{g,s}$ is the asymptotic size of a fish of stock *s* and sex *g*,

$\kappa^{g,s}$ is the growth rate parameter for a fish of stock *s* and sex *g*,

$t_0^{g,s}$ is the 'age at zero length' for a fish of stock *s* and sex *g*, and

$a^{g,s}, b^{g,s}$ are the parameters of the weight-length relationship for stock *s* and sex *g*.

The variance of the logarithm of length-at-age is assumed to change linearly with length, i.e.

$$\sigma_a^{g,s} = \sqrt{(\tilde{\sigma}_0^{g,s})^2 + [(\tilde{\sigma}_{50}^{g,s})^2 - (\tilde{\sigma}_0^{g,s})^2]\frac{L_a^{g,a}}{50}} \tag{4.8}$$

where $\tilde{\sigma}_0^{g,s}$ is the standard deviation of the logarithm of the length of a fish of stock *s* and sex *g* whose expected length is 0cm, and

$\tilde{\sigma}_{50}^{g,s}$ is the standard deviation of the logarithm of the length of a fish of stock *s* and sex *g* whose expected length is 50cm.

The values for $\sigma_0^{g,s}$ and $\sigma_{50}^{g,s}$ for each stock and sex were calculated by regressing the variance of the logarithm of length-at-age on mean length-at-age, weighting each data point by its sample size (Figure 47). The data for blue grenadier, eastern gemfish, pink ling, spotted warehou, and western gemfish are suggestive of declining variance with age while the data suggest that the variance for remainder of the species is independent of age.

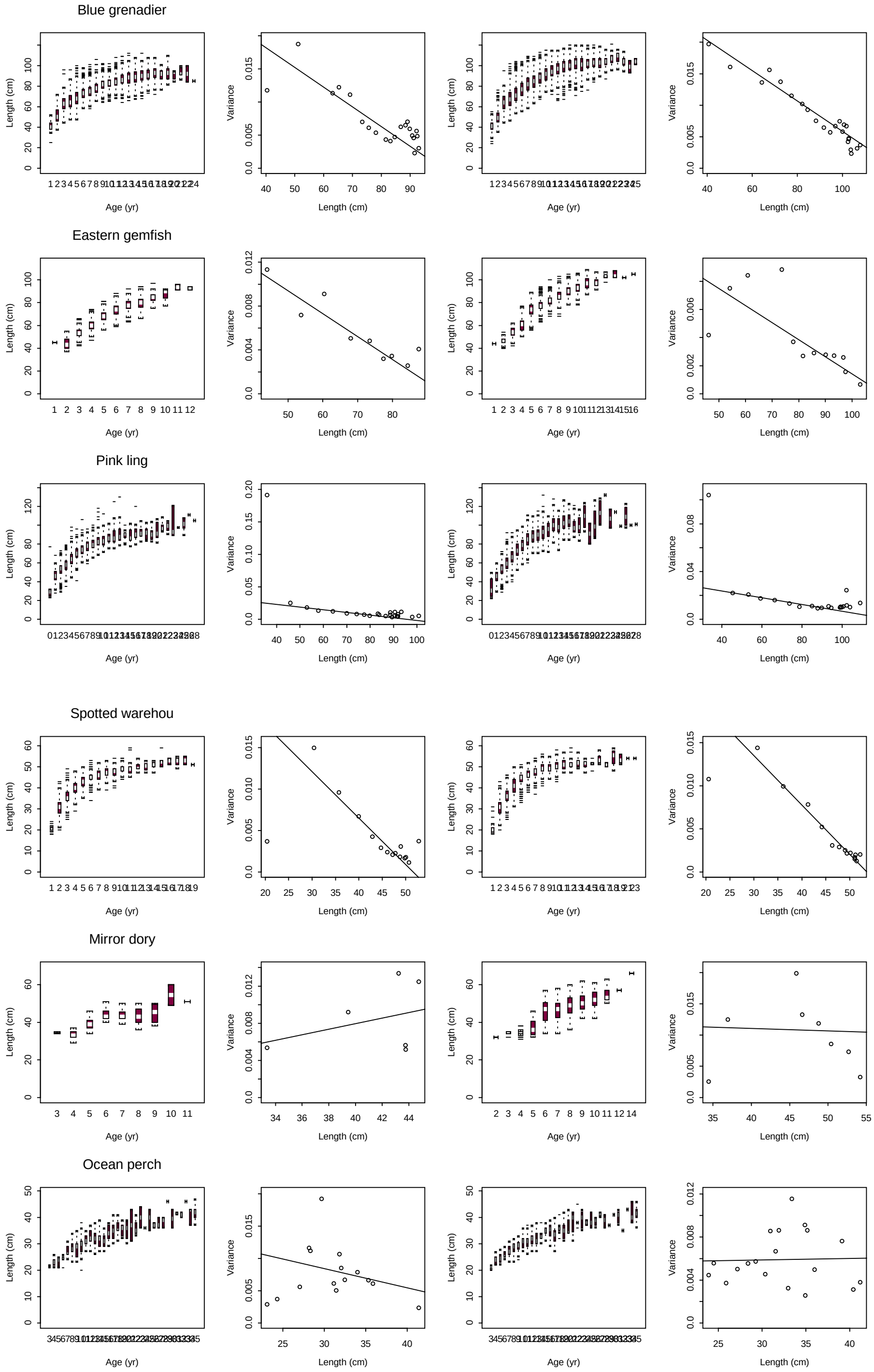


Figure 47.Length-at-age by stock, and the fit of a straight line to the relationship between the variance of the logarithm of length-at-age and mean length-at-age (each data point relates to the length data for a single age-class).

The results for males are in the left panels and those for females are in the right panels.

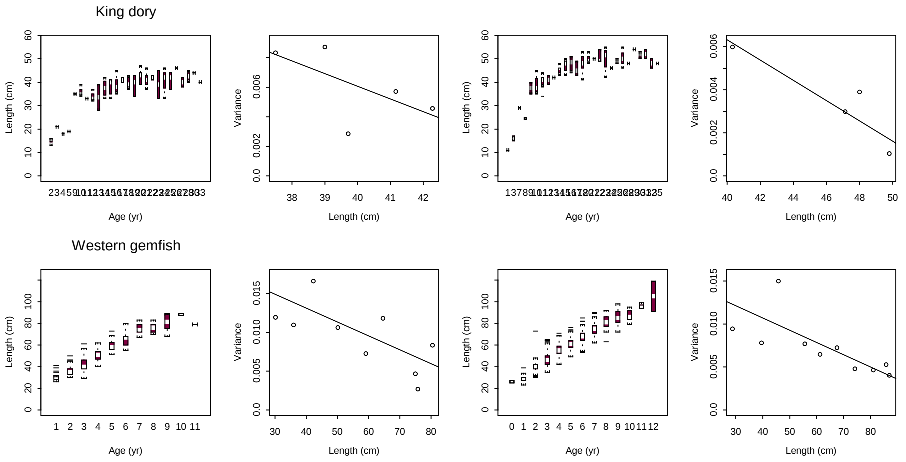


Figure 47. (continued) Length-at-age by stock, and the fit of a straight line to the relationship between the variance of the logarithm of length-at-age and mean length-at-age (each data point relates to the length data for a single age-class).

The results for males are in the left panels and those for females are in the right panels.

For all stocks except eastern gemfish, fecundity-at-age is assumed to be the product of female weight-at-age (at the start of the year) and a knife-edged maturity function, i.e.:

$$f_a^s = \begin{cases} 0 & \text{if } a < a_m^s \\ w_a^{\mathrm{f},s} & \text{otherwise} \end{cases} \qquad (4.9)$$

where a_m^s is the age-at-maturity for stock *s*.

For eastern gemfish, fecundity-at-age is assumed to be the product of selectivity to the winter (spawning) fishery and begin-year weight-at-age.

The proportion spawning parameter, $\breve{\mu}$, only impacts the ability to fit the survey-based estimates of spawning biomass and so $\breve{\mu}$ can be assumed to be 1 without loss of generality for all species except blue grenadier. It is known from data from New Zealand (Livingston *et al.*, 1997) that not all blue grenadier spawn annually. Assessments in New Zealand (e.g. McAllister *et al.*, 1994) are based on the assumption that 77 % (the average of the range of 68–85 % reported by Livingston *et al.* (1997)) of the potential spawners spawn each year. The same assumption is made here.

For those species for which assessments exist, the extent of recruitment variation has been set equal to the values assumed in the most recent assessments: blue grenadier (1 – Punt *et al.*, 2001a), eastern gemfish (0.6 – Smith and Punt, 1998); spotted warehou (0.6 – Thomson, 2002), and pink ling (0.6 – Klaer, 2003). The extent of recruitment variability has been set equal to 0.6, a value close to the median of the posterior medians for σ_R obtained in Chapter 3 of 0.615, for the remaining stocks (Table 26).

Discussion

The eight stocks considered in this chapter differ markedly in terms of the data available for assessment purposes. Blue grenadier can be considered to be 'data-rich' because information is available on catches from close to the start of the fishery, extensive age- and length-frequency data are available, and estimates of absolute abundance from fishery-independent surveys are available. Ageing of this species also appears reasonably reliable (see Figure 46).

Eastern gemfish, spotted warehou and pink ling can be considered to be 'data-moderate' because indices of abundance based on standardizing catch and effort data are available, and length-frequency and age-composition data are available for most of the recent years. However, fishery-independent estimates of relative (and absolute) abundance are not available for these species and the catches are subject to substantial uncertainty (particularly for spotted warehou).

The remaining four stocks (western gemfish, mirror dory, king dory and ocean perch) are clearly 'data-poor'. There are no fishery-independent data for these species, catches are uncertain due to substantial discarding, and length-frequency and age-composition information is limited. Of these stocks, the first two have much more data that the last two, making these last two species the most 'data-poor' species considered in this report.

Table 19. Catches (1986–2002; tonnes) by 'major stock' and fleet (values in underlined italics) and the percentage of the catch of the other stocks / fleets caught with these 'major stock' and fleets.

Species	Fleet	Blue grenadier	Gemfish	Pink ling	Spotted warehou	King dory	Ocean perch	Mirror Dory
Blue grenadier	1	*7456*	27.5	49.6	16.0	83.1	43.2	34.2
	2	*1486*	27.6	51.5	16.9	80.3	40.9	25.7
	3	*16824*	43.0	83.5	58.4	84.8	77.6	67.5
	4	*38227*	54.4	86.5	91.9	84.4	90.4	78.4
Eastern gemfish	2	61.4	*13155*	55.5	22.0	51.3	52.5	75.4
Pink ling	1	76.9	44.0	*6870*	44.1	80.4	91.4	64.2
	2	90.3	59.6	*3816*	47.9	86.2	88.4	69.2
	3	73.4	27.8	*4977*	55.3	82.6	79.3	53.1
	4	25.0	41.2	*642*	52.0	84.4	78.5	69.1
Spotted warehou	1	26.3	20.8	18.7	*6214*	28.8	12.3	18.7
	2	37.5	10.1	26.9	*7900*	27.7	15.5	10.6
	3	33.8	29.8	44.7	*15357*	25.2	27.0	55.2
	4	45.9	35.4	59.4	*4382*	51.7	32.0	68.2

Table 20. The total annual catches (trawl and non-trawl) by stock.

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Trawl catches																		
Blue grenadier	0	0	0	0	0	0	0	0	0	0	0	512	857	470	815	941	1342	1201
Eastern gemfish	1440	1460	1470	1480	1500	1460	1752	1652	3392	4676	6672	5162	6040	4700	4230	3715	3398	3406
Ling	0	0	0	0	0	0	0	0	149	224	299	299	448	598	523	672	770	698
Spotted warehou	0	0	0	0	0	0	0	0	0	0	0	0	183	365	548	731	914	1096
Mirror dory	0	0	0	40	90	170	200	290	420	580	860	420	290	160	310	220	241	377
Ocean perch (offshore)	0	0	0	0	0	0	0	0	0	200	250	200	200	250	275	400	287	271
King dory	0	0	0	0	0	0	0	0	0	0	17	163	147	258	159	133	81	55
Western gemfish	0	0	0	0	0	0	0	0	0	0	195	401	492	974	928	757	429	445
Non-trawl catches																		
Ling	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	54
Spotted warehou	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Trawl catches																	
Blue grenadier	1476	2137	2197	1996	2363	3690	3294	3373	3172	2767	3054	4548	5733	9313	8655	9124	9156
Eastern gemfish	3951	4762	3745	2167	1645	1067	1060	1348	513	512	554	594	391	278	119	106	64
Ling	715	882	772	833	730	798	895	1617	1434	1700	1987	1987	1702	1705	1605	1356	1071
Spotted warehou	1279	1147	1618	1038	1359	1480	818	2217	2724	2535	2738	2785	2410	2738	3726	3294	4090
Mirror dory	487	569	483	650	300	246	214	335	322	281	403	546	425	352	208	303	306
Ocean perch (offshore)	243	231	256	248	199	249	234	395	355	378	395	464	377	399	381	394	522
King dory	55	64	57	99	67	141	112	148	166	168	155	147	123	93	97	141	155
Western gemfish	445	361	332	226	196	392	126	135	138	124	208	227	185	272	349	253	132
Non-trawl catches																	
Ling	86	88	103	115	82	82	274	615	496	415	591	225	178	247	226	316	465
Spotted warehou	1	1	6	21	24	55	85	61	79	97	165	169	66	31	4	1	1

Table 21. Trawl catches (t) by stock and fleet

(a) 1968-1985

Stock	Fleet	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Blue grenadier	1	0	0	0	0	0	0	0	0	0	0	0	70	117	64	111	128	183	163
	2	0	0	0	0	0	0	0	0	0	0	0	9	16	9	15	17	25	22
	3	0	0	0	0	0	0	0	0	0	0	0	170	285	156	271	312	445	399
	4	0	0	0	0	0	0	0	0	0	0	0	263	440	242	419	483	689	617
Eastern gemfish	1	0	20	30	40	60	20	20	40	40	170	450	460	440	190	270	305	300	205
	2	1440	1440	1440	1440	1440	1440	1732	1612	3352	4506	6222	4702	5600	4510	3960	3410	3098	3201
Ling	1	0	0	0	0	0	0	0	0	64	96	128	128	191	255	223	287	329	298
	2	0	0	0	0	0	0	0	0	31	47	63	63	94	125	109	141	161	146
	3	0	0	0	0	0	0	0	0	48	72	96	96	145	193	169	217	248	225
	4	0	0	0	0	0	0	0	0	6	9	12	12	18	25	21	28	32	29
Spotted warehou	1	0	0	0	0	0	0	0	0	0	0	0	0	50	101	151	202	252	303
	2	0	0	0	0	0	0	0	0	0	0	0	0	46	93	139	185	232	278
	3	0	0	0	0	0	0	0	0	0	0	0	0	76	153	229	305	382	458
	4	0	0	0	0	0	0	0	0	0	0	0	0	10	19	29	38	48	57
Mirror dory	1	0	0	0	19	43	80	95	137	199	274	407	199	137	76	147	104	114	178
	2	0	0	0	12	26	49	58	84	122	168	250	122	84	46	90	64	70	109
	3	0	0	0	9	20	39	45	66	95	132	195	95	66	36	70	50	55	86
	4	0	0	0	0	1	2	2	3	4	6	9	4	3	2	3	2	2	4
Ocean perch (offshore)	1	0	0	0	0	0	0	0	0	0	131	163	131	131	163	180	262	188	177
	2	0	0	0	0	0	0	0	0	0	37	46	37	37	46	51	74	53	50
	3	0	0	0	0	0	0	0	0	0	28	35	28	28	35	38	56	40	38
	4	0	0	0	0	0	0	0	0	0	4	5	4	4	5	6	8	6	6
King dory	1	0	0	0	0	0	0	0	0	0	0	2	17	14	42	18	31	15	14
	2	0	0	0	0	0	0	0	0	0	0	0	3	3	8	3	6	3	3
	3	0	0	0	0	0	0	0	0	0	0	14	154	123	376	157	275	134	121
	4	0	0	0	0	0	0	0	0	0	0	1	13	11	32	14	24	12	10
Western gemfish	3	0	0	0	0	0	0	0	0	0	0	192	394	483	957	912	744	421	437
	4	0	0	0	0	0	0	0	0	0	0	4	7	9	18	17	14	8	8

(b) 1986-2002

Stock	Fleet	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Blue grenadier	1	285	504	478	583	724	995	734	792	630	398	330	453	472	994	526	410	206
	2	99	172	220	108	180	85	37	56	133	16	23	60	132	278	121	135	17
	3	872	775	1157	1271	929	1811	1671	1524	1191	1150	1194	891	1589	1738	1738	788	1377
	4	221	686	342	33	531	799	852	1001	1218	1204	1507	3144	3540	6303	6270	7791	7557
Eastern gemfish	1	130	80	175	175	80	50	30	312	106	50	66	63	74	40	20	39	25
	2	3821	4682	3570	1992	1565	1017	1030	1036	407	462	488	531	317	238	99	67	39
Ling	1	305	389	364	369	331	388	451	768	691	741	916	746	645	690	524	455	310
	2	150	242	275	233	234	143	253	380	335	347	328	432	362	473	426	256	205
	3	231	211	122	225	151	257	183	440	376	519	625	724	632	463	555	561	487
	4	29	40	12	6	15	11	8	28	32	93	118	85	63	78	100	84	69
Spotted warehou	1	353	186	251	266	310	309	368	502	806	688	1043	789	439	205	214	261	403
	2	325	217	675	127	742	473	204	766	1019	851	371	431	480	694	586	456	366
	3	534	598	634	641	256	675	222	884	757	780	1194	1480	1321	1411	1770	1570	2180
	4	67	146	58	5	51	22	23	65	143	216	130	85	170	427	1156	1007	1141
Mirror dory	1	230	172	161	132	125	115	110	171	224	187	167	172	163	113	97	91	92
	2	141	376	298	504	165	114	92	143	77	48	94	190	120	165	82	78	45
	3	111	20	23	11	10	17	12	21	20	41	132	179	140	72	27	129	163
	4	5	2	2	2	0	0	0	0	0	5	10	6	3	3	2	5	6
Ocean perch (offshore)	1	159	132	165	153	119	168	156	264	262	236	268	279	234	268	252	258	322
	2	45	43	76	78	62	41	52	94	58	62	65	91	70	85	75	80	107
	3	34	53	14	17	15	38	26	37	27	68	51	86	65	39	50	52	84
	4	5	3	0	0	2	1	0	1	7	12	11	9	8	7	4	4	9
King dory	1	5	7	10	12	12	17	14	27	16	10	9	14	8	20	13	20	23
	2	1	1	10	5	3	1	1	5	8	1	2	0	1	3	2	4	1
	3	45	49	36	80	49	120	91	110	137	144	124	124	104	64	73	109	121
	4	4	7	1	2	3	3	6	6	5	14	20	8	9	5	10	9	11
Western gemfish	3	437	355	330	225	195	392	126	119	138	124	208	226	185	271	346	249	130
	4	8	6	2	0	1	0	0	16	0	0	0	1	0	1	3	4	2

Table 22. The discard rates by stock and fleet. '-' denotes that data are not available for the stock, fleet and year concerned.

(a) Point estimates

	Fleet	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Blue grenadier	1	0.001	0.001	0.160	0.303	0.644	0.469	0.047	0.003	0.001	0.002
	2	-	-	-	-	0.535	-	0.007	0.008	0.006	-
	3	-	0.007	0.009	0.365	0.724	0.553	0.029	0.013	0.002	0.002
	4	-	-	-	-	-	0.030	0.001	-	-	-
Eastern gemfish	1	0.006	0.260	0.103	0.467	0.289	0.058	0.231	0.026	0.151	0.230
	2	0.878	-	0.117	0.115	0.052	0.067	0.181	0.222	0.055	0.206
Pink ling	1	0.003	0.005	0.009	0.020	0.067	0.026	0.004	0.004	0.006	0.013
	2	0.001	0.021	0.033	0.008	0.165	0.011	0.003	-	0.001	0.001
	3	-	0.000	0.002	0.018	0.042	0.028	0.012	0.019	0.004	0.003
	4	-	-	-	-	-	0.029	0.001	-	-	-
Spotted warehou	1	0.010	0.009	0.231	0.013	0.010	0.016	0.002	0.011	0.167	0.362
	2	0.078	0.005	0.587	0.198	0.255	0.055	0.003	0.002	0.208	0.155
	3	-	0.024	0.079	0.313	0.383	0.678	0.045	0.017	0.192	0.047
	4	-	-	-	-	-	0.176	0.101	-	0.011	-
Ocean perch	1	0.209	0.717	0.799	0.575	0.432	0.305	0.241	0.367	0.673	0.344
	2	0.185	0.612	0.630	0.484	0.189	0.157	0.045	0.423	0.779	0.288
	3	-	0.254	0.009	0.014	0.002	0.005	0.001	0.014	0.161	0.049
	4	-	-	-	-	-	-	-	-	0.035	-
Mirror dory	1	0.534	0.476	0.852	0.333	-	0.385	0.353	0.398	0.641	0.333
	2	-	-	0.680	0.274	-	0.302	-	-	0.484	0.527
	3	-	0.625	0.115	0.232	0.101	0.356	0.240	0.114	0.180	0.072
	4	-	-	-	-	-	-	-	-	-	-
King dory	1	-	-	-	0.162	0.105	0.122	0.069	0.029	0.038	0.048
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	0.046	0.090	0.102	0.245	0.098	0.060	0.047	0.017
	4	-	-	-	-	-	0.032	0.229	-	-	-
Western gemfish	3	-	0.067	0.058	0.084	0.204	0.044	0.009	0.058	0.035	0.059
	4	-	-	-	-	-	-	-	-	-	-

(b) Coefficients of variation

	Fleet	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Blue grenadier	1	0.710	1.082	0.602	0.243	0.105	0.375	0.863	0.359	0.238	0.361
	2	-	-	-	-	0.235	-	0.480	0.620	0.606	-
	3	-	0.495	0.353	0.192	0.075	0.139	0.343	0.320	0.404	0.523
	4	-	-	-	-	-	0.494	0.522	-	-	1.372
Eastern gemfish	1	0.668	0.675	0.512	0.734	0.314	0.559	0.388	0.427	0.411	0.334
	2	0.072	-	0.675	0.508	0.552	0.404	0.347	0.365	0.406	0.408
Pink ling	1	0.610	0.413	0.336	0.245	0.248	0.241	0.284	0.405	0.395	0.464
	2	1.097	0.645	0.395	0.478	0.244	0.563	0.662	-	0.794	0.503
	3	-	1.045	0.633	0.683	0.598	0.373	0.616	0.641	0.402	0.569
	4	-	-	-	-	-	0.882	1.014	-	-	-
Spotted warehou	1	0.685	0.524	0.450	0.702	0.467	0.473	0.472	0.540	0.486	0.468
	2	0.463	0.460	0.304	0.533	0.506	0.987	1.085	0.851	0.416	0.891
	3	-	0.687	0.718	0.220	0.524	0.197	0.540	0.543	0.358	0.350
	4	-	-	-	-	-	0.531	0.823	-	0.416	-
Ocean perch	1	0.238	0.104	0.070	0.092	0.221	0.199	0.160	0.162	0.076	0.245
	2	0.436	0.299	0.169	0.224	0.314	0.419	0.382	0.142	0.095	0.245
	3	-	0.415	0.544	0.711	0.632	0.517	0.996	0.587	0.398	0.445
	4	-	-	-	-	-	-	-	-	0.519	-
Mirror dory	1	0.109	0.111	0.072	0.198	-	0.159	0.127	0.162	0.090	0.142
	2	-	-	0.154	0.214	-	0.272	-	-	0.220	0.150
	3	-	0.117	0.139	0.133	0.157	0.107	0.133	0.233	0.166	0.163
	4	-	-	-	-	-	-	-	-	-	-
King dory	1	-	-	-	0.303	0.220	0.454	0.166	0.125	0.466	0.188
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	0.211	0.268	0.191	0.166	0.231	0.627	0.187	0.202
	4	-	-	-	-	-	0.785	0.271	-	-	-
Western gemfish	3	-	0.323	0.523	0.402	0.550	0.453	0.342	0.444	0.574	0.228
	4	-	-	-	-	-	-	-	-	-	-

Table 23. Standardized catch-rate indices by stock and fleet.

	Eastern gemfish	Blue grenadier			Pink ling				Spotted warehou				Western gemfish	Mirror dory
	Fleet 2	Fleet 2	Fleet 3	Fleet 4	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 3	Fleet 2
1973	2811													
1974	3082													
1975	2533													
1976	3440													
1977	3237													
1978	3562													
1979	2780													
1980	3127													
1981	2717													
1982	2100													
1983	1163													
1984	1259													
1985	1537		43.36	282.71	3.92	-1.00	23.26			16.11		177.82	2.507	
1986	1414	7.244	34.16	173.12	4.05	3.90	17.54		2.99	11.75	35.58	102.59	2.642	0.939
1987	1766	8.617	40.44	182.47	4.10	4.18	21.53		10.48	19.17	49.20	129.70	2.742	1.148
1988		10.415	48.72	383.16	4.35	5.10	18.82	6.60	11.23	17.31	42.77	153.87	2.695	1.114
1989	1294	5.841	46.63	105.49	3.92	4.35	21.21		4.23	19.48	25.06	122.76	2.415	1.604
1990	1165	4.228	39.25	168.78	4.31	7.10	18.99		11.52	14.95	49.90	85.33	1.513	0.946
1991	930	3.406	43.43	407.25	3.88	6.19	17.97		11.00	9.33	32.12	87.32	1.562	1.278
1992		2.764	44.82	256.51	3.90	5.92	13.74		11.97	13.28	12.53	71.15	1.128	1.026
1993		1.773	29.35	355.49	4.37	5.61	18.90		11.64	12.09	21.23	89.61	1.018	0.991
1994		1.175	27.16	280.64	4.34	6.36	22.62	4.07	11.48	14.43	31.58	83.03	1.149	0.764
1995		0.769	18.67	135.83	4.68	9.32	22.99	3.05	9.58	12.30	30.37	64.51	1.022	0.649
1996	1371	0.950	16.07	198.12	4.09	6.30	23.65	4.63	7.53	11.33	15.47	80.29	1.073	0.740
1997	643	1.389	13.26	166.19	3.80	7.22	25.47	4.89	5.41	10.65	17.50	95.11	1.000	0.821
1998	926	1.000	26.19	181.50	3.86	7.65	26.14	3.74	15.45	8.54	17.31	113.52	1.059	1.000
1999		0.803	26.93	151.85	3.58	8.45	20.47	2.51	10.40	6.18	19.81	99.99	1.029	0.936
2000		0.545	23.69	178.37	2.77	6.48	19.03	3.39	26.13	6.67	17.53	84.06	1.137	0.707
2001		0.623	12.50	294.79	2.18	4.74	17.82	2.85	18.19	6.93	18.55	65.30	0.847	0.902
2002		0.358	14.75	210.42	1.84	4.02	15.87	2.39	16.73	9.01	15.12	67.17		0.643

Table 24. Number of catch-effort records by fleet and the number used when standardizing the catch and effort data.

	Total records				Blue grenadier		Pink ling				Spotted warehou			
	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 3	Fleet 4	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 1	Fleet 2	Fleet 3	Fleet 4
1985	15567	430	1334	94	452	40	442	0	174	0	27	0	323	0
1986	46337	15404	4265	269	1345	74	1427	442	656	0	124	205	881	16
1987	41571	14352	5519	441	1369	152	1380	556	578	0	93	154	434	41
1988	45731	15907	5756	191	1401	89	1185	564	611	11	248	330	433	33
1989	45930	16118	5712	210	1771	24	1438	615	897	0	459	125	528	4
1990	39990	13321	7100	823	1200	126	1329	391	931	0	335	293	456	30
1991	33634	11270	6223	326	2067	85	1718	474	1506	0	616	308	569	24
1992	24844	7860	5161	322	2009	185	1908	634	1533	0	681	227	506	32
1993	25412	9353	6185	412	2377	129	2794	919	2098	0	1144	536	1321	32
1994	28135	8967	6011	622	2075	298	3505	1131	1762	31	1716	610	1330	111
1995	25238	8101	8061	787	3144	406	3808	1326	2931	145	1664	522	1394	250
1996	28507	10003	8113	945	2966	334	4372	1110	2843	234	2533	743	1325	185
1997	30133	10123	8070	769	3131	364	4709	1399	3327	294	2139	719	1830	122
1998	30367	9679	7624	821	3530	538	4254	1274	3441	288	1460	527	1739	184
1999	30412	10450	8028	1250	4167	824	4460	1644	3407	362	1210	701	2367	420
2000	27181	9380	8999	1165	4617	918	4581	1573	3926	487	1227	997	2792	600
2001	23998	8498	9673	1374	4198	1030	4091	1306	4061	517	1119	696	3154	591
2002	24227	8808	9187	1296	4219	942	3456	1264	3985	434	1480	740	3532	664

Table 24. (continued) Number of catch-effort records by fleet and the number used when standardizing the catch and effort data.

	Total records				Eastern gemfish	Western gemfish	Mirror dory
	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 2	Fleet 3	Fleet 2
1985	15567	430	1334	94	0	481	0
1986	46337	15404	4265	269	1344	1316	244
1987	41571	14352	5519	441	1610	915	271
1988	45731	15907	5756	191	1084	995	331
1989	45930	16118	5712	210	901	857	322
1990	39990	13321	7100	823	503	767	196
1991	33634	11270	6223	326	286	1282	100
1992	24844	7860	5161	322	321	701	128
1993	25412	9353	6185	412	768	696	216
1994	28135	8967	6011	622	680	768	226
1995	25238	8101	8061	787	469	799	189
1996	28507	10003	8113	945	731	902	230
1997	30133	10123	8070	769	756	1168	282
1998	30367	9679	7624	821	549	1086	184
1999	30412	10450	8028	1250	627	1427	296
2000	27181	9380	8999	1165	645	1353	255
2001	23998	8498	9673	1374	382	1283	184
2002	24227	8808	9187	1296	461	1135	247

Table 25. Port length-frequency sample sizes. The underlined values indicated were not extracted from raw length-frequency information.

The sample sizes for blue grenadier (1984–89) are set to nominal values of 500.

(a) Sex-aggregated

		1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
B. grenadier	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	164	40	1425	478	0	*500*	*500*	0	500	500	500
	4	0	0	0	0	0	0	0	0	0	500	500	0	0	500	0
E. gemfish	1	2550	417	2365	3069	7360	5542	3160	1440	4063	2250	761	1691	441	1238	1349
	2	1412	2178	7490	5407	5311	10075	16865	9843	8900	6512	7709	6718	8046	8999	9359
Pink ling	1	0	0	0	0	0	0	0	0	0	0	0	1957	4723	1233	0
	2	0	0	0	0	0	0	0	0	0	0	0	432	718	1137	59
	3	0	0	0	0	114	86	602	120	0	0	0	0	4007	3681	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S. warehou	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	1194	854	110
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M. dory	1	37	348	2603	555	0	0	0	62	189	499	109	577	2415	0	0
	2	629	669	1248	1808	0	0	0	3045	2519	1759	2052	2681	2915	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O. perch	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	32	168	461	118	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K. dory	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	30	0	47	40	0	0	0	0	2546	1659	697
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W. gemfish	3	0	0	0	0	0	105	1399	121	0	0	0	0	21273	15200	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 25 (continued)

(a) Sex-aggregated (continued)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
B. grenadier	0	394	1307	1050	433	50	567	631	1388	4579	3112	4114	1858
	0	74	117	0	29	0	0	477	190	1353	1068	398	841
	0	459	2408	437	8162	6888	4830	10083	14656	7354	9433	7447	6717
	0	0	774	0	1038	465	927	851	1648	10076	5629	7876	2476
E. gemfish	127	27	362	3483	1648	5281	1485	2244	2850	1672	1613	3107	1567
	4938	4870	4598	3012	0	4433	0	101	347	1592	994	3007	1344
Pink ling	402	100	0	0	0	57	0	102	928	1120	334	338	1945
	0	0	54	0	0	191	0	0	489	362	155	7	868
	0	0	399	0	0	784	1180	2340	1311	925	1364	2293	1829
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	4021	10319
S. warehou	0	246	439	542	110	241	883	1114	4272	4464	3949	6907	9254
	0	27	1209	545	105	259	131	648	2114	1883	3466	1051	3725
	0	51	1630	1702	1761	4002	5715	8874	9500	7799	5201	6849	9064
	0	0	139	40	41	649	308	0	204	50	106	129	0
M. dory	0	0	0	0	0	0	0	0	347	593	250	1936	710
	0	0	0	0	0	0	0	0	44	79	124	289	459
	0	0	0	0	0	0	0	164	0	0	0	36	103
	0	0	0	0	0	0	0	0	0	0	0	0	0
O. perch	0	0	0	214	0	0	0	0	1497	4007	3186	6107	2775
	0	0	0	0	0	0	0	0	628	1776	855	286	834
	0	0	0	159	0	0	133	0	0	154	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
K. dory	0	0	0	0	0	0	0	0	0	297	218	0	27
	0	25	0	0	0	0	0	0	0	91	0	0	0
	0	112	0	95	0	0	87	334	0	64	124	820	953
	0	0	0	0	0	0	0	0	0	0	0	0	0
W. gemfish	0	126	463	1605	8153	2495	4223	4604	5551	3312	5803	5263	3939
	0	0	0	0	76	0	0	0	0	0	0	0	0

Table 25 (continued)

(b) Males

		1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
B. grenadier	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. gemfish	2	0	0	0	0	0	*4672*	0	*4702*	*4107*	*3120*	*3841*	*3065*	*4152*	*4932*	*3936*
Pink ling	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
B. grenadier	0	0	0	0	0	0	0	0	0	*5929*	*2957*	*4255*	*1220*
E. gemfish	*2115*	*1893*	*1450*	*1134*	*1988*	*2290*	*6014*	*3105*	*5264*	*1186*	*936*	0	0
Pink ling	0	0	0	0	0	0	0	0	0	0	0	0	720

(c) Females

		1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
B. grenadier	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. gemfish	2	0	0	0	0	0	*5403*	0	*5143*	*4794*	*3392*	*3869*	*3655*	*3894*	*4067*	*5425*
Pink ling	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
B. grenadier	0	0	0	0	0	0	0	0	0	*4147*	*2672*	*3619*	*1255*
E. gemfish	*2823*	*2977*	*3150*	*2297*	*1119*	*2146*	*5488*	*4457*	*4609*	*1033*	*666*	0	0
Pink ling	0	0	0	0	0	0	0	0	0	0	0	0	694

Table 26. Specifications for the pre-specified parameters of the population dynamics model for each of the eight stocks.

Quantity	Blue grenadier[1]		Eastern gemfish	
	Females	Males	Females	Males
Natural mortality, M (yr^{-1})	0.2	0.25	0.4[2]	0.6[2]
Growth parameters				
ℓ_∞ (cm)	94.0	94.0	109.4[3]	97.5[3]
κ (yr^{-1})	0.2219	0.2219	0.18[3]	0.212[3]
t_0 (yr)	-1.09	-1.09	-0.63[3]	-0.54[3]
$\tilde{\sigma}_0$	0.173	0.173	0.116	0.141
$\tilde{\sigma}_{50}$	0.134	0.123	0.087	0.097
Length-weight – a	0.00375	0.00375	0.00143[4]	0.00143[4]
Length-weight – b	3.013	3.013	3.39[4]	3.39[4]
Age-at-maturity, a_m	5		A	
Fraction spawning, μ	0.77		1	
Maximum age, x	20		15	
Extent of recruitment variation, σ_R	1		0.6	
Stock-recruitment steepness, h^s	0.9		0.5	
Discard-related parameters				
Length-at-50%-retention, ϕ_{50}	54.69 cm		35.75 cm	
Length-at-50%-retention, ϕ_{95}	40.07 cm		26.40 cm	

1 – Punt *et al.* (2001a)

2 – Smith and Punt (1998)

3 – Rowling and Reid (1992)

4 – K. Rowling (NSW FRI, pers. commn)

A – Assumed to be the same as selectivity to the winter fishery (Smith and Punt, 1998)

Table 26 (continued)

Quantity	Pink Ling[1]		Spotted warehou[2]	
	Females	Males	Females	Males
Natural mortality, M (yr^{-1})	0.2	0.2	0.25	0.25
Growth parameters				
ℓ_∞ (cm)	109.96	109.96	50.69	50.69
κ (yr^{-1})	0.135	0.135	0.372	0.372
t_0 (yr)	-2.72	-2.72	-0.451	-0.451
$\tilde{\sigma}_0$	0.188	0.199	0.175	0.170
$\tilde{\sigma}_{50}$	0.145	0.137	0.045	0.030
Length-weight – a	0.0293	0.0293	0.0065	0.0065
Length-weight – b	3.139	3.139	3.27	3.27
Age-at-maturity, a_m	5 (67cm)		3 (37cm)	
Fraction spawning, μ	1		1	
Maximum age, x	25		15	
Extent of recruitment variation, σ_R	0.6		0.6	
Stock-recruitment steepness, h^s	0.75		0.75	
Discard-related parameters				
Length-at-50%-retention, ϕ_{50}	40.58 cm		30.48 cm	
Length-at-50%-retention, ϕ_{95}	31.83 cm		22.63 cm	

1 – Klaer (2003)

2 – Thomson (2002)

Table 26 (continued)

Quantity	Mirror dory		Ocean perch	
	Females	Males	Females	Males
Natural mortality, M (yr^{-1})	0.38[1]	0.38v	0.12[2]	0.1[2]
Growth parameters				
ℓ_∞ (cm)	60.9[1]	60.9[1]	42.87[2]	42.87[2]
κ (yr^{-1})	0.2[1]	0.2[1]	0.07[2]	0.07[2]
t_0 (yr)	0.18[1]	0.18[1]	-5.96[2]	-5.96[2]
$\tilde{\sigma}_0$	0.099	0.092	0.077	0.087
$\tilde{\sigma}_{50}$	0.099	0.092	0.077	0.087
Length-weight – a	0.0164[4]	0.0164[4]	0.0181[2]	0.0181[2]
Length-weight – b	3[4]	3[4]	2.997[2]	2.997[2]
Age-at-maturity, a_m	2		31 cm[3] (12.4)	
Fraction spawning, μ	1		1	
Maximum age, x	20		40	
Extent of recruitment variation, σ_R	0.6[5]		0.6[5]	
Stock-recruitment steepness, h^s	0.75[5]		0.75[5]	
Discard-related parameters				
Length-at-50%-retention, ϕ_{50}	34.27 cm		27.27 cm	
Length-at-50%-retention, ϕ_{95}	29.92 cm		24.40 cm	

1 – Smith and Stewart (1994)

2 – Smith and Wayte (2002)

3 – Lyle and Ford (1993)

4 – Robin Thomson (CSIRO, pers. commn)

5 – Default values

Table 26 (continued)

Quantity	King dory		Western gemfish	
	Females	Males	Females	Males
Natural mortality, *M* (yr^{-1})	0.1[1]	0.1[1]	0.25[3]	0.25[3]
Growth parameters				
ℓ_∞ (cm)	51.36[1]	51.36[1]	98.12[2]	98.12[2]
κ (yr^{-1})	0.1[1]	0.1[1]	0.19[2]	0.19[2]
t_0 (yr)	-0.83[1]	-0.83[1]	-1.0[2]	-1.0[2]
$\tilde{\sigma}_0$	0.059	0.077	0.128	0.142
$\tilde{\sigma}_{50}$	0.059	0.077	0.097	0.106
Length-weight – *a*	0.0771[2]	0.0771[2]	0.072[2]	0.072[2]
Length-weight – *b*	3.148[2]	3.148[2]	3.00[2]	3.00[2]
Age-at-maturity, a_m	12.5		60-70cm	
	(35-40cm)			
Fraction spawning, μ	1		1	
Maximum age, *x*	40		20	
Extent of recruitment variation, σ_R	0.6[3]		0.6[3]	
Stock-recruitment steepness, h^s	0.75[3]		0.75[3]	
Discard-related parameters				
Length-at-50%-retention, ϕ_{50}	22.46 cm		41.94 cm	
Length-at-50%-retention, ϕ_{95}	18.52 cm		29.39 cm	

1 – Smith and Stewart (1994)

2 – D.C. Smith (MSFRI), pers. commn.

3 – Default values

Table 27. Number of animals aged by stock.

	Sex	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
B. grenadier	M+F	0	0	0	0	767	603	174	514	531	502	0	193	1187	1362	1610	1344	1832	2338	2089	1574	2349	1953	1687
	M	0	0	0	0	389	349	96	133	226	211	0	135	672	826	836	559	1009	834	724	900	1265	848	885
	F	0	0	0	0	368	241	78	164	229	262	0	58	485	452	647	751	642	663	971	674	1073	990	802
E. gemfish	M+F	1278	0	1752	0	870	0	1297	0	562	0	554	1144	65	526	498	0	0	595	521	202	0	0	0
	M	507	0	800	0	344	0	551	0	257	0	314	422	55	139	192	0	0	244	265	104	0	0	0
	F	771	0	952	0	526	0	746	0	305	0	240	722	6	377	256	0	0	349	256	98	0	0	0
Pink ling	M+F	0	0	0	0	491	0	0	567	327	190	0	0	0	65	237	1110	1029	1163	879	1366	565	876	732
	M	0	0	0	0	192	0	0	208	164	90	0	0	0	21	45	525	405	556	316	668	330	393	245
	F	0	0	0	0	153	0	0	279	148	95	0	0	0	40	96	498	489	563	432	602	234	466	463
S. warehou	M+F	0	0	0	0	0	0	0	456	140	0	0	0	0	370	359	451	515	566	585	903	470	997	627
	M	0	0	0	0	0	0	0	221	59	0	0	0	0	159	132	130	197	295	281	402	210	482	251
	F	0	0	0	0	0	0	0	235	76	0	0	0	0	184	158	292	270	267	271	452	258	510	340
M. dory	M+F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	399	77	0	0
	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	6	0	0
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	325	71	0	0
O. perch	M+F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	507	111	121	0
	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	225	47	46	0
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	231	64	74	0
W. gemfish	M+F	0	0	0	0	0	0	0	0	0	0	0	0	10	133	133	498	312	0	0	0	0	464	494
	M	0	0	0	0	0	0	0	0	0	0	0	0	2	86	39	72	45	0	0	0	0	79	87
	F	0	0	0	0	0	0	0	0	0	0	0	0	8	17	33	346	122	0	0	0	0	383	399

Table 28. Number of otoliths for which multiple age-readings are available (by stock) and the estimates for the parameters of the model for age-reading error.

Stock	Number of otoliths	CV-1 (age)	CV-2 (age)	CV-3 (age)
Blue grenadier	3789	0.163 (1)	0.063 (11)	0.113 (22)
Eastern gemfish	372	0.242 (1)	0.109 (6)	0.341 (13)
Pink ling	1401	0.207 (1)	0.042 (14)	0.151 (28)
Spotted warehou	1114	0.161 (1)	0.098 (9)	0.145 (18)
Mirror dory	119	0.118 (1)	0.137 (5)	0.043 (10)
Ocean perch	217	0.121 (1)	0.021 (20)	0.220 (40)
King dory	N/A			
Western gemfish	401	0.175 (1)	0.116 (5)	0.054 (10)

Chapter 5: An Approach to Informing 'Data-Poor' Species Using Information for 'Data-Rich' Species

Introduction

Stock assessment methods are used to provide estimates of a variety of quantities for use in fisheries management. These quantities include historical and current biomass, the ratio of the current biomass to some historical, target or limit biomass, and the implications of future sequences of catches or levels of fishing effort. Stock assessment methods such as production models, yield-per-recruit analysis, and separable population analysis were designed for application to single stocks based on the data for the stock concerned and for that stock only. In recent years, however, two ways have arisen in which allowance can be made for the data for one stock to influence the results of stock assessments for other stocks.

The first of these ways relates to the use in assessments of prior probability distributions. Prior probability distributions can be used to summarize the information about the value of a particular parameter based on the results of assessments of other stocks/species. Prior probability distributions are used most naturally and straightforwardly when conducting stock assessments using Bayesian methods (e.g. McAllister *et al.*, 1994; Punt and Hilborn, 1997; McAllister and Kirkwood, 1998; Ianelli *et al.*, 2000) although prior distributions can also be incorporated in non-Bayesian assessments by using them as penalty functions (Punt and Hilborn, 1996; Schweder and Ianelli, 1998) or as bounds (Punt and Butterworth, 2002). As noted in Chapter 3 Results and discussion – Impact of covariates, prior distributions based on the results of analyses for other stocks/species are already available for a variety of model parameters, including the steepness of the stock-recruitment relationship, the variability about the stock-recruitment relationship, and survey selectivity.

The second way in which the results from the assessments of one stock can influence those of another stock occurs when multiple stocks are assessed simultaneously. For example, Francis *et al.* (2002) assess the two stocks of blue grenadier off New Zealand within the same assessment framework because some of the indices of abundance (e.g. the surveys on the Chatham Rise) pertain to both stocks. Similarly, Punt *et al.* (2000) conducted assessments of the school shark, *Galeorhinus galeus*, off southern Australia using a population dynamics model that includes two stocks. Pribac *et al.* (in press) assess the gummy shark population, *Mustelus antarcticus*, off southern Australia using an assessment model in which some of the key population dynamics parameters (such as the Maximum Sustainable Yield rate, *MSYR*) are the same for several stocks of gummy shark.

The approaches taken by Francis *et al.* (2002), Punt *et al.* (2000), and Pribac *et al.* (in press) all involve multiple stocks of the same species. This chapter extends this by assessing multiple stocks of several species simultaneously. It is clearly not possible to share values of parameters (such as the age-at-maturity) among different species. However, it seems plausible that if multiple stocks/species are exploited by the same fleet (where fleet is defined as a group of vessels fishing in the essentially the same fishing grounds at the same time), the trend in fishing mortality for that fleet should be similar for all of the stocks/species. This assumption is the same as that which underlies multi-species yield-per-recruit analysis (e.g. Murawski, 1996; Pikitch, 1987). It is not only trends in fishing mortality by fleet which might be expected to be common across stocks/species. It also seems likely that the annual deviations in recruitment about the stock-recruitment relationship for different stocks/species would be correlated (positively or negatively) due to the impact of common environmental variables, and that selectivity as a function of length (before discarding) should be relatively similar across various fleets.

Although it seems plausible that, for example, selectivity-at-length for a given fleet should be similar across stocks/species, there are also good reasons related to the behaviour of fishers and fish, why, for example, selectivity-at-length for different stocks/species should not be identical. The approach outlined below therefore allows for stock-specific values for all of the model parameters, but adds penalties on how different the values for these parameters may be across stocks.

The difference between the conventional approach to conducting fisheries stock assessments and that developed in this project is highlighted in Figs 48a and 48b. Figure 48a shows how assessments for multiple stocks are conducted conventionally - the objective function minimized to obtain the point estimates for the model parameters is the sum of stock-specific objective functions. As a result, the same answers would be obtained irrespective of whether the assessments are conducted simultaneously or separately. Figure 48b shows how the assessments of this chapter are conducted. The objective function minimized contains contributions for the fit to the data for each stock, but there are also contributions to the objective function related to the differences in selectivity-at-length among fleets, the deviations about the stock-recruitment relationship among stocks, and the pattern of fishing mortality over time among fleets. As a result, this approach to stock assessment has to be applied to all stocks simultaneously.

This chapter first outlines a multi-stock, multi-fleet population dynamics model and the objective function that is minimized to estimate the values for the parameters of this model. This objective function consists of contributions from the data available for assessment purposes and the penalties on inter-stock/species deviations in fishing mortality, selectivity and the recruitment deviations. This model is then fitted to the data for eight stocks (based on seven species) in Australia's SESS[3]. Results are shown based on minimizing the objective function and by applying the Markov Chain Monte Carlo algorithm to generate a set of equally likely parameter values from the posterior distribution.

The population dynamics model

Basic dynamics

The dynamics of the each of the stocks included in the assessment are assumed to be governed by the standard age-structured equations, i.e.:

$$N^{g,s}_{y+1,a} = \begin{cases} 0.5\,R^{s}_{y+1} & \text{if } a = 0 \\ (N^{g,s}_{y,a-1}e^{-M^{g,s}/2} - \sum\limits_{f}^{n_f} C^{g,s,f}_{y,a-1})e^{-M^{g,s}/2} & \text{if } 1 \le a < x \\ ((N^{g,s}_{y,x-1} + N^{g,s}_{y,x})e^{-M^{g,s}/2} - \sum\limits_{f}^{n_f} \{C^{g,s,f}_{y,x-1} + C^{g,s,f}_{y,x}\})e^{-M^{g,s}/2} & \text{if } a = x \end{cases} \qquad (5.1)$$

where	$N^{g,s}_{y,a}$	is the number of animals of stock *s*, sex *g* and age *a* at the start of year *y*,
	$M^{g,s}$	is the instantaneous rate of natural mortality on animals of stock *s* and sex *g* (assumed to be independent of age and time),
	$C^{g,s,f}_{y,a}$	is the catch (in numbers) of fish of stock *s*, sex *g* and age *a* by fleet *f* during year *y*,
	R^{s}_{y}	is the recruitment to stock *s* during year *y*,
	n_f	is the number of fleets, and

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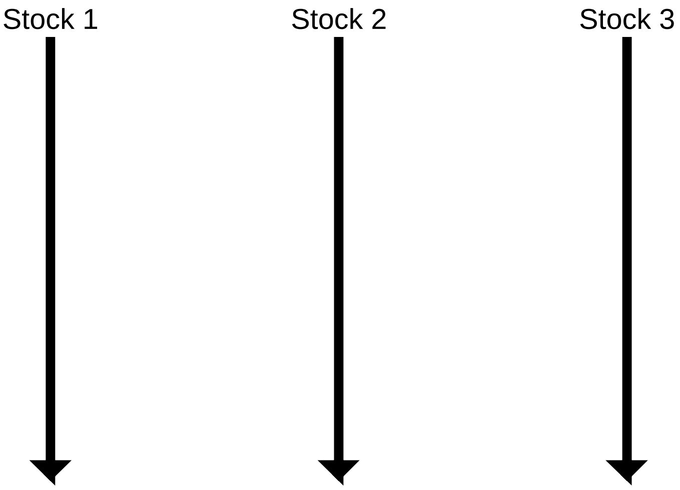
[3] This example effectively combines the three case studies by considering multiple species and multiple areas.

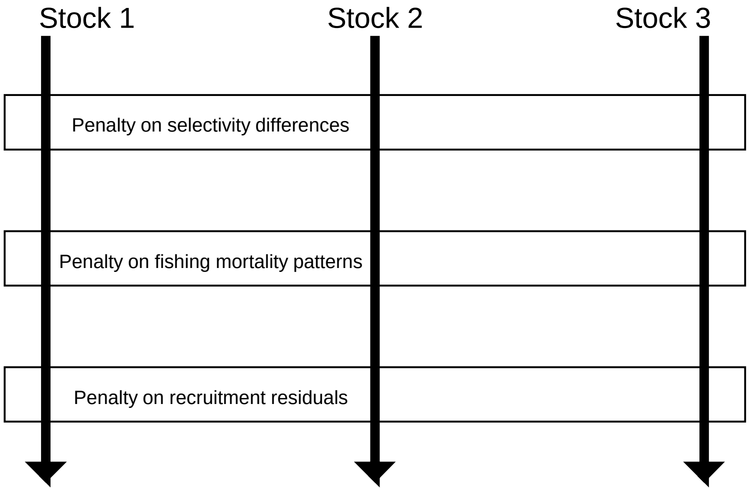
x is the maximum age-class (treated as a plus-group)[4].

a) Conventional approach



The objective function is the sum of the contributions by data for each stock

b) Multi-stock approach of this report



The objective function is the sum of the contributions by data for each stock plus inter-stock differences in fishing pattern, selectivity and recruitment

Figure 48. Comparison of how the objective function is developed for the conventional approach to fisheries stock assessment and that of the approach of this paper.

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[4] x is taken to be independent of stock. This assumption can be made without a loss of generality.

Stock and recruitment

The number of zero-year-olds added to the population each year is assumed to be governed by a stochastic version of the Beverton-Holt stock-recruitment relationship:

$$R_y^s = \frac{4h^s R_0^s S_y^s}{(1-h^s)S_0^s + (5h^s - 1)S_y^s} e^{\varepsilon_y^s - (\sigma_R^s)^2/2} \qquad (5.2)$$

where R_0^s is the expected number of zero-year-olds (of both sexes) in stock *s* in the absence of exploitation,

S_y^s is the spawning biomass of stock *s* at the start of year *y*:

$$S_y^s = \mu^s \sum_{a=1}^{x} f_a^s N_{y,a}^{\mathrm{f},s} \qquad (5.3)$$

f_a^s is the fecundity of an animal of stock *s* and age *a*,

μ^s is the proportion of mature females of stock *s* that spawn each year,

h^s is the steepness of the stock-recruitment relationship (the fraction of R_0^s to be expected when the spawning biomass is reduced to $0.2\,S_0^s$) for stock *s*,

ε_y^s is the deviation during year *y* about the stock-recruitment relationship for stock *s* (the recruitment residual for stock *s* and year *y*), and

σ_R^s is the extent of variability in recruitment about the stock-recruitment relationship.

Catches

The total catch (in numbers) by fleet, year, stock, sex and age-class is given by:

$$C_{y,a}^{g,s,f} = F_y^{s,f} S_a^{g,s,f} \left(N_{y,a}^{g,s} e^{-M^{g,s}/2} - \sum_{f'<f} C_{y,a}^{g,s,f'}\right) \qquad (5.4)$$

where $S_a^{g,s,f}$ is the selectivity of fleet *f* on animals of stock *s*, sex *g* and age *a* (assumed to be time-invariant),

$F_y^{s,f}$ is the exploitation rate on fully selected (i.e. $S_a^{g,s,f} \to 1$) animals of stock *s* by fleet *f* during year *y*, i.e.:

$$F_y^{s,f} = \tilde{C}_y^{s,f} / B_y^{e,s,f} \qquad (5.5)$$

$B_y^{e,s,f}$ is the exploitable biomass of stock s in year y prior to removal of the catch by fleet f:

$$B_y^{e,s,f} = \sum_g \sum_{a=0}^{x} w_{a+1/2}^{g,s} (1-\phi_a^{g,s,f}) S_a^{g,s,f} (N_{y,a}^{g,s} e^{-M^{g,s}/2} - \sum_{f'<f} C_{y,a}^{g,s,f'}) \tag{5.6}$$

$\tilde{C}_y^{s,f}$ is total catch (in weight) by fleet, year and sex,

$w_{a+1/2}^{g,s}$ is the weight of a fish of stock s, sex g, and age a in the middle of the year, and

$\phi_a^{g,s,f}$ is the fraction of the catch by fleet f of animals of stock s, sex g and age a that is discarded.

The model (Equations 5.1 and 5.6) assumes that the catch is taken in a pulse in the middle of the year and that the catches by each fleet are taken sequentially (i.e. the fisheries are assumed to be gauntlet fisheries). These assumptions are made to avoid having to treat the fully-selected exploitation rate for each year, fleet and stock as estimable parameters.

The landed and discarded total catches (in numbers and weight respectively) are:

$$C_{y,a}^{\mathrm{L},g,s,f} = (1-\phi_a^{g,s,f}) C_{y,a}^{g,s,f}\ ; \qquad C_{y,a}^{D,g,s,f} = \phi_a^{g,s,f}\, C_{y,a}^{g,s,f} \tag{5.7a}$$

$$\tilde{C}_y^{\mathrm{L},s,f} = \sum_g \sum_{a=1}^{x} w_{a+1/2}^{g,s}\, C_{y,a}^{\mathrm{L},g,s,f}\ ; \quad \tilde{C}_y^{\mathrm{D},s,f} = \sum_g \sum_{a=1}^{x} w_{a+1/2}^{g,s}\, C_{y,a}^{\mathrm{D},g,s,f} \tag{5.7b}$$

Selectivity and discarding

Two general selectivity[5] patterns (logistic and normal) are available. These two patterns allow the analyst to specify that selectivity is either asymptotic (logistic) or domed-shaped (normal). The logistic selectivity model (Equation 5.8a) can be used to represent situations in which the probability of capturing an animal increases ($L_{95}^{s,f} > L_{50}^{s,f}$) or decreases ($L_{50}^{s,f} > L_{95}^{s,f}$) with length while two variants of the normal selectivity model (Equation 5.8b) are available depending on whether the selectivity pattern is assumed to be symmetric ($\Omega_L^{s,f} = \Omega_R^{s,f}$) or not ($\Omega_L^{s,f} \neq \Omega_R^{s,f}$).

$$S_a^{g,s,f} = [1+\exp(-\ell n 19 \tfrac{L_{a+1/2}^{g,s} - L_{50}^{s,f}}{L_{95}^{s,f} - L_{50}^{s,f}})]^{-1} \tag{5.8a}$$

where $L_{50}^{s,f}$ is the length-at-50%-selectivity for fleet f on fish of stock s,

$L_{95}^{s,f}$ is the length-at-95%-selectivity for fleet f on fish of stock s, and

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[5] The term ‘Selectivity’ is used here. In fact, the ‘selectivity’ is the combined impact of availability and gear selectivity.

$L_a^{g,s}$ is the expected length of a fish of stock *s*, sex *g* and age *a* (given by a von Bertalanffy growth equation).

$$S_a^{g,s,f} = \begin{cases} \exp[-(L_{a+1/2}^{s,f} - \bar{L}^{s,f})^2 / \Omega_L^{s,f}] & \text{if } L_{a+1/2}^{s,f} \le \bar{L}^{s,f} \\ \exp[-(L_{a+1/2}^{s,f} - \bar{L}^{s,f})^2 / \Omega_R^{s,f}] & \text{otherwise} \end{cases} \tag{5.8b}$$

where $\bar{L}^{s,f}$ is the length corresponding to maximum selectivity for fleet *f* when fishing stock *s*,

$\Omega_L^{s,f}$ is the parameter that determines how rapidly selectivity for fleet *f* increases with length for stock *s*, and

$\Omega_R^{s,f}$ is the parameter that determines how rapidly selectivity for fleet *f* declines with length for stock *s*.

This formulation for selectivity assumes that the probability of capture is a function primarily of the length (rather than the age) of an animal. It also assumes that selectivity is only sex-specific to the extent that growth is sex-specific.

The probability of fleet *f* discarding an animal of stock *s*, sex *g* and age *a* is assumed to be a function of length, i.e.:

$$\phi_a^{g,s,f} = [1 + \exp(-\ell n 19 \tfrac{L_a^{g,s} - \phi_{50}^{s,f}}{\phi_{95}^{s,f} - \phi_{50}^{s,f}})]^{-1} \tag{5.9}$$

where $\phi_{50}^{s,f}$ is the length at which 50% of animals of stock *s* are discarded by fleet *f*,

$\phi_{95}^{s,f}$ is the length at which 95% of animals of stock *s* are discarded by fleet *f*.

The analyses of this chapter are based on the assumption that the probability of a fish being discarded as a function of length is independent of fleet. This assumption is based on the results in Figure 42.

Initial conditions

The initial conditions correspond to a population at its deterministic unfished level with the corresponding age-structure, i.e.:

$$N_{y_1,a}^{g,s} = \begin{cases} 0.5 R_0^s \, e^{-aM^{g,s}} & \text{if } 0 \le a < x \\ 0.5 R_0^s \, e^{-xM^{g,s}} / (1 - e^{-M^{g,s}}) & \text{if } a = x \end{cases} \tag{5.10}$$

where y_1 is the first year for which catches are available.

The objective function

The objective function includes contributions from the data available for assessment purposes (discard rates, fishery landed age-composition data, fishery landed size-composition data, survey estimates of female spawning biomass, and catch-rates) and priors (penalties) imposed on the recruitment residuals, selectivity, steepness, and fishing mortality.

The likelihood function

The equations listed below assume that data for each data-type are available for every year, every stock and every fleet. This is not the case in reality and the equations are modified appropriately in the absence of data for specific years, stocks, and fleets.

Discard rates

The contribution of the estimates of discard rate (in mass) by fleet, stock and year to the negative of the logarithm of the likelihood function is based on the assumption that the errors in measuring discard rate are log-normal, i.e.:

$$\ell \mathrm{n} L_1 = \sum_s \sum_f \sum_y \left(\ell \mathrm{n} \sigma_d^{s,f} + \frac{1}{2(\sigma_d^{s,f})^2} [\ell \mathrm{n} D_y^{s,f} - \ell \mathrm{n} D_y^{obs,s,f}]^2 \right) \tag{5.11}$$

where D_y is the model-estimate of the fraction of the catch of stock *s* by fleet *f* that was discarded during year *y*:

$$D_y^{s,f} = \frac{\tilde{C}_y^{D,s,f}}{\tilde{C}_y^{L,s,f} + \tilde{C}_y^{D,s,f}} \tag{5.12}$$

$D_y^{obs,s,f}$	is the observed fraction of the catch (in mass) of stock *s* by fleet *f* that was discarded during year *y* (Table 22a), and
$\sigma_d^{s,f}$	is (approximately) the coefficient of variation of the discard rates for stock *s* and fleet *f* (Table 22b).

Age- and size-composition data

The contribution of the age- and size-composition data (the proportion of the catch that is landed by age-/size-class by fleet, stock and year) to the negative of the logarithm of the likelihood function is based on the robust likelihood formulation of Fournier *et al.* (1990). The contribution of the age-/size-composition data for stock *s*, fleet *f* and year *y* to the negative of the logarithm of the likelihood function is therefore given by:

$$\ell \mathrm{n} L_2^{s,f,y} = -\sum_i \ell \mathrm{n} \left[\exp \left\{ \frac{-(\rho_i - \rho_i^{obs})^2}{2[(1-\rho_i^{obs})\rho_i^{obs} + \frac{0.1}{N_I}]\tau^2} \right\} + 0.01 \right] \tag{5.13}$$

where	ρ_i^{obs}	is the observed proportion of the landed catch in age-/size-class *i*,
	ρ_i	is the model-estimate of the proportion of the landed catch in age-/size-class *i*,
	N_I	is the number of age-/size-classes, and
	τ^2	is the inverse of minimum of the sample size and 1000.

The model-estimates used in Equation 5.13 depend on whether the data are age- or size-composition data:

$$\begin{aligned}\rho_{t,a}^{g,s,f} &= \sum_{a''} Y_{a'',a}^{s}\, C_{y,a''}^{L,s,g,f} \Big/ \sum_{a'} C_{y,a'}^{L,s,g,f} && \text{age-composition data} \\ \rho_{t,l}^{g,s,f} &= \sum_{a} X_{a,l}^{g,s}\, C_{y,a}^{L,s,g,f} \Big/ \sum_{a'} C_{y,a'}^{L,s,g,f} && \text{size-composition data}\end{aligned} \qquad (5.14)$$

where $X_{a,l}^{g,s}$ is the probability that an animal of stock *s*, sex *g* and age *a* is in size-class *l*,

$$X_{a,l}^{g,s} = \int_{\bar{L}_l-\Delta L/2}^{\bar{L}_l+\Delta L/2} \frac{1}{\sigma_a^{g,s}\,\ell\sqrt{2\pi}} e^{-\frac{(\ell n\ell-\ell nL_{a+1/2}^{g,s})^2}{2(\sigma_a^{g,s})^2}}\, d\ell \qquad (5.15)$$

$\bar{L}_l$ is the midpoint of the *l*th length-class,

ΔL is the width of each length-class,

$\sigma_a^{g,s}$ is the coefficient of variation of the length of a fish of stock *s*, sex *g*, and age *a*, and

$Y_{a'',a}^{s}$ is the age-reading error matrix (the probability that an animal of actual age *a′* is aged to be age *a*).

The upper and lower limits of the summation in Equation 5.13 are not necessarily the youngest and oldest age-classes and the smallest and largest size-classes. Rather, age- and size-classes may be pooled to increase sample size.

Estimates of spawning biomass

The contribution of the estimates of spawning biomass for stock *s* to the negative of the logarithm of the likelihood function is given by:

$$\ell nL_3 = \sum_{y} (S_y^s - B_y^{obs,s})^2 / (2(\sigma_y^s)^2) \qquad (5.16)$$

where $B_y^{obs,s}$ is the estimate of female spawning biomass for stock *s* and year *y*, and
σ_y^s is the standard error of $B_y^{obs,s}$.

Catch-rate series

The contribution of the catch-rate data to the negative of the logarithm of the likelihood function is based on the assumption that fluctuations in catchability are independent and log-normally distributed with a coefficient of variance of $\sigma_q^{s,f}$:

$$\ell nL_4 = \frac{1}{2(\sigma_q^{s,f})^2} \sum_{s}\sum_{f}\sum_{y} (\ell nI_y^{s,f} - \ell n[q^{s,f} B_y^{e,s,f}(1-F_y^{s,f}/2)])^2 \qquad (5.17)$$

where $q^{s,f}$ is the catchability coefficient for stock *s* and fleet *f*,
$I_y^{s,f}$ is the catch-rate index for stock *s*, fleet *f* and year *y*, and
$\sigma_q^{s,f}$ is (approximately) the coefficient of variation of the random fluctuations in catchability.

The penalty functions

Recruitment residuals

The recruitment residuals are assumed to be normally distributed and correlated among stocks/species, i.e.:

$$P_1 = \tfrac{1}{2} \sum_y \underline{\varepsilon}_y^T \, \mathbf{V}^{-1} \, \underline{\varepsilon}_y \tag{5.18}$$

where V is a variance-covariance matrix, i.e. for three stocks/species:

$$\mathbf{V} = \begin{pmatrix} (\sigma_R^1)^2 & \tau^{1,2}\,\sigma_R^1\,\sigma_R^2 & \tau^{1,3}\,\sigma_R^1\,\sigma_R^3 \\ \tau^{1,2}\,\sigma_R^1\,\sigma_R^2 & (\sigma_R^3)^2 & \tau^{2,3}\,\sigma_R^2\,\sigma_R^3 \\ \tau^{1,3}\,\sigma_R^1\,\sigma_R^3 & \tau^{2,3}\,\sigma_R^2\,\sigma_R^3 & (\sigma_R^3)^2 \end{pmatrix} \tag{5.19}$$

$\tau^{i,j}$ is the *apriori* correlation between the recruitment residuals for stock/species *i* and those for stock/species *j*.

Selectivity deviations

A penalty is placed on the differences for each fleet in the length-at-50% selectivity among stocks:

$$P_2 = \frac{1}{2\sigma_S^2} \sum_s \sum_f (L_{50}^{s,f} - \overline{L}_{50}^{f})^2 \tag{5.20}$$

where $\overline{L}_{50}^{f}$ is mean (across stocks) length-at-50%-selectivity for fleet *f*, and

σ_S^2 is the between-stock variance in the length-at-50%-selectivity.

Fishing mortality deviations

A penalty is placed on the relative trend in fishing mortality:

$$P_3 = \omega \sum_f \sum_s \sum_y (F_y^{s,f} / \overline{F^{s,f}} - \overline{\overline{F_y^f}})^2 \tag{5.21}$$

where ω is the weight assigned the fishing mortality penalty,

$\overline{F^{s,f}}$ is the mean (over years) exploitation rate by fleet *f* on stock *s*, and

F_y^f is the mean (over years) value of $F_y^{s,f} / F^{s,f}$.

Steepness

The penalty placed on the steepness of the stock recruitment relationship for each stock is based on assumption that the logit of (*h*-0.2)/0.8 is normally distributed, i.e.

$$P_4 = \sum_s \left(\frac{[\ell\mathrm{n}(\{1-h^s\}/\{h^2-0.2\}) - \mu^s]^2}{2(\sigma_h^s)^s} \right) \tag{5.22}$$

An example application

The example application is based on seven species (blue grenadier, gemfish, pink ling, spotted warehou, mirror dory, king dory, and offshore ocean perch). Gemfish has been divided into two stocks (eastern and western) for assessment and management purposes (Rowling, 1994) so the example application is based on a total of eight stocks. The five fleets (and the rationale for their selection) are described in Chapter 4. Chapter 4 outline the data on which the example application is based.

Parameterization

Table 29 lists the parameters of the population dynamics model and how each parameter is treated in the example application. Several of the parameters that could potentially be estimated by fitting the model (e.g. natural mortality) are pre-specified for the purposes of the example application.

The number of selectivity patterns and the form of each selectivity pattern (logistic or normal) was chosen based on preliminary analyses (using AIC to select the most parsimonious, yet adequate, model for selectivity). The selectivity patterns assumed are as follows:

1. Blue grenadier. Two selectivity patterns are estimated: (a) a domed-shaped (three parameter normal) selectivity function for fleets 1-3, and (b) an asymptotic (increasing with length) selectivity function for fleets 4 and 5.
2. Eastern gemfish. Two selectivity patterns are estimated: (a) an asymptotic (declining with length) selectivity function for fleet 1, and (b) an asymptotic (increasing) selectivity function for fleets 2 and 5.
3. Pink ling. Three selectivity patterns are estimated: (a) an asymptotic (increasing with length) selectivity function for fleets 1 and 2, (b) an asymptotic (increasing with length) selectivity function for fleets 3 and 4, and (c) an asymptotic (increasing with length) selectivity function for fleet 5.
4. Spotted warehou. Two selectivity patterns are estimated: (a) an asymptotic (increasing with length) selectivity function for fleet 1, and (b) an asymptotic (increasing with length) selectivity function for fleets 2 – 5.
5. Mirror dory: A single selectivity pattern (asymptotic logistic function) is estimated and applied to all fleets.
6. Ocean perch: A single selectivity pattern (asymptotic logistic function) is estimated and applied to all fleets.
7. King dory: A single selectivity pattern (asymptotic logistic function) is estimated and applied to all fleets.
8. Western gemfish: A single selectivity pattern (asymptotic logistic function) is estimated and applied to all fleets.

A greater number of selectivity patterns are estimated for the 'data-rich' and 'data-moderate' stocks than for the 'data-poor' stocks. This does not necessarily imply that selectivity is independent of fleet for the 'data-poor' stocks, but rather than the data for these stocks are insufficient to support estimation of more than one selectivity pattern.

Model fitting

The age- and length-frequency data are pooled at young ages / small sizes and large ages / large sizes. The specifications for these groups were chosen to avoid large numbers of age- and length-classes with virtually no data. The stock-specific plus- and minus-groups are listed along with the effective sample sizes used when weighting the age- and length-frequency data in Table 30. The effective sample sizes in Table 30 were chosen so that the realized effective sample sizes were similar to those assumed when fitting the model. The value assumed for τ^2 for each year, fleet and stock (see Equation 5.13) is calculated using the formula:

$$(\tau^2)_y^{s,f} = 1/(\tilde{N}^{s,f}\, Q_y^{s,f} / \overline{Q}^{s,f}) \tag{5.23}$$

where	$\tilde{N}^{s,f}$	is the effective sample size for stock *s* and fleet *f*,
	$Q_y^{s,f}$	is the number of fish measured / aged for stock *s* and fleet *f* during year *y*, and
	$\overline{Q}^{s,f}$	is average number of fish measured / aged for stock *s* and fleet *f*.

The coefficients of variation assumed for each of the catch-rate series are listed in Table 31. The example application downweighted the contribution of the discard rate data by 0.001 because the model was not able to mimic these data well.

The results for the example application are based solely on sex-aggregated data (i.e. the sex-specific length-frequency information for eastern gemfish and blue grenadier are ignored). Also, even though length-frequency data for blue grenadier, pink ling and spotted warehou exist for some years and fleets for which age-length keys are not available, the number of years is very low. These length-frequency data are therefore also ignored when fitting the models

The results for four variants of the assessment model are reported to enable the impact of different assumptions regarding how the modeling framework can be applied to be examined. The factors considered in these four models (Table 32) are: a) whether penalties are placed on between-stock fishing mortality and between-stock selectivity-at-length, b) whether steepness is estimated or pre-specified, and c) whether the catch-rate data for mirror dory and the recent catch-rate series for eastern and western gemfish are included in the analyses. None of the analyses allow for between-stock correlation in the deviations about the stock-recruitment relationship (i.e. $\tau^{i,j}=0$ for all of the analyses of this chapter).

The results of the various models can be compared to address the following questions:

a) What are implications of including between-stock penalties when assessing multiple stocks simultaneously (model A (the ‘base-case’ model) vs. model B)?

b) What are implications of estimating rather than pre-specifying the value for the steepness of the stock-recruitment relationship (model A vs. model C)?

c) What are implications of ignoring the catch rate data for mirror dory and eastern and western gemfish (model A vs. model D)?

The third of these questions provides a way to determine whether allowing for between-stock constraints can compensate for a lack of catch-rate data (the primary source of information in trends in abundance for SESSF species). Although CPUE series are available for mirror dory and western gemfish, these are omitted from models A-C so that these two species are 'data-poor' in that there is no direct information on relative abundance for them.

The penalties for the models which impose between-stock constraints (models A, C and D) are:

1. Length-at-50%-selectivity. A constraint is placed in the difference between the length-at-50%-selectivity for eastern gemfish (fleet 1) and western gemfish (all fleets). The value of σ_S^- (see Equation 5.20) is assumed to be equal to 0.05 so that considerable weight is assigned to this penalty.
2. Fishing pattern over time. Two constraints of this type are considered:

a Fishing by fleet 2 on eastern gemfish, pink ling, mirror dory and ocean perch.

b Fishing by fleet 3 on blue grenadier, king dory and western gemfish.

The value of the weight assigned to this penalty (ω - see Equation 5.21) is assumed to be 10.

Quantifying uncertainty

The variances for the estimates of the model parameters and for the other quantities of interest are determined using Bayesian methods. The Metropolis-Hastings variant of the Markov-Chain Monte Carlo (MCMC) algorithm was used to sample 1,800 equally likely parameter vectors from the joint posterior density function. The samples on which inference is based were generated by running 5,000,000 cycles of the MCMC algorithm, discarding the first 500,000 as a burn-in period and selecting every 2,500th parameter vector thereafter. The initial parameter vector was taken to be the vector of maximum posterior density (MPD) estimates.

Preliminary analyses suggested that it was unlikely that the MCMC algorithm would generate samples which adequately reflect the posterior distribution (in the sense of satisfying the statistics and diagnostic plots commonly used to evaluate convergence of the MCMC algorithm (see Chapter 3: Results and Discussion). Therefore, in addition to evaluating uncertainty using Bayesian methods, an approach based on approximating the variance-covariance matrix by inverting the Hessian matrix at the point corresponding to the MPD estimates was applied. Standard deviations (and hence 90% confidence intervals) were determined for the logarithms of the annual spawning biomass estimates and the annual ratios of spawning biomass to spawning biomass at the start of 1968. The adequacy of these standard deviations depends critically on the extent to which the objective function is quadratic near its minimum.

Results

Ability to mimic the data

The evaluation of the ability to mimic the data is based on model D rather the 'base-case' model (model A) or one of the other two models. This is because: a) this model fits to the largest data set (unlike models A-C, the catch-rate data for mirror dory and eastern and western gemfish are included when estimating the values for the model parameters for model D) thereby increasing the chance of conflicts among the various data sources, b) model D includes more penalties than model B), and c) model D has fewer parameters than model C).

Figure 49 plots the observed and model-predicted catch-rate series. The bars in Figure 49 are the 95% confidence intervals based on the assumed residual standard deviations (Table 33).

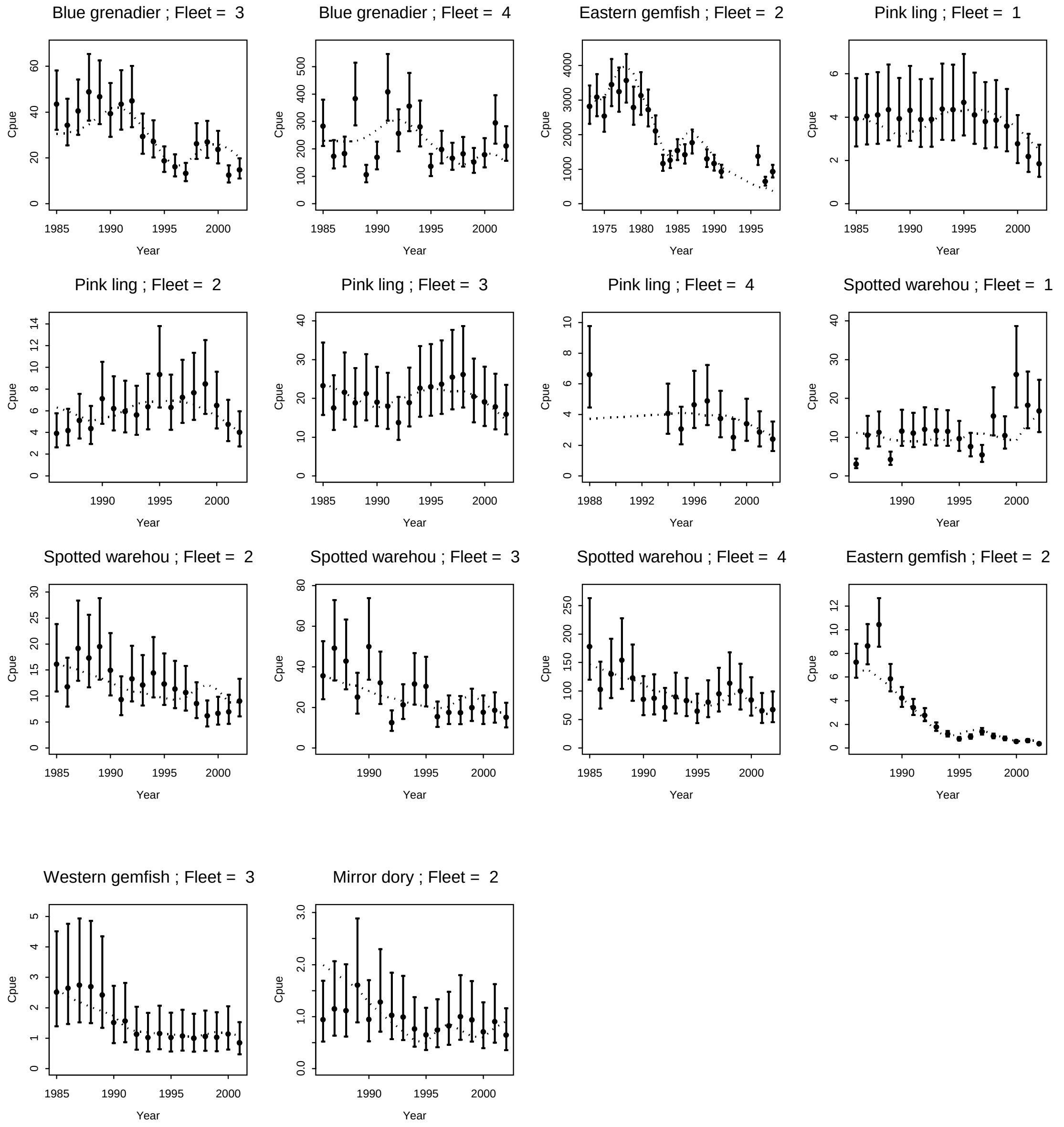


Figure 49. Observed and model predicted catch-rate series. The model-predictions are based on model D.

It is difficult to evaluate the ability to mimic the catch-rate data based on Figure 49. Figure 50 therefore provides the same information as Figure 49, except that results are shown without the confidence intervals for the data and in terms of observed versus model-predicted catch-rates.

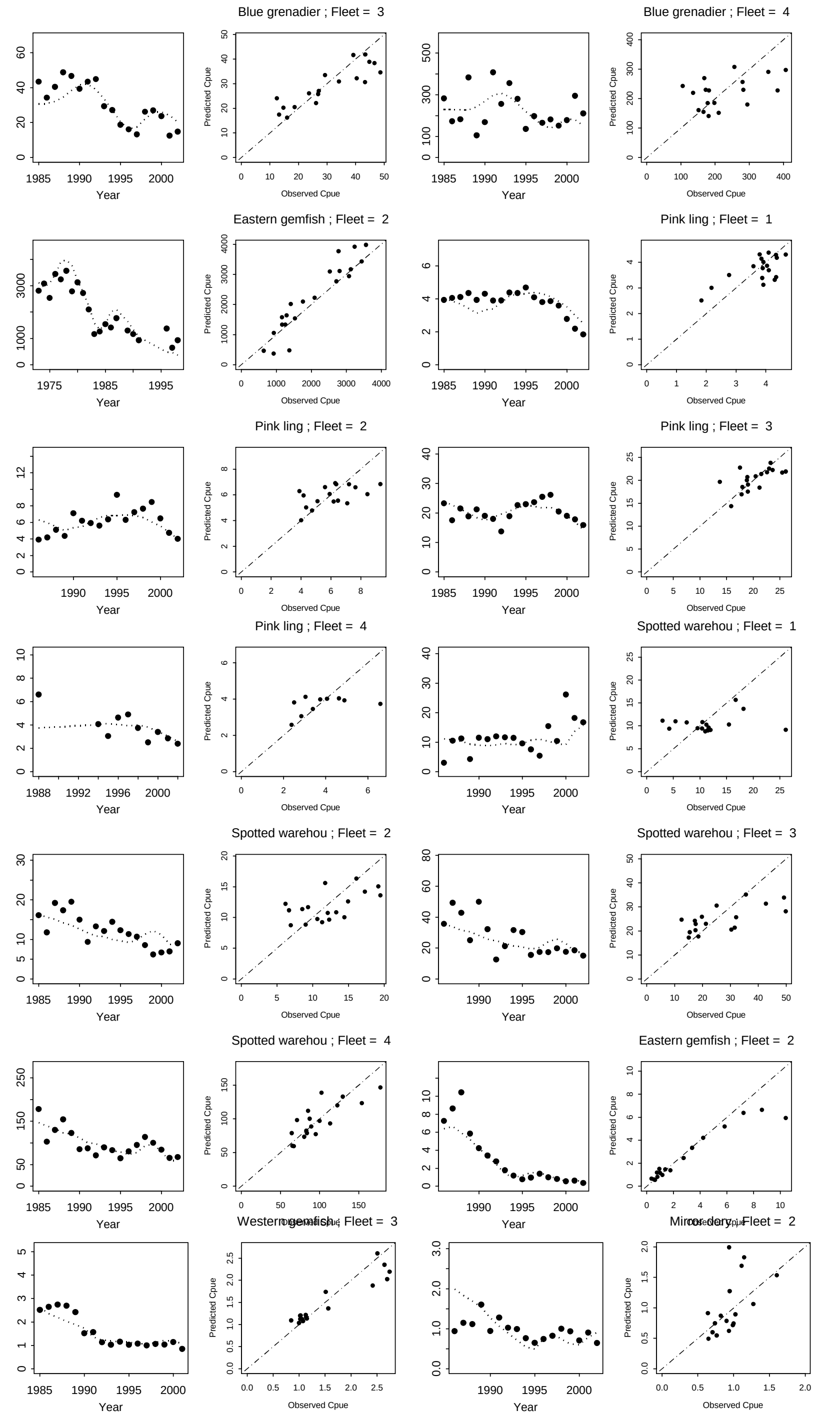


Figure 50. Observed and model predicted catch-rate series. The model-predictions are based on model D.

Whether the model is able to mimic the data for a catch-rate series adequately can be evaluated by: a) whether the model predictions fall within the confidence intervals for the data (Figure 49), b) whether the relationship between the observed and model-predicted catch-rates falls along the 1:1 line (Figure 50), and whether the standard deviation of the residuals is reasonably similar to the assumed residual standard deviation (Table 33). Model D is generally able to mimic the catch rate data, although there are some noteworthy exceptions.

1. The fits to the catch-rate series for blue grenadier are not as good as expected from the assumed residual standard deviations (the standard deviations of the residuals are quite substantially larger than the assumed standard deviations, with the consequence that some of the model estimates do not intersect the 95% confidence intervals for the data).
2. The fits to the catch-rate data for eastern gemfish also provide some evidence for an inability to mimic the assessment data. The misfits to the catch-rates for eastern gemfish tend to occur after 1995 (early series) and before 1990 (later series) suggesting that the two catch-rate series are inconsistent to some extent.
3. The model over-predicts the pre-1990 catch-rates for mirror dory; the standardized catch-rate indices suggest stability from 1986 to 2002, but the model indicates a decline in abundance from 1986–95.

Appendix 5.1(a)-(g) shows the fits to the catch age-composition data for seven of the eight stocks (no catch age-composition data for king dory are included in the analyses owing to low sample size). Results are shown separately for each combination of stock, year and fleet. The model-predicted effective sample size for each such combination are included in the captions to the figures.

The effective sample sizes for blue grenadier are comparable with the values assumed when fitting the population dynamics model except for the years prior to 1992 (Table 30b; Appendix 5.1a). A major reason for the relatively high model-predicted effective sample sizes is that the fishery has been dominated by the 1994 and 1995 cohorts in recent years. These cohorts have constituted the bulk of the catch (in numbers) since about 1998 (although many animals from these cohorts were discarded by fleets 1–3 during 1996 and 1997). The model is also able to capture some of the other strong cohorts (e.g. that which was spawned in 1986).

The fits to age-composition data for eastern gemfish caught by fleet 1 are relatively poor (model-predicted effective sample sizes between 3 and 16) although the effective sample size assumed when the fitting the model to the data for this fleet is also quite low (10 – Table 30b). The catches by this fleet are usually only fish aged 2–4 years and there is little evidence for strong or weak cohorts passing through the catches of this fleet. The fits to age-composition data for fleet 2 are substantially better than to the age-composition data for fleet 1, except after about 1997 when the targeted fishery for eastern gemfish ceased.

The model-predicted effective sample sizes for the fits to the age-composition data for pink ling average close to 10 (Appendix 5.1c) – the value assumed when fitting the model. However, the fits for some fleets / years (e.g. 1989 by fleet 2) are very poor. Unlike the case for blue grenadier, and to a lesser extent eastern gemfish, several of the fits to the age-composition data for pink ling show ‘runs’ of residuals.

Some of the fits to the catch-age composition data for spotted warehou are quite good (e.g. fleet 3, 2001). However, other fits (e.g. to the data for fleet 3 in 1988) are very poor. It should be noted, however, that the sample sizes for some of the early years are very small (e.g. the age-composition data for 1988 is only based 140 otoliths – Table 27). The fits to the data for fleets 3 and 4 for recent years are generally fairly good, which is pleasing because the bulk of the catches of spotted warehou have been taken by fleet 3 since about 1996 (Table 21).

There is very little information on the age-structure of the catch of mirror dory owing primarily to a lack of ageing information. The model does not adequately capture the catch age-composition information for this stock (Appendix 5.1e). The fits to the age-composition data for ocean perch are also poor (Appendix 5.1f) with the model being largely unable to capture the change in the number of animals in the plus-group. The age-composition data for western gemfish do not provide a clear signal regarding trends in fishing mortality and year-class strength with the result that the model fits for western gemfish are also poor (Appendix 5.1g).

Appendix 5.2(a)-(e) shows the fits to the catch length-frequency data for eastern gemfish, mirror dory, ocean perch, king dory and western gemfish. Note that the model is only fitted to the length-frequency information for a given fleet and year if there are no age-composition data for that fleet and year.

The length-frequency data for gemfish caught by fleet 1 (Appendix 5.2a) are very variable with the result that the effective sample sizes are very low for some years. The fits to the length-frequency data for fleet 2 are better, except after 1992 when the fishery changed and stopped focusing on spawning run fish. The model also struggles to mimic the length-frequency data for mirror dory (Appendix 5.2b). This is primarily because large fish may or may not be present is some years (e.g. there were many large fish and few small fish in 1987 but exactly the opposite pattern is evident for 2001). The fits to the length-frequency data for ocean perch (Appendix 5.2c) are also very variable. However, unlike the case for the catch age-composition data, the model occasionally under-predicts the number of fish in the plus-group.

The length-frequencies for king dory are highly variable (perhaps due to the impact of small sample size) and, although the model generally captures the dynamics of the plus group, the effective sample sizes are fairly low (Appendix 5.2d). The model generally captures the overall shape of the length-frequency distribution for western gemfish (Appendix 5.2e) although this is definitely not the case for 1992 when the model is unable to mimic even the lengths which form the bulk of the catch.

The model is not able to mimic the changes over time in the discard rate estimates (Figure 51). For example, the model underpredicts the discard rates of blue grenadier between 1995–8. The fits to the discard data for remaining stocks are also poor.

The selectivity ogives

Figures 52 and 53 show the 13 estimated selectivity patterns (as a function of age – Figure 52, and as a function of length – Figure 53). The results in Figures 52 and 53 are based on model A, the 'base-case' model for the analyses of this chapter. The results Figures 52 and 53 are largely as expected given the catch age- and size-composition data. For example, selectivity for fleets 1-3 for blue grenadier is dome-shaped while fleet 4 is predicted to only capture large animals. The estimated selectivity patterns for pink ling and spotted warehou are worthy of additional comment. Fleet 1 (east coast, non-winter) captures the broadest range of sizes (specifically, this fleet captures the smallest fish), fleets 2-3 capture larger fish, and fleet 5 (non-trawl) captures only large fish.

The selectivity pattern estimated for western gemfish also warrants some comment. A penalty on difference between the length-at-50%-selectivity for this stock and that of eastern gemfish (fleet 2) is included in the objective function. Perhaps as a result of this, the length-at-50%-selectivity for western gemfish (72.3cm) is almost identical to that for eastern gemfish caught by fleet 2 (71.1cm). However, there are marked differences in the shape of the selectivity patterns for eastern and western gemfish, with that for western gemfish capturing a wider range of sizes and ages. This is, however, not inconsistent with the length-frequency data for these stocks which are also quite different (Appendix 5.2), presumably due to differences in the nature of the fisheries concerned. Ignoring the penalty on the length-at-50%-selectivity (model B) leads to a selectivity pattern for western gemfish with a much lower length-at-50%-selectivity (50.7cm) and more asymptotic behaviour at large size (Figure 54).

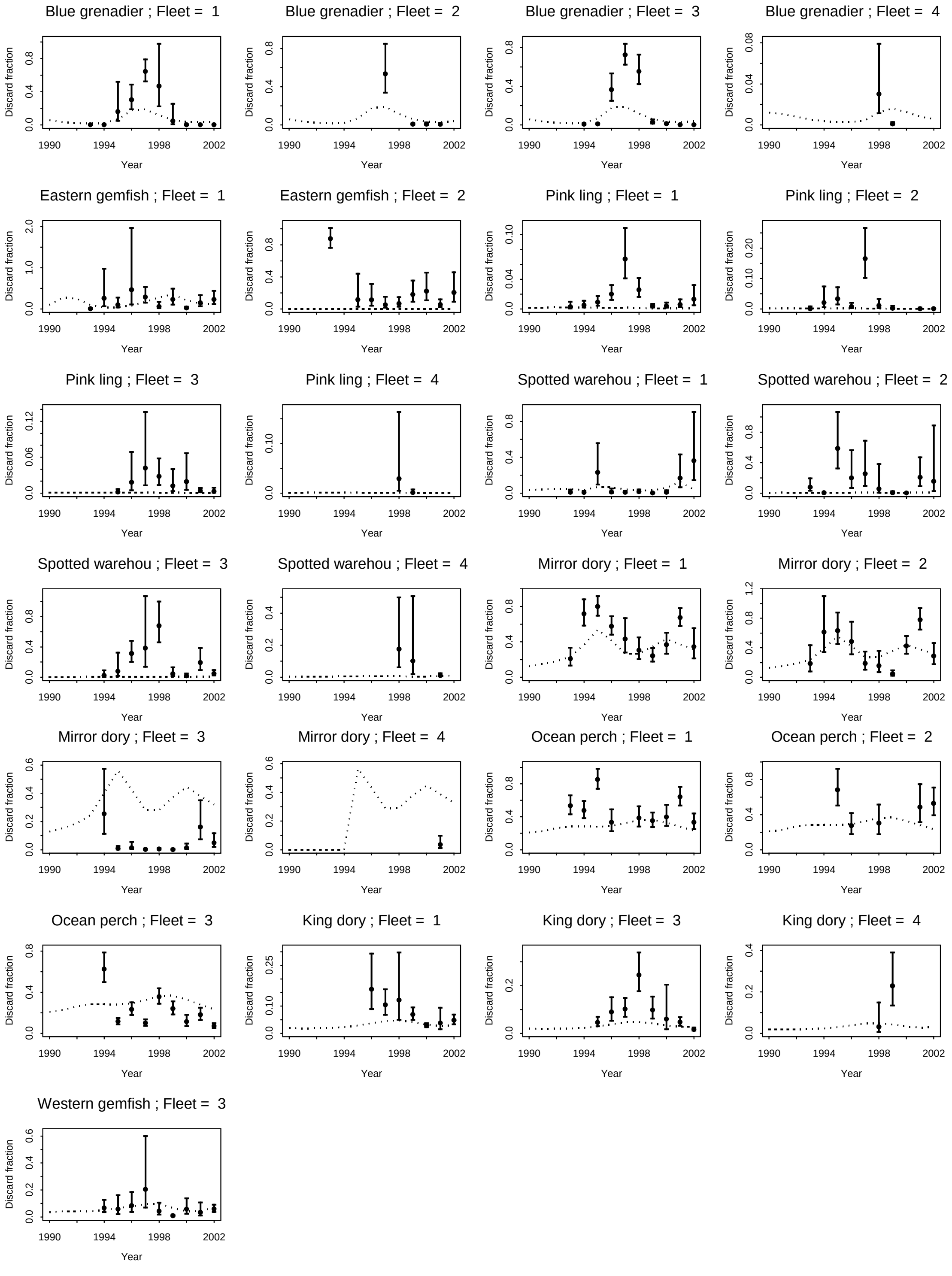


Figure 51. Observed (dots) and model D-predicted (solid lines) discard rates. The vertical bars are 95% confidence intervals for the data points.

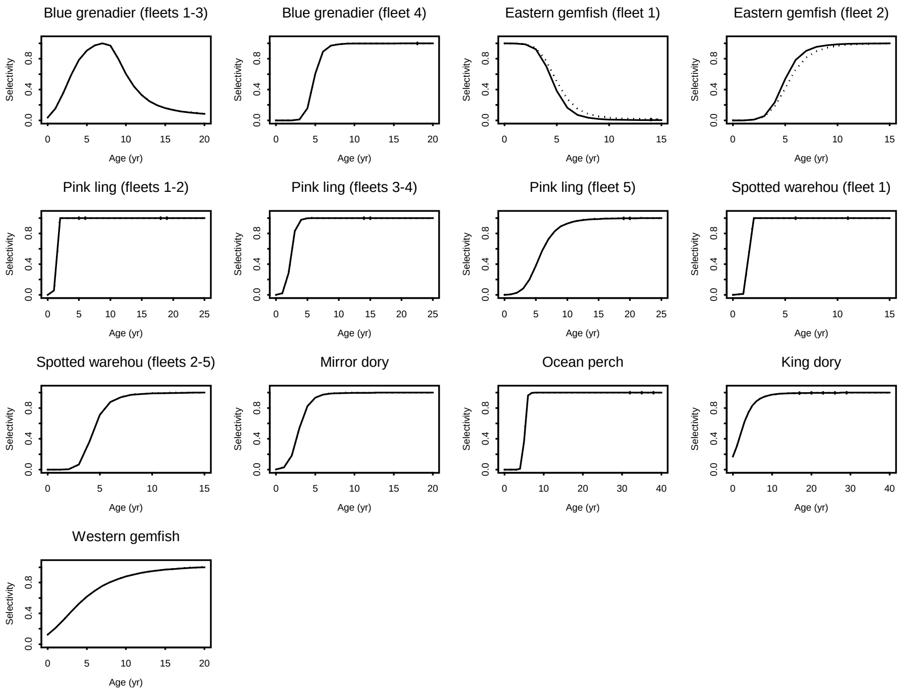


Figure 52. Selectivity as a function of age (males – solid lines; females – dotted lines) for each of the eight stocks considered in the example application. The results in this figure are based on model A.

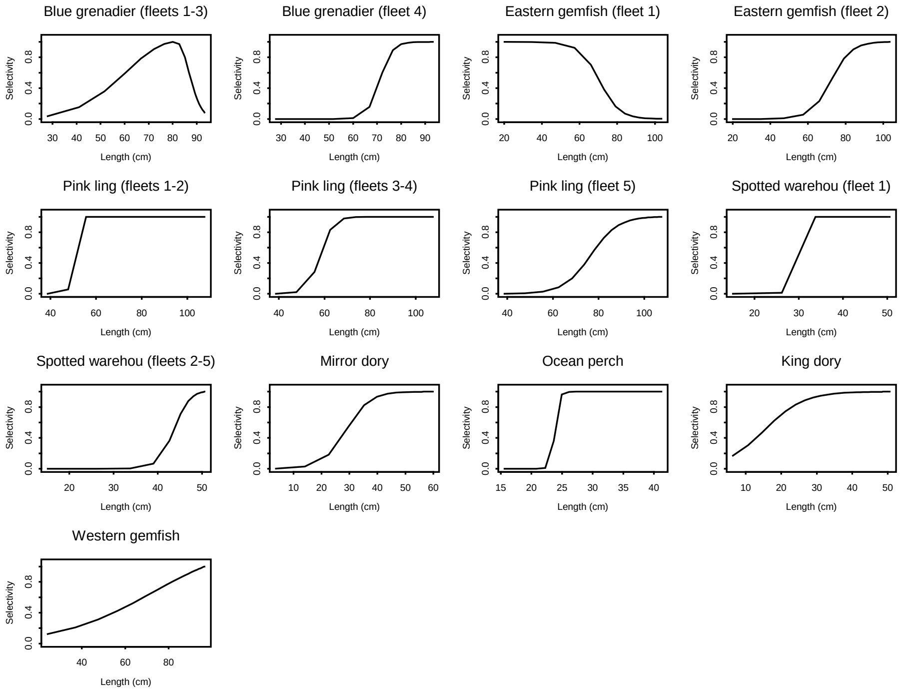


Figure 53. Selectivity as a function of length for each of the eight stocks considered in the example application. The results in this figure are based on model A.

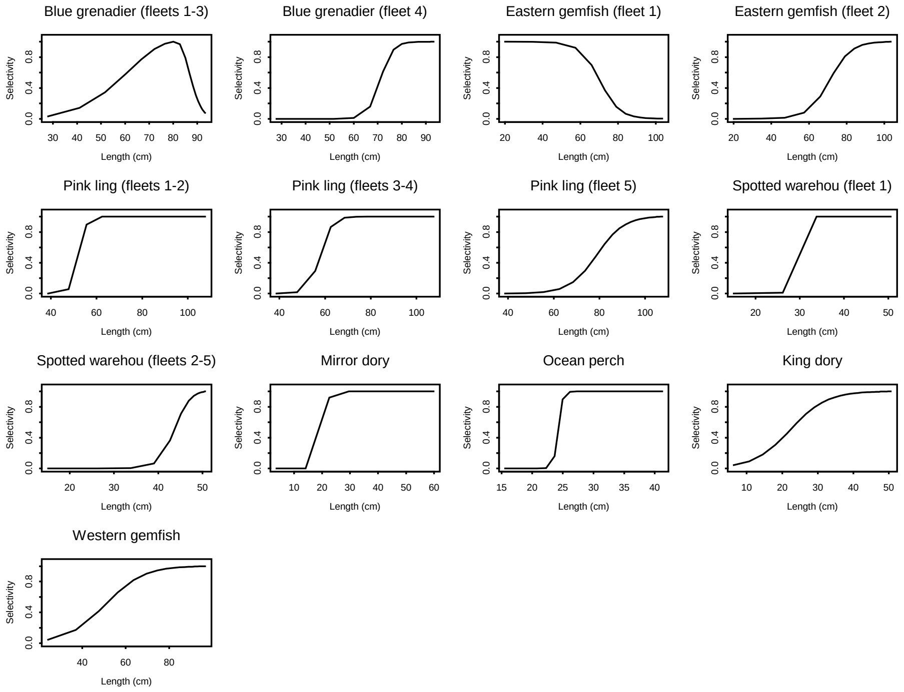


Figure 54. Selectivity as a function of length for each of the eight stocks considered in the example application. The results in this figure are based on model B.

Ability to quantify uncertainty

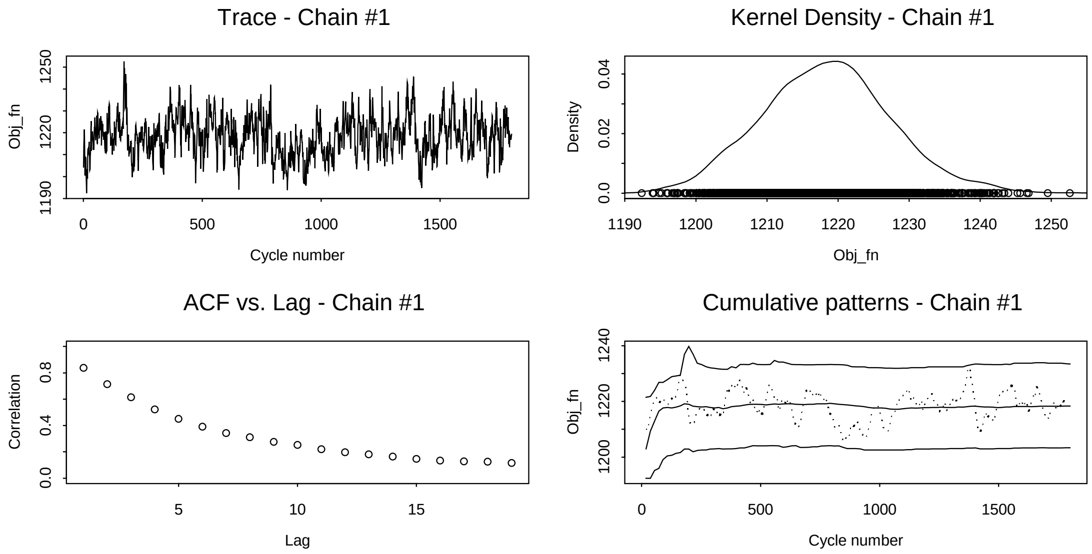
Even though the MCMC algorithm was conducted based on 5,000,000 cycles, there is nevertheless evidence for lack of convergence. Table 34 lists the values of the 'single chain Gelman statistic' for the objective function, the estimates of the logarithms of the virgin recruitments, and the selectivity parameters. As noted in Chapter 3: Results and Discussion, a value of 1.05 for 'single chain Gelman statistic' can be considered as evidence for lack of convergence. The results in Table 34 suggest that many of the parameters fail this diagnostic statistic.

Further evidence for lack of convergence of the MCMC algorithm is provided in Figures 55(a)-(d) which show four diagnostic plots (see Chapter 3: results and discussion for details) for the objective function for each of the four models. These plots highlight the very high correlations among elements of the chain. Such correlation could only be removed by increasing the number of cycles to a prohibitive (e.g. 10-100 fold) extent.

One of the reasons for the poor performance of the MCMC algorithm is the high correlation among some of selectivity parameters (Table 35). An attempt to generate a set of parameter vectors from the Bayesian posterior for model A was therefore made in which the values for the selectivity parameters were set equal to the estimates corresponding to the maximum of the posterior distribution. The results of this exercise are summarized in Table 34 (column 'A-2') and in Figure 56. The values for the diagnostics statistics and plots provide no evidence for a lack of convergence of the MCMC algorithm, suggesting that the correlation among the selectivity parameters may well be the reason for the problems evident in Figure 55. The only parameter for which there is some evidence for convergence problems is the virgin recruitment for king dory (species 7 in Figure 56).

Given the relatively little confidence that can be placed in the Bayesian results owing to the evidence for lack of adequate convergence of the MCMC algorithm, uncertainty is quantified by means of asymptotic standard deviations and confidence intervals *and* the Bayesian posteriors. Agreement between these two approaches to quantifying uncertainty (both of which are subject to problems) will tend to provide some confidence that the estimates of uncertainty are at least qualitatively reliable.

a) Model A



b) Model B

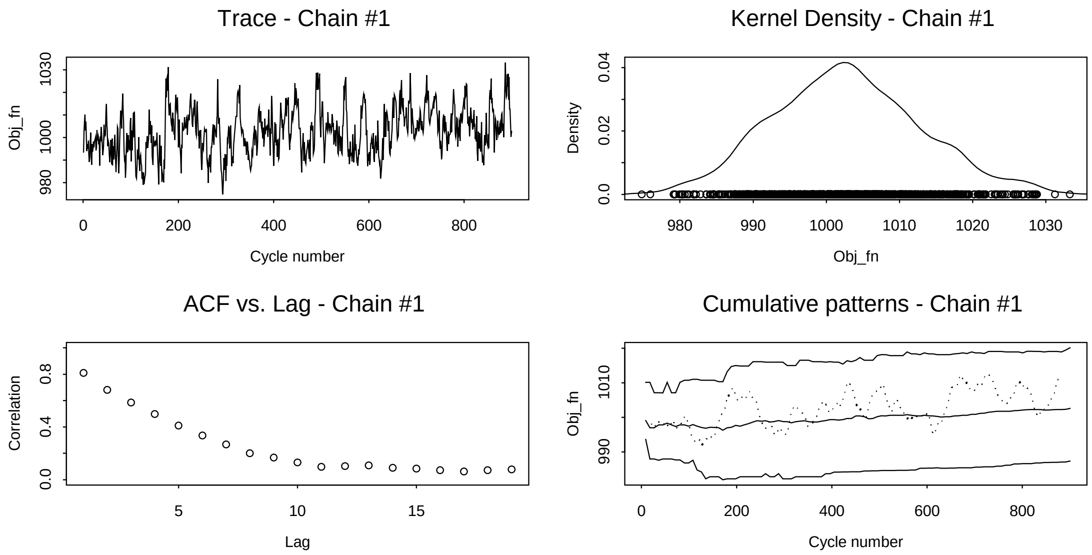
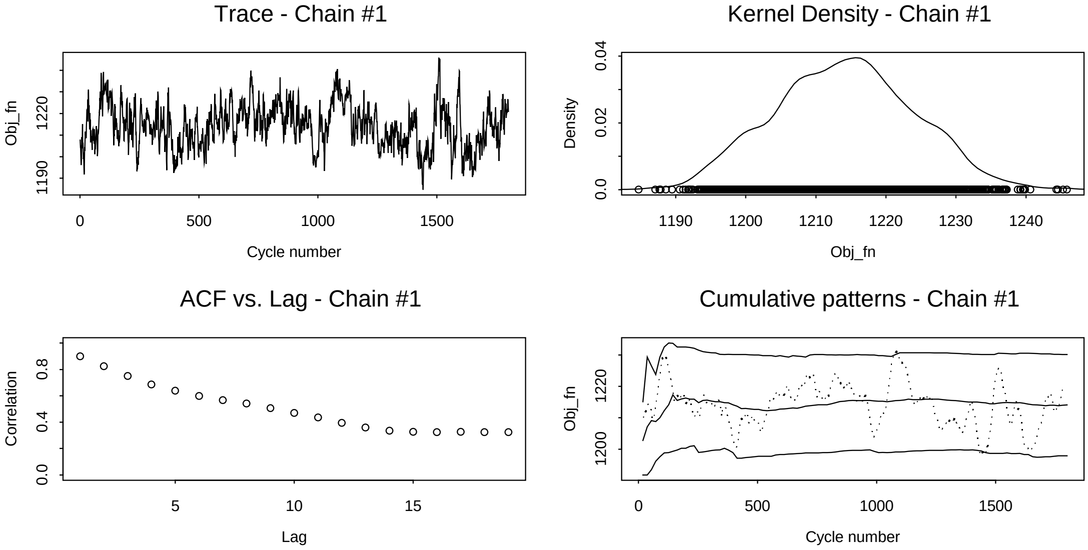


Figure 55. Diagnostic statistics (see Chapter 3: Results and Discussion for details) for the objective function.

Results are shown for each of the four models.

c) Model C



d) Model D

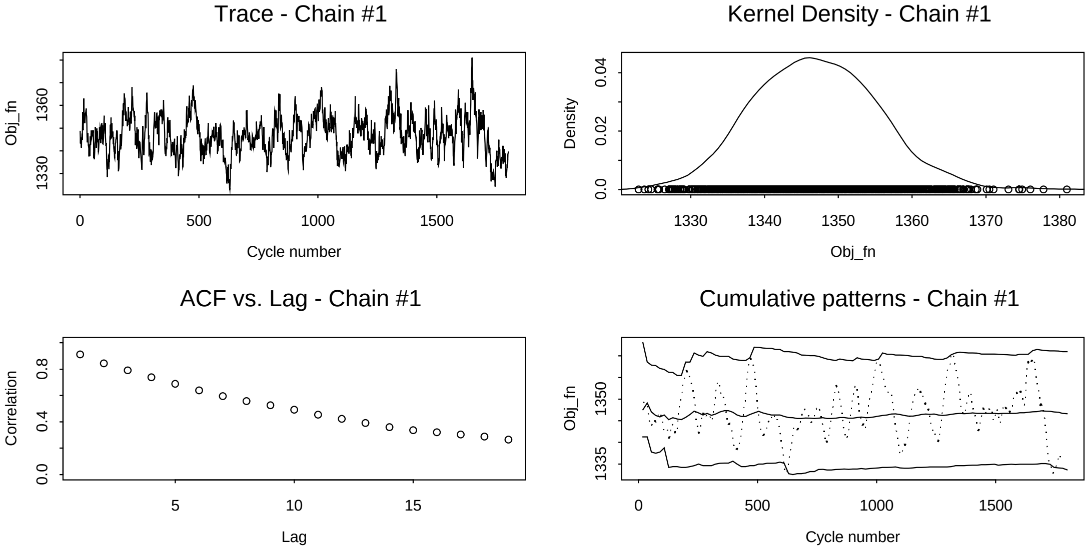


Figure 55 (continued) Diagnostic statistics (see Chapter 3: Results and Discussion for details) for the objective function.

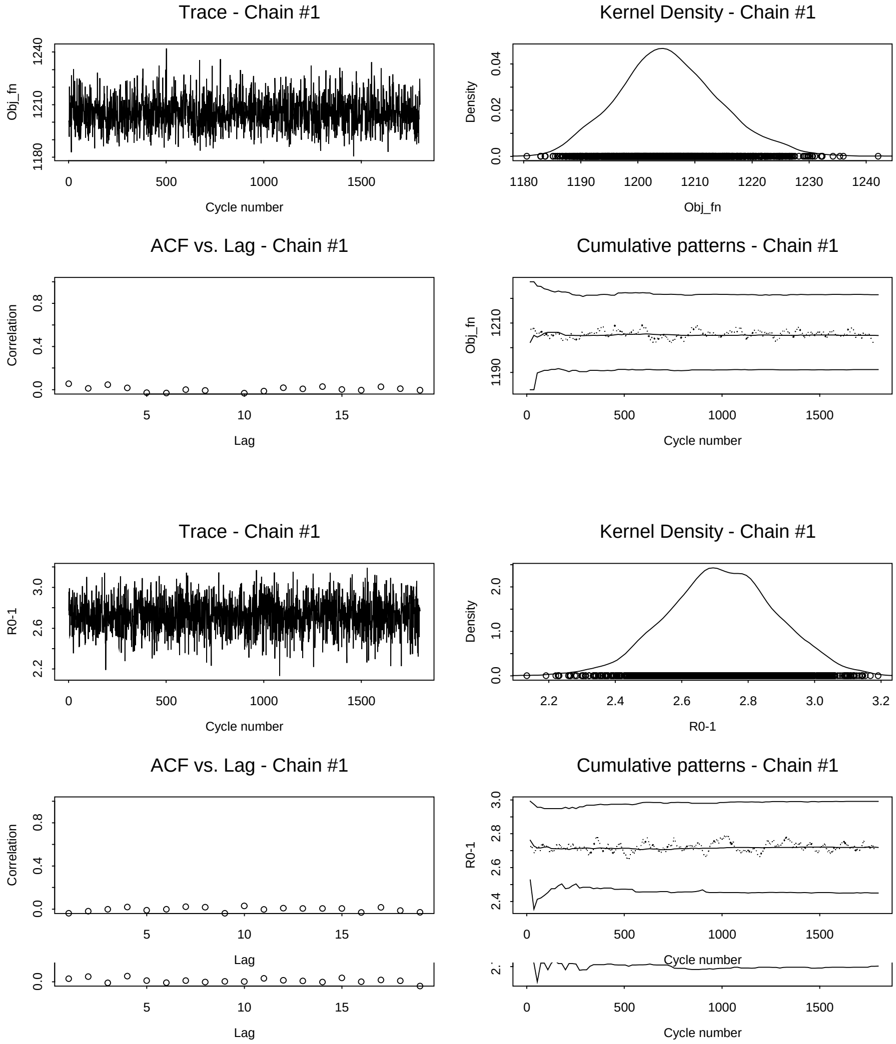
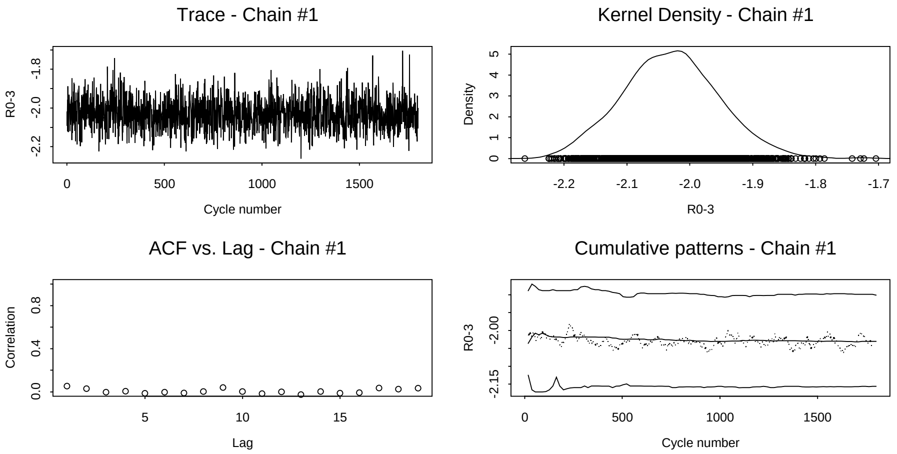
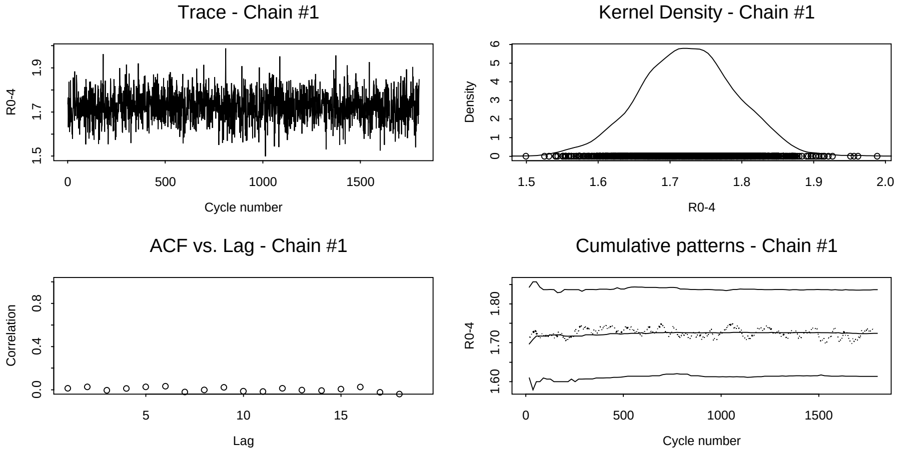


Figure 56. Diagnostic statistics (see Chapter 3: Results and Discussion for details) for the objective function and the logarithms of the eight virgin recruitments

Results are shown for a variant of model A in which the selectivity parameters are fixed equal to the estimates corresponding to the maximum of the posterior density function.





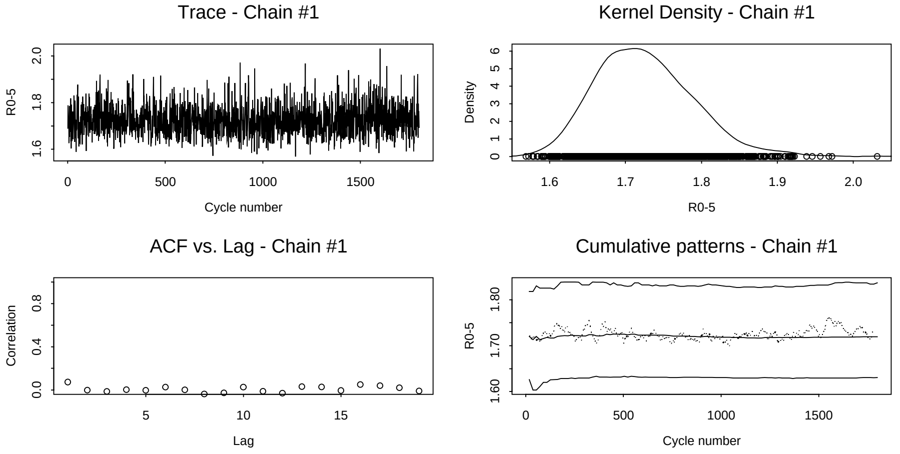


Figure 56. (continued) Diagnostic statistics (see Chapter 3: Results and Discussion for details) for the objective function and the logarithms of the eight virgin recruitments

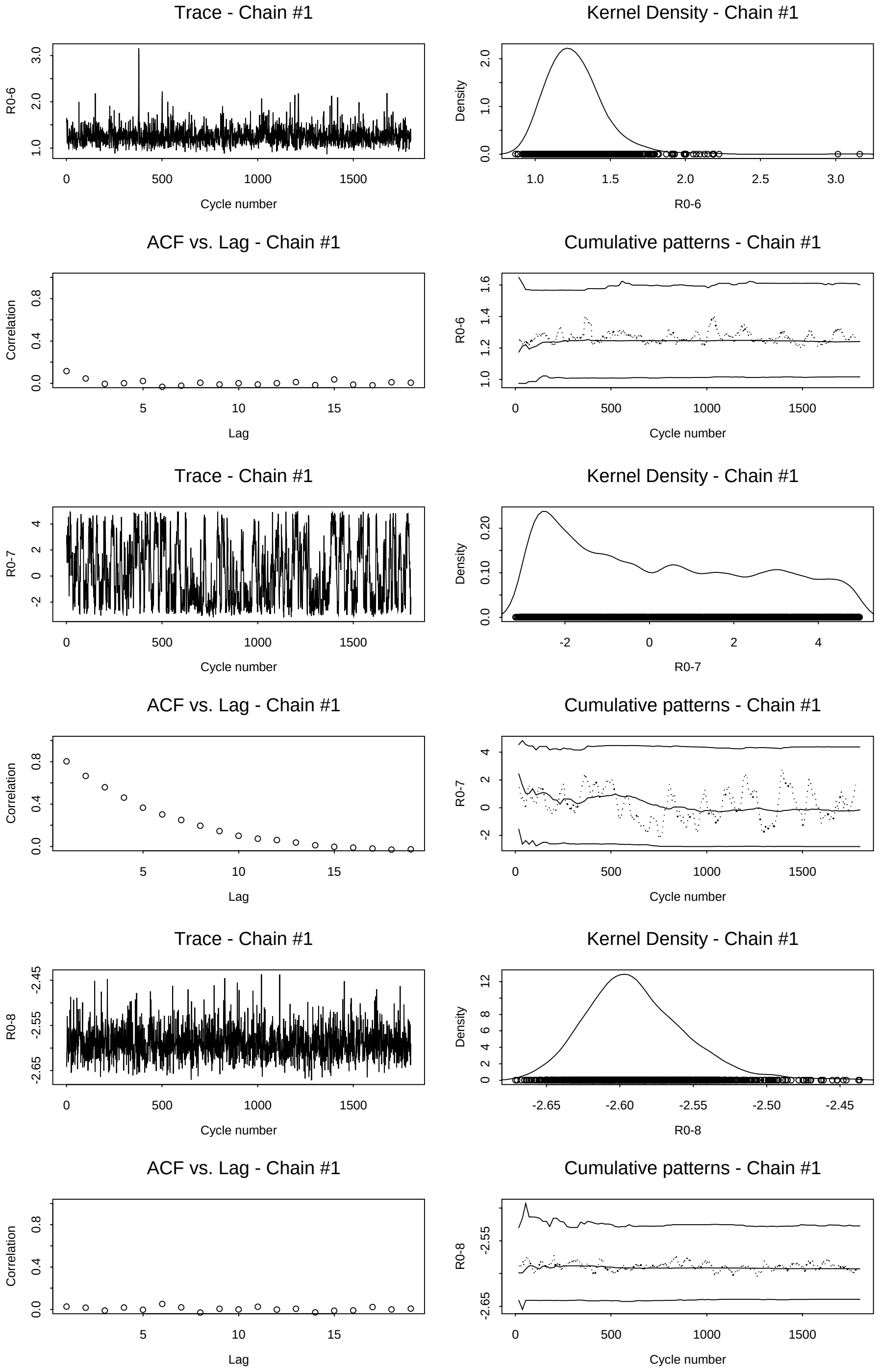


Figure 56. (continued) Diagnostic statistics (see Chapter 3: Results and Discussion for details) for the objective function and the logarithms of the eight virgin recruitments

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Detailed assessment results – model A

Figures 57 – 59 summarize the point estimates of the model outputs for model A (the base-case model – see Table 32). Figure 57 plots the time-trajectories of spawning biomass and recruitment for the eight stocks.

The results for blue grenadier, pink ling and spotted warehou are roughly consistent with those expected from the actual assessments for these stocks (there are differences owing, for example, to somewhat different population dynamics models and data set choices). The estimates of spawning biomass for eastern gemfish for the recent past are much more optimistic that would be expected from the most recent assessment of this stock (Punt, 2000). This is due primarily to the lack in model A of an index of relative abundance for eastern gemfish for the years after 1996.

Aspects of the results that are somewhat surprising include that almost all of the estimated recruitments for pink ling and ocean perch are larger than the recruitment in an unfished state. The results also suggest that the western stock of gemfish is currently depleted to well below its pre-fishery level, but that it has been relatively stable at this depleted level for over a decade. Of the other three stocks that have not been assessed using population dynamics models in the past, king dory and ocean perch exhibit noteworthy and continuing declines (although these stocks are both estimated to be above 40% of the 1968 level at present) while mirror dory is estimated to have been depleted to about 40% of its pre-fishery abundance since about 1990.

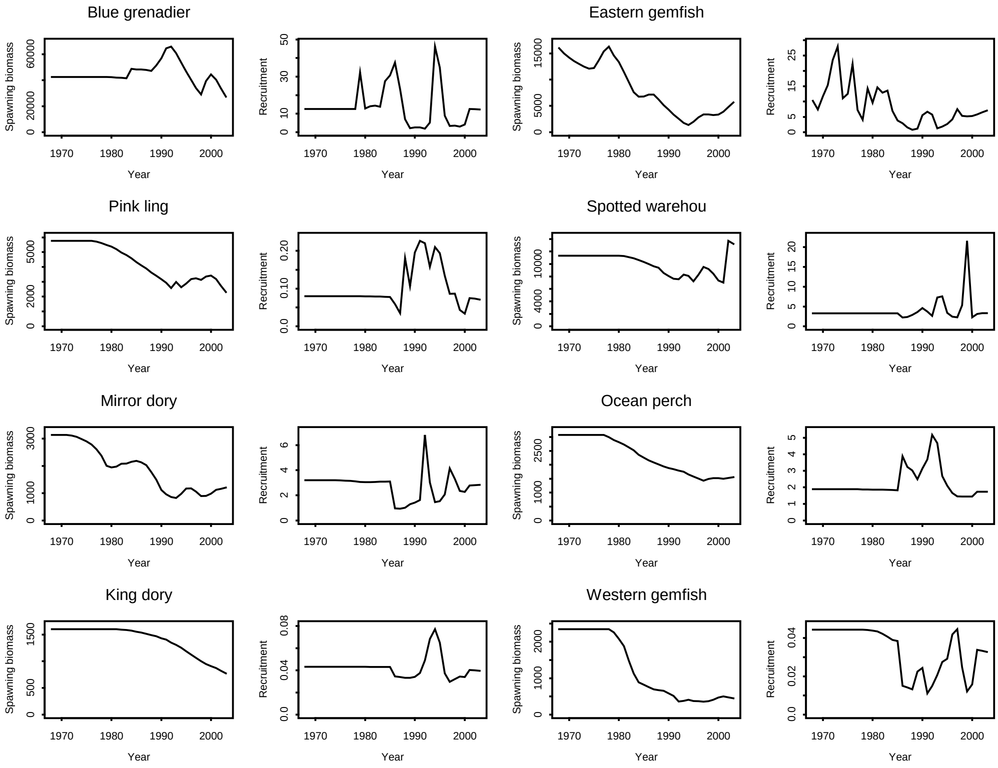


Figure 57. Time-trajectories of spawning biomass and recruitment for the eight stocks considered in the example application.

The results in this figure are based on model A.

Figure 58 plots the time-trajectories of exploitation rate by stock and fleet. The results mimic the patterns expected from the catch data (Table 21) and the changes over time in abundance (Figure 57).

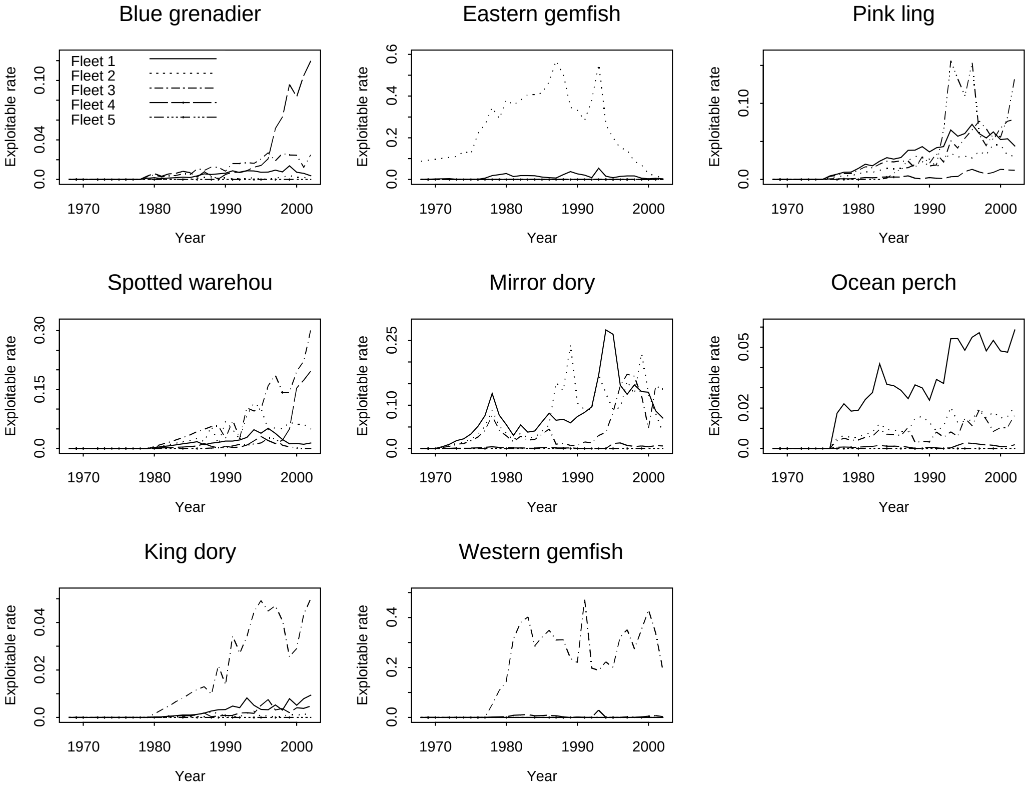


Figure 58. Time-trajectories of exploitation rate by fleet and stock.

The results in this Figure are based on model A.

Figure 59 shows the time-trajectories of the exploitation rates by fleet and stock normalized to the mean exploitation rate by fleet and stock. The results for fleets 1 and (particularly) 4 are fairly variable while the exploitation rates for fleets 2 and 3 (which are penalized to some extent when fitting model A) exhibit what are qualitatively quite similar patterns.

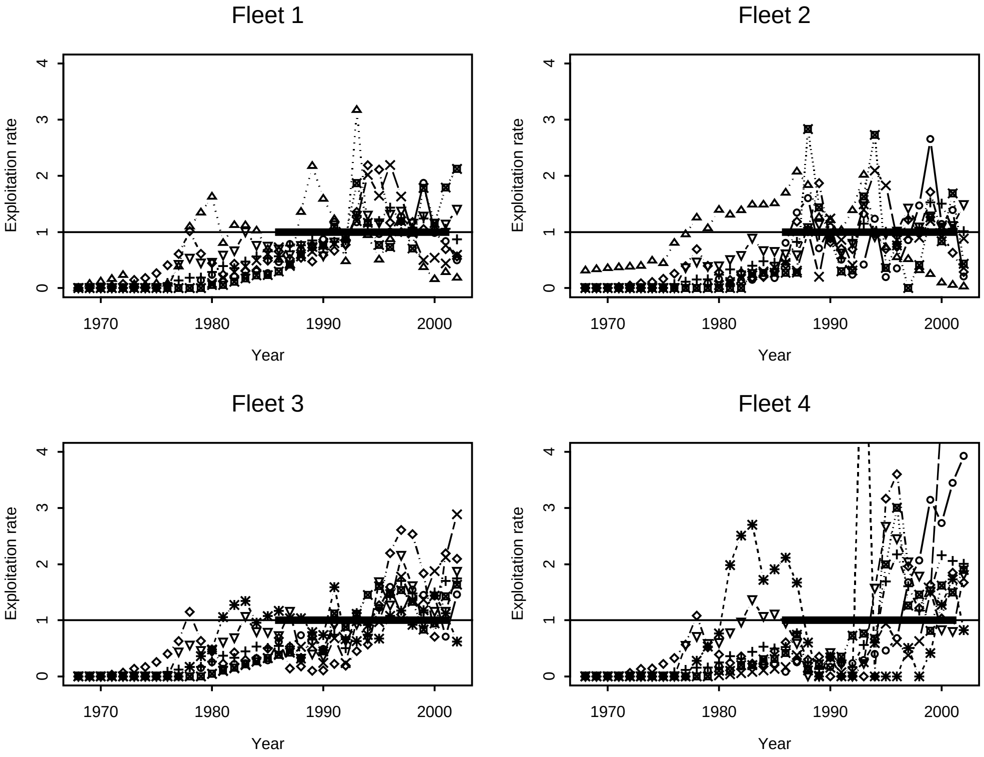


Figure 59. Time-trajectories of exploitation rate by fleet and stock.

The results in this figure are based on model A.

Comparison among models

Figures 60 and 61 compare the estimates of spawning biomass for the eight stocks among the four models in Table 32. Results are shown for spawning biomass in absolute terms (Figure 60) and expressed relative to the 1968 spawning biomass (Figure 61). The results anticipated from the structure of the model and the criteria behind how the penalties are implemented would be that the estimates of spawning biomass for all models would be near identical for the data-rich and data-moderate stocks (blue grenadier, eastern gemfish, pink ling, and spotted warehou), but the estimates of spawning biomass for the four data-poor stocks may differ substantially.

The expected outcomes are largely borne out by the results in Figures 60 and 61. Specifically, the estimates of spawning biomass (in absolute and relative terms) for blue grenadier and spotted warehou are essentially indistinguishable among the models. In relative terms, the estimates of spawning biomass for eastern gemfish and pink ling are the same for models A-C (the estimates of spawning biomass for eastern gemfish for model D differ from those for the remaining models because model D includes an additional catch-rate series; Table 32). The estimates of spawning biomass for the three data-poor stocks based on models A and C are very similar. Expressed relative to the spawning biomass in 1968, the estimates of spawning biomass based on model D are also very similar to those based on models A and C. In contrast, the estimates of spawning biomass for ocean perch, king dory and western gemfish based on model B (which ignores the among-stock constraints) are quite different from those based on models A, C and D (which include such constraints).

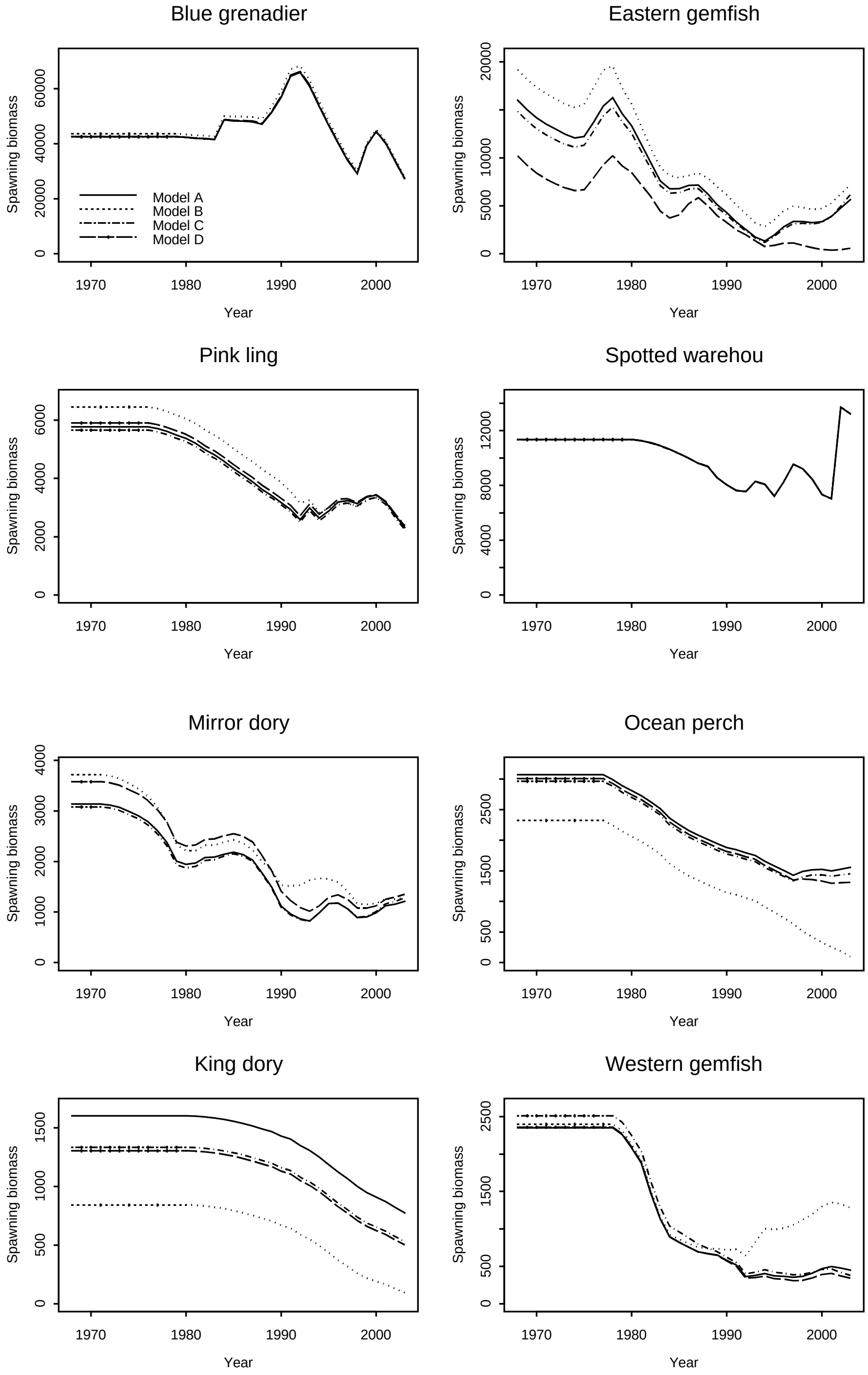


Figure 60. Time-trajectories of spawning biomass by stock for the four models.

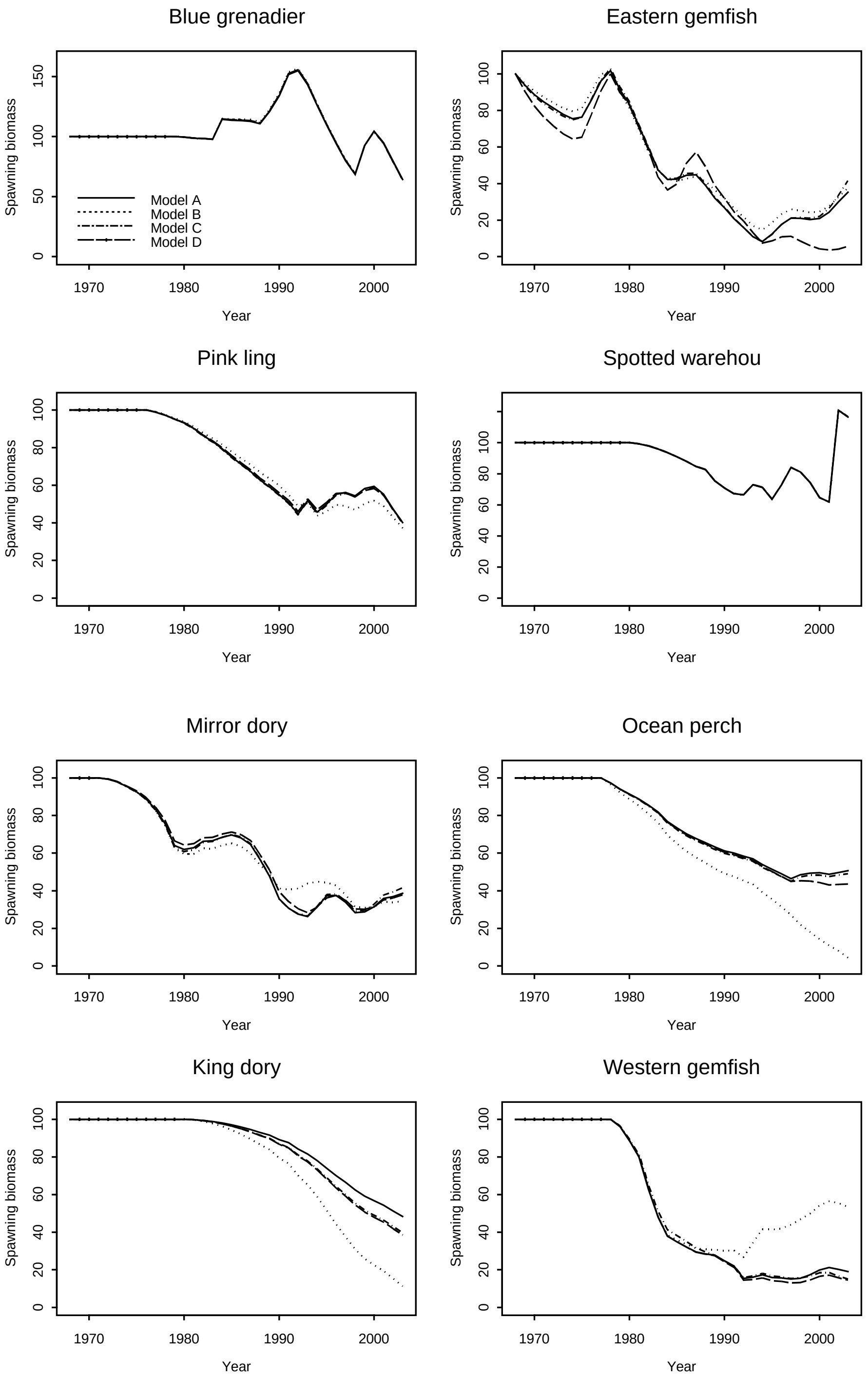
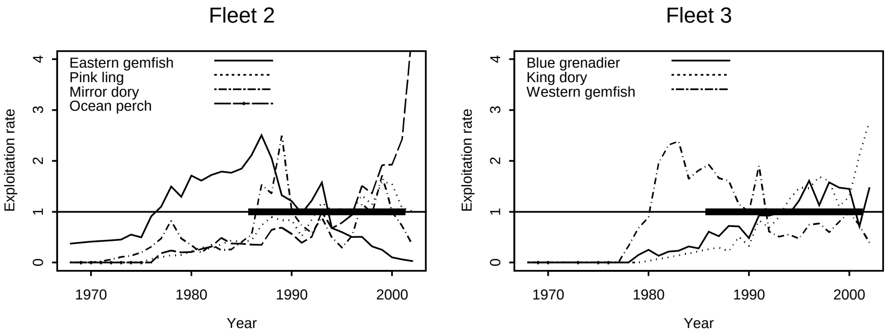


Figure 61. Time-trajectories of spawning biomass by stock (expressed as a percentage of the spawning biomass in 1968) for the four models.

The estimates of spawning biomass for western gemfish based on model B increase after 1992 whereas those based on models A, C, and D are stable. In contrast, model B predicts that ocean perch and king dory to be near collapse; models A, C and D suggest instead that these stocks are close to 40% of the unfished level at present.

Figure 62 illustrates the reason for the difference in results between models B and A. Figure 62 shows the time-trajectories of exploitation rate (scaled to the average exploitation rate) for these two models. The exploitation rate on ocean perch by fleet 2 and that on king dory by fleet 3 based on model B both increase substantially towards the end of the time-series (Figure 62a). However, this is not the case for model A (Figure 62b). The rapidly increasing exploitation rates for ocean perch and king dory probably arise to fit some aspect of the length-composition data for these stocks. However, including a penalty on the inter-species patterns in fishing mortality reduces the 'value' of fitting such data.

a) Model B



b) Model A

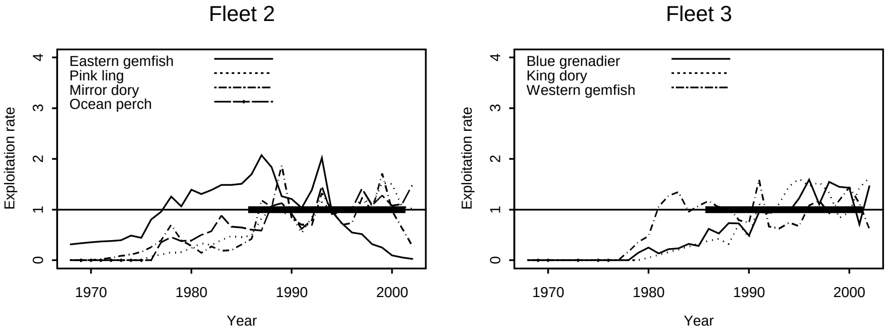


Figure 62. Time-trajectories of exploitation rate by fleet and stock. The results in this figure are based on models B and A.

Figure 63–66 contrast the 90% confidence intervals (90% probability intervals for the Bayesian analyses) for spawning biomass and spawning biomass expressed relative to that in 1968. Results based on the asymptotic method of variance estimation are shown in Figures 63 and 64 and results based on the sample from the Bayesian posterior distributions are shown in Figures 65 and 66

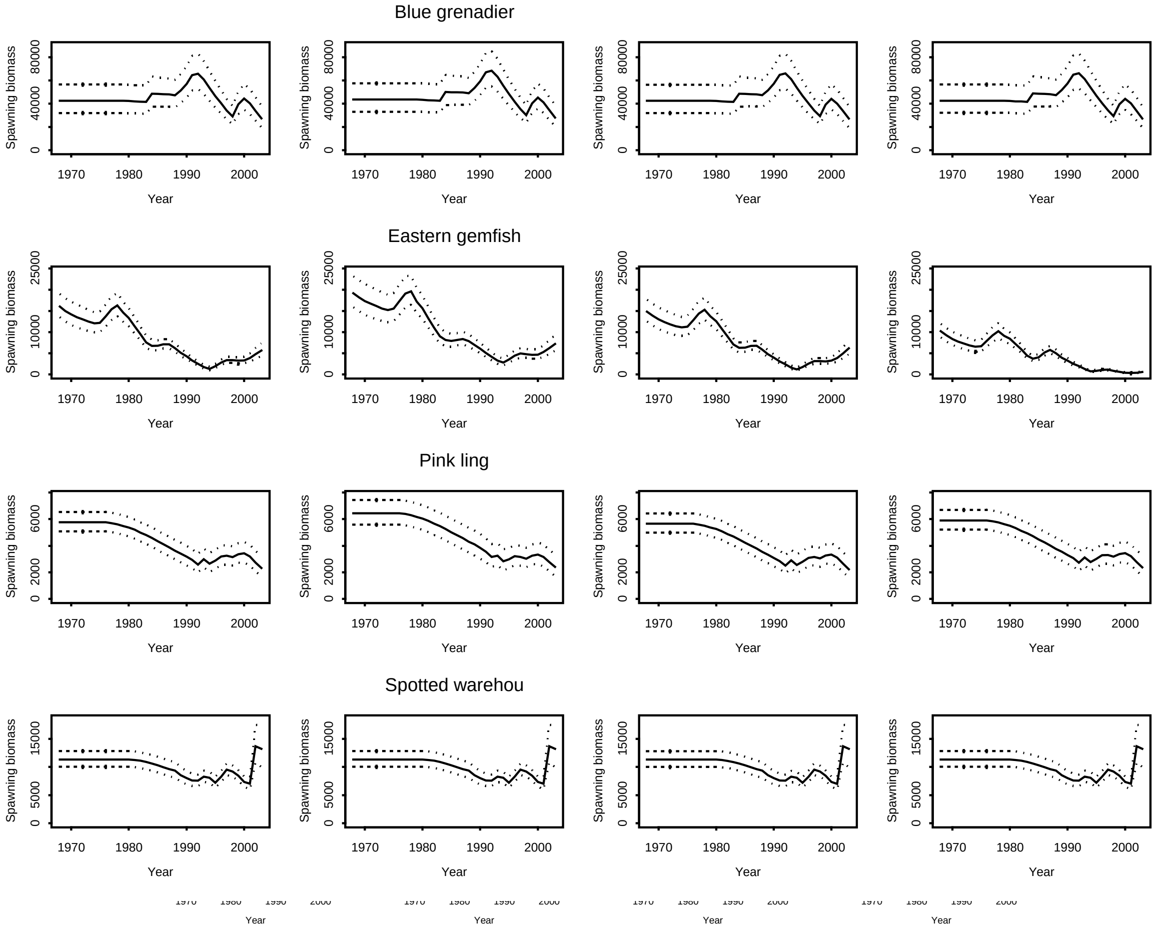


Figure 63. 90% confidence intervals for spawning biomass based on the asymptotic method of variance estimation.

Results are shown for the eight stocks and the four models (rows and columns respectively).

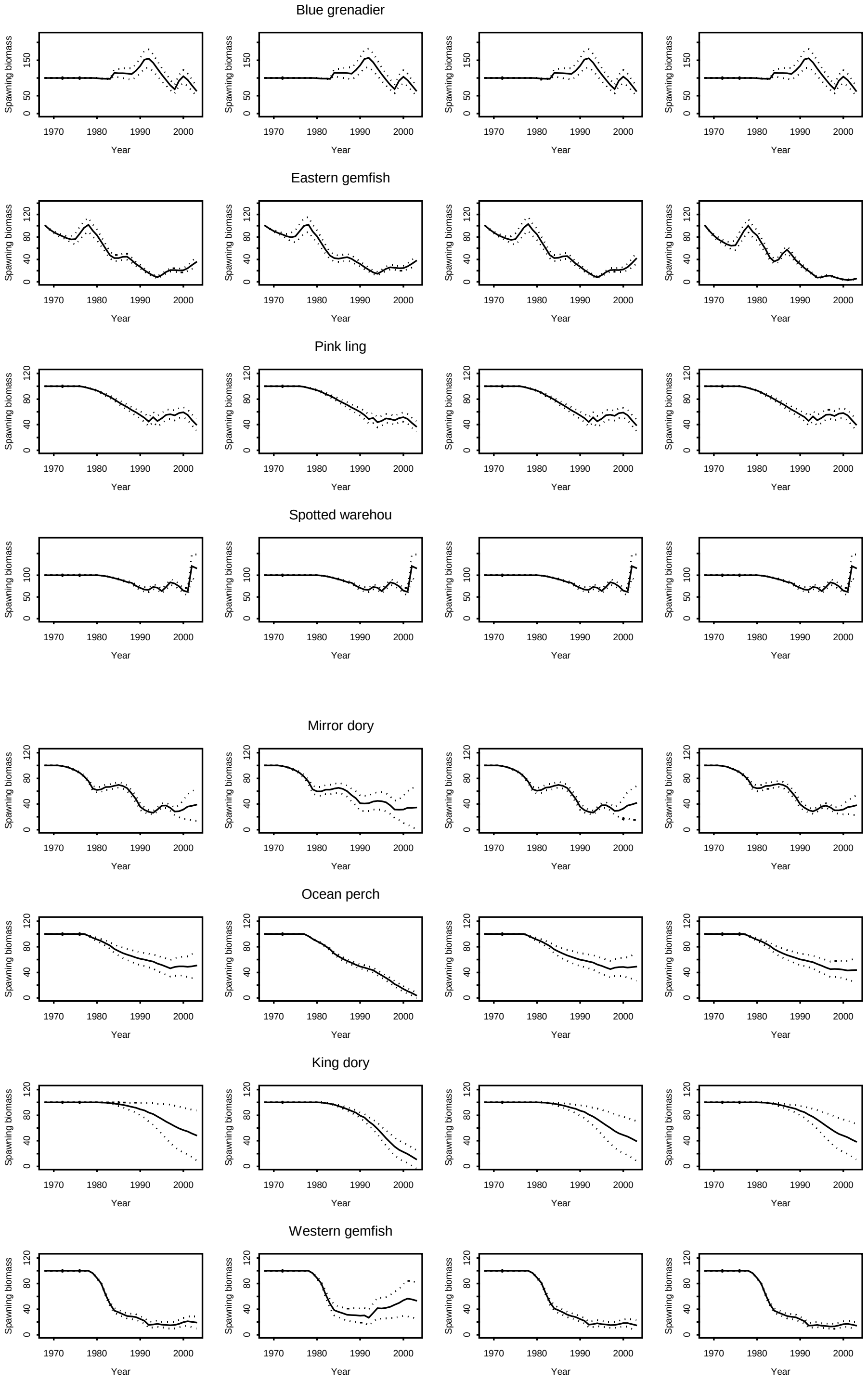


Figure 64. 90% confidence intervals for spawning biomass expressed relative to that for 1968 based on the asymptotic method of variance estimation.

Results are shown for the eight stocks and the four models (rows and columns respectively).

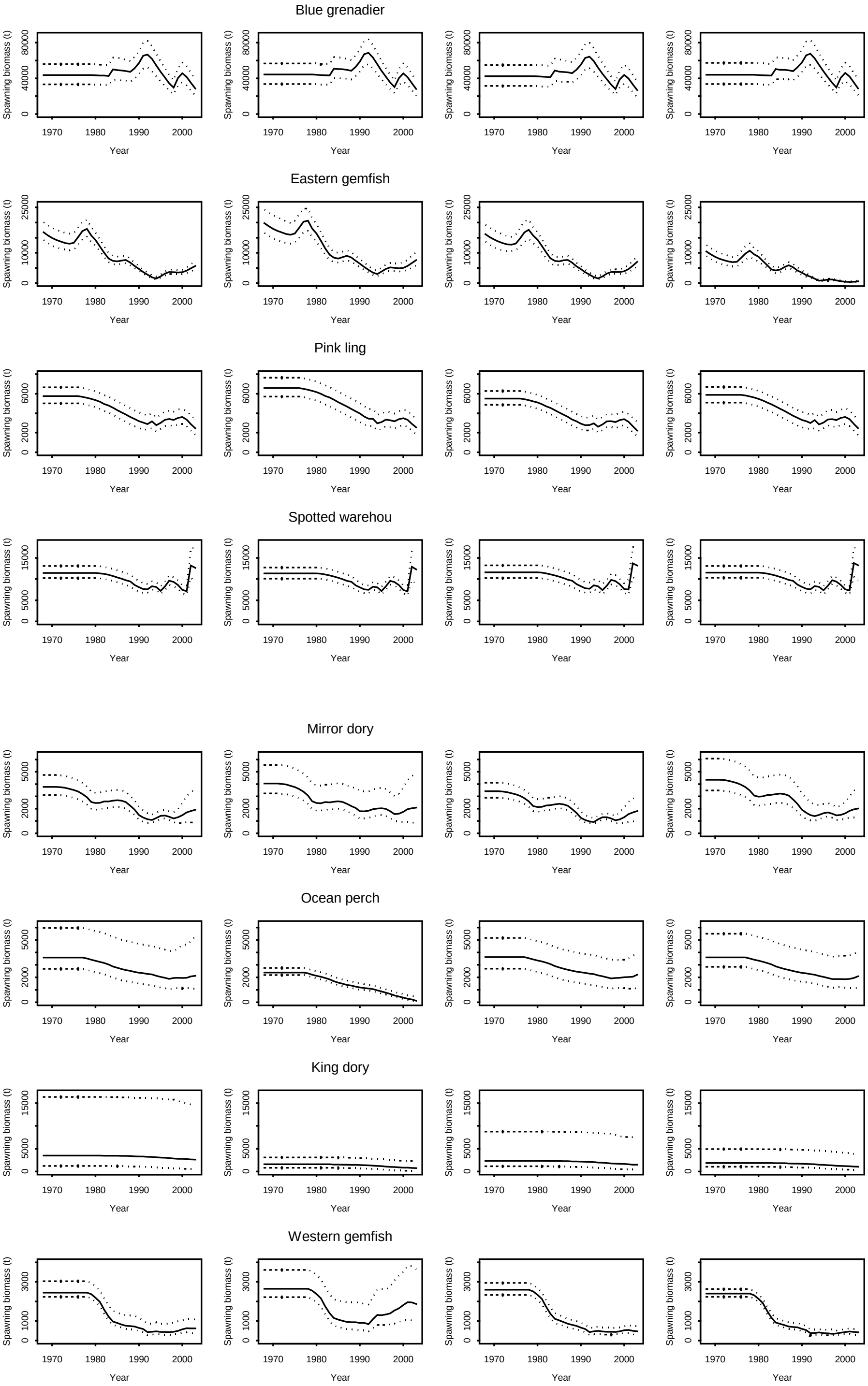


Figure 65. 90% probability intervals for spawning biomass based on the samples from the Bayesian posterior distribution.

Results are shown for the eight stocks and the four models (rows and columns respectively).

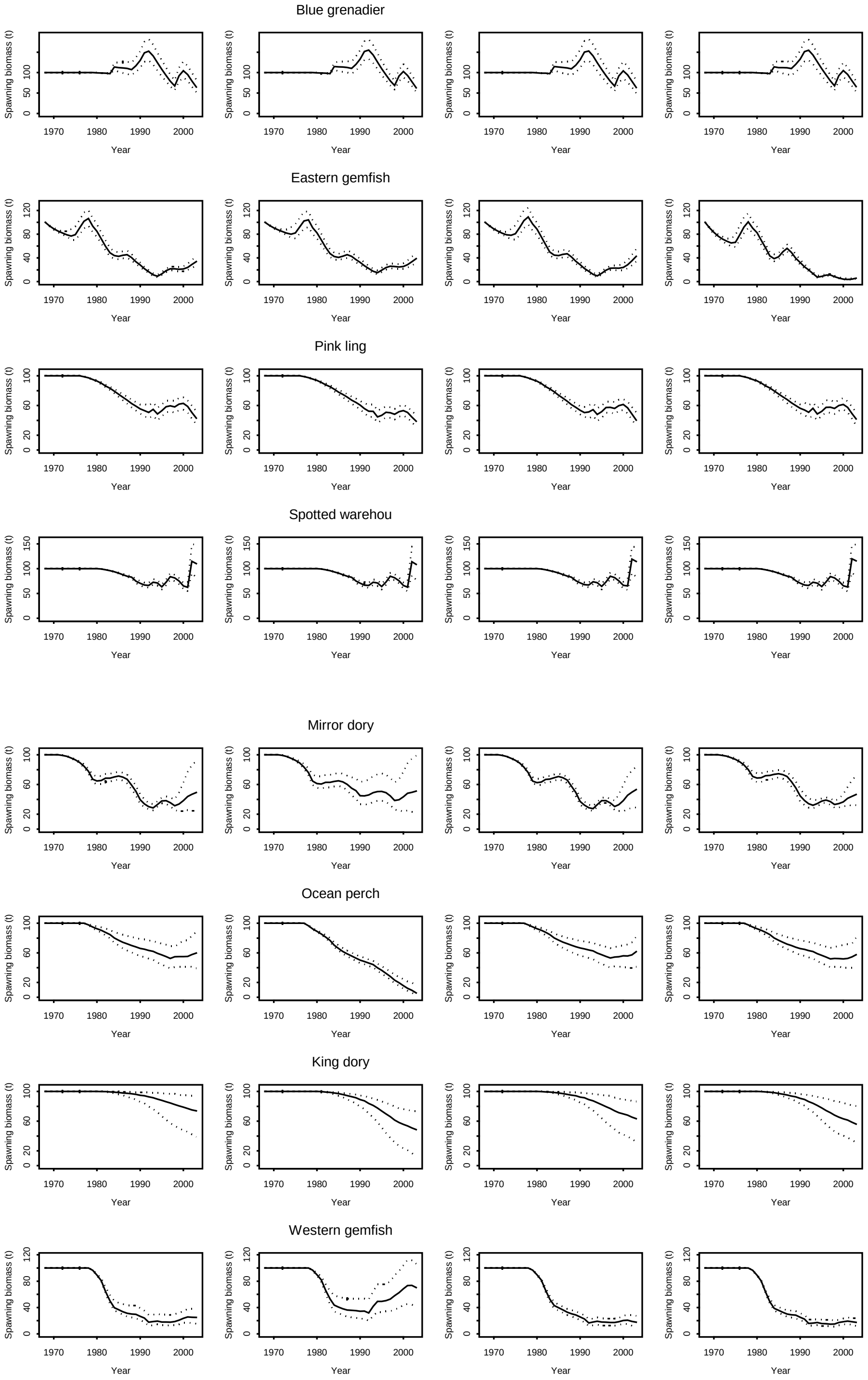


Figure 66. 90% probability intervals for spawning biomass expressed relative to that for 1968 based on the samples from the Bayesian posterior distribution

Results are shown for the eight stocks and the four models (rows and columns respectively).

The 90% confidence intervals (based on the asymptotic method of variance estimation) and the 90% probability intervals (based on the samples from the Bayesian posterior) are generally remarkably similar. This is perhaps surprising given the clear evidence for lack of convergence of the MCMC algorithm (Figure 55; Table 32). The 90% confidence intervals and the 90% probability intervals are essentially identical for the four data-rich / data-moderate stocks. The measures of uncertainty for spawning biomass expressed relative to that in 1968 are more similar than those for spawning biomass in absolute terms. The posterior medians for the four data-poor stocks are not the same as the estimates corresponding to maximum of the posterior density function (the posterior modes). For example, the posterior median for the current depletion of the king dory stock is higher than the corresponding posterior mode.

Given the way the objective function is developed, the expectation is that the posterior / confidence intervals for the data-rich and data-moderate stocks would not differ among models whereas the estimates based on models A, C and D would be more precise than those based on model B. The expectation is clearly borne out for mirror dory and western gemfish (the 90% posterior / confidence intervals are much narrower for models A, C and D than for model B), but it is not the case for ocean perch and king dory. The reason for the latter result is that these stocks are estimated by model B to be virtually extirpated. Unlike the case for the other stocks therefore, the constraint that the population may not be extinct at present comes into play for these stocks. That this is the reason for the difference between the expected result and that in Figures 63 and 64 is supported by the fact that for the Bayesian posteriors (Figures 65 and 66) the posterior medians do not suggest that the king dory stock is virtually extirpated and the posterior intervals are very wide.

Discussion

The chapter outlines an approach to fisheries stock assessment which is able to assess multiple stocks/species simultaneously accounting for relationships among stocks/species in terms of the length-at-50%-selectivity, the time-trajectory in fishery exploitation rate by fleet, and the deviations about the stock-recruitment relationships. This approach allows information for data-rich and data-moderate stocks to influence the results of assessments for data-poor stocks.

The advantages of this approach would be expected to be more stability and precision in the results of assessments for data-poor stocks because these results would be less susceptible to being corrupted by the model attempting to fit to some quirk in a noisy data series.

The example application of this chapter is based on five fleets (four trawl fleets and a non-trawl fleet) and eight stocks. The expectations of improved stability and precision are largely borne out – the results of the analyses of this chapter, specifically, the trends in the abundance of ocean perch, king dory and western gemfish differ fairly substantially when among-stock constraints are taken into account. Furthermore, the precision of some of the key outputs from an assessment (the trends in spawning biomass and spawning biomass expressed relative to the unfished level) for the data-poor stocks is much greater when among-stock constraints are taken into account.

One possible negative feature of the approach outlined in this chapter is that the inclusion of among-stock constraints could impact the results for the data-rich and data-moderate stocks. However, there is no evidence for this in Figures 63–66. Another potential disadvantage of the method outlined in this chapter is that poor choices could be made regarding how any among-species constraints are imposed. The changes in the selectivity curve for western gemfish when among-stock constraints are and are not imposed (Figures 53 and 54) perhaps suggests that it is inappropriate to assume that the length-at-50%-selectivity for western and eastern gemfish should be similar.

Table 29. The parameters of the population dynamics model. Parameters marked by an asterisk are those for which priors could, in principle, be specified.

Parameter	Treatment
Natural mortality, $M^{g,s}$	Pre-specified *
Virgin recruitment, R_0^s	Estimated
Stock-recruitment steepness, h^s	Pre-specified / Estimated *
Fecundity-at-age, f_a^s	Pre-specified
Proportion spawning, μ^s	Pre-specified
Recruitment deviations, ε_y^s	Estimated *
Extent of variation in recruitment, σ_R^s	Pre-specified *
Weight-at-age, $w_a^{g,s}$	Pre-specified
Length-at-age, $L_a^{g,s}$	Pre-specified
Selectivity-at-age, $L_{50}^{s,f}$, $L_{95}^{s,f}$, $L^{s,f}$, $\Omega_L^{s,f}$, $\Omega_R^{s,f}$	Estimated *
Retention probability, $\varphi_{50}^{s,f}$, $\varphi_{95}^{s,f}$	Computed from auxiliary information
Maximum age, x	Pre-specified

The values for the pre-specified parameters are listed in Table 26.

Table 30. The plus- and minus groups, and the effective sample sizes for the age- and length-frequency data.

(a) Length-frequency data

Stock	Minus / plus groups	Fleet				
	(cm)	1	2	3	4	5
Eastern gemfish	30 / 110	10	25	-	-	-
Mirror dory	5 / 60	5	5	-	-	-
Ocean perch	5 /40	5	5	-	-	-
King dory	5 / 50	-	-	5	-	-
Western gemfish	30 / 100	-	-	5	-	-

(b) Age-composition data

Stock	Minus / plus groups	Fleet				
	(yr)	1	2	3	4	5
Blue grenadier	3 / 15	25	25	25	25	-
Eastern gemfish	2 / 10	10	50	-	-	-
Pink ling	1 / 13	10	10	10	-	10
Spotted warehou	1 / 13	10	10	10	10	-
Mirror dory	2 / 10	5	5	-	-	-
Ocean perch	5 / 20	5	5	-	-	-
Western gemfish	2 / 10	-	-	-	5	-

Table 31. The values assumed for the residual standard deviations when fitting the catch-rate indices.

Stock	Fleet			
	1	2	3	4
Blue grenadier	-	-	0.15	0.15
Eastern gemfish	-	0.10	-	-
Pink ling	0.20	0.20	0.20	0.20
Spotted warehou	0.20	0.20	0.20	0.20
Mirror dory	-	0.30	-	-
Western gemfish	-	-	0.30	-

Table 32. The specifications of the four models considered in the analyses of this chapter.

Model	With all CPUE series	With penalties	Steepness estimated
A	No	Yes	No
B	No	No	No
C	No	Yes	Yes
D	Yes	Yes	No

Table 33. The assumed residual standard deviations for the catch-rate series and the values inferred from the fit of model D.

Stock / fleet	Assumed residual standard deviation	Inferred residual standard deviation
Blue grenadier – fleet 3	0.15	0.240
Blue grenadier – fleet 4	0.15	0.350
Eastern gemfish – fleet 2	0.1	0.353
Eastern gemfish – fleet 2	0.1	0.281
Pink ling – fleet 1	0.2	0.167
Pink ling – fleet 2	0.2	0.213
Pink ling – fleet 3	0.2	0.131
Pink ling – fleet 4	0.2	0.260
Spotted warehou – fleet 1	0.2	0.522
Spotted warehou – fleet 2	0.2	0.294
Spotted warehou – fleet 3	0.2	0.323
Spotted warehou – fleet 4	0.2	0.172
Western gemfish – fleet 3	0.3	0.150
Mirror dory– fleet 2	0.3	0.328

Table 34. Values for the single chain Gelman statistic for the objective function, the logarithms of the virgin recruitments, and the selectivity parameters for the four models.

	Model				
Quantity	A-1	A-2	B	C	D
Objective fn	1.062	0.999	1.118	1.129	1.071
R0-1	1.029	1.000	1.057	1.085	1.122
R0-2	1.197	0.999	1.129	1.097	1.121
R0-3	1.070	1.001	1.101	1.058	1.129
R0-4	1.085	1.002	1.117	1.141	1.145
R0-5	1.308	1.004	1.062	1.096	1.553
R0-6	1.182	1.000	1.256	1.163	1.252
R0-7	1.489	1.041	1.739	1.502	1.665
R0-8	1.235	1.001	1.477	1.101	1.248
Select-1	1.030	-	1.145	1.173	1.137
Select-2	1.099	-	1.291	1.210	1.306
Select-3	1.041	-	1.084	1.197	1.117
Select-4	1.088	-	1.141	1.097	1.076
Select-5	1.060	-	1.231	1.167	1.056
Select-6	1.104	-	1.145	1.225	1.335
Select-7	1.195	-	1.752	2.079	1.324
Select-8	1.101	-	1.116	1.325	1.568
Select-9	1.210	-	1.089	1.446	1.147
Select-10	1.016	-	1.035	1.008	1.138
Select-11	1.089	-	1.059	1.036	1.132
Select-12	1.133	-	1.095	1.227	1.115
Select-13	1.147	-	1.162	1.231	1.127
Select-14	1.223	-	1.044	1.082	1.487
Select-15	1.309	-	1.631	1.101	1.244
Select-16	1.266	-	1.501	1.471	1.304
Select-17	4.114	-	2.092	1.003	1.000
Select-18	1.364	-	2.075	1.441	2.858
Select-19	2.480	-	1.908	2.638	1.963
Select-20	1.102	-	1.362	1.308	1.504
Select-21	1.165	-	2.519	1.214	1.136
Select-22	1.082	-	1.065	1.049	1.054
Select-23	1.090	-	1.061	1.036	1.066
Select-24	1.093	-	1.087	1.259	1.240
Select-25	1.025	-	1.089	1.180	1.279
Select-26	1.035	-	1.066	1.069	1.034
Select-27	1.061	-	1.065	1.054	1.069

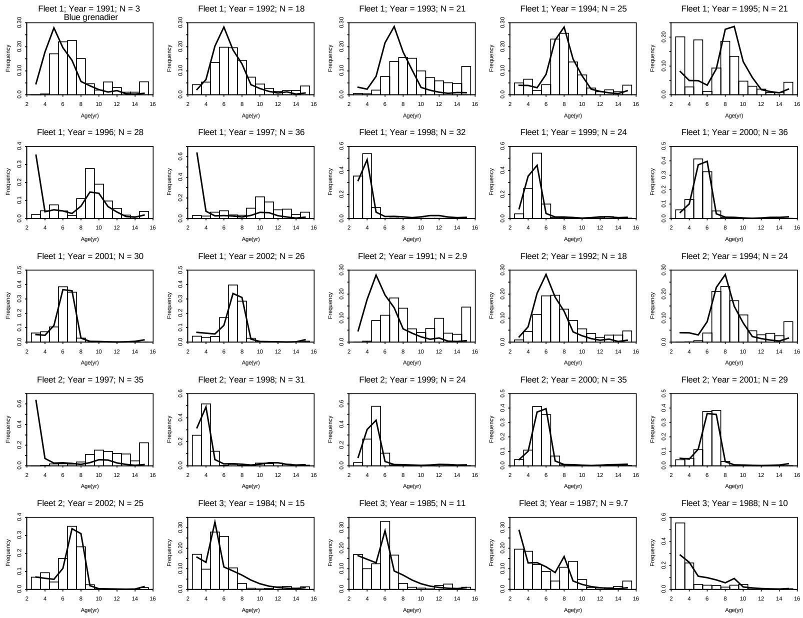
Two sets of results are shown for model A

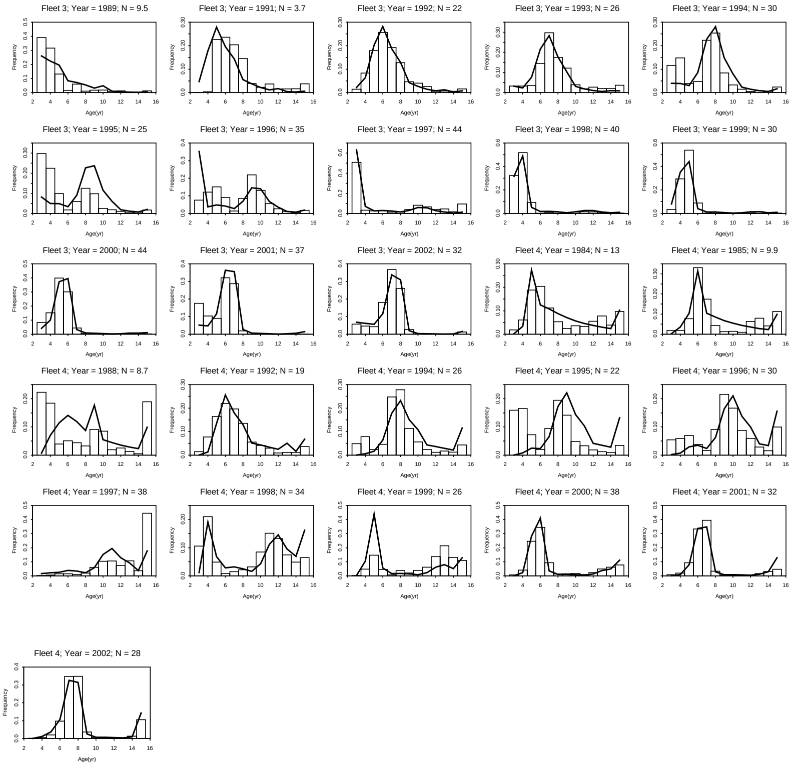
Table 35. Correlation matrix for the 27 selectivity parameters. Correlations that exceed 0.8 in absolute value are indicated in bold-underline.

2	0.60	1.00																								
3	**-0.93**	-0.55	1.00																							
4	0.04	-0.02	0.02	1.00																						
5	-0.01	-0.02	0.02	0.56	1.00																					
6	0.00	0.00	0.00	0.00	0.00	1.00																				
7	0.00	0.00	0.00	0.00	0.00	0.41	1.00																			
8	0.00	0.00	0.00	0.00	0.00	0.07	0.04	1.00																		
9	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.62	1.00																	
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00																
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00															
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00														
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.80**	1.00													
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	1.00												
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.19	1.00											
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.01	1.00										
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00									
18	0.01	0.00	-0.04	-0.03	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00								
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.45	1.00							
20	0.00	0.00	0.00	0.00	0.00	0.07	0.04	**0.95**	0.59	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	1.00						
21	0.02	0.02	-0.02	-0.01	0.00	0.01	0.01	0.14	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.15	1.00					
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00				
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	1.00			
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	-0.02	1.00		
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	-0.01	0.58	1.00	
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**

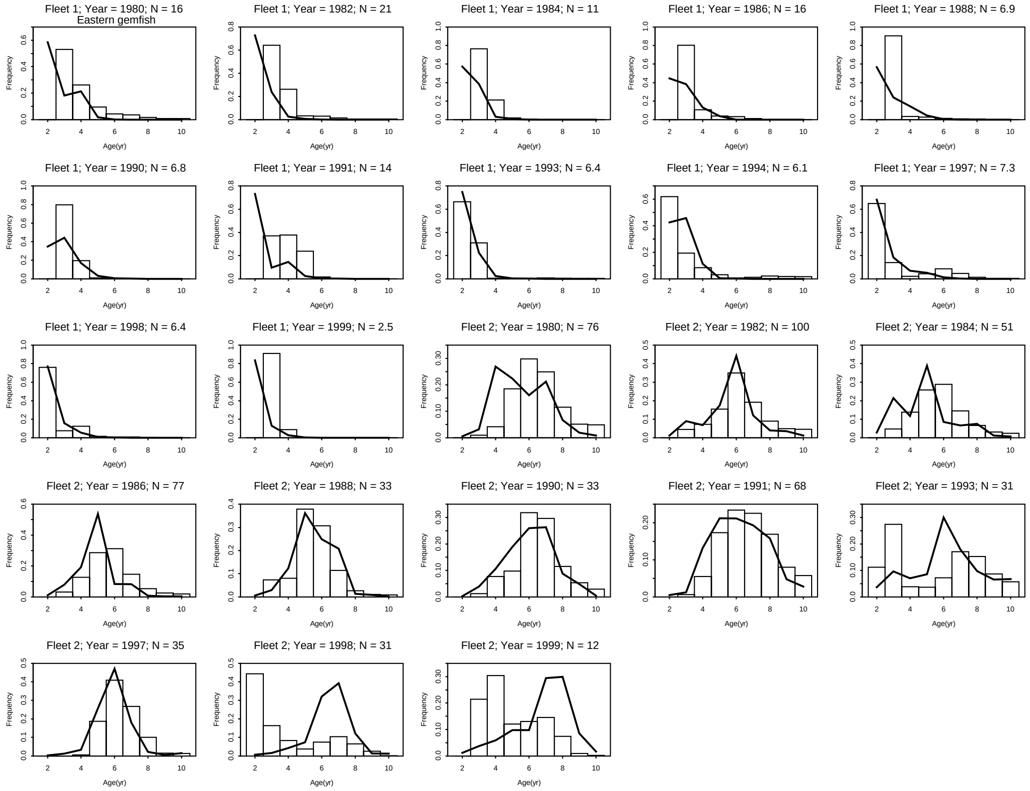
Appendix 5.1. Observed (bars) and model D-predicted (solid lines) catch age-compositions.

a) Blue grenadier

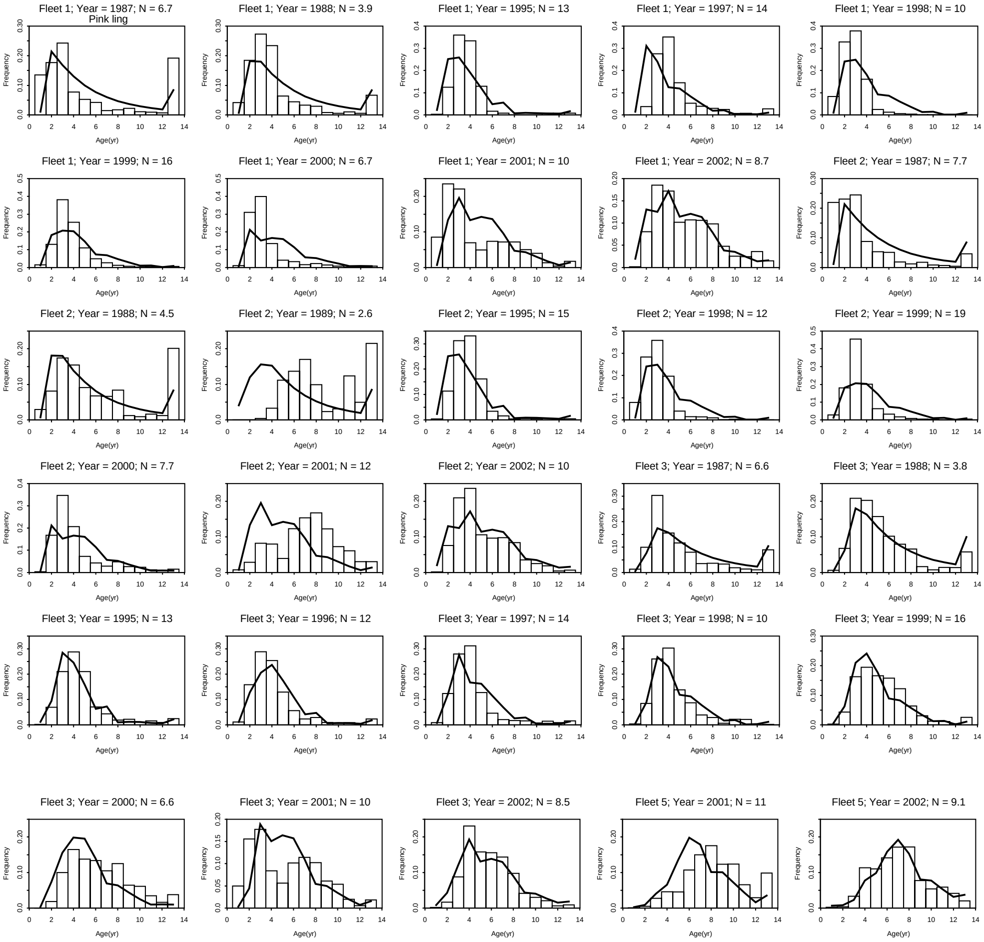




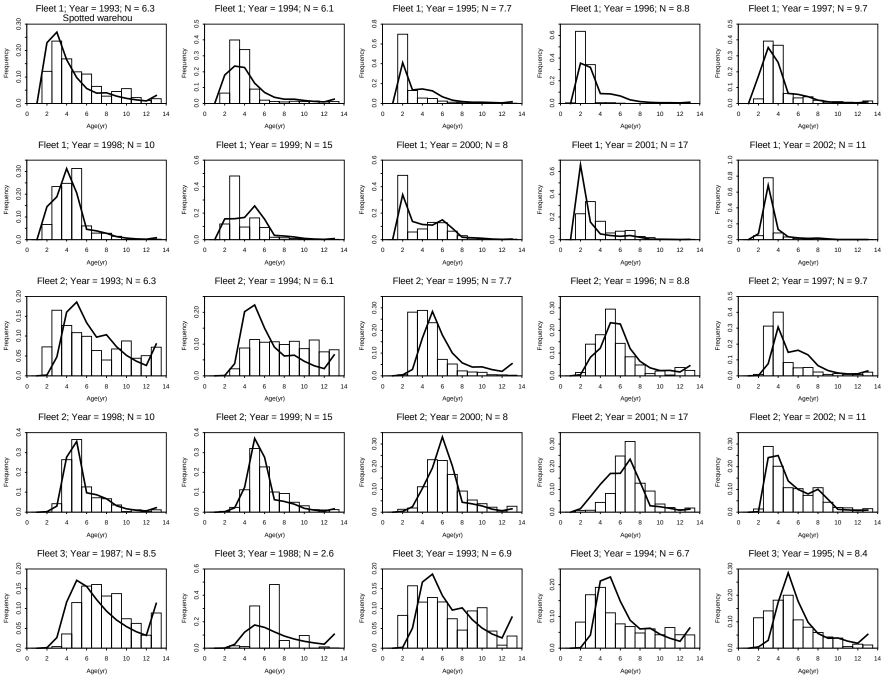
b) Eastern gemfish

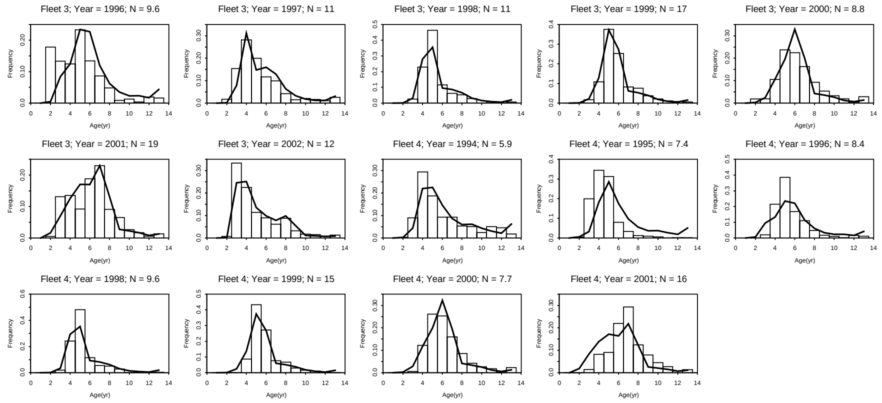


c) Pink ling

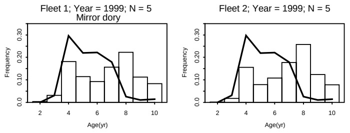

Fleet 1; Year = 1987; N = 6.7
Pink ling
Fleet 1; Year = 1988; N = 3.9
Fleet 1; Year = 1995; N = 13
Fleet 1; Year = 1997; N = 14
Fleet 1; Year = 1998; N = 10
Fleet 1; Year = 1999; N = 16
Fleet 1; Year = 2000; N = 6.7
Fleet 1; Year = 2001; N = 10
Fleet 1; Year = 2002; N = 8.7
Fleet 2; Year = 1987; N = 7.7
Fleet 2; Year = 1988; N = 4.5
Fleet 2; Year = 1989; N = 2.6
Fleet 2; Year = 1995; N = 15
Fleet 2; Year = 1998; N = 12
Fleet 2; Year = 1999; N = 19
Fleet 2; Year = 2000; N = 7.7
Fleet 2; Year = 2001; N = 12
Fleet 2; Year = 2002; N = 10
Fleet 3; Year = 1987; N = 6.6
Fleet 3; Year = 1988; N = 3.8
Fleet 3; Year = 1995; N = 13
Fleet 3; Year = 1996; N = 12
Fleet 3; Year = 1997; N = 14
Fleet 3; Year = 1998; N = 10
Fleet 3; Year = 1999; N = 16
Fleet 3; Year = 2000; N = 6.6
Fleet 3; Year = 2001; N = 10
Fleet 3; Year = 2002; N = 8.5
Fleet 5; Year = 2001; N = 11
Fleet 5; Year = 2002; N = 9.1
Frequency
Age(yr)
0 2 4 6 8 10 12 14

d) Spotted warehou

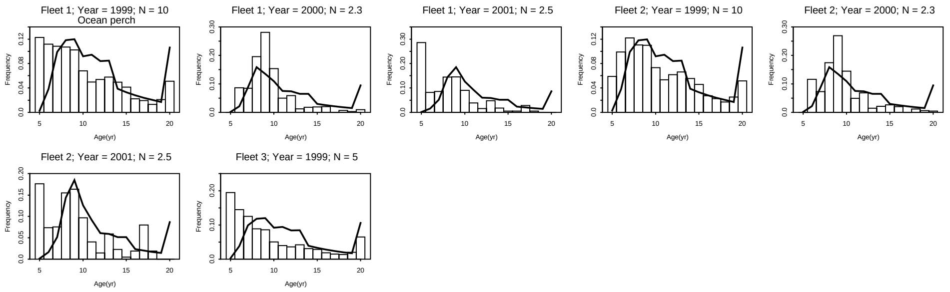




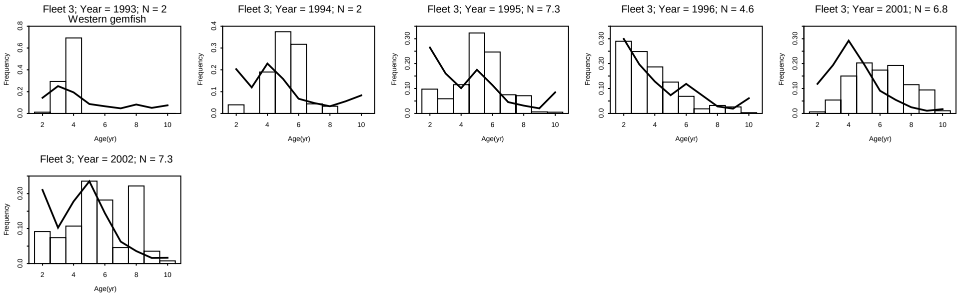
e) Mirror dory



f) Ocean perch

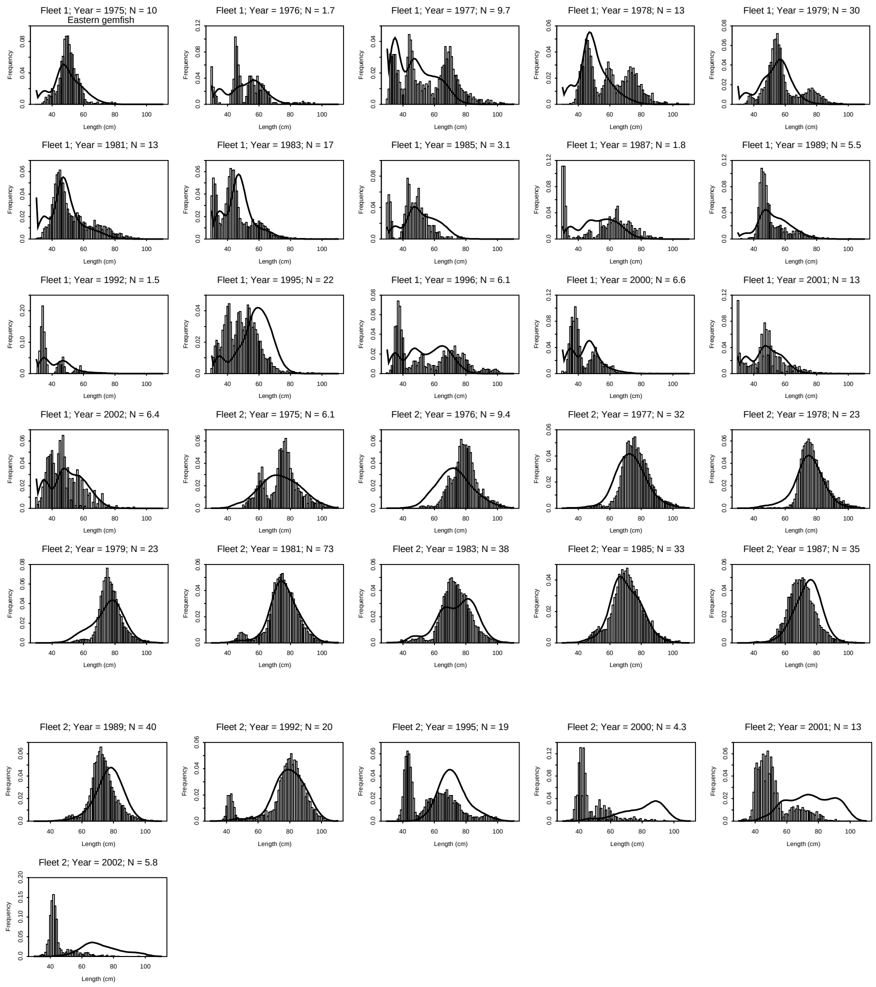


g) Western gemfish

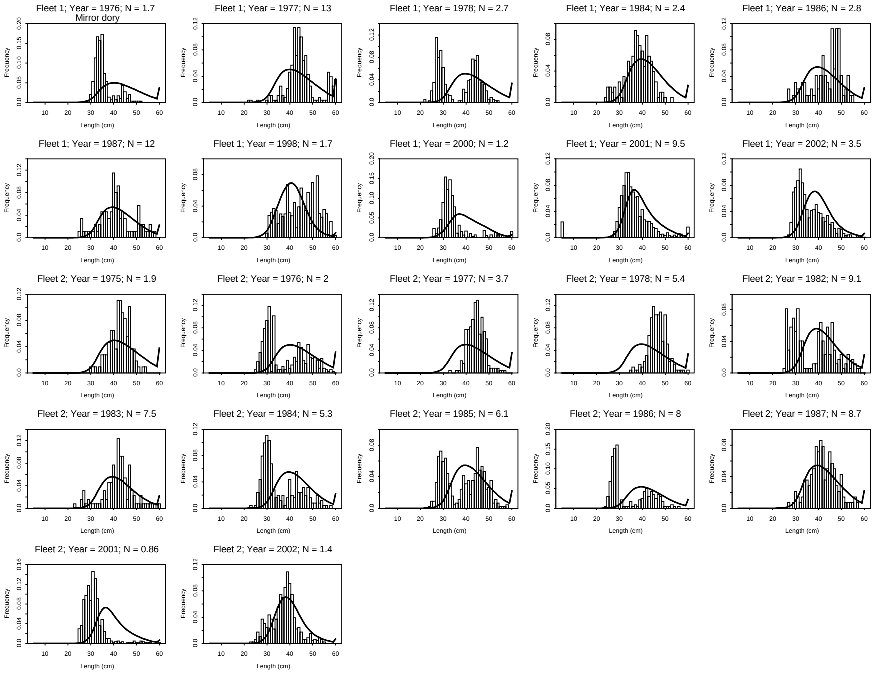


Appendix 5.2. Observed (bars) and model D-predicted (solid lines) catch length-frequency information.

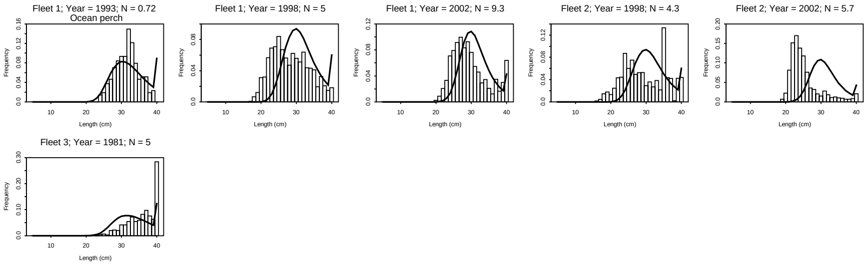
a) Eastern gemfish



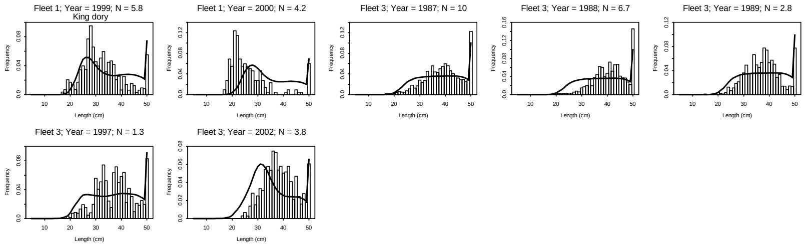
b) Mirror dory



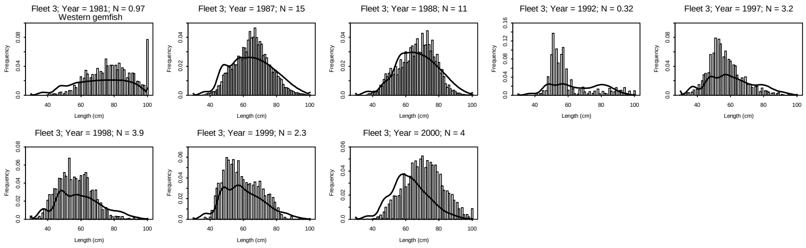
c) Ocean perch



d) King dory



e) Western gemfish



Chapter 6: Simulation Evaluation of Approach to Informing 'Data-Poor' Species Using Information for 'Data-Rich' Species

Introduction

The method outlined in Chapter 5 aims to provide improved estimates of management-related quantities such as current biomass, trends in biomass and current depletion for 'data-poor' species using information for 'data-rich' species. However, prior to the adoption and use of any new method of analysis, it is necessary to show that it can perform at least as well as, and preferably better than, alternative approaches. This is particularly the case for methods of analysis (such as that outlined in Chapter 5) that are to be applied to provide the basis for management decisions, given that a poor analysis method can have substantial economic, social, and biological consequences.

It is not valid to evaluate the potential of a new method of analysis by applying it to an actual data set because the correct answer is seldom known for an actual data set (and certainly not for the species / stocks considered in Chapter 5). One way to evaluate a new method is through cross validation: the analysis method is applied to a subset of the data, and the results of that analysis used to make predictions of the remainder of the data set. Unfortunately, cross validation cannot be applied in this instance because the data sets are too small and the evaluation would consequently be based on an unrealistically uninformative data set compared to that to which it is intended to be applied.

Simulation can be used to evaluate elements of a management system. Specifically, simulation can be used to evaluate:

a decision rules (e.g. Butterworth and Bergh, 1993; Cochrane *et al.*, 1998; Butterworth and Punt, 1999; Punt and Smith, 1999; Geromont *et al.*, 1999; Hilborn *et al.*, 2002; Punt *et al.*, 2002b);

b methods of stock assessment (e.g. Kirkwood, 1981; de la Mare, 1986; Punt, 1989, 1990; Pope and Shepherd, 1985; Bence *et al.*, 1993; Patterson and Kirkwood, 1995; NRC, 1998; Sampson and Yin, 1998; Ianelli, 2002; Punt *et al.*, 2002a);

c methods for conducting future projections (e.g. Maunder and Watters, 2003; Punt and Methot, in press);

d empirical indicators of stock status (e.g. Punt *et al.*, 2001b; Fulton *et al.*, 2004); and

e methods of CPUE standardization (e.g. Porch and Scott, 1994; Maunder, 2001).

The advantages of using simulation to evaluate elements of a management system (see Figure 67 for an overview of the steps used when evaluating stock assessment methods) are numerous (e.g. Punt, 1992; Cooke, 1999). These include that there are no consequences to the actual resource of evaluating a poor method and that the true situation is known exactly. However, the validity of the results of a simulation evaluation are only as good as the scenarios represented in the simulations, specifically whether the simulations adequately represent the vagaries associated with monitoring fisheries resources, conducting stock assessments, and implementing decision rules. Therefore, depending on whether the simulations over- or under-represent uncertainty, they will tend to over- or under-estimate the utility of the method under investigation. The problem of the simulations not representing reality very well will be reduced to some extent by comparing several alternative methods using the same simulation protocol.

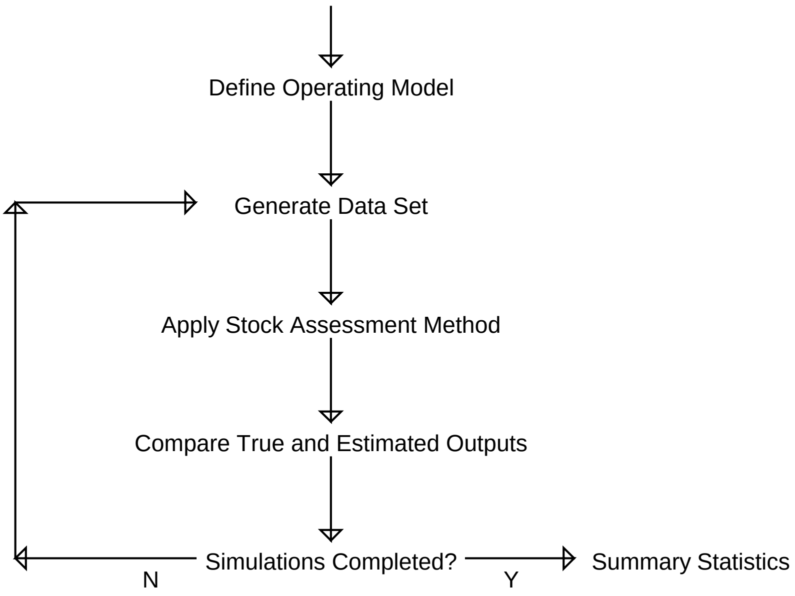


Figure 67. Flowchart of the approach used to evaluate a method of stock assessment.

The analyses of this chapter compare the default situation of conducting separate assessments of each new stock / species with the approach of Chapter 5. The success of the method of Chapter 5 can be evaluated by the extent to which:

a including data for 'data-poor' species with those for 'data-rich' species when conducting assessments leads to poorer estimation performance for the 'data-rich' species; and

b including data for 'data-poor' species with those for 'data-rich' species when conducting assessments leads to better estimation performance for the 'data-poor' species.

The operating model

Overview

The operating model is set up to mimic roughly the situation to which the assessment method is applied in Chapter 5. It includes four species, one that is 'data-rich' (Species 1), two that are 'data-moderate' (Species 2 and 3) and one that is 'data-poor' (Species 4). Species 1–3 are meant to mimic (roughly) blue grenadier, eastern gemfish and pink ling. The values for the biological (natural mortality, growth, etc.) and technological (e.g. selectivity, probability of discarding) parameters of the operating model for Species 4 are set to those for spotted warehou, but the data generated for Species 4 are much less extensive than is actually the case in reality for spotted warehou. The operating model considers the period 1920–2002. It is projected forward from unexploited equilibrium at the start of 1920 with variable recruitment thereafter. This specification implies that the age-structure of the population will not be in equilibrium at the start of 1968, as is assumed by the method of stock assessment described in Chapter 5.

There are a total of five fleets. Fish of the 'data-rich', 'data-poor' and one of the 'data-moderate' species (Species 3) are caught by all five fleets while fish of the other 'data-moderate' species (Species 2) are only caught by two of the fleets (Fleets 1 and 2).

Population dynamics model

The population dynamics model component of the operating model is essentially identical to that underlying the stock assessment methods (see Chapter 5: The population dynamics model; Equations 5.1–5.10). A key exception to this is that rather than specifying the historical catches, the historical exploitation rate is instead computed using the equation:

$$F_y^{s,f} = Q^s\, q^{s,f} E_y^f\, e^{\varepsilon_y^{s,f} - (\sigma_f^F)^2/2} \qquad \underline{\varepsilon}_y^f \sim N(\underline{0}, \mathbf{V}^f) \tag{6.1}$$

where $F_y^{s,f}$ is the exploitation rate on fully selected animals of species *s* by fleet *f* during year *y*,

$q^{s,f}$ is the relative catchability of species *s* by fleet *f* (Table 36),

Q^s is the overall catchability coefficient for species *s*,

E_y^f is the (relative) effort for fleet *f* during year *y*,

$\mathbf{V}^f$ is the variance-covariance matrix for fleet *f*, i.e.:

$$V^f = (\sigma_y^f)^2 \begin{vmatrix} \rho^f & 1 & \rho^f \\ \rho^f & \rho^f & 1 \end{vmatrix} \tag{6.2}$$

ρ^f is the correlation among species in the residuals about the average exploitation pattern, and

σ_y^f is the standard deviation of the residuals about the average exploitation pattern.

The time-trajectory of effort by fleet (see Figure 68) captures the situation in which fleets 1 and 2 started first followed later by fleets 3–5. Effort by fleet 2 peaked in the mid-1980s and then declined substantially. Effort by the remaining fleets increased and then remained constant. Roughly speaking, fleets 1 and 2 mimic the trawl fishery off the east coast of Australia while fleets 3–5 mimic the trawl fleets off western Victoria and Tasmania and the non-trawl fishery. The values for $q^{s,f}$ in Table 36 were chosen to mimic roughly the spatial patterns of fishing-related impact on the four species included in the operating model

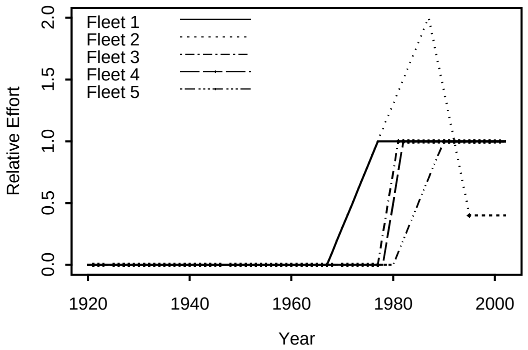


Figure 68. Relative effort for each of the five fleets.

Table 37 lists the baseline values for the parameters of the operating model and the values examined in the tests of sensitivity. Values are not specified in Table 36 for the overall catchability coefficients (Q^s in Equation 6.1). The values for these parameters are instead determined so that if the operating model is projected forwards from 1920 to 2003, the depletion in 2003 equals the pre-specified value in Table 37.

Figures 69 and 70 show the relationships between selectivity and age, and between the probability of being discarded and age in the operating model.

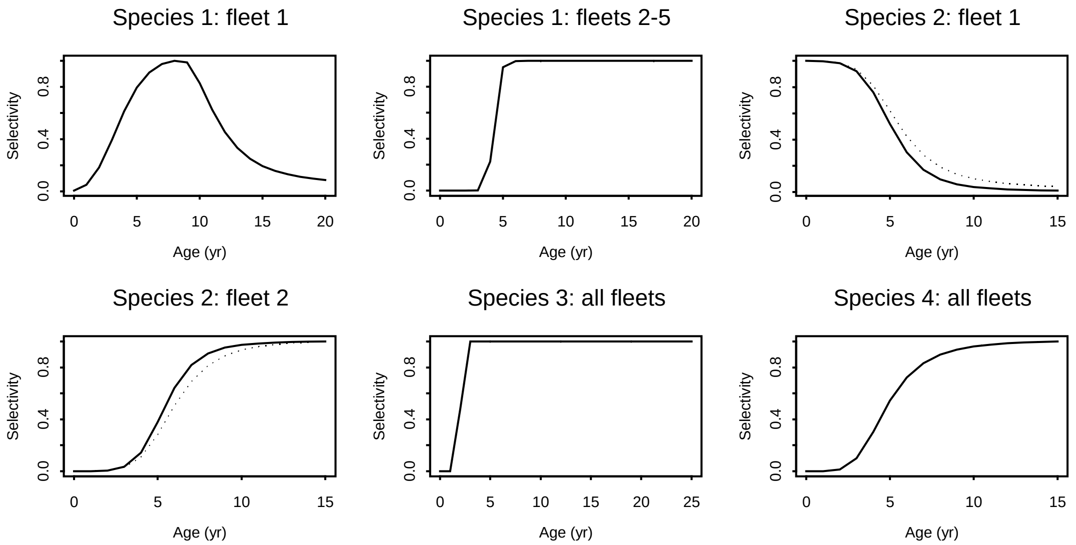


Figure 69.Age-specific selectivity patterns for the four species (solid lines: females; dotted lines: males).

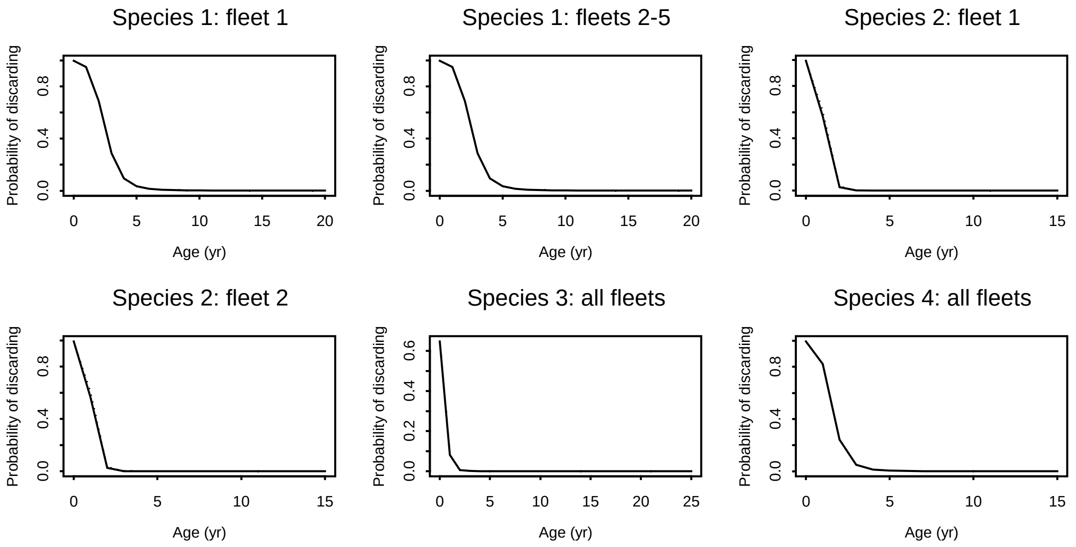


Figure 70. Probability of discarding as a function of age for each of four species.

Data generation

The data generated by the operating model include landed catches, discard rates, catch-rate-based indices of abundance, catch age-composition data, catch size-composition data, and survey estimates of abundance.

Catch data

The landed catches by fleet and year are assumed to be known without error.

Discard rate

The estimates of discard rate are assumed to be unbiased and log-normally distributed, i.e.:

$$D_y^{obs,s,f} = \frac{C_y^{D,s,f}}{\tilde{C}_y^{L,s,f} + \tilde{C}_y^{D,s,f}} e^{\delta_u^{D,s,f} - (\sigma_d^{s,f})^2/2} \qquad \delta_y^{D,s,f} \sim N(0;(\sigma_d^{s,f})^2) \qquad (6.3)$$

where $D_y^{obs,s,f}$ is the observed fraction of the catch (in mass) of species *s* by fleet *f* that was discarded during year *y*,

$\tilde{C}_y^{D,s,f}$ is total catch (in weight) discarded by fleet, year and sex,

$\tilde{C}_y^{L,s,f}$ is total catch (in weight) landed by fleet, year and sex,

$\sigma_d^{s,f}$ is (approximately) the coefficient of variation of the discard rates for species *s* and fleet *f*.

All of the simulations are based on the assumption that estimates of the fraction of the total catch that is discarded are available from 1991–2002 for each fleet. The value of $\sigma_d^{s,f}$ is set equal to 0.3 for all years, fleets and species.

Catch-rate-based indices of abundance

The catch-rate-based indices of abundance are assumed to be related linearly to exploitable biomass, i.e.:

$$I_y^{s,f} = \tilde{q}^{s,f} B_y^{e,s,f}(1 - F_y^{s,f}/2) e^{\eta_y^{s,f} - (\sigma_y^{s,f})^2/2} \qquad \eta_y^{s,f} \sim N(0;(\sigma_y^{s,f})^2) \qquad (6.3)$$

where $\tilde{q}^{s,f}$ is the catchability coefficient for species *s* and fleet *f*,

$I_y^{s,f}$ is the catch-rate index for species *s*, fleet *f* and year *y*, and

$\sigma_q^{s,f}$ is (approximately) the coefficient of variation of the random fluctuations in catchability.

Catch-rate indices are available for two of the fleets for the 'data-rich' species, for one of the fleets for one of the 'data-moderate' species (Species 2), and for four fleets for the other 'data-moderate' species (Species 3) – no catch-rate indices are available for the 'data-poor' species and no catch-rate indices are available for the fifth fleet. Table 38 lists the specifications for each of the catch-rate series available for assessment purposes.

Age- and size-composition data

The catch age- and size-composition data are generated by sampling multinomially from the operating model catch-at-age and catch-at-size compositions (see Equation 5.14). The multinomial sample sizes for the age- and size-composition data by fleet and year are listed in Table 39. Age-composition data are only available for Species 1–3 while relatively imprecise size-composition data are available for Species 4.

Survey estimates of abundance

Unbiased estimates of spawning biomass are generated for 1994 and 1995 for Species 1. These estimates are assumed to be log-normally distributed with a coefficient of variation of 0.2.

Specifications for the estimation model

The assessment models applied to the data generated by the operating model are similar to those examined in Chapter 5. The assumptions common to all of the assessment methods considered in this chapter are:

a the rate of natural mortality, *M*, (Table 31) is known for each species;

b maturity as a function of size is known exactly;

c the form of the selectivity pattern for each species (see Figure 69) is known (but the values for the parameters of the selectivity pattern have to be estimated from the data);

d the residual standard deviations for the discard data and the catch-rate data are known exactly, as are the effective sample sizes for the age- and size-composition data;

e the probability of discarding as a function of size (Figure 70) is known exactly;

f there is no ageing error, and ageing error is ignored when fitting the population dynamics model;

g the same plus and minus groups are assumed when fitting the assessment model to the age- and size-composition data as was the case when it was fit to the actual data for blue grenadier, eastern gemfish, pink ling and spotted warehou (Table 30);

h recruitment is estimated for a subset of the years included in the operating model (Species 1– 1979-2000; Species 2 – 1968-2000; Species 3 – 1986-2000; Species 4 – 1986-2000) – these particular years were chosen to match the years for which age- and size-composition data are available (Table 39); and

i the extent of variation in recruitment is known exactly.

The five assessment models considered in the simulation study are:

a steepness is known exactly and there is no sharing of parameters among species (abbreviation 'Current');

b steepness is known exactly, and there is a prior on changes in exploitation rate among species (species 1-4 for fleet 1; species 1-4 for fleet 2; species 1, 3 and 4 for fleet 3; species 1,3 and 4 for fleet 4). A weight of 10 is assigned to this penalty (abbreviation 'with F prior');

c As for the 'with F prior' assessment model, except that a prior is also placed on the difference in the lengths-at-50%-selectivity for species 1 caught by fleet 4, species 2 caught by fleet 2, species 3 caught by all fleets, species 4 caught by all fleets. A weight of 10 is assigned to this penalty (abbreviation 'with F and S priors');

d As for the 'Current' assessment model, except that steepness is estimated (abbreviation 'Current + steepness').

e As for 'with F prior' assessment model, except that steepness is estimated (abbreviation 'With F prior + steepness').

Performance measures

There are a very large number of potential performance measures for evaluating whether: a) including data for 'data-poor' species with those for 'data-rich' species when conducting assessments leads to poorer estimation performance for the 'data-rich' species; and b) including data for 'data-poor' species with those for 'data-rich' species when conducting assessments leads to better estimation performance for the 'data-poor' species.

The specific performance measures chosen for each species are:

a The time-trajectory for the relative errors (medians and 90% intervals) for the estimates of spawning biomass.

b The time-trajectory for the medians of the absolute relative errors for the estimates of spawning biomass.

c The time-trajectory for the relative errors (medians and 90% intervals) for the estimates of the ratios of the spawning biomass each year to the spawning biomass at the start of 1920.

d The time-trajectory for the medians of the absolute relative errors for the estimates of the ratios of the spawning biomass each year to the spawning biomass at the start of 1920.

e The histogram of relative errors for the estimate of the spawning biomass at the start of 1920, S_0^s.

f The histogram of the relative errors for the estimate of steepness.

g Box and whisker plots for the rel;ative error of:

- The spawning biomass at the start of 1920.
- The spawning biomass at the start of 1986.
- The spawning biomass at the start of 2003.
- The ratio of the spawning biomass at the start of 1986 to that at the start of 1920.
- The ratio of the spawning biomass at the start of 2003 to that at the start of 1920.
- The ratio of the spawning biomass at the start of 1995 to that at the start of 1986.
- The ratio of the spawning biomass at the start of 2003 to that at the start of 1986.

The box and whisker plots provide the primary basis for the evaluation of performance because the results for several assessment models can be displayed on the same plot for a given operating model variant or the results for several operating model variants can be shown for a given assessment model on a single plot. Performance measures a) - f) are used primarily to explore why a particular result arose.

Spawning biomass is the focus for the evaluation because most management objectives for SESSF species are expressed in terms of spawning biomass. Focus is placed on the 1986 and 2003 spawning biomasses because 2003 is the most recent year and 1986 is the first year for which catch-rate data are available for the bulk of the SESSF species for which such information is available (e.g. Table 38). The ratio of the 1995 to the 1986 spawning biomass and the ratio of the 2003 to the 1986 spawning biomass are reported because Punt *et al.* (2002a) found that the ratio of the spawning biomass in a recent year to S_0^s can be very poorly determined.

Results and discussion

Baseline trial

Each simulation trial consists of 250 simulations. Figure 71 shows box and whisker plots of the relative errors for seven management-related quantities for three assessment model variants for the baseline operating model ($\sigma_y^f = 0.1;\ \rho^f = 0.7$; Species 4 depleted to 0.5 S_0 in 2003). The y-axis is square root transformed to better visualize the results. The three assessment model variants in Figure 71 are: 'Current', 'With F prior', and 'With F and S priors'. The relative performances of the three assessment model variants can be compared in terms of whether they lead to improved accuracy (the solid dots closer to the zero line) and increased precision (narrower interquartile ranges). The 'Current', 'With F prior' and 'With F and S priors' variants achieve the lowest absolute median relative errors for 7, 12 and 9 respectively of the 28 quantities in Figure 71 while they achieve the lowest interquantile ranges for 10, 16 and 2 respectively of these quantities.

The 'With F and S priors' variant is fairly variable (wide interquartile range) and also leads to substantial bias when estimating biomass for the first 'data-moderate' species (Species 2) and (to a lesser extent) for the 'data-poor' species (Figure 71). Consequently, this variant of the assessment model is not considered further in the analyses of this chapter.

Comparing the 'With F prior' and 'Current' variants of the assessment model directly, the 'With F prior' variant outperforms the 'Current' variant in terms of both bias and precision (it achieves the lower median relative error for 16 of the 28 quantities and the lower interquartile range for 18 of the 28 quantities; Table 40). Of specific interest may be that the 'With F prior' variant generally outperforms the 'Current' variant for

Species 4 (the ‘data-poor’ species), although the improvement in performance is frequently not particularly substantial (e.g. the spawning biomass in 1986 for Species 2 and 4).

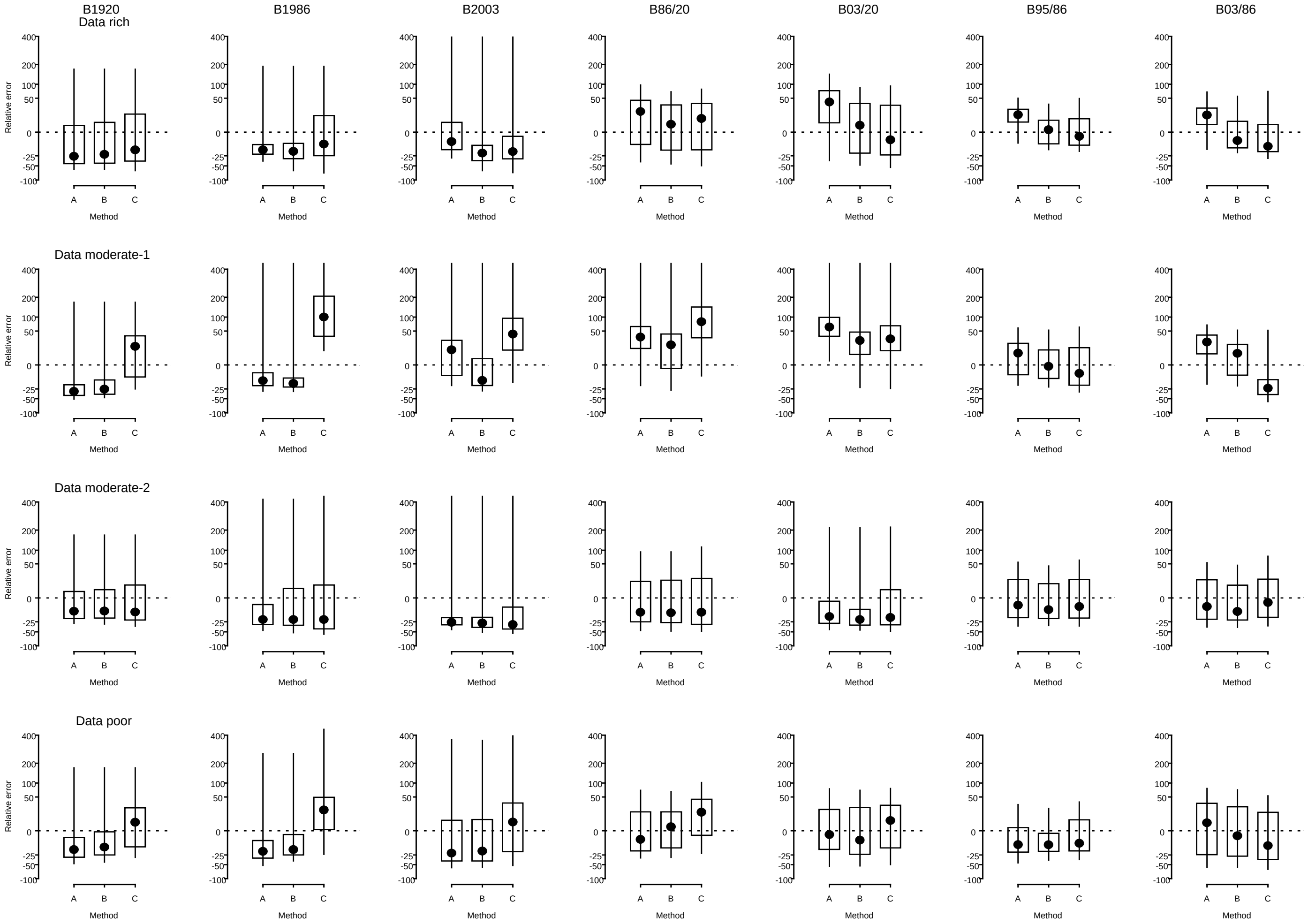


Figure 71. Box and whisker plots of the relative errors for seven management-related quantities for three assessment models (A – 'Current', B – 'With F prior', C – 'With F and S priors') for the baseline operating model.

As expected, the interquartile ranges for Species 4 are generally larger than those for Species 1—3 irrespective of the choice of an assessment method, confirming the expectation that while some improved performance may be achieved by placing priors on inter-species differences in parameters, this cannot turn a 'data-poor' species into a 'data-rich' species – that requires actual data. The 'With F prior' variant is more biased and variable for the second 'data-moderate' species (Species 3) than the 'Current' variant (Figure 71), suggesting that the improved estimation performance for Species 4 does come at a price in terms of possible poorer estimation performance for 'data-rich' and 'data-moderate' species.

Figure 72 shows the time-trajectories of relative error (1st column: spawning biomass, 2nd column: spawning biomass relative to that in 1920) and histograms of relative error for the spawning biomass in 1920 and steepness (columns 3 and 4). The results in this figure pertain to the baseline operating model and the 'With F prior' variant of the assessment model.

The relative errors for steepness in Figure 72 are all zero because the variant of the stock assessment model concerned 'knows' the correct value of steepness. S_0 is actually more uncertain for the 'data-rich' species than for the 'data-moderate' and 'data-poor' species. This is likely a reflection of the fact that σ_r =1 for the 'data-rich' species and only 0.6 for the remaining species (Table 31). Thus, the assumption that S_{1968}=S_0 is likely violated to a greater extent for the 'data-rich' species.

As expected from the results of many previous studies, the estimates of spawning biomass relative to that in 1920 are estimated more accurately and precisely than spawning biomass in tonnes. The 90% intervals of the relative errors of spawning biomass get wider with time. This is unsurprising for the relative measures (because the ratio of spawning biomass to S_0 is 1 in 1920 by definition), but is still of some concern. It should be noted, however, that the 90% intervals do not necessarily give a good impression of, for example, the interquartile range.

Sensitivity tests

The sensitivity tests examine the implications, in terms of the comparison between the 'Current' and 'With F Prior' variants of the assessment model, of: a) the status of Species 4 at the start of 2003, b) the extent of variation and correlation in exploitation rate about that expected from the pre-specified effort patterns, and c) the effective sample size for the size-composition data for Species 4 being 100 rather than 20. Table 40 summarizes the results of the baseline simulation trial and the sensitivity tests in terms the number of cases (out of 28) in which each model variant achieves the lower median relative error and interquartile range. Results are shown by species and for all species combined.

The 'With F prior' variant outperforms the 'Current' variant to a greater extent in terms of reduced bias for the '2003 depletion = 0.1', '$\sigma_y^f = 0.99$', and the 'Better data for Species 4' sensitivity tests, and in terms of reduced variation for the first of these sensitivity tests. The 'Current' variant never performed better than the 'With F prior' variant for Species 4 (in terms of achieving the greater number of lower median relative errors), and only outperformed the 'with F prior' variant for the $\sigma_y^f = 0$ sensitivity test. Figure 73 compares the 'Current' and 'With F prior' variants for the 'Better data for Species 4' sensitivity test - the only sensitivity test in which the 'Current' variant is more precise on average than the 'With F prior' variant.

One of the key factors driving the results in Figures 71 and 73 and the first eight rows of Table 40 is the fact that recruitment variation occurs prior to 1968 but the assessment models ignores this. Figure 74 and the row 'Deterministic' in Table 40 examine the consequences of there being no recruitment variation before the year assumed by assessment model to be that in which recruitment variation started. Although somewhat unrealistic, the 'Current' variant outperforms the 'With F prior' variant in terms of bias for this sensitivity test. This result is, however, somewhat misleading because both assessment models are biased (Figure 74).

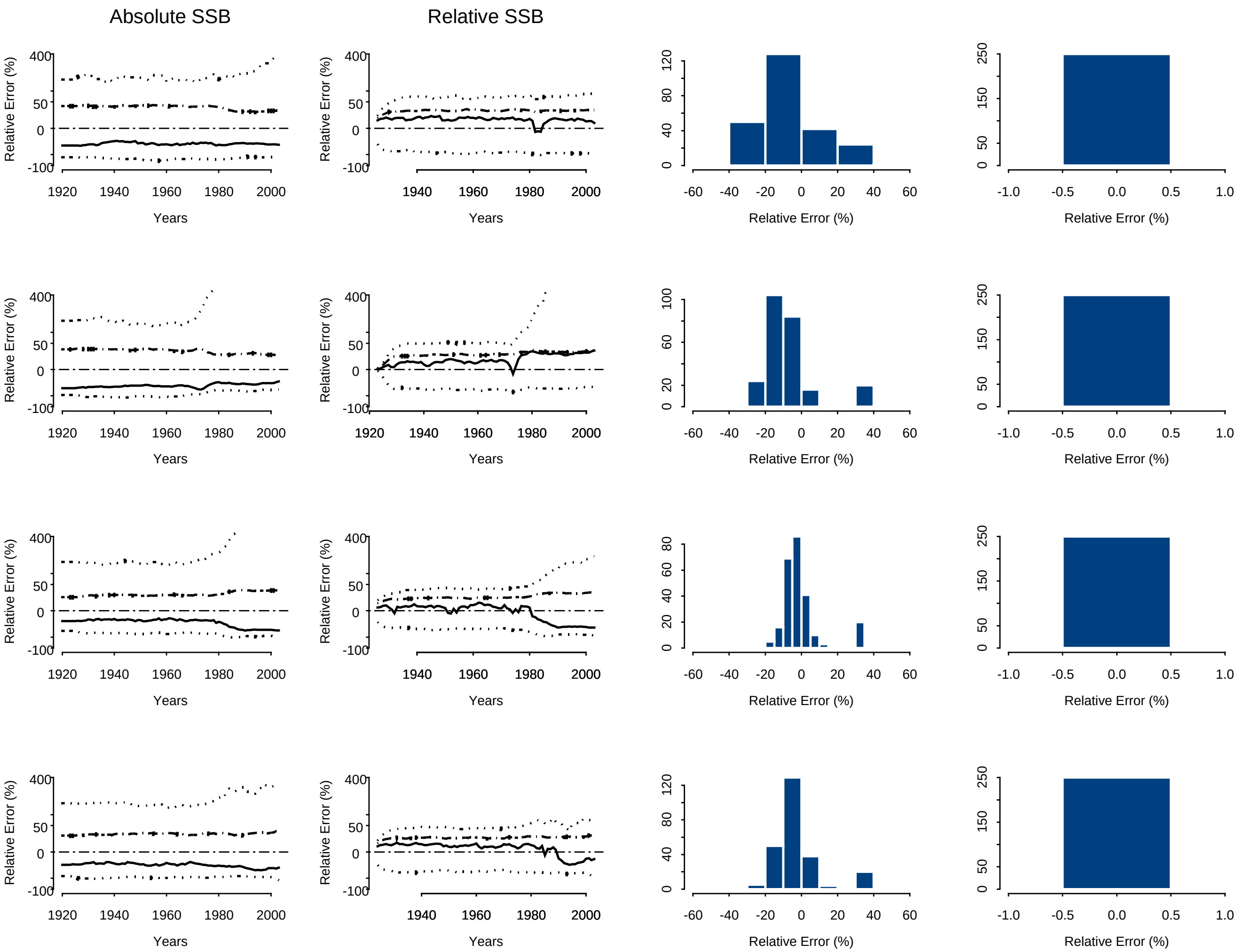


Figure 72. Time-trajectories of relative error (median relative error: solid line; 90% intervals: dotted lines; median absolute relative error: dashed line) (1st column: spawning biomass, 2nd column: spawning biomass relative to that in 1920) and histograms of relative error for the spawning biomass in 1920 and steepness (columns 3 and 4).

The results in this figure pertain to the baseline operating model and the 'With F prior' variant of the assessment model.

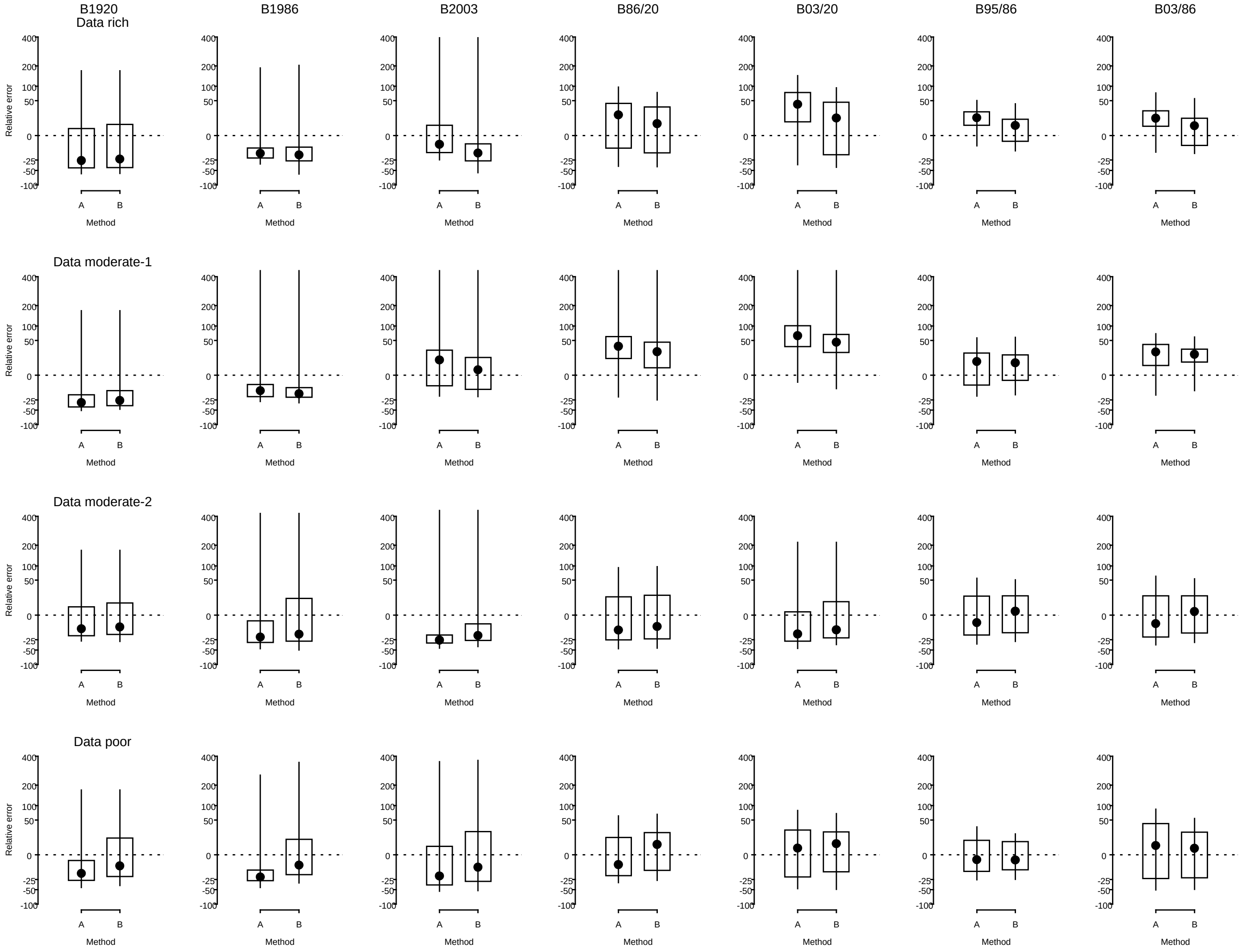


Figure 73. Box and whisker plots of the relative errors for seven management-related quantities for two assessment models (A – 'Current', B – 'With F prior') for the sensitivity test in which the size-composition sample size for Species 4 is increased from 20 to 100.

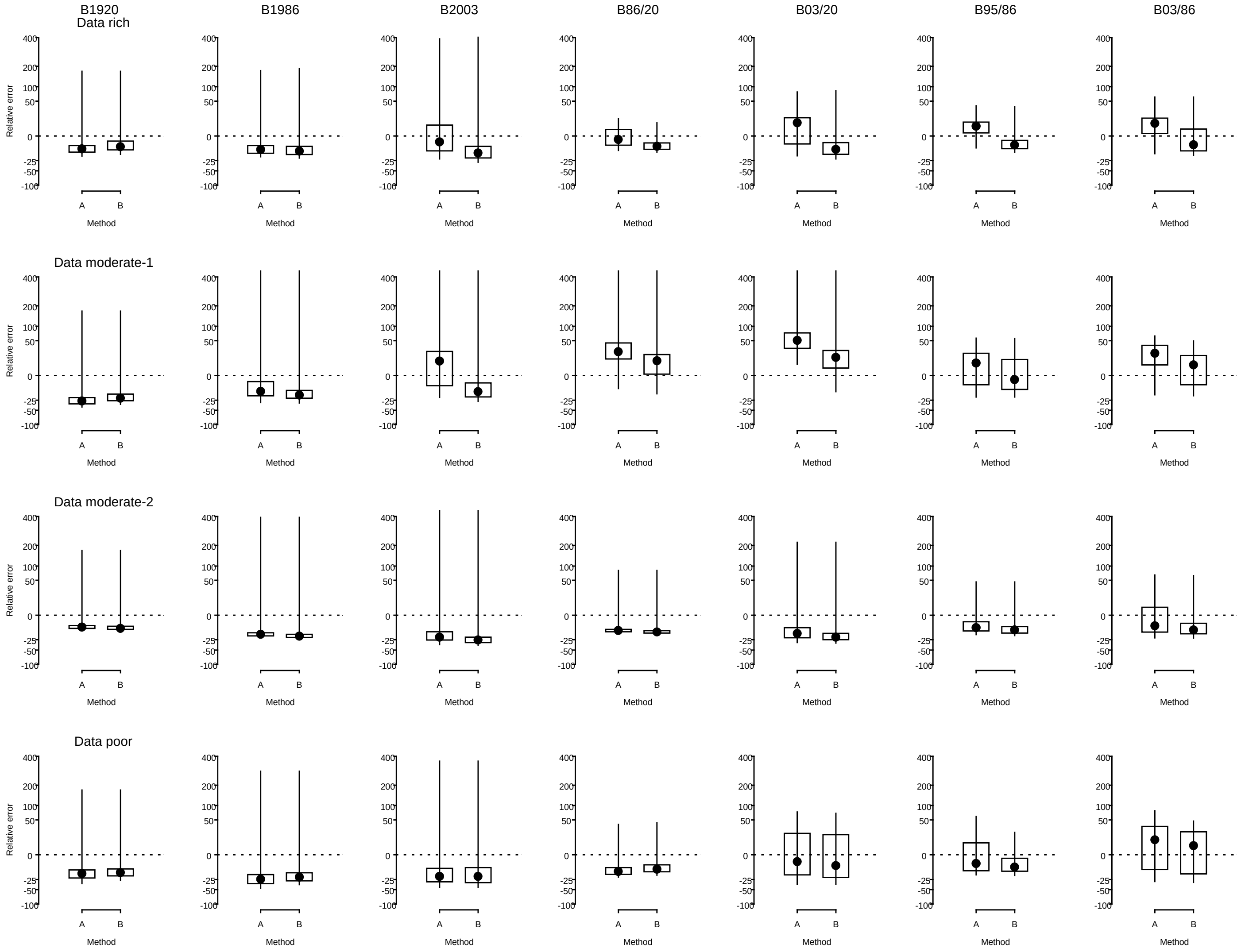


Figure 74. As for Figure 73, except that the results relate to the sensitivity test in which recruitment variability only occurs for recent years.

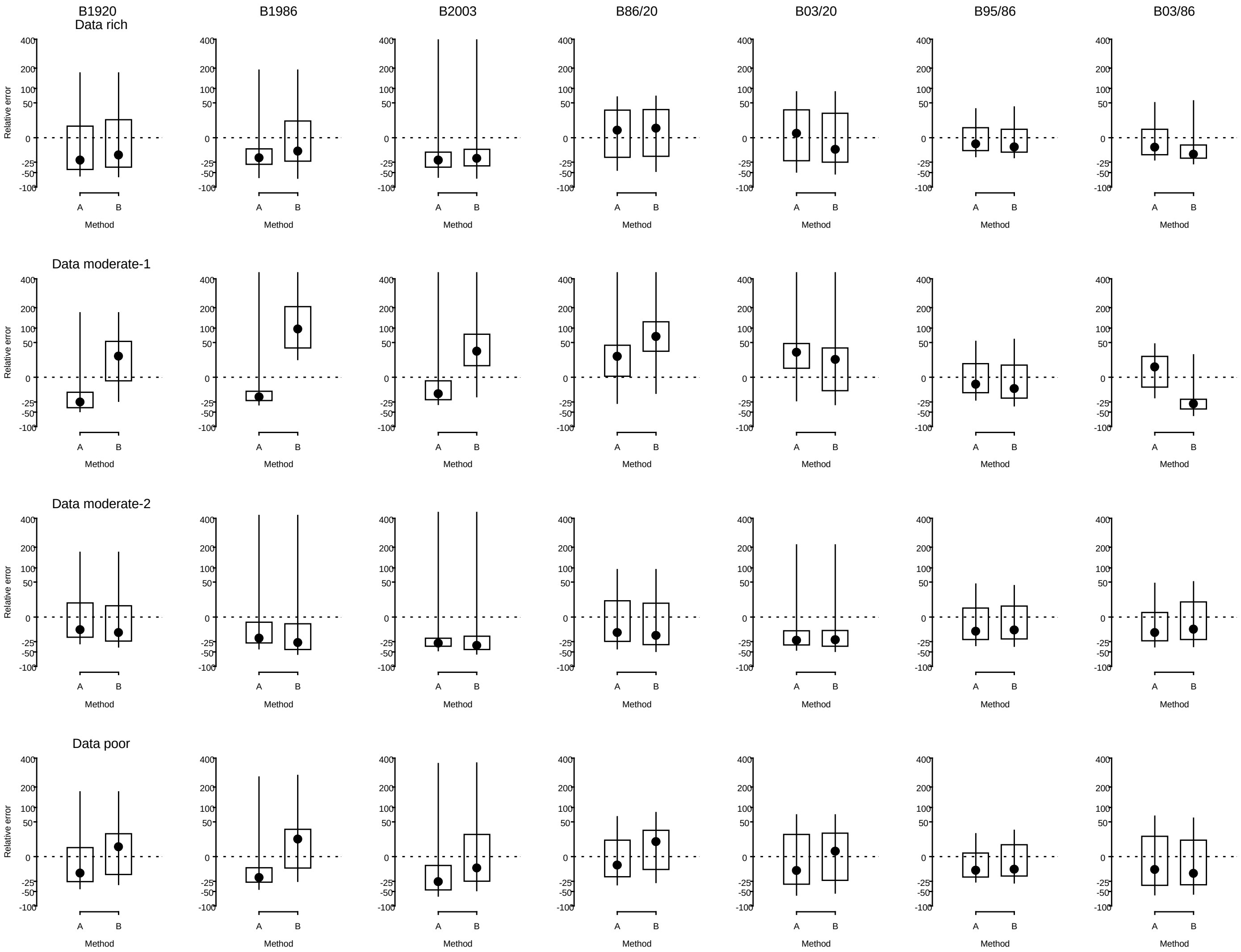


Figure 75. As for Figure 73, except that steepness is treated as an estimable parameter.

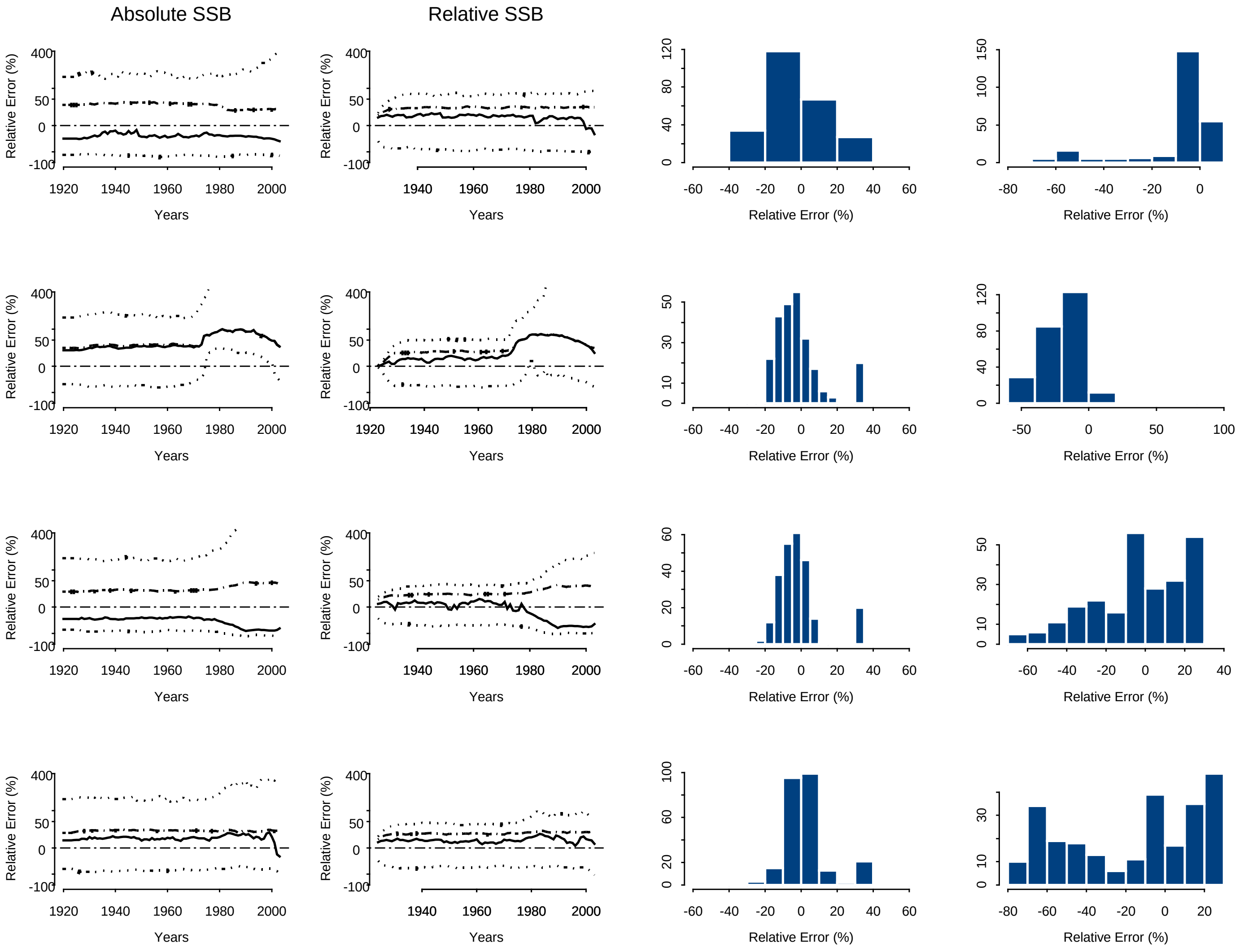


Figure 76. As for Figure 72, except that the assessment model treats steepness as an estimable parameter.

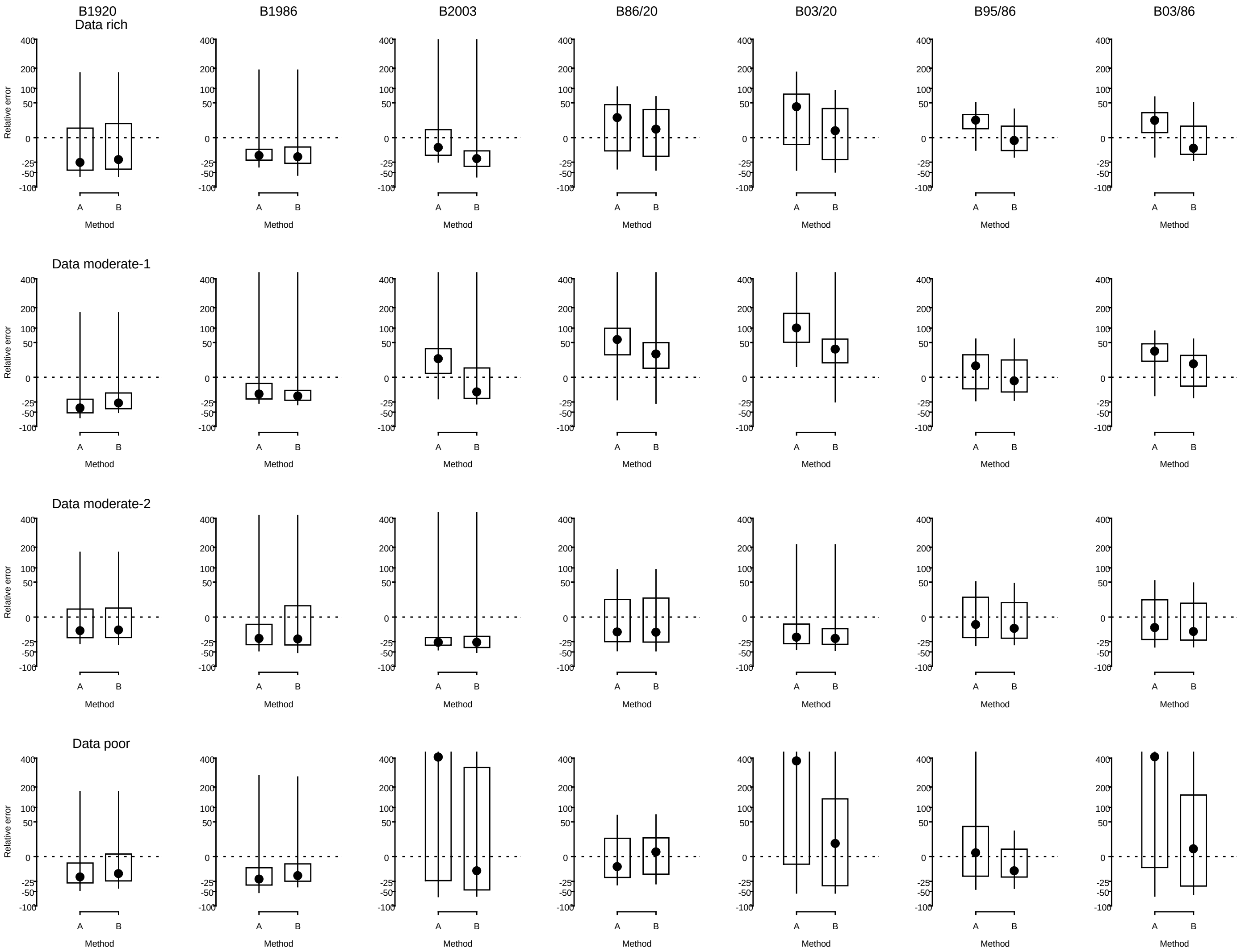


Figure 77. As for Figure 73, except that σ_r is assumed to be 5 when applying the stock assessment model.

The performance of the 'With F prior' variant deteriorates markedly when steepness is estimated within the assessment (Figures 75 and 76, Table 40 row 'Steepness estimated'). The estimates of steepness are both biased and imprecise (Figure 75) even though a prior is placed on this parameter.

Figure 77 examines the consequences of dropping the penalty on recruitment variation when fitting the model (by setting $\sigma_r = 5$). Performance for the 'data-rich' and 'data-moderate' species does not change much but the estimates of spawning biomass for the 'data-poor' species are much more imprecise than was the case in Figure 71.

Conclusion

The results of the analyses of this chapter indicate that, in almost all cases, including a prior on the inter-fleet differences in relative exploitation rate is likely to lead to improved estimation performance. Some quantities may, however, be estimated worse when a prior on the exploitation rate is included in the assessment. Overall, however, there does appear to be value in placing priors on the inter-fleet differences in relative exploitation rate.

Table 36. The values for the fleet- and species-specific catchability coefficients.

Species	Fleets				
	1	2	3	4	5
1	0.10	0.05	0.10	1.00	0.00
2	0.25	1.00	0.00	0.00	0.00
3	0.50	0.50	0.50	0.50	1.00
4	0.25	0.25	1.00	1.00	0.10

Table 37. Baseline values for the parameters of the operating model and the values considered in the tests of sensitivity.

Parameter	Baseline value	Sensitivity values
Depletion in 2003		
Species 1	0.6	
Species 2	0.1	
Species 3	0.25	
Species 4	0.5	0.1 / 0.9
Correlation in exploitation rate, ρ'	0.7	0.2 / 0.99
Standard deviation in exploitation rate, σ'_y	0.1	0 / 0.5

Table 38. The specifications for the catch-rate series.

Species	Fleet	First year	Last year	σ_q
1	3	1986	2002	0.15
1	4	1986	2002	0.15
2	1	1973	1999	0.15
3	1	1986	2002	0.20
3	2	1986	2002	0.20
3	3	1986	2002	0.20
3	4	1986	2002	0.20

Table 39. The specifications for the catch age- and size-composition data generated by the operating model.

(a) Catch age-composition data

Species	Fleet	Year range	Sample size
1	1, 2, 3, 4	1979–2002	100
2	1, 2	1982–1990 (every 2nd year)	100
2	1, 2	1991–2002	100
3	1, 2, 3, 4, 5	1987–2002	100

(b) Catch size-composition data

Species	Fleet	Year range	Sample size
1	1, 2, 3, 4	1979–2002	100
2	1, 2	1975–2002	100
3	1, 2, 3, 4, 5	1987–2002	100
4	1, 2, 3, 4 ,5	1987–2002	20

Combinations of species and fleet for which age- / size-composition data are not generated are omitted from this table.

Table 40. Comparison of the 'Current' and 'With F prior' variants of the assessment model for the baseline simulation trial and the sensitivity tests.

Case	Median Relative Error					Interquartile Range				
	All	1	2	3	4	All	1	2	3	4
Baseline	12/16	2 / 5	2 / 5	6 / 1	2 / 5	10/18	3 / 4	1 / 6	4 / 3	2 / 5
2003 depletion = 0.1	3/25	1 / 6	0 / 7	1 / 6	1 / 6	9/19	2 / 5	2 / 5	2 / 5	0 / 7
2003 depletion = 0.9	12/16	2 / 5	2 / 5	7 / 0	1 / 6	11/17	3 / 4	1 / 6	4 / 3	3 / 4
$\sigma_y^f = 0$	11/17	2 / 5	1 / 6	4 / 3	4 / 3	12/16	3 / 4	3 / 4	5 / 2	1 / 6
$\sigma_y^f = 0.99$	8/20	1 / 6	1 / 6	5 / 2	1 / 6	10/18	3 / 4	1 / 6	4 / 3	2 / 5
$\rho^f = 0.99$	12/16	2 / 5	2 / 5	7 / 0	1 / 6	11/17	3 / 4	1 / 6	4 / 3	3 / 4
$\rho^f = 0.2$	13/15	2 / 5	2 / 5	6 / 1	3 / 4	10/18	3 / 4	1 / 6	4 / 3	2 / 5
Better data for Species 4	6/22	2 / 5	1 / 6	0 / 7	3 / 4	12/16	3 / 4	1 / 6	4 / 3	4 / 3
Deterministic	15/13	4 / 3	2 / 5	7 / 0	2 / 5	8/20	3 / 4	0 / 7	3 / 4	2 / 5
Steepness estimated	15/13	4 / 3	5 / 2	4 / 3	2 / 5	23/5	5 / 2	6 / 1	7 / 0	5 / 2

The values presented are the number of cases (out of 28) in which each model variant achieves the lower median relative error and interquartile range. Results are shown by species and for all species combined.

Chapter 7: Benefits

The benefits of this project will flow directly to the fishers in the trawl and non-trawl sectors of the Southern and Eastern Scalefish and Shark Fishery (SESSF) through an improved basis for providing scientific management advice for 'data-rich' and 'data-poor' species. The assessments of 'data-rich' species will be improved by a stronger scientific basis for the appropriate ranges for consideration in assessments for the steepness of the stock-recruitment relationship and the extent of variation in recruitment. The assessments of 'data-poor' species will be improved because information from assessments of 'data-rich' species can be used formally (rather than informally) to place constraints on model outcomes. Irrespective of whether this tool is used as the basis for actual assessments, it can be used to identify those 'data-poor' species for which additional research and monitoring is most warranted because they are the most likely to be depleted or declining. At present, such species can only be identified robustly using catch-rate indices of abundance and catch curve analyses.

Benefits of this project flow to many of the fisheries managed by AFMA because the priors and relationships in Chapters 2 and 3 can be used for assessments other than for those of SESSF species. The ADMB code for the method outlined in Chapters 3 and 5 can be tailored to other situations fairly straightforwardly.

Additional benefits relate to specific results and approaches taken in the project. The model developed to deal with age-reading errors can be applied to any study or assessment, and provides a basis for determining the relationship between the number of otoliths read several times and the resultant precision and bias of the relationship between ageing error and age. Most CPUE analyses for SESSF species have included an area term in the GLMs to accommodate the impact of differences in availability and abundance among sectors of the fishery. However, the results here show that for many species there is a year*area interaction, indicating that trends in abundance differ among areas. Consequently, future analyses of catch and effort data should, at least initially, be undertaken separately for each area. This will inform future assessments.

Chapter 8: Further Development

Priors for biological parameters

a The ability to conduct meta-analyses and hence identify relationships among biological characteristics depends on the size of the database analyzed. The database considered in the report substantially exceeds that considered by Koopman *et al*. (2000). However, it is almost certainly the case that additional data exist. An international collaborative effort is needed to expand the existing database and to provide more rigorous peer-review of the basic data. The current database only includes vertebrate fish – future efforts should concentrate on non-teleost fish (in particular sharks and skates), invertebrates, as well as on vertebrates.

b The analyses of this report focused solely on the Beverton-Holt and Ricker forms of the stock-recruitment relationship. Future research should expand the class of stock-recruitment functions to include, for example, the Shepherd form (Shepherd, 1982) and the possibility of depensation at low stock size. Furthermore, consideration should be given to include variables that index changes in climate to assess whether the effects of climate can be detected.

c Inter-species/ stock correlations in recruitment are believed to occur in the SESSF and elsewhere. A meta-analysis should be conducted to quantify the extent of such correlation and how it could be incorporated into stock assessments.

Data for use in stock assessments

a Multiple copies of the SEF1 database exist. Each of these differs in terms of the errors that have been corrected. A project that leads to a unified, corrected, and easily accessible version of the SEF1 database would facilitate comparison of results among assessment authors and lead to more efficient use of the analyst's time.

b A project should be developed which has the objective of linking the SEF1 records to the SEF2 database. Availability of a linked database would allow different approaches for developing catch length-frequencies to be applied.

c Catch-effort standardization methods are not applied in a consistent way among SESSF species. A project that provides a unified approach to catch-effort standardization (including default methods for model selection and default diagnostic statistics) would reduce the potential for arbitriness when conducting catch-effort standardizations. Such a project would also provide guidelines for defining 'fleets' and for defining 'targeted' fishing. In addition, there are statistically significant interactions of catch rate with year for several species. The solution adopted in this study to overcome this problem is to define fleets in terms of a number of spatial zones. However, the general issue of how to develop catch-rate indices in the face of interactions with year warrants further consideration.

d Most of the recent length and age information is stored in the ISMP database. However, the historical information is not stored in a particularly consistent manner. Development of a SEF-wide database that includes all of the data for all of the SEF species would facilitate more efficient use of scarce resources.

Multi-species stock assessments

a The model of Chapter 5 currently assumes that selectivity-at-length by fleet is time-invariant. Consideration needs to be given to allowing selectivity to change slowly over time, possibly by allowing for a random walk in one of the parameters of the selectivity function.

b Biologically, many of the SESSF species operate on a year which differs from the standard calendar year. For example, assessments of blue warehou are based on a year which ranges from May to April (Punt and Smith, in press). Changing the framework to accommodate non-standard years may be complicated if the biological years for different species are inconsistent, but could also lead to improved fits to the monitoring data.

c Considerable research has been directed towards defining ‘métiers’ in European fisheries (e.g. Beaseau, 1988; Biseau and Gondeaux, 1988; Pelletier and Ferraris, 2000). These approaches could be applied to the data for the SESSF to identify fleets for use in stock assessments.

d The estimates of the precision of spawning biomass and spawning biomass expressed relative to the unfished level based on asymptotic and Bayesian methods were very similar even though there was evidence for lack of convergence of the MCMC algorithm. Given that it is not uncommon for there to be problems obtaining convergence of the MCMC algorithm, it would be of interest to determine the value of samples based on a chain that shows evidence for lack on convergence.

e Future evaluation of the method of Chapter 5 should focus on the implications for the performance of the method of: a) greater variation in discard and catch-rates, b) variation over time in selectivity, including white and red noise; c) ageing error; d) assuming the wrong values for some the pre-specified parameters of the model and / or functional forms; and e) larger and smaller effective sample sizes for the catch age- and size-composition data.

Chapter 9: Planned Outcomes

The main outcome from this project is the development and testing of an analytical tool that can be applied to the many low value species in the SESSF to help formally assess the status of the stocks. As SESSRAG is currently developing harvest strategies for the fishery, the results of this project provide an improved ability to advise fishery managers on appropriate indicators and reference points for some 'data-poor' quota species that will probably provide better indicators of trend that either CPUE or age-structure alone, because the approach integrates all of the available data. Ultimately it will provide a costs-effective means of undertaking more formal assessments of the many SESSF species that currently have no formal assessment. At the very least, the approach developed here will be of value to identify species that should be the focus of increased data collection and analysis.

Benefits of this project also flow to many of the fisheries managed by AFMA and state agencies because the priors and relationships developed can be used for assessments other than for those of SESSF species.

Chapter 10: Conclusions

Stock assessment methods are used to provide estimates of a variety of quantities for use in fisheries management. These quantities include historical and current biomass, the ratio of the current biomass to some historical, target or limit biomass, and the implications of future sequences of catches or levels of fishing effort. These implications often form a key component of the management advice for a fish stock. However, it is, and will likely remain, almost impossible to conduct stock assessments for all of the species for which they are needed unless inferences for 'data-poor' stocks are based in part on information for 'data-rich' stocks, and, more generally, on knowledge for other species and stocks. Formally, this information can be included in assessments in the form of 'prior distributions' (or penalty functions).

This report considers two ways to include 'prior distributions' in assessments. Chapters 2 and 3 examine whether the data for 'data-rich' species/stocks can be used to develop prior distributions for some of the key input parameters included in stock assessment models (Objectives 1 and 2). The results in the Chapter 2 identify that the best way to estimate the rate of natural mortality is Hoenig's (1983) equation (or the variant thereof based on the data analysed in this report) while the method developed by Pauly (1980) seems very sensitive to whether data for species with high M are included in the analysis. Chapter 2 identifies several relationships among biological parameters, but the predictive ability of most of these is reasonably weak. The fact that ℓ_∞ was found to correlate well with several other biological parameters highlights the importance of conducting ageing studies for as many species as possible (even if the sample sizes are only sufficient to estimate the parameters of a growth curve) and / or to conduct a catch-curve analysis.

Chapter 3 analyses data on stock and recruitment to estimate priors for the steepness of the stock-recruitment relationship. These data suggest that steepness for Clupeiformes, Pleuronectiformes, and Gadiformes is higher than that for "other" species. This needs to be accounted for when selecting the data on which to base priors for steepness for SESSF species as only blue grenadier is in this group of "high steepness" fishes. In contract, steepness is notably lower for species not in these three families and this should therefore be expected of most of the species in the SESSF. The results in Chapter 3 found no covariates that explain steepness (although the sample sizes for some of the covariates are quite small) except whether the fish is a Clupeiform, Pleuronectiform, or Gadiformes. The results in Chapter 3 can be used to develop base-case priors for steepness and the extent of variation in recruitment, and the values for these quantities to be used in tests of sensitivity.

The second approach to make use of information for 'data-rich' species when conducting assessments for 'data-poor' species is to conduct assessments of several species ('data-rich' and 'data-poor') simultaneously and to impose penalties on the differences in biological parameters (e.g. steepness, selectivity-at-length) among species/stocks (Objectives 3 to 5).

The technical details of such an approach are outlined in Chapter 5 (Objective 3), tested by means of simulation in Chapter 6 (Objective 5), and applied in Chapter 5 to data for eight stocks (seven species) in the SESSF (Objective 4). Note Objective 4 specifies three case studies, but the example application effectively combines four case studies by considering multiple species and multiple areas simultaneously.

The results of the simulations and the example application confirm that there is value in imposing cross-stock/species constraints. However, the effects may be quite small, and the consequences, in terms of bias and precision, may be negative for some of the 'data-rich' species. Nevertheless, the assessments for ocean perch and western gemfish are clearly more plausible when among-stock constraints are imposed. The results of the approach in Chapter 5 cannot turn a 'data-poor' stock into a 'data-rich' stock, but will be of value to identify species that should be the focus of increased data collection and analysis. In the context of the example application of this study, the results suggest that the stock of western gemfish may be depleted (although it should be noted that the fishery is at the eastern end of the species' range) while there are declining trends in ocean perch and king dory that warrant further data collection and analysis.

References

Adams, P.B. 1992. Progress in rockfish recruitment studies. U.S. National Marine Fisheries Service. Admin. Rep. T-92-01. 63 p.

Ahrenholz, D.W. 1991. Population biology and life history of the North American menhadens, *Brevoortia spp*. *Marine Fisheries Review* 53: 3–19.

Akazaki, M. 1960. Growth and age of the sea bream, *Chrisophrys major*, caught in Wakasa Bay. *Bulletin of the Japanese Society of Scientific Fisheries* 26: 216–222.

Albert, G.E. 1995. Completion Report. 1994. Lake Pepin. Minnesota Deptartment of Natural Resources. F-29-R(P)-14.

Alegria-Hernandez, V. and S. Jukic. 1988. Stock-recruitment relationship for the hake (*Merluccius merluccius*) from the Open Middle Adriatic-Jabuka Pit. *FAO Fisheries Report* 394: 137–141.

Almeida, F. P. and E. D. Anderson. 1981. NEFC Woods Hole Ref. Doc. No. 81-37.

Almeida, F.P. 1987. Status of the silver hake resource off the Northeast coast of the United States-1987. Woods Hole Laboratory Reference Document No. 87-03. 60 p.

Annala, J.H. and K.J. Sullivan. 1996: Report from the Fishery Assessment Plenary, April-May 1996: stock assessments and yield estimates. Unpublished report held in NIWA library, Wellington. 308 p.

Annala, J.H., Sullivan, K.J., O'Brien, C.J. and S.D. Iball. 1998. Report from the Fishery Assessment Plenary, May 1998: stock assessments and yield estimates. Unpublished report held in NIWA library, Wellington. 409 p.

Annand, M.C., Beanlands, D. and J. McMillian. 1988. Assessment of divisions 4VWX and Subarea 5 pollock (*Pollachius virens*). CAFSAC Research Document. 88/71. 65 p.

Anon. 1975. Report of the Mackerel Working Group. ICES Doc. C.M. 1975/H: 3.

Anon. 1976. Report of the North East Arctic Fisheries Working Group. ICES Doc. C.M. 1976/F: 10.

Anon. 1981. Report of the Irish Sea and Bristol Channel Working Group. ICES Doc. C.M. 1981/G: 10.

Anon. 1981. Report of the North Sea Roundfish Working Group. ICES Doc. C.M. 1981/G: 8.

Anon. 1982. Report of the North Sea Flatfish Working Group ICES Doc. C.M. 1982/Assess: 3.

Anon. 1986. Report of the herring assessment working group for the area south of 62°N. ICES Doc. C.M. 1986/Assess: 19.

Anon. 1987. Report of the North-Western Working Group. ICES Doc. C.M. 1987/Assess: 2.

Anon. 1988. Provisional report of scientific council, June 1988 meeting. NAFO SCS Doc. 88/20: 117 p.

Anon. 1988. Report of the Arctic Fisheries Working Group. ICES Doc. C.M. 1988/Assess: 5.

Anon. 1988. Report of the Blue Whiting Assessment Working Group. ICES Doc. C.M. 1988/Assess: 6.

Anon. 1988. Report of the Herring Assessment Working Group for the Area South of 62N. ICES Doc. C.M. 1988/Assess: 17.

Anon. 1988. Report of the North Sea Roundfish Working Group. ICES Doc. C.M. 1988/Assess: 21.

Anon. 1988. Report of the Working Group on Assessment of Pelagic Stocks in the Baltic. ICES Doc. C.M. 1988/Assess: 18.

Anon. 1989. Advice on the management of groundfish stocks in 1990. CAFSAC Advisory Doc. 89/12. 82 p.

Anon. 1989. International Pacific Halibut Commission. Annual Report 1989.

Anon. 1989. Report of the Fall 1989 NEFC Stock Assessment Workshop (Ninth SAW). NEFC Ref. Doc. 89-09.

Anon. 1990. Advice on the management of groundfish stocks. CAFSAC Res. Doc. 90/5.

Anon. 1990. Advice on the management of herring stocks on the Atlantic coast of Canada for 1991. CAFSAC Adv. Doc. 90/4: 27 p

Anon. 1990. Cod in subdivision 3Ps. CAFSAC Adv. Doc. 90/8: 8 p.

Anon. 1990. Report of Industrial Fisheries Working Group. ICES Doc. C.M. 1990/Assess: 13.

Anon. 1990. Report of the Arctic Fisheries Working Group. ICES Doc. C.M. 1990/Assess:4.

Anon. 1990. Report of the Division IIIa Demersal Stocks Working Groups. ICES Doc. C.M. 1990/Assess: 20.

Anon. 1990. Report of the Eleventh NEFC Stock Assessment Workshop, Fall 1990. NEFC Ref. Doc. 90-09.

Anon. 1990. Report of the Herring Assessment Working Group for the Area South of 62N. ICES Doc. C.M. 1990/Assess: 14.

Anon. 1990. Report of the ICES Study Group on cod stock fluctuations. ICES Doc. C.M. 1990/G: 50.

Anon. 1990. Report of the Mackerel Working Group. ICES Doc. C.M. 1990/Assess: 19.

Anon. 1990. Report of the North-Western Working Group. ICES Doc. C.M. 1990/Assess: 20.

Anon. 1990. Report of the Roundfish Working Group. ICES Doc. C.M. 1990/Assess: 7.

Anon. 1990. Report of the Working Group on Assessment of Demersal Stocks in the Baltic. ICES Doc. C.M. 1990/Assess: 17.

Anon. 1990. Report of the Working Group on Assessment of Pelagic Stocks in the Baltic. ICES Doc. C.M. 1990/Assess: 18.

Anon. 1990. Report of the Working Group on Cod off East Greenland. ICES Doc. C.M. 1990/Assess: 20.

Anon. 1990. State of marine stocks and environmental conditions in Icelandic waters 1989. Fishing prospects 1990. Reykjavík 1989. 126pp.

Anon. 1991. Mackerel Working Group. ICES Doc. C.M. 1991/Assess: 19.

Anon. 1991. Report of Industrial Fisheries Working Group. ICES Doc. C.M. 1991/Assess: 14.

Anon. 1991. Report of the Blue Whiting Assessment Working Group. ICES Doc. C.M. 1991/Assess: 2.

Anon. 1991. Report of the Division IIIa Demersal Stocks Working Groups. ICES Doc. C.M. 1991/Assess: 9.

Anon. 1991. Report of the Herring Assessment Working Group for the Area South of 62N. ICES Doc. C.M. 1990/Assess: 14.

Anon. 1991. Report of the Irish Sea and Bristol Channel Working Group. ICES Doc. C.M. 1991/Assess: 1.

Anon. 1991. Report of the North Sea Roundfish Working Group. ICES Doc. C.M. 1988/Assess: 21.

Anon. 1991. Report of the North-Western Working Group. ICES Doc. C.M. 1991/Assesss: 21.

Anon. 1991. Report of the Roundfish Working Group. ICES Doc. C.M. 1991/Assess: 4.

Anon. 1991. Report of the Twelfth Northeast Assessment Workshop (12th SAW). Northeast Fisheries Science Center Reference Document 91-03.

Anon. 1991. Report of the Working Group on Assessment of Demersal Stocks in the Baltic. ICES Doc. C.M. 1991/Assess: 16.

Anon. 1991. Report of the Working Group on Assessment of Pelagic Stocks in the Baltic. ICES Doc. C.M. 1991/Assess: 18.

Anon. 1991. Report or the Roundfish Working Group. ICES Doc. C.M. 1991/Assess: 4.

Anon. 1991. Stock Assessment Review Committee Consensus Summary of Assessments. Thirteenth Northeast Regional Stock Assessment Workshop. Dec. 1991.

Anon. 1992. Report of the Blue Whiting Assessment Working Group. ICES Doc. C.M. 1992/Assess: 3.

Anon. 1992. Report of the Fall Stock Assessment Workshop (13th SAW). Northeast Regional Stock Assessment Workshop No. 13. February 1992. NEFC Reference Document 92-02.

Anon. 1992. Report of the Fourteenth Northeast Regional Stock Assessment Workshop (14th SAW). Northeast Fisheries Science Center Reference Document 92-07.

Anon. 1992. Report of the North Sea Flatfish Working Group. ICES Doc. C.M. 1992/Assess: 6.

Anon. 1992. Report of the North-Western Working Group. ICES Doc. C.M. 1992/Assess: 14.

Anon. 1992. Report of the Roundfish Working Group. ICES Doc. C.M. 1992/Assess: 4.

Anon. 1992. Report of the Working Group on the Assessment of Southern Shelf Demersal Stocks. ICES Doc. C.M. 1993/Assess: 3.

Anon. 1993. Annual Report of the Inter-American Tropical Tuna Commission.

Anon. 1993. Report of the Working Group on the Assessment of Demersal Stocks in the Baltic. ICES Doc. C.M. 1993/Assess: 16.

Anon. 1993. Report of the Working Group on the Assessment of Northern Shelf Demersal stocks. ICES Doc. C.M. 1993/Assess: 20.

Anon. 1993. Report of the Working Group on the Assessment of Southern Shelf Demersal Stocks. ICES Doc. C.M. 1993/Assess: 3.

Anon. 1993. Report of the Working Group on the Assessment of Southern Shelf Demersal Stocks. ICES Doc. C.M.1996/Assess: 5.

Anon. 1993. State of Marine Stocks in Icelandic Waters 1992/93, Prospects for the Quota Year 1993/94, 2nd edition, 1993. Hafrannsoknastofnun Fjolrit NR. 34. p.145-150.

Anon. 1993. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak. ICES Doc. C.M. 1993/Assess: 5.

Anon. 1994. Report of the Arctic Fisheries Working Group. ICES Doc. C.M. 1994/Assess: 2.

Anon. 1995. Report of the Arctic Fisheries Working Group. ICES Doc. C.M. 1995/Assess:3.

Anon. 1995. Report of the Working Group on the Assessment of Southern Shelf Demersal Stocks. ICES Doc. C.M. 1996/Assess: 5.

Anon. 1996. Report of the Arctic Fisheries Working Group. ICES Doc. C.M. 1995/Assess:4.

Anon. 1996. Report of the working group on the assessment of demersal stocks in the North Sea and Skagerrak. ICES Doc. C.M. 1996/Assess: 6.

Anon. 1996. Report of the working group on the assessment of northern shelf demersal stocks. ICES Doc. C.M. 1996/Assess: 1.

Anon. 1996. Report of the Working Group on the Assessment of Pelagic Stocks in Divisions VIIIc & IXa and Horse Mackerel. ICES Doc. C.M. 1996/Assess: 7.

Anon. 1996. Working Group on the Assessment of the Stocks of Sardine, Horse Mackerel, Anchovy. ICES Doc. C.M. 1996/Assess: 7.

Anon. 1997. Report of the Working Group on the Assessment of Southern Shelf Demersal Stocks. Part 3 of 4. ICES Doc. C.M.1997/Assess: 5.

Anon. 1997. Stock assessment review committee consensus summary of assessments. 24th Northeast Regional Stock Assessment Workshop. June 1997.

Anon. 1997. Capelin in SA2 + Div. 3KL. CSAS Research Document 97/29. 188pp.

Anon. 1997. Report of the Northern Pelagic Blue Whiting Fisheries Working Group. ICES Doc. C.M. 1997/Assess: 14.

Anon. 1997. Report of the North-Western Working Group. ICES Doc. C.M.1997/Assess: 13.

Anon. 1978. Report of Working Group on Fish Stocks at Faroes. ICES Doc. C.M. 1978/G: 2.

Anon. 1998. 26th Northeast Regional Stock Assessment Workshop (26th SAW), Stock Assessment Review Committee (SARC), Consensus Summary of Assessments. Northeast Fisheries Science Center Document 98-03, NMFS: Woods Hole.

Anon. 2000. 30th Northeast Regional Stock Assessment Workshop (30th SAW), Stock Assessment Review Committee (SARC), Consensus Summary of Assessments. 2000. Northeast Fisheries Science Center Document 00-3, NMFS: Woods Hole.

Anon. 2000. Report of the Northeast Regional Stock Assessment Workshop (30th SAW). Northeast Fisheries Science Center Ref. Doc. 00-03.

Anon. 2000. Report of the Working Group on the Assessment of Southern Shelf Demersal Stocks. ICES Doc. C.M. 2000/ACFM:4.

Anon. 2000. Status of bigeye tuna in the Eastern Pacific Ocean. INTER-AMERICAN TROPICAL COMMISSION. Inter-American Tropical Tuna Commission.

Anon. 2001. Comparative data on fish life history. IFREMER. (http://www.ifremer.fr/maerha/life_history.html)

Anthony, V.C. and G.T. Waring. 1980. Estimates of herring spawning stock biomass and egg production for the Georges Bank-Gulf of Maine region. NAFO SCR Doc. 80/IX/135 (Corrigendum): 1 p.

Arancibia, H., Cubillos, L., Arocos, D., Grechina, A.S. and L. Vilugron. 1995. The fishery of horse mackerel (*Trachurus symmetricus murphyi*) in the South Pacific Ocean, with notes on the fishery off central southern Chile. *Scientia Marina* 59: 589–596

Archibald, C.P., D. Fournier, and B.M. Leaman. 1983. Reconstruct of stock history and development of rehabilitation strategies for Pacific ocean perch in Queen Charlotte Sound, Canada. *North American Journal of Fisheries Management* 3: 283–294.

Arneri, E. 2001. Age determination and growth of turbot and brill in the Adriatic Sea: reversal of the seasonal pattern of otolith zone formation. *Journal of Applied Ichthyology* 17: 256–261.

Astudillo, A. 1986. The anchovy in the Bay of Biscay: recent data on the fishery.. ICES C.M. 1986/H:45.

Atkinson, D. B., and D. Power. 1986. The stock complex of redfish in NAFO divisions 3KLNOPs. NAFO SCR Doc. 86/38: 18 p.

Atkinson, D. B. and D. Power. 1990. Some analyses of data for redfish off the south coast of Newfoundland (NAFO div. 3P/4V). CAFSAC Res. Doc. 90/57: 53 p.

Atlantic States Marine Fisheries Commission. 1999. 1999 Status of the Atlantic Striped Bass: Report to the ASMFC Striped Bass Management Board, August 1999. Report of the Atlantic States Marine Fisheries Commission striped bass Technical Committee. Washington, D.C. 37 p.

Avial de Melo, A.M., Alpoim A,R., and F. Saborido-Rey. 1999. Analytical assessment of redfish in Flemish Cap (NAFO Div. 3M). NAFO SCR Doc. 99/52. 54 p.

Avila de Melo, A.M., Alpoirn, R., Saborido-Rey, F., and L. Motos. 1997. Status of the redfish stocks in NAFO Div. 3M (Flemish Cap) in 1996. NAFO SCR Doc. 97/44. 25 p.

Babayan, V. and T.I. Bulgakova. 1983. Estimation of natural mortality and growth parameters for cape horse mackerel (*Trachurus trachurus capensis*) in division 1.3 + 1.4. Collect. Sci. Pap. ICSEAF-RECL. Doc. Cipase 10(1): 49–53.

Backiel, T. and J. Zawisza. 1968. Synopsis of biological data on the bream *Abramis brama* (Linnaeus, 1758). FAO Fish. Synop. 36 p.

Bagge, O. 1981. The yearly consumption of cod in the Baltic and the Kattegat as estimated from stomach content. ICES CM 1981/J:27.

Bailey, R.S. and P.A. Kunzlik. 1984. Variation in Growth and Mortality Rates of Norway Pout *Trisopterus esmarkii* (Nilsson). ICES CM 1984/ G:70.

Baird, J.W., Bishop, C.A., Brodie, W.B. and E.F. Murphy. 1992. An assessment of the cod stock in NAFO divisions 2J3KL. NAFO SCR Doc. 92/18: 69 p.

Bakkala, R.G. Wespestad, V. and L. Low. 1982. The yellowfin sole (Limanda aspera) resources of the eastern Bering Sea- its current and future potential for commercial fisheries. NOAA Tech. Memo. 43 p.

Balbontin, F. and W. Fischer. 1981. Ciclo sexual y fecundidad de la merluza, *Merluccius gayi gayi*, en la costa de Chile. *Revista de Biología Marina y Oceanografía* 17: 285–334.

Barger, L.E. 1990. Age and growth of bluefish *Pomatomus saltatrix* from the northern Gulf of Mexico and U.S. south Atlantic coast. *Fisheries Bulletin* 88: 805–809.

Baumgartner, T.R., Soutar, A. and V. Ferriera-Bartrina. 1992. Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin, California. *CalCOFI Rep*. 33: 24–40.

Beardsley, G.L., Conser, R.J., López, A.M., Brassfield, M. and D. McClellan. 1978. Length-weight data for Western Atlantic swordfish, *Xiphias gladius*. *ICCAT Collective Volume of Scientific Papers* 8(2): 490–495.

Bence, J.R., Gordoa, A. and J.E. Hightower. 1993. Influence of age-selective surveys on the reliability of stock synthesis assessments. *Canadian Journal of Fisheries and Aquatic Sciences* 50: 827–840.

Berg, L., Bogdanov, L.S., Kozhin N.I. and T.S. Rass, Editors. 1949. Commercial fishes of the USSR. Pshchepromizdat.

Bernard, D.R. 1981. Multivariate analysis as a means of comparing growth in fish. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 233–236.

Beverton, R.J.H. 1963. Maturation, growth and mortality of clupeid and engraulid stocks in relation to fishing. *Journal du Conseil International pour l'Exploration de la Mer* 154: 44–67.

Beverton, R.J.H. 1965. Catch effort of some I.C.N.A.F. fisheries. *ICNAF Research Bulletin* 2: 59–72.

Beverton, R.J.H. 1992. Patterns of reproductive strategy parameters in some marine teleost fishes. *Journal of Fish Biology* 41 (suppl. B):137–160.

Beverton, R.J.H. and S.J. Holt. 1959. A review of the lifespans and mortality rates of fish in nature and their relation to growth and other physiological characteristics. pages 142–180 *in* G.E.W. Wolstenholme and M.

O'Connor, editors. CIBA Foundation colloquia on ageing: the lifespan of animals. Volume 5. J & A Churchill Ltd, London.

Bezzi, S., Canete, G., Perez, M., Renzi, M. and H. Lassen. 1994. Report of the INIDEP working group on assessment of hake (*Merluccius hubbsi*) north of 48 S (Southwest Atlantic Ocean). INIDEP Documento Cientifico 3.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. *Fishery Bulletin Of The Fish and Wildlife Service* 53: 1–557.

Biseau, A. 1988. Definition of a directed fishing effort in a mixed-species trawl fishery, and its impact on stock assessments. Aquatic Living Resources 11: 119–136.

Biseau, A. and E. Gondeaux. 1988. Apport des methods d'ordination en typology des flottilles. *Journal du Conseil International Pour L'exploration de la Mer* 44: 286–296.

Bishop C.A., Murphy, E.F., Davis, M.B., Baird, J.W. and G.A. Rose. 1993. An assessment of the cod stock in NAFO divisions 2J+3KL. NAFO SCR Doc. 93/86. 51 p.

Bishop, C.A., Baird J.W. and E.F. Murphy. 1991. An assessment of the cod stock in NAFO subdivision 3Ps. CAFSAC Res. Doc. 91/36:56 p.

Bishop, C.A., Baird, J.W. and H.F. Hicks. 1987. Biomass and abundance of haddock in NAFO division 3NO and subdivision 3Ps from research vessel surveys along with estimates of commercial catch and effort. CAFSAC Res. Doc. 87/48: 22 p.

Blacker, R. 1971. Synopsis of biological data in haddock *Melanogrammus aeglefinus* (Linnaeus) 1758. *FAO Species Synopsis* (84).

Boe, S.J. 1995. Completion report 1994: Upper Red Lake. Minnesota Department of Natural Resources. F-29-R(P)-14.

Boerema, L.K., Saetersdal, G., Tsukayama, I., Valdivia J.E. and B. Alegre. 1965. Report on the effects of fishing on the Peruvian stock of anchovy. FAO Fisheries Technical Paper 55: 44 p.

Bowering, W.R. and W.B. Brodie. 1991. Distribution of commercial flatfishes in the Newfoundland-Labrador region of the Canadian Northwest Atlantic and changes in certain biological parameters since exploitation. *Netherland Journal of Sea Research* 27: 407–422.

Bridger, J.P. 1961. On fecundity and larval abundance of Downs herring. MAF Fisheries Investigations London 23: 30 p.

Brodie, W.B. 1986. An assessment of yellowtail flounder in NAFO div. 3LNO. NAFO SRC Doc. 86/40: 20 p.

Brodie, W.B., Walsh, S.J. and W.R. Bowering. 1990. Yellowtail flounder in NAFO div. 3LNO - an assessment of stock status. NAFO SCR Doc. 90/86: 24 p

Brodie, W.B., Bowering, W.R. and J.W. Baird. 1990. An assessment of the American plaice stocks in division 3LNO. NAFO SCR Doc. 90/80: 32 p.

Brown, R. 2000. Haddock. Status of Fishery Resources off the Northeastern United States for 1999. Electronic Publication: (http://www.nefsc.noaa.gov/sos/spsyn/pg/ haddock/)

Buijse, A.D., van Densen, W.L.T. and L.A. Schaap. 1992. Year-class strength of eurasian perch (*Perca fluviatilis*) and pikeperch (*Stizostedion lucioperca*) in relation to stock size, water temperature and wind in Lake Ijssel, the Netherland, 1966–1989 *in* A. D. Buijse, editor. Dynamics and exploitation of unstable percid populations. Wageningen: Landbouwununiversiteit.

Bulman, C.M., Koslow, J.A. and K.A. Haskard. 1999. Estimation of the spawning stock biomass of blue grenadier (*Macruronus novaezelandie*) off western Tasmania based upon the annual egg production method. *Marine and Freshwater Research* 50: 197–207.

Burd, A.C. 1978. Long-term changes in North Sea herring stocks. Rapp. P.-V. Réun. CIEM 172: 137–153.

Butterworth, D.S., and M.O. Bergh. 1993. The development of a management procedure for the South African anchovy resource Pages 83–89 *in* S.J. Smith, J.J. Hunt and D. Rivard, editors. Risk evaluation and biological reference points for fisheries management, *Canadian Special Publication of Fisheries and Aquatic Sciences*. 120.

Butterworth, D.S. and A.E. Punt. 1999. Experiences in the evaluation and implementation of management procedures. *ICES Journal of Marine Science* 56: 985–998.

Caddy, J.F. 1977. Some approaches to elucidation of the dynamics of swordfish (*Xiphias gladius*) populations. Canadian Fisheries and Environment MS Report 1439. 1 p.

Cailliet, G.M. 2000. Biological Characteristics of Nearshore Fishes of California: A Review of Existing Knowledge and Proposed Additional Studies. Final Report to the Pacific States Marine Fisheries Commission. 103 p.

Campana, S. and J. Hamel. 1991. Status of the 1991 4X cod fishery. CAFSAC Res. Doc. 92/46: 42 p.

Carlile, D.W., Larson, R.C. and T.A. Minicucci. 1996. Stock assessments of Southeast Alaska herring in 1994 and forecasts for 1995 abundance. Alaska Department of Fish and Game Regional Information Report 1J96-05.

Casey, J. and J. Pereiro. (1995). European hake (*M. merluccius*) in the NorthEast Atlantic. *in* Alheit, J. and J. Pitcher, editors. Hake: Biology, Fishery and Markets. p. 125–147. (Chapman and Hall: London).

Casselman, J. 1996. Age, growth and environmental requirements of pike. In Craig, J.F. editor. Pike: biology and exploitation. pp. 69–101. (Chapman and Hall: London).

Cergole, M.C. and H. Valentini, 1994. Growth and mortality estimates of *Sardinella brasiliensis* in the southeastern Brazilian Bight. *Boletim do Instituto Oceanografico (Sao Paulo)* 42(1/2): 113–127.

Cergole, M.C. 1995. Stock assessment of the Brazilian sardine, *Sardinalla brasiliensis*, of the southeastern Coast of Brazil. *Scientia Marina* 59(3-4): 597–610.

Cervino, S. and A. Vazquez. 2000. An assessment of the cod stock in NAFO division 3M. NAFO SCR Doc. 00/40.

Chadwick E.M.P. and D.K. Cairns. 1988. Assessment of Atlantic herring in NAFO division 4T, 1987. CAFSAC Res. Doc. 88/38: 54 p.

Chavez, E.A. and F. Arreguin-Sanchez. 1995. Optimising yields of the king mackerel (*Scomberomorus cavalla*) fishery in the western and southern Gulf of Mexico. *Scientia Marina* 59(3-4): 629–636.

Chesson, J. and D.J. Staples. 1995. *Blue Grenadier 1994*, Stock Assessment Report, Blue Grenadier Assessment Group, South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Chevalier, J.R. 1977. Changes in walleye (*Stizostedion vitreum vitrem*) population in Rainy Lake and factors in abundance, 1924-1975. *Journal of the Fisheries Research Board of Canada* 34: 1696–1702.

Chikuni, S. 1975. Biological study on the population of the Pacific Ocean perch in the north Pacific. *Bulletin of the Far Seas Fisheries Research Laboratory 12*:120 p.

Chouinard, G.A. and A. Frechet. 1994. Fluctuations in the cod stocks of the Gulf of St. Lawrence. *ICES Marine Science Symposia* 198: 121–139.

Chuenpagdee, R. 1990. Population study of female plaice (*Pleuronectes platessa* L.) in Anglesey: sexual maturity, growth and mortality. M.S. thesis, University of Wales, U.K. 70 p.

Cisneros-Mata, M.A., Nevarez-Martinez, M.O. and M.G. Hamann. 1995. The rise and fall of the Pacific sardine , *Sardinops sagax caeruleus* Girard, in the Gulf of California, Mexico. CalCOFI. Rep. 36: 136–142.

Clark, W.G. 1992. Estimation of halibut body size from otolith size. Scientific Report of the International Pacific Halibut Commission 75. 31 p.

Clay, D. and H. Clay. 1991. Determination of age and growth of white hake (*Urophycis tenuis* Mitchill) from the southern Gulf of St. Lawrence, Canada (including techniques for commercial sampling). Canadian Technical Report of Fisheries and Aquatic Sciences 1828. 29 p.

Clay, D. 1987. Assessment of Gulf white hake from NAFO division 4T in 1987. CAFSAC Res. Doc. 87/81.

Clay, D., and T. Hurlbut. 1990. White hake (*Urophycis tenuis*) from the southern Gulf of St. Lawrence: a review of the fishery in 1989. CAFSAC Res. Doc. 90/74.

Clayden, A.D. 1972. Simulation of the changes in abundance of the cod (*Gadus morhua* L.) and the distribution of fishing in the north Atlantic. MAF Fisheries Investigations London. 27: 58 p.

Cleary, L. 1983. An assessment of the southern Gulf of St. Lawrence herring stock complex. CAFSAC Res Doc 83/69: 40 p.

Cochrane, K.L., Butterworth, D.S., De Oliveira, J.A.A., and B.A. Roel. 1998. Management procedures in a fishery based on highly variable stocks and with conflicting objectives: experiences in the South African pelagic fishery. *Reviews in Fish Biology and Fisheries* 8: 177–214.

Cohen, D.M., Inada, T., Iwamoto, T. and N. Scialabba. 1990. FAO species catalogue. Vol. 10. Gadiform fishes of the world (Order Gadiformes). An annotated and illustrated catalogue of cods, hakes, grenadiers and other gadiform fishes known to date. FAO Fisheries Synopsis. 10 (125). 442 p.

Collette, B.B. and C.E. Nauen. 1983. FAO species catalogue. Vol. 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date.. FAO Fisheries Synopsis. 125(2): 137 p.

Cooke, J.G. 1999. Improvement of fishery-management advice through simulation testing of harvest algorithms. *ICES Journal of Marine Science* 56: 797–810.

Coull, K.A., Jermyn, A.S., Newton, A.W., Henderson G.I. and W.B. Hall. 1989. Length/weight relationships for 88 species of fish encountered in the North Atlantic. Scottish Fisheries Research Report. (43): 80 p.

Crecco, V.A. and M. Gibson. 1990. Stock assessment of river herring from selected Atlantic Coast Rivers. Special Report No. 19. of the Atlantic States Marine Fisheries Commission.

Crone, P.R., Methot, R.D., Conser, R.J., Lauth, R.R. and M.E. Wilkins. 1997. Status of the sablefish resource off the U.S. Pacific coast in 1997. Appendix to Status of the Pacific Coast Groundfish Fishery Through 1997 and Recommended Acceptable Biological Catches for 1998. Stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, Oregon.

Cury, P. and C. Roy. 1989. Optimal environmental window and pelagic fish recruitment success in upwelling areas. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 670–680.

Cushing, D.H. 1992. A short history of the Downs stock of herring. *ICES Journal of Marine Science* 49: 437–443.

Daan, N. 1974. Growth of the North Sea cod, *Gadus morhua*. *Netherlands Journal of Sea Research* 8(1): 27–48.

Dale, C.E., and R.G. Halliday. 1987. Stock status of Atlantic argentine in div. 4VWX. CAFSAC Res. Doc. 87/19: 11 p.

Dark, T. 1975. Age and growth of Pacific hake, *Merluccius productus*. *Fishery Bulletin* 73(2): 336–355.

de Cardenas, E. 1997. An assessment on American plaice in Division 3M. NAFO SCR Doc. 97/45.

de Cardenas, E. and A. Avila de Melo. 1991. Trends in the population of 3M cod and biological reference points: an approach using survey data. NAFO SCR Doc. 91/67: 13 p.

de la Mare, W.K. 1986. Fitting population models to time series of abundance data. *Reports of the International Whaling Commission* 36: 399–418.

Deniel, C. 1990. Comparative study of growth of flatfishes on the west coast of Brittany. *Journal of Fish Biology* 37(1):149–166.

DiCosimo, J. 1997. A summary of current stock assessment information used in managing Alaskan groundfish stocks. NPFMC. Anchorage, Alaska.

Dorn, M.W. 2002. Advice on West Coast rockfish harvest rates from Bayesian meta-analysis of stock-recruit relationships. *North American Journal of Fisheries Management* 22: 280–300.

Dragesund, O. and O. Ulltung. 1975. Stock Size Fluctuations and Rate of Exploitation of the Norwegian Spring Spawning Herring 1950-1975. ICES Doc. C.M. 1975

Du Paul, W.D. and J.D. McEachran. 1973. Age and growth of butterfish, *Peprilus traicanthus*, in the Lower York river. *Chesapeake Science* 14(3):205–207.

Duhamel, G. and C. Ozouf-Costaz. 1985. Age, growth and reproductive biology of *Notothenia squamifrons* Gunther, 1880 from the Indian sector of the southern ocean. *Polar Biology* 4: 143–153.

Dulcic, J. and M. Kraljevic. 1996. Weight-length relationship for 40 fish species in the eastern Adriatic (Croatian waters). *Fisheries Research* 28(3): 243–251.

Dyakov, P. 1995. Reproduction of some flounder species from the West Kamchatka Shelf. page 17–33. *in* Proceeding of the International Symposium on North Pacific Flatfish. Alaska Sea Grant College Program. AK-SG-95-04. (University of Alaska, Fairbanks).

Echeverria, T.W. 1987. Thirty Four Species of California Rockfishes: Maturity and Seasonality of Reproduction. *Fishery Bulletin* 85(2): 229–250

Eibler, J. 1995. Completion Report 1994 Rainy Wood. Minnesota Department of Natural Resources. Report F-29-R(P)-14.

Emery, A.R. and F.D. McCraken. 1966. Biology of the Atlantic argentine (*Argentina silus* Ascanius) on the Scotian Shelf. *Journal of the Fisheries Research Board of Canada* 23: 1145–1160.

Fanning, L.P. and W.J. MacEachern. 1991. Assessment of 4VsW cod in 1990. CAFSAC Res. Doc. 91/44: 42 p.

Fanning, L.P., Waldron, D.E. and C. Bourbonnais. 1987. Scotian shelf silver hake population size in 1986. NAFO SCR Doc. 87/56: 24 p.

Fargo, J. 1991. Flatfish. p. 71-115. in Fargo J. and B.M. Leaman editors. Groundfish stock assessments for the west coast of Canada in 1990 and recommended yield options for 1991. *Canadian Technical Report of Fisheries and Aquatic Sciences* 1778. 320 p.

Fernandez, I and M. Devaraj. 1996. Dynamics of the Bombay duck (*Harpodon nehereus*) stock along the northwest coast of India. *Indian Journal of Fisheries* 43: 1–11.

Fishbase. (http://www.fishbase.org)

Fournier, D.A., Sibert, J.R., Majkowski, J. and J. Hampton. 1990. MULTIFAN: A likelihood-based method for estimating growth parameters and age composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyii*). *Canadian Journal of Fisheries and Aquatic Sciences* 47: 301–317.

Francis, R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 922–930.

Francis, R.I.C.C., Cordue, P.L. and V. Haist. 2002. Review of the 2001 hoki stock assessment. *New Zealand Fisheries Assessment Report* 2002/42.

Frechet, A. 1988. Evaluation du stock de morue de la subdivision 3Pn et des divisions 4R et 4S de l'OPANO. CAFSAC Res. Doc. 88/24: 66 p.

Frisk, M.G., Miller, T.J. and M.J. Fogarty. 2001. Estimation and analysis of biological parameters in elasmobranch fishes: a comparative life history study. *Canadian Journal of Fisheries and Aquatic Sciences* 58(5): 969–981.

Froese, R. and C.C. Frieß, 1992. Synopsis of biological data on *Platichthys flesus* (L.), ICES assessment units 22 and 24, using the FISHBASE format. ICES C.M.1992/J:41. (ICES, Copenhagen).

Froese, R., Rosenboom, S. and B. Ueberschär, 1982. Fischkrankheiten in Verbindung mit Umweltparametern in der westlichen Ostsee. Semesterabschlußarbeit, Institute of Marine Science, Kiel. 56 p.

Froese, R. and D. Pauly. Editors. 2004. FishBase. World Wide Web electronic publication. www.fishbase.org.

Fry, F.E.J. and K.E.F. Watt. 1957. Yields of year class of the small mouth bass hatched in the decade of 1940 in Manitoulin Island waters. *Transactions of the American Fisheries Society* 85: 135–143.

Fulton, E.A., Smith, A.D.M. and A.E. Punt. 2004. Which ecological indicators can robustly detect effects of fishing? *ICES Journal of Marine of Science*. 62 540–551.

Funicane, J.H., Collins, L.A., Brusher H.A. and C.H. Saloman. 1986. Reproductive biology of king mackerel, *Scomberomorus cavalla*, from the southeastern United States. *Fishery Bulletin* 84(4): 841–850.

Funk J.L. and W.L. Pflieger. 1975. Management by water level manipulation. pp 224-269. *in* Stroud R.H. and H. Clepper. editors. Black Bass Biology and Management. Sport fishing Institute, Washington, D. C.

Gauld, J.A. and J.R. Hucheon. 1990. Spawning and fecundity in the lesser sandeel, Ammodytes marinus Raitt, in the north-western North Sea. *Journal of Fisheries Biolog*. 36: 611–613.

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 2272–2275.

Gavaris, S., Clark, D. and P. Perley. 1994. Assessment of Cod in Division 4X. DFO Atlantic Fisheries Research Document. 94/036: 27 p.

Gelman, A., Carlin, J.B., Stern, H.S. and D.B. Rubin. 1995. *Bayesian Data Analysis*. Texts in Statistical Science. Chapman & Hall, New York.

Geromont, H.F., De Oliveira, J.A.A., Johnston, S.J. and C.L. Cunningham. 1999. Development and application of management procedures for fisheries in southern Africa. *ICES Journal of Marine Science* 56: 953–966.

Geweke, J. 1992. Evaluating the accuracy of sampling-based approaches to the calculation of posterior moments. p. 169–193 *in* J.M. Bernardo, J. Berger, A.P. Dawid and A.F.M. Smith, editors. Bayesian Statistics 4, Oxford University Press, Oxford.

Gilbert, D.J. and K.J. Sullivan. 1994. Snapper stock assessment for the 1992-93 fishing year. New Zealand Fisheries Assessment Research Document 94/3: 37 p.

Golden, J.T. and C. Wood. 1990. Status of Canary Rockfish in the INPFC Vancouver, Columbia and Eureka Regions and Recommended ABC for 1991. Pacific Fisheries Management Council.

Goodyear, C.P. 1995. Red snapper in U.S. waters of the Gulf of Mexico. NOAA Contribution: MIA-95/96-05.

Groslein, M., and P. Hememuth. 1970. Spawning Stock and other factors related to recruitment of Haddock on Georges Bank. ICES Doc. C.M. 1970.

Gundersen, A.C., Boje, J. and A.K. Woll. 1997. Greenland halibut (*Reinhardtius hippoglossoides* Walbaum) in East Greenland waters. ICES CM 1997/BB:05.

Gunderson, D.R. and P.H. Dygert. 1988. Reproductive effort as a predictor of natural mortality rate. *Journal du Conseil International pour l'Exploration de la Mer* 44: 200–209.

Haddon, M. 2002a. Interim report on blue grenadier standardized catch rates up to the year 2001. BWAG/BGAG working paper 2002/201.

Haddon, M. 2002b. Spotted warehou standardized catch rates up to the year 2001. BWAG/BGAG working paper 2002/201.

Haist, V. and J.F. Schweigert. 1991. Stock assessment for British Columbia herring in 1991 and forecasts of the potential catch in 1992. PSARC Working Paper H91-1: 70 p.

Hampton, I. 1996. Acoustic and egg-production estimates of South African anchovy biomass over a decade: comparisons, accuracy and utility. *ICES Journal of Marine Science* 53: 493–500.

Hanchet, S.M. and V. Haist. 1994. Southern blue whiting (*Micromesistius australis*) fishery assessment for the 1994-95 fishing year. New Zealand Fisheries Assessment Research Document 94/22 41 p.

Hansen, H. and E. Buch. 1986. Prediction of Year-class Strength of Atlantic Cod (*Gadus morhua*) off West Greenland. *NAFO Scientific Council Studies* 10: 7–11.

Hansen, P. 1949. Studies on the biology of the cod in Greenland waters. *Rapports et Proces-verbaux des Réunions. Conseil International pour l'Éxploration de la Mer* 123: 1–77.

Harley, S.H. and R.A. Myers 2001. Hierarchical Bayesian models of length-specific catchability of research trawl surveys. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 1569–1584.

Harley, S.H., Myers, R.A. and A. Dunn 2001. Is catch-per-unit-effort proportional to abundance? *Canadian Journal of Fisheries and Aquatic Sciences* 58: 1760–1772.

Hart, J.L. 1973. Pacific fishes of Canada. *Fisheries Research Board of Canada Bulletin* 180: 1–740.

Hartman, K.J. and F.J. Margraf. 1993. Evidence of predatory control of yellow perch (*Perca flavescens*) recruitment in Lake Erie, U.S.A. *Journal of Fish Biology* 43: 109–119.

Hastings, W.K. 1970. Monte Carlo sampling methods using Markov chains and their applications. *Biometrika* 57: 97–109.

Haukos, N.A. 1995. Completion Report. 1994. Leech Lake. Minnesota Department of Natural Resources. F-29-R(P)-14.

Havey, K.A. 1961. Restoration of anadromous alewives at Long Pond, Maine. *Transactions of the American Fisheries Society* 90: 281–286.

Heidelberger, P. and P.D. Welch. 1983. Simulation run length control in the presence of an initial transient. *Operations Research* 31: 1109–1144.

Heifetz, J., Ianelli, J.N. and D.M. Clausen. 1995. Slope rockfish. *in* Stock assessment and fishery evaluation report for the 1996 Gulf of Alaska groundfish, Appendix IV. North Pacific Fishery Management Council, Anchorage, AK 99510.

Heinrich, T. 1995. Completion Report. 1994. Lake of the Woods. Minnesota Department of Natural Resources. Report F-29-R(P) –14.

Helser, T.E. 1996. Growth of silver hake within the U.S. continental shelf ecoystem of the northwest Atlantic Ocean. *Journal of Fish Biology* 48(6): 1059–1073.

Henderson, B.A. 1985. Factors affecting growth and recruitment of yellow perch, Perca flavescens Mitchill, in South Bay, Lake Huron. *Journal of Fish Biology* 26: 449–458.

Henderson, P.A. and M. Cops. 1997. The role of temperature and cannibalism in interannual recruitment variation of bass in British waters. *Journal of Fish Biology* 50: 280–295.

Hightower, J.E. and W.H. Lenarz. 1990. Status of the widow rockfish fishery in 1990. i*n* Status of the Pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991: stock assessment and fishery evaluation, appendix F (in Appendix Volume 2). Pacific Fishery Management Council, Portland, Oregon. 48 p.

Hilborn, R. and M. Liermann 1998. Standing on the shoulders of giants: learning from experience in fisheries. *Reviews in Fish Biology and Fisheries* 8: 273–283.

Hilborn, R., Parma, A. and M. Maunder. 2002. Exploitation rate reference points for west coast rockfish: Are they robust and are there better alternatives? *North American Journal of Fisheries Management* 22: 365–375.

Hilborn, R., Pikitch, E.K. and M.K McAllister. 1994. A Bayesian estimation and decision analysis for an age-structured model using biomass survey data. *Fisheries Research* 19: 17–30.

Hiyama, Y., Nishida H. and T. Goto. 1995. Interannual Fluctuations in Recruitment and Growth of the Sardine, *Sardinops melanostictus*, in the Sea of Japan and Adjacent Waters. *Researches on Population Ecology* 37(2): 177–183.

Holden, M.J. 1981. Long Term Changes in Landings of Fish from the North Sea with particular reference to the periods 1930-38 and 1960-69. Symposium on the Changes in North Sea Fish Stocks and their causes. No. 15.

Holmgren-Urba, D. and T.R. Baumgartner. 1993. A 250-year history of pelagic fish abundances from the anaerobic sediments of the Central Gulf of California. *CalCOFI Rep* 34: 60–68.

Hoenig, J.M. 1983. Estimating total mortality rate from longevity data. PhD Thesis University of Rhode Island, Kingston.

Hsu, C.C., Liu, H.C., Wu, C.L., Huang S.T. and H.K. Liao. 2000. New information on age composition and length-weight relationship of bluefin tuna, *Thunnus thynnus*, in the southwestern North Pacific. *Fisheries Scienc*. 66(3): 485–493.

Hughes, S.E. 1974. Stock composition, growth, mortality and availability of Pacific saury, *Cololabis saira*, of the northeastern Pacific Ocean. *Fishery Bulletin* 72(1): 121–131.

Huntsman, G.R., Vaughan D. S. and J. Potts. 1994. Trends in population status of the red porgy (*Pagrus pagrus*) in the Atlantic ocean off North Carolina and South Carolina, USA, 1972-1992. Report to the South Atlantic Fishery Management Council from National Marine Fisheries Service,. Southeast Fisheries Science Center. Beaufort Lab, Beauford, NC.

Hurley, P.C.F., Black, G.A.P., Mohn, R. and P. Comeau. 1997. Assessment of 4X haddock in 1996 and the first half of 1997. DFO Atlantic Fisheries Research Document 97/108.

Hynd, J. and C. Lucas, 1974. Population dynamics of the southern bluefin tuna. *Proceedings of the Indo-Pacific Fisheries and Council* 15(3): 424–435.

Ianelli, J.N. 2002. Simulation analyses testing the robustness of productivity determinations from west coast Pacific Ocean perch stock assessment data. *North American Journal of Fisheries Management* 22: 301–310.

Ianelli, J.N., Ito D.H. and M. Martin. Thornyheads (*Sebastolobus*) sp. Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. 1997. North Pacific Fishery Management Council. p 327–358.

Ianelli, J.N, Wilderbuer T.K. and T.M. Staple. 1997. Stock assessment of Greenland turbot. North Pacific Management Council, November 1997.

IATTC. 1997. Assessment studies of bigeye tuna in the eastern Pacific ocean. Background Paper 5, June-3-5, 1997.

ICES 1990. Report of the ICES Study Group on Cod Stock Fluctuations. Cod and Climate Change (CCC), framework for the Study of Global Ocean Ecosystem Dynamics. ICES CM 1990/G:50 Ref C+L. 29 p.

ICES .1995. Report of the Atlanto-Scandian Herring and Capelin Working Group, Copenhagen 17-21 October 1994. ICES CM 1995/Assess:9, 101 p.

Ianelli, J.N., Wilkins, M. and S. Harley. 2000. Status and future prospects for the Pacific Ocean perch resources in waters off Washington and Oregon as assessed in 2000. In: Appendix to the Status of the Pacific Coast Groundfish Fishery through 2000 and Recommended Acceptable Biological catches for 2001 Stock Assessment and Fishery Evaluation, Pacific Fishery Management Council, Portland, OR.

Ito, D.H., and J.N. Ianelli. 1995. Pacific Ocean Perch. *in*: Stock assessment and fishhery evaluation report for the 1996 Bering Sea and Aleution Islands Region groundfish fishery. Chapter 9. (North Pacific Fishery Management Council, Anchorage).

Japp, D.W. 1990. A new study on age and growth of kingklip *Genypterus capensis* off the south and west coasts of South Africa, with comments on its use for stock identification. *South African Journal of Marine Science* 9: 223–237.

Jennings, S., Reynolds J.D. and S.C. Mills. 1998. Life history correlates of responses to fisheries exploitation. *Proceedings of the Royal Society. Series B. Biological Sciences* 265: 333–339.

Jenson, J.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 820–822.

Jessop, B.M. 1990. Stock-recruitment relationships of alewives and blueback herring returning to the Mactaquac Dam, Saint John River, New Brunswick. *North American Journal of Fisheries Management* 10: 19–32.

Jones, B.W. 1966. The cod and the cod fishery at Faroe. *MAF Fisheries Investigations London*. 24(5): 1–32.

Jones, B.W. and J. Jónsson. 1971. Coalfish tagging experiments at Iceland. *Rit. Fiskideildar* 5(1):27 p.

Jones, R. 1983. An investigation of north sea haddock, (*Melanogrammus aeglefinus*) length-at-age data, with particular reference to the effects on growth of the outstanding year classes of 1962 and 1967. *Journal du Conseil International pour l'Exploration de la Mer* 41: 50–62.

Jones, R. and J.R.G. Hislop. 1975. Changes in the North Sea haddock and whiting. ICES Symposium on the Changes in the North Sea Fish stocks and their Causes. (25). 32 p.

Jonsson, J. 1965. Temperature and growth of cod in Icelandic waters. *ICNAF Special Publication* 6: 537–539.

June, F. and W. Nicholson, 1964. Age and size composition of the menhaden catch along the Atlantic coast of the United States, 1958. U.S. Fish and Wildlife Service Special Scientific Report 446.

Kalish, J.M., Johnstone, J.M., Smith, D.C., Morison, A.K., and S.G. Robertson. 1997. Application of the bomb radiocarbon chronometer to the validation of blue grenadier *Macruronus novaezelandiae*. *Marine Biology* 128: 557–563.

Kalish, J., Johnston, J., Smith, D., Morison, S. and S. Robertson. 2002a. Validation of pink ling (*Genypterus blacodes*) age based on otolith radiocarbon. Pages 130–138 in J.M. Kalish, editor. Use of the Bomb Radiocarbon Chronometer to validate fish age. Report for FRDC Project 93/109.

Kalish, J. and J. Johnston. 2002b. Application of the bomb radiocarbon chronometer to the validation of king dory (*Cyttus traverse*) age. Pages 139–147 in J.M. Kalish, editor. Use of the Bomb Radiocarbon Chronometer to validate fish age. Report for FRDC Project 93/109.

Karacam, H. and E. Düzgünes. 1990. Age, growth and meat yield of the European anchovy (*Engraulis encrasicolus*, L. 1758) in the Black Sea.. *Fisheries Research* 9(2): 181–186.

Kelley, D.F. 1988. Age determination in bass and assessment of growth and year-class strength. *Journal of the Marine Biological Association of the United Kingdom* 68: 179–214.

Ketchen, K.S. 1964. Preliminary results of studies on growth and mortality of Pacific cod (*Gadus macrocephalus*) in Hecate Strait. *Journal of the Fisheries Research Board of Canada* 21(5): 1051–1068.

Ketchen, K.S. and C.R. Forrester. 1966. Population dynamics of the petrale sole, *Eopsetta jordani*, in the waters off western Canada. *Fishery Research Board of Canada Bulletin* 153. 195 p.

Kimura, D.K. 1981. Standardized measures of relative abundance based on modelling log(c.p.u.e.), and the application to Pacific ocean perch (Sebastes alutus). *Journal du Conseil International pour l'Exploration de la Mer* 39: 211–218.

Kipling, C. 1983. Changes in the Population of Pike (*Esox Lucius*) in Windermere from 1944 to 1981. *Journal of Animal Ecology* 52: 989–999.

Kirkwood, G.P. 1981. Estimation of stock size using relative abundance data. *Reports of the International Whaling Commission* 31: 729–735.

Kitahara, T. 1974. On the sweeping trammel net fishery along the Coast in the San'in District - yearly variation in the population size of Branquillos in Wakasa Bay. *Bulletin of the Japanese Society of Scientific Fisheries* 40(2): 141–152.

Klaer, N.L. 1994. Methods for standardization of catch/effort and data requirements. p. 86–90 *in* D.A. Hancock, editor. Population Dynamics for Fisheries Management. Australian Government Publishing Service, Canberra.

Klaer, N.L. 2003. Data summary and assessment update for pink ling (*Genypterus blacodes*) in the South East Fishery. Document Ling WS 2003 presented the May 2003 Ling Workshop.

Klaer, N.L. 2004. Abundance indices for main commercial fish species caught by trawl from the south-eastern Australian continental shelf from 1918 to 1957. *Marine and Freshwater Research* 55: 561–571.

Knaggs, E.H. and R.H. Parrish, 1973. Maturation and growth of Pacific mackerel, *Scomber japonicus* Houttuyn. *Californian Fish and Game* 59(2):114–120.

Knuckey, I.A., Grieve, C. and D.C. Smith. 1999. Evolution of the integrated scientific monitoring programme in Australia's South East Fishery. p. 231–248 *in* C.P. Nolan, editor. Proceedings of the International Conference on Integrated Fisheries Monitoring. FAO, Rome

Koch, K.H. 1992. Antarctic fish and fisheries. Cambridege University Press: Cambridge. 359 p.

Kompowski, A. 1983. Studies on growth rate of yellow notothenia, *Notothenia gibberifrons* Lönnberg, 1905 off South Georgia. *Acta Ichthyologica et Piscatoria* 13(2): 3–22.

Koopman, M.T., Punt, A.E. and D.C. Smith. 2000. Production parameters from the fisheries literature for SEF-like species. Report of ARF project R99/0308.

Kume, S. and J. Joseph. 1966. Size composition, growth and sexual maturity of bigeye tuna, *Thunnus obesus* (Lowe), from the Japanese longline fishery in the Eastern Pacific Ocean. *Inter-American Tropical Tuna Commission Bulletin* 11(2): 47–49.

Kunzmann, A. 1986. Kiemenmorphometrie von zwei antarktischen fischarten *Pleurogramma antarcticum* and *Notothenia gibberifrons*. Ph.D. thesis, Kiel University. 84 p.

Kushneriuk, R.S., Lester N.P. and R.M. Korver. 1996. A compendium of life history characteristics of walleye in Ontario Waters. Percid Community Synthesis, December 1996. Ontario Ministry of Natural Resources, Fish and Wildlife Branch.

Kuzin, S.A. 1990. Stock Assessments, age-length composition and maturity stages of the Flemish cap cod. NAFO SCR Doc. 90/23.

Labelle, M. 1991. Estimates of age and growth for South Pacific albacore. Fourth South Pacific Albacore Research Workshop, National Taiwan University, Taipei, Taiwan, Working Paper 5:1–17.

Larrañeta, M.G. 1975. La pesqueria pelagica de las costas de Alicante. *Investigacion Pesquera*. 39: 79–117.

Lee, J.U. and C.H. Park. 1978. Estimation of length and age composition of white croaker, *Argyrosomus argentatus* Houttuyn, in the southern part of the Yellow Sea and the East China Sea. *Bulletin of the Fisheries Research and Development Agency (Korea)* 19: 63–84.

Letourneur, Y., Kulbicki, M. and P. Labrosse. 1998. Length-weight relationships of fish from coral reefs and lagoons of New Caledonia, southwestern Pacific Ocean: an update. *Naga ICLARM* 21(4): 39–46.

Liermann, M. and R. Hilborn. 1997. Depensation in fish stocks: a hierarchic Bayesian meta-analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 1976–1984.

Liggins, G.W., Bradley, M.J. and S.J. Kennelly. 1997. Detection of bias in observer-based estimates of retained and discarded catches from multi species trawl fishery. *Fisheries Research* 32: 133–147.

Livingston, M.E., Vignaux, M. and K.A. Schofield. 1997. Estimating the annual proportion of nonspawning adults in New Zealand hoki, *Macruronus novaezelandiae*. *Fishery Bulletin* (*US*) 95: 99–113.

Lloret, J. 1996. Population dynamics of American Plaice (*Hippoglossoides platessoides*) off West Greenland. NAFO SCR Doc. 96:5 24 p.

Lo, N.C.H. and R.D. Methot. 1989 Spawning biomass of the northern anchovy in 1988. CALCOFI Rep. 30: 18–31.

Love, M., Morris, P., McCrae M. and R. Collins. 1987. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the Southern California Bight. NMFS Technical Report. 87, 38 p.

Lowe S.A. and L.W. Fritz. 1997. Atka Mackerel. pp 406-461 in Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1998. North Pacific Fisheries Management Council, Anchorage, Alaska.

Luccio, A.R. 1967. Datos biometricos y biologicos sobre el carbonero (Pollachius virens) del sur de Terranova. *Boletin del Instituto Espanol de Oceanografia* 133: 1–23.

Lyle, J.M. and W.B. Ford. 1993. Review of trawl research 1979-1987, with summaries of biological information for the major species. *Technical Report, Tasminian Department of Primary Industries and Sea Fisheries* 46.

MacCall, A.D. 1979. Population Estimates for the Waning years of the Pacific Sardine Fishery. CalCOFI Rep. 20.

Maguire, J.J. and P.M. Mace. (1993). Biological reference points for Canadian Atlantic gadoid stocks. *in* S.J. Smith, J.J. Hunt and D. Rivard, editors. Risk Evaluation and Biological Reference Points for Fisheries Management. *Canadian Special Publication of Fisheries and Aquatic Sciences* 120: 321–331.

Mann, R.H.K. 1973. Observation on the age, growth, reproduction and food of the roach *Rutilus rutilus* (L.) in two rivers in southern England. *Journal of Fish Biology* 5: 707–736.

Mansueti, R. 1961. Age, growth and movements of the striped bass, *Roccus saxatilis*, taken in size selective gear. *Chesapeake Science* 2(1-2): 9–36.

Matarese, A.C., Kendall Jr., A.W., Blood, D.M. and B.M. Vinter. 1989. Laboratory guide to early life history stages of northeast Pacific fishes. U. S. Department of Commerce, NOAA Tech. Rep. NMFS 80: 1–652.

Matsuda, H., Kishida, T. and T. Kidachi. 1992. Optimal harvesting policy for chub mackerel (*Scomber japonicus*) in Japan under a fluctuating environment. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 1796–1800.

Maunder M.N. 2001. A general framework for integrating the standardization of catch per unit of effort into stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 795–803.

Maunder, M.N. and G.M. Watters 2003. A general framework for integrating environmental time series into stock assessment models: model description, simulation testing, and example. *Fishery Bulletin* 101: 89–99.

Maxim, C. 1995. Horse mackerel and false scad stock assessment and catch projections, CECAF Divisions 34.1.3 and 34.3.1. *Scientia Marina* 59(3-4):611–627.

Mayo, R.K. 1998. Silver hake. *in* S.H. Clark, editor. Status of fishery resources off the northeastern United States for 1998. NOAA Tech. Memo. NMFS. 115: 60–63.

McAllister, M.K. and J.N. Ianelli. 1997. Bayesian stock assessment using catch-age data and the sampling/importance resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 284–300.

McAllister, M.K. and G.P. Kirkwood. 1998. Bayesian stock assessment and policy evaluation: A review and example using the logistic model. *ICES Journal of Marine Science* 55: 1031–1060.

McAllister, M.K., Pikitch, E.K., Punt, A.E. and R. Hilborn. 1994. A Bayesian approach to stock assessment and harvest decisions using the sampling/importance resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 2673–2687.

McQuinn, I.H. 1988. An assessment of the west coast of Newfoundland (NAFO division 4R) herring resource in 1987. CAFSAC Res. Doc. 88/52: 40 p.

Megalofonou, P. 1998. Biology and dynamics of albacore *Thunnus alalunga* (Bonnaterre 1788) in the Eastern Mediterranean Sea. Ph.D. Thesis, University of Athens, Greece. 265 p.

Megrey, B.A. 1991. Population dynamics and management of walleye pollock (*Theragra chalcogramma*) in the Gulf of Alaska, 1976-1986. *Fisheries Research* 11: 321–354.

Megrey, B.A., Hollowed, A.B. and R.D. Methot. 1990. Stock assessment and fishery evaluation report for the 1992 Gulf of Alaska groundfish fishery. Gulf of Alaska Groundfish Plan Team, Nov 1991.

Merella, P., Quetglas, A., Alemany F. and A. Carbonell. 1997. Length-weight relationship of fishes and cephalopods from the Balearic Islands (western Mediterranean). Naga ICLARM Q. 20(3/4): 66–68.

Miller, P.P. 1985. Life history study of the shortspine thornyhead, *Sebastolobus alascanus*, at Cape Ommaney, Southeatern Alaska. M.S. Thesis, University of Alaska, Juneau.

Millar, C. and R.D. Methot 2002. Age-structured meta-analysis of U.S. West Coast rockfish (Scorpaenidae) populations and hierarchical modeling of trawl survey catchabilities. *Canadian Journal of Fisheries and Aquatic Sciences* 59: 383–392.

Mills, E.L., Forney, J.L. and K.J. Wagner. 1986. Fish Predation and Its Cascading Effect on the Oneida Lake Food Chain. *in* Kerfoot, W.C. and A. Sih editors. Predation Direct and Indirect Impacts on Aquatic Communities. (University Press of New England: Hanover).

Mills, C.A. and R.H.K. Mann. 1985. Environmentally-induced fluctuations in year-class strength and their implications for management. *Journal of Fish Biology* 27(Supplement A): 209–226.

Mohn, R. and W.J. MacEachern. 1994. Assessment of 4VsW cod in 1993. DFO Atlantic Fisheries Research Document. 94. 39 p.

Molloy, J. 1967. Irish sprats and sandeels. *Irish Fisheries Investigations* 2: 5–18.

Mooij, W.M., Van Denses, W.L.T. and E.H.R.R. Lammens. 1996. Formation of year-class strength in the bream population in the shallow eutrophic Lake Tjeukemeer. *Journal of Fish Biology* 48: 30–39.

Mooney-Seus, M.L. and G.S. Stone. 1997. The forgotten giants: giant ocean fishes of the Atlantic and the Pacific. Ocean Wildlife Campaign, Washington, USA. New England Aquarium, Boston. 64 p.

Moore, H.L. 1951. Estimation of age and growth of yellowfin tuna (*Neothunnus macropterus*) in Hawaiian waters by size frequencies. *Fisheries Bulletin* 52(65): 131–149.

Moores, J.A., Winters G.H. and L.S. Parsons. 1975. Migrations and biological characteristics of Atlantic mackerel (*Scomber scombrus*) occurring in Newfoundland waters. *Journal of the Fisheries Research Board of Canada* 32(8): 1347–1357.

Morison, A.K. (1996). Age and growth of major species in the South East Fishery. The Central Ageing Facility, Marine and Freshwater Resources Institute, Department of Natural Resources and Environment, Queenscliff, Victoria.

Morison, A.K. and S.G. Robertson. (1995). Age of blue-eye trevalla. Internal Report No. 218. Victorian Fisheries Research Institute. Queenscliff. 17 p.

Morse, W.W. 1981. Reproduction of the summer flounder, *Paralichthys dentatus*. *Journal of Fish Biology* 19: 189–203

Mosher, K.H. 1953. Use of otoliths for determining the age of several fishes from the Bering Sea. *Journal du Conseil* 19: 337–344.

Muir, B.S. 1961. Estimates of mortalities and population size for the Nogies Creek maskinonge (*Esox masquinongy* Mitchill). PhD. Thesis, University of Toronto. Toronto, Ontario.

Muller, M. and C.C. Friess. 1996. An assessment of the flounder (*Platichthys flesus*) stock in ICES sub-division 24 and 25. ICES C.M. 1996/J:20.

Munk, K.M. 2001. Maximum ages of groundfishes in waters off Alaska and British Columbia and considerations of age determination. *Alaska Fishery Research Bulletin* 8: 12–21.

Murawski, S.A. 1996. Factors influencing by-catch and discard rates: analyses from multispecies/multifishery sea sampling. *Journal of Northwest Atlantic Fisheries Science* 19: 31–39.

Murphy, E.F. and C.A. Bishop. 1995. An update of the stock status of 3Ps Haddock. Newfoundland Regional Groundfish Stock Assessment. WP 95/33, 30 p.

Murty, V.S. 1980. Observations on some aspects of biology of the black croaker *Atrobucca nibe* from Kakinada. *Indian Journal of Fisheries* 27(1/2): 66–76.

Muus, B.J. and J.G. Nielsen. 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p.

Myers, R.A. 2000. The synthesis of dynamic and historical data on marine populations and communities; putting dynamics into the Ocean Biogeographical Information System. Oceanography 13(3): 56–59.

Myers, R.A., Bridson, J. and N.J. Barrowman. 1995. Summary of worldwide stock and recruitment data. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2024.

Myers, R.A., Bowen, K.G. and N.J. Barrowman. 1999. Maximum reproductive rate of fish at low population sizes. *Canadian Journal of Fisheries and Aquatic Sciences* 56: 2404–2419.

Myers, R.A., MacKenzie, B.R., Bowen, K.G. and N.J. Barrowman 2001. What is the carrying capacity for fish in the ocean? A meta-analysis of population dynamics of North Atlantic cod. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 1464–1476.

Myers, R.A., Barrowman, N.J., Hilborn, R. and D.G. Kehler. 2002. Inferring Bayesian priors with limited direct data: Applications to risk analysis. *North American Journal of Fisheries Management* 22: 351–364.

Naish, K.A., Hecht T. and A.I.L. Payne. 1991. Growth of cape horse mackerel *Trachurus trachurus capensis* off South Africa. *South African Journal of Marine Science* 10: 29–35.

Nakamura, E.L. and J.H. Uchiyama, 1966. Length-weight relations of Pacific tunas. Pages 197–201. *in* T.A. Manar, editor. Proceedings of the Governor's Conference on Central Pacific Fishery Resources. Honolulu, Hawaii.

Nakamura, I. and N.V. Parin. 1993. FAO species catalogue. Snake mackerels and cutlassfishes of the world (Families Gempylidae and Trichiuridae). FAO Fisheries Synopsis 15(125): 136 p.

National Research Council (NRC). 1998. Improving Fish Stock Assessments. National Academy Press, Washington, D.C.

Naymark. Y.B. 1993. Analysis of the population of the White Sea Herring. *Journal of Ichthyology* 33(2): 48–55.

Neilson, J. D. and P. Perley. 1986. A review of the status of the 4VWX flatfish stocks. CAFSAC Research Document. 86/48: 31 p.

Ni, I.H. and E.J. Sandeman. 1984. Size at maturity for Northwest Atlantic redfishes. *Canadian Journal of Fisheries and Aquatic Sciences* 41: 1753–1762.

Nishimura, A. and J. Yamada. 1988. Geographical differences in early growth of walleye pollock *Theregra chalcogramma*, estimated by back-calculation of otolith daily growth increments. *Marine Biology* 97: 459–465.

Northeast Fisheries Science Center. 1995. Report of the 19th Regional Stock Assessment Workshop (19th SAW). The Plenary. NEFSC Reference Document 95-09/SAW 19. p 96–107.

O'Boyle, R.N., Simon, J. and K. Frank. 1988. An evaluation of the population dynamics of 4X haddock during 1962-88 with yield projected to 1989. CAFSAC Research Document. 88/72: 59 p.

O'Boyle, R.N., Frank K. and J. Simon. 1989. An evaluation of the population dynamics of 4X haddock during 1962-88 with yield projected to 1990. CAFSAC Research Document. 89/58: 59 p.

O'Brien, L., Burnett, J. and Mayo, R.K. 1992. Maturation of nineteen species of finfish off the northeast coast of the United States, 1985-1990. NOAA Technical Report, NMFS 113: 66 p.

O'Gorman, R., Bergstedt, R.A. and T.H. Eckert. 1987. Prey fish dynamics and salmonine predator growth in Lake Ontario, 1978-84. *Canadian Journal of Fisheries and Aquatic Sciences* 44(suppl. 2): 390–403.

Ontario Ministry of Natural Resources, Fish and Wildlife Branch, 1997. Lake Erie fisheries report 1996. Lake Erie Committee Meeting, Great Lakes Fishery Commission, Ann Arbor, Michigan. 26 p.

Ortega-Salas, A.A. 1988. Age and growth of the dab, Limanda limanda (Linnaeus) in the Isle of Man waters, U.K. *Anales del Instituto de Ciencias del Mar y Limnologia, Universidad Nacional Autonoma de Mexico* 15(1): 1–18.

Ouchi, A. 1978. Studies on the age and growth of common mackerel, *Scomber japonicus* in the waters west of Kyushu and east of Tsushima Islands. *Bulletin of the Seikai National Fisheries Research Institute* 51: 97–110.

Parmanne, R. 1990. Growth, morphological variation and migration of herring (*Clupea harengus* L.) in the northern Baltic Sea. *Finnish Fisheries Research* 10: 1–48.

Parsons, J.W. 1967. Contributions of year-classes of blue pike to the commercial fishery of Lake Erie, 1943-1959. *Journal of the Fisheries Research Board of Canada* 24(5): 1035–1066.

Parsons, L.S. and V.M. Holder. 1975. Biological characteristics of Southwest Newfoundland herring. *International Commission for the Northwest Atlantic Fisheries Research Bulletin* 11: 147–159.

Patterson, K.R. and G.P. Kirkwood. 1995. Comparative performance of ADAPT and Laurec-Shepherd methods for estimating fish population parameters and in stock management. *ICES Journal of Marine of Science* 52: 183–196.

Patterson, K., Cook, R., Darby, C., Gavaris, S., Kell, L., Lewy, P., Mesnil, B., Punt, A., Restrepo, V., Skagen, D.W. and G. Stefansson. 2001. Estimating uncertainty in fish stock assessment and forecasting. *Fish and Fisheries*. 2: 125–157.

Paul, L.J. 1976. A study on age growth and population structure of the snapper, *Chrysophrys auratus* in Hauraki Gulf. New Zealand Fisheries Research Bulletin, Ministry of Agriculture and Fisheries, N.Z. 13: 63 p.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *Journal du Conseil International pour L'Exploration de la Mer* 39: 175–193.

Pauly, D., Cabanban A. and F.S.B. Torres, Jr. 1996. Fishery biology of 40 trawl-caught teleosts of Western Indonesia. p. 135–216. *in* D. Pauly and P. Martosubroto, editors. Baseline studies in biodiversity: the fish resources of western Indonesia. ICLARM Studies and Reviews 23.

Pauly, D., and G.I. Murphy. 1980. Theory and management of tropical fisheries. ICLARM. Manila.

Pauly, D., and I. Tsukayama. 1980. On the seasonal growth, monthly recruitment and monthly biomass of Peruvian anchoveta (*Engraulis ringens*) from 1961 to 1979. *FAO Fisheries Report* 291(30): 988–1004.

Pawson, M.G. 1992. Climatic influences on the spawning success, growth, and recruitment of bass (*Dicentrarchus labrax*) in British waters. *ICES Marine Science Symposia* 195: 388–392.

Payne, A.I.L. and A.E. Punt. 1995. Biology and fisheries of the South African Cape hakes (*M. capensis* and *M. pa*radoxus). p. 15–47. *in* J. Alheit and T.J. Pitcher, editors. Hake: Fisheries, Ecology and Markets. London: Chapman and Hall.

Pellerier, D. and J. Ferraris. 2000. A multivariate approach for defining fishing tactics from commercial catch and effort data. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 51–65.

Penas Lado, E. 1978. Estudio sobre la dinámica y la estrategia de explotacion del 'stock' desardina (*Sardina pilchardus*, Walbaum) de la costas de Castellon. *Boletin del Instituto Espanol de Oceanografia* 4(3): 143–160.

Pentilla, J.A. and V.M. Gilford. 1976. Growth and mortality rates for cod from the Georges Bank and Gulf of Maine areas. ICNAF *Research Bulletin* 12: 29–36.

Peterman, R.M., Bradford, M.J. and G.H. Kruse. 1987. Simulation model of English sole (*Parophrys vetulus*) population dynamics in Washington and Oregon coastal waters. *Canadian Journal of Fisheries and Aquatic Sciences* 44(11): 1870–1878.

Pikitch, E.K. 1987. Use of a mixed-species yield-per-recruit model to explore the consequences of various management policies for the Oregon flatfish fishery. *Canadian Journal of Fisheries and Aquatic Sciences* 44 (Supl. 2): 349–359.

Pitt, T.K. 1975. Changes in the abundance and certain biological characteristics of Grand Bank American plaice, *Hippoglossoides plattessoides*. *Journal of the Fisheries Research Board of Canada* 32(8): 1383–1398.

Polacheck, T. and K. Sainsbury. 1993. Age structure assessments with multiple and conflicting information: A case study based on Southern Bluefin Tuna. Working Paper Prepared for the Australian Society for Fish Biology Workshop on 'Population Dynamics for Fisheries Management'.

Pope, J.G. and C.T. Macer. 1996. An evaluation of the stock structure of North Sea cod, haddock, and whiting since 1920, together with a consideration of the impacts of fisheries and predation effects on their biomass and recruitment. *ICES Journal of Marine Science* 53: 1157–1169.

Pope, J.G. and J.G. Shepherd. 1985. A comparison of the performance of various methods for tuning VPAs using effort data. *Journal du Conseil International pour l'Exploration de la Mer* 42 : 129–151.

Porch, C.E. and G.P. Scott. 1994. A numerical evaluation of GLM methods for estimating indices of abundance from west Atlantic bluefin tuna catch per trip data when a high proportion of the trips are unsuccessful. *Collected Volume of Scientific Papers, ICCAT* 42(1): 241–245.

Portela, J.M., González M.C. and J.M. Bellido 2002. Preliminary results of an exploratory fishing targeting deep-water species off Uruguay. ICES ASC Session L: 04.

Potts, J.C. and C.S. Manooch III. 2002. Estimated ages of red porgy (*Pagrus pagrus*) from fishery-dependent and fishery-independent data and a comparison of growth parameters. *Fishery Bulletin* 100(2): 81–89.

Prager, M.H. and A.D. MacCall, 1988. Revised estimates of historical spawning biomass of the Pacific mackerel, *Scomber japonicus*. *CalCOFI Report* 29: 81–90.

Prager, M.H. and A.D. MacCall, 1993. Detection of contaminant and climate effects on spawning success of three pelagic fish stocks off southern *California Fishery Bulletin* 91: 310–327.

Pribac, F., Punt, A.E., Walker, T.I. and B.L. Taylor. In press. The value of length, age and tagging data in a stock assessment of a length selective fishery for gummy shark *(Mustelus antarcticus)*. *Journal of Northwest Atlantic Fisheries Science* 00: 00–00.

Prodanov, K., Mikhailov, K., Daskalov, G., Maxim, K., Ozdamar, E., Shlyakhov, V., Chashchin, A. and A. Arkhipov, 1997. Environmental management of fish resources in the Black Sea and their rational exploitation. Studies and Reviews. GFCM. 68. Rome, FAO. 178 p.

Punt, A.E. 1989. Bias and variance of catch-effort based model estimation procedures used in the management of the ICSEAF hake stocks - a preliminary comparative investigation. *Selected Papers of the International Commission for the South East Atlantic Fisheries* 1: 39–54.

Punt, A.E. 1990. Is B_1 = K an appropriate assumption when applying an observation error production model estimator to catch-effort data? *South African Journal of Marine Science* 9: 249–259

Punt, A.E. 1992. Selecting management methodologies for marine resources, with an illustration for southern African hake. *South African Journal of Marine Science* 12: 943–958.

Punt, A.E. 2000. Bayesian assessment of the eastern stock of gemfish using data for the 2000 winter fishing season. Document submitted to 16-17 August 1999 meeting of EGAG.

Punt, A.E. and D.S. Butterworth. 1999. On assessment of the Bering-Chukchi-Beaufort Seas stock of bowhead whales (*Balaena mysticetus*) using a Bayesian approach. *Journal of Cetacean Research and Management* 1: 53–71

Punt, A.E. and D.S. Butterworth 2002. Why do Bayesian and maximum likelihood assessments of the Bering-Chukchi-Beaufort Seas stock of bowhead whales differ? *Journal of Cetacean Research and Management* 2: 125–133

Punt, A.E. and R. Hilborn. 1996. Biomass dynamic models. User's manual. *FAO Computerized Information Series (Fisheries).* No. 10. Rome, FAO.

Punt, A.E. and R. Hilborn. 1997. Fisheries stock assessment and decision analysis: A review of the Bayesian approach. *Reviews in Fish Biology and Fisheries* 7: 35–63.

Punt, A.E. and D.W. Japp. 1994. Stock assessment of the kingklip *Genypterus capensis* off South Africa. *South African Journal of Marine Science* 14: 133–149.

Punt, A.E. and R.B. Kennedy. 1997. Population modelling of Tasmanian rock lobster, *Jasus edwardsii*, resources. *Marine and Freshwater Research* 48: 967–980.

Punt, A.E. and R.W. Leslie. 1991. Estimates of some biological parameters for the cape hakes off the South African west coast. *South African Journal of Marine Science* 10: 271–284.

Punt, A.E. and R.D. Methot. In press. The impact of recruitment projections on rebuilding rates for overfished marine resources. Pages 00–00. In: Gallucci, V. , [Ed.] Assessment and Management of New and Developed Fisheries in Data-limited situations. Alaska Sea Grant College Program, AK-SG-0?-??, Fairbanks, AK.

Punt, A.E. and A.D.M. Smith. 1999. Harvest strategy evaluation for the eastern stock of gemfish (*Rexea solandri*). *ICES Journal of Marine Science* 56(6): 860–875.

Punt, A.E. and D.C. Smith. In press. Stock assessment for the blue warehout (*Seriolella brama*) based on data up to 2003. Pages 00–00. In: Tuck, G.N. and A.D.M. Smith [Ed.] Stock Assessment for South East and Southern Shark Species. Report for FRDC Project 2001/05.

Punt, A.E. and D.C. Smith. 2001. Assessments of species in the Australian South East Fishery can be sensitive to the method used to convert from size- to age-composition data. *Marine and Freshwater Research* 52: 683–690.

Punt, A.E., Pribac, F., Walker, T.I., Taylor, B.L. and J.D. Prince. 2000. Stock assessment of school shark *Galeorhinus galeus* based on a spatially-explicit population dynamics model. *Marine and Freshwater Research* 51: 205–220.

Punt, A.E., Rowling, K. and J. Prince. 2000. Summary of data for use in the assessments of the eastern stock of gemfish based on the 2000 fishing season. Document presented to the 15-16 August 2000 meeting of EGAG.

Punt, A.E., Smith, D.C., Thomson, R.B., Haddon, M., He, X. and J.M. Lyle. 2001a. Stock assessment of the blue grenadier *Macruronus novaezelandiae* resource off south-eastern Australia. *Marine and Freshwater Research* 52: 701–717.

Punt, A.E., Campbell, R. and A.D.M. Smith. 2001b. Evaluating empirical indicators and reference points for fisheries management: Application to the broadbill swordfish fishery off Eastern Australia. *Marine and Freshwater Research* 52: 819–832.

Punt, A.E., Smith, A.D.M. and G. Cui. 2002a. Evaluation of management tools for Australia's South East Fishery. 2. How well do commonly-used stock assessment methods perform? *Marine and Freshwater Research* 53: 631–644.

Punt, A.E., Smith, A.D.M. and G. Cui. 2002b. Evaluation of management tools for Australia's South East Fishery. 3. Towards selecting appropriate harvest strategies. *Marine and Freshwater Research* 53: 645–660.

Raftery, A.E. and S. Lewis. 1992. How many iterations in the Gibbs sampler? p. 763–773 *in* J.M. Bernardo, J. Berger, A.P. Dawid and A.F.M. Smith, editors. Bayesian Statistics 4, Oxford University Press, Oxford.

Raftery, A.E., Givens, G.H. and J.H. Zeh. 1995. Inference from a deterministic population dynamics model for bowhead whales. *Journal of the American Statistical Association* 90: 402–416.

Raitt, D. 1966. The biology and commercial potential of the blue whiting (*Micromesistius poutassou*) in the Northeast Atlantic. ICES Symp. Ecology of Pelagic Fishes in Arctic Waters.

Ralston, S., Pearson, D. and J. Reynolds. 1998. Status of the Chilipepper rockfish stock in 1998. Pacific Fishery Management Council, Portland, Oregon.

Reuben, S., Vijayakumaran K. and M. Chandra Sekhar. 1993. Growth, maturity and mortality of false trevally *Lactarius lactarius* Bloch & Schneider from Andhra Pradesh-Orissa coast. *Indian Journal of Fisheries* 403: 156–161.

Richards, L.J. and N. Olsen. 1996. Slope rockfish stock assessment for the west coast of Canada in 1996 and recommended yields for 1997. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2134. 91 p.

Rijnsdorp, A.D., Daan, N., Beek F. A. and H.J.L. Heesen. 1991. Reproductive variability in North Sea plaice, sole, and cod. *Journal du Conseil International pour l'Exploration de la Mer* 47: 352–375.

Rikhter, V.A. and I. P. Golubiatnikova. 1996. Results of comparison of some biological parameters and abundance dynamics of silver hake (*Merluccius bilinearis*) from Scotian Shelf and cape hake (*Merluccius capensis*) from Namibia Area. NAFO. SCR 96/1. 13 p.

Ritchie, B.J. and P.J. Colby. 1988. Even-odd year difference in walleye year-class strength related to mayfly production. *North American Journal of Fisheries Management* 8: 210–215.

Rowling, K.R. 1994. Gemfish *Rexea solandri*. p. 115–123 *in* R.D.J. Tilzey, editor. The South East Fishery. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Rowling, K. and D.D. Reid. 1992. Effect of temporal change in size composition on estimates of von Bertalanffy growth parameters for gemfish, *Rexea solandri* (Cuvier), Gempylidae. *Australian Journal of Marine and Freshwater Research* 43: 1229–1239.

Rubin, D.B. 1987. Comment: The calculation of posterior distributions by data augmentation. *Journal of the American Statistical Association* 82: 543–546.

Saishu, K. 1968. Reproductive curve of the stock of *Argyrosomus nibe*, Kuroguchi, in the East China Sea. *Japanese Journal of Ecology* 18: 32–39.

Saishu, K. 1970. Reproductive curve of the Kiangsu province group of yellow croaker, *Pseudociaena polyactis,* in the East China Sea. *Japanese Journal of Ecology* 20: 31–39.

Saishu, K. 1973. Reproduction curve of the Yellow Sea bream in the East China Sea. *Bulletin of the Seikai Regional Fisheries Research Laboratory* 43: 1–22.

Saishu, K. 1974. The Reproduction Curve of the sea Bream, *Chrysophrys major*, in the Yellow Sea. *Bulletin of the Seikai Regional Fisheries Research Laboratory* 44: 27–33.

Sakamoto, T. 1984. Age and growth of the red sea bream in the outer waters adjacent to the Kii Strait. *Bulletin of the Japanese Society of Scientific Fisheries* 50(11):1829–1834.

Salerno, D.J., Burnett, J. and R.M. Ibara. 2001. Age, growth, maturity and spatial distribution of bluefish, *Pomatomus saltatrix*, off the Northeast Coast of the United States, 1985-96. *Journal of Northwest Atlantic Fishery Science* 29: 31–39.

Sampson, D.B., and Y. Yin. 1998. A Monte Carlo evaluation of the stock synthesis assessment program. Pages 315–338 *in* F. Funk, T.J. Quinn II, J. Heifetz, J.N. Ianelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan and C.I. Zhang, editors. Fishery stock assessment models. University of Alaska Sea Grant AK-SG-98-01, Fairbanks, AK.

Saunders, M.W. and G.A. McFarlane. 1990. Sablefish. pp. 127-149. in A.V. Tyler and J. Fargo, editors. Groundfish stock assessments for the west coast of Canada in 1989 and recommended yield options for 1990. *Canadian Technical Report of Fisheries and Aquatic Sciences* 1732. 343 p.

Savoy, T.J. and V.A. Crecco. 1988. The timing and significance of density-dependent and density-independent mortality of American shad, *Alosa sapidissima*. *Fishery Bulletin* 86: 467–482.

Scott, W.B. and M.G. Scott. 1988. Atlantic Fishes of Canada. *Canadian Bulletin of Fisheries and Aquatic Sciences* 219: 731 p.

Schweder, T. and J.N. Ianelli. 1998. Bowhead assessment by likelihood synthesis, methodology and difficulties. Paper SC/50/AS2 presented to the IWC Scientific Committee, April 1998.

Serebryakov, V.P. and A.K. Chumakov. 1992. Spawning stock, population fecundity and year-class strength of Greenland halibut (*Reinhardtius hippoglossoides*) in the Northwest Atlantic, 1969-88. *Journal of Northwest Atlantic Fishery Science* 14: 107–113.

Serns, S.D. 1982. Influence of various factors on density and growth of age-0 walleyes in Escanaba Lake, Wisconsin, 1958-1980. *Transactions of the American Fisheries Society* 111: 299–306.

Shepherd, J.G. 1982. A family of general production curves for exploited populations. *Mathematical Bioscience* 59: 77–93.

Shindo, S. 1960. Studies on the stock of yellow sea bream in the East China Sea. Seikai Regional Fisheries Res. Laboratory Report 20.

Shindo, S. 1972. Note on the study on the stock of lizard fish, Saurida tumbil in the East China Sea. *Proceedings of the Indo-Pacific Fish Conference* 13(3): 298–305.

Shojima, E. and H. Otaki. 2000. Stock Assessment of the East China Sea Population of White Croaker, *Argyrosomus argentatus*. *Bulletin of the Seikai Regional Fisheries Research Laboratory* 60: 11–29

Shuter, B.J., Koonce, J.F., and H.A. Regier. 1979. Modeling the western Lake Erie walleye population: A feasibility study. Great Lakes Fishery Commission. Technical Report No.32. 40 p.

Sinclair, A.F. 2001. Natural mortality of cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. *ICES Journal of Marine Science* 58: 1–10.

Sinclair, A.F., Chouinard, G., Swain, D., Hebert, R., Nielsen, G., Hanson, M., Currie, L., and T. Hurlbut. 1994. Assessment of the Fishery for Southern Gulf of St. Lawrence cod: May, 1994. DFO Atlantic Fisheries Research Document 94/77. 116 p.

Smale, M.J. 1983. Resource partitioning by two top predatory teleosts in the eastern Cape coastal waters (South Africa). PhD thesis. Rhodes University. Grahamstown. 285 p.

Smidt, E. 1969. The Greenland halibut, *Rheinhardtius hippoglossoides* (Waldb.), biology and exploitation in West-Greenland. Meddelser fra Danmarks *Fiskeri-og Havunderogelser* 6(4): 79–148.

Smith, A.D.M. 1994. Blue grenadier, *Macruronus novazelandie*. p. 137–148 *in* R.D.J. Tilzey, editor. The South East Fishery. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Smith, A.D.M. and A.E. Punt. 1998. Stock assessment of gemfish (*Rexea solandri*) in eastern Australia using maximum likelihood and Bayesian methods. p. 245–286. In: T.J. Quinn II, F. Funk, J. Heifetz, J.N. Ianelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan and C-I Zhang [Ed.] Fisheries Stock Assessment Models, Alaska Sea Grant College Program, AK-SG-98-01.

Smith, A.D.M. and S.E. Wayte (Eds). 2002. *The South East Fishery 2002*. Fishery Assessment Report compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Smith, D.C. 1989. The fisheries biology of jackass morwong (*Nemadactylus macropterus* Bloch and Schneider) in south-eastern Australian waters. PhD Thesis University of New South Wales, Australia.

Smith, D.C. 1998. *Blue Grenadier 1998*, Stock Assessment Report, Blue Grenadier Assessment Group, South East Fishery Assessment Group. Australian Fisheries Management Authority: Canberra.

Smith, D.C. and B.D. Stewart. 1994. Development of methods to age commercially important dories and oreos. Fisheries Research and Development Corporation Final Report. Victorian Fisheries Research Institute, Queenscliff.

Smith, D.C., Huber, D., Woolcock, J., Withel, A.F. and J.W.J. Wankowski. 1995. Western Bass Strait trawl fishery assessment program. Final report of FRDC Project 86/39, MAFRI, Queenscliff.

Smith, D.C., Smith, A.D.M. and A.E. Punt. 2001. Approach and process for stock assessment in the South East Fishery, Australia: A perspective. *Marine and Freshwater Research* 52: 671–681.

Smith, L.L. Jr. 1977. Walleye (*Stizostedion vitreum*) and yellow perch (*Perca flavescens*) populations and fisheries of the Red Lakes, Minnesota, 1930-75. *Journal of the Fisheries Research Board of Canada* 34: 1774–1783.

Smith, P.E. 1978. Biological effects of ocean variability: time and space scales of biological response. *Rapports et Proces-verbaux des Réunions. Conseil International pour l'Éxploration de la Mer* 173: 117–127.

Smith, P.E. 1990. Monitoring interannual changes in spawning area of Pacific sardine (*Sardinops sagax*). CALCOFl Report 31: 145–151.

Somerton, D.A. and B.S. Kikkawa. 1992. Population dynamics of pelagic armourhead *Pseudopentaceros wheeleri* on Southeast Hancock Seamount. *Fishery Bulletin* 90: 756–769.

Soutar, A. and J.D. Issacs. 1974. Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediment off the Californias. *Fishery Bulletin U.S.* 72: 257–273.

Spiegelhalter, D.J., Best, N.G., Carlin, B.P. and A. van der Linde. 2002. Bayesian measures of model complexity and fit. *Journal of the Royal Statistical Society B* 64: 583–639.

Stephensen, R.L., Power, M.J. and T.D. Iles. 1975. Assessment of the 1986 4WX herring fishery. CAFSAC 87/75: 39 p.

Stobo, W. and J. Hunt. 1974. Mackerel biology and history of the fishery in subarea 4. ICNAF Fisheries Research Document 74/9.

Stocker, M. and R. Blackwel. 1988 Biomass and yield estimates for alfonsino in BYX 2 for the 1991-92 fishing year . New Zealand Fisheries Assessment Research Document 91/12. 12 p.

Stocker, M. and D.J. Noakes, 1988. Evaluating forcasting procedures for predicting Pacific herring *Clupea harengus pallasi* recruitment in B.C. *Canadian Journal of Fisheries and Aquatic Sciences* 45(6): 928–935.

Stocker, M. and M.W. Saunders. 1997. Utility of an age and sex structured model for sablefish, *Anoplopoma fimbria*, stock assessment off the west coast of Canada. *in* M. Wilkins and M. Saunders, editors. Biology and management of sablefish (*Anoplopoma fimbria*), papers from the International Symposium on the Biology and Management of Sablefish, Seattle WA. NOAA Technical Report NMFS 130.

Su, M.S. and H.C. Liu. 1975. Age and growth of yellow sea bream *Dentex tumifrons* from the East and South China Seas. *Acta Oceanographica Taiwanica* 5: 139–151.

Sunada, J. 1974. Age and growth of the Pacific saury, *Cololabis saira*. *Californian Fish and Game* 60(2): 64–73.

Tagart, J.V. 1988. Status of the yellowtail rockfish stocks in the International North Pacific Fishery Commission Vancouver and Columbia areas. Washington Department of Fisheries Technical Report No. 104. 118 p.

Tankevich, P.B. 1990. Growth, age and natural mortality of *Notothenia rossii rossii* in the Kerguelen Islands area. *Cybium* 14(3): 269–276.

Taylor, B.L. and D.C. Smith. 2004. Stock assessment of spotted warehou (*Seriolella punctata*) in the South East Fishery. Document presented to the August 2004 meeting of Slope FAG.

Temming. A. (1983). On the stock situation of common dab in the Belt Sea. 1983. ICES CM 1983/G:65; 19 p

Templeman, W., Hodder, V.M. and R. Wells. 1978. Sexual maturity and spawning in haddock *Melanogrammus aeglefinus* of the southern Grand Bank. *ICNAF Research Bulletin* 13: 53–65.

Thomson, R.B. 2002. Stock assessment of spotted warehou (*Seriolella punctata*) in the South East Fishery, July 2002. Document presented to the July 2002 meeting of the Blue Warehou Assessment Group.

Thomson, R.B., Furlani, D. and X. He. 2001. Pink ling (*Genypterus blacodes*). p. 51-82 *in* R.B. Thomson and X. He, editors. Modelling the population dynamics of high priority SEF species. Final Report of FRDC Project 1997/115.

Tilzey, R.D.J. 1994. Ling, *Genypterus blacodes*. Pages 198–207 *in* R.D.J. Tilzey, editor. The South East Fishery. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Tilzey, R.D.J. 1994.The South East Fishery: a scientific review with particular reference to quota management. Bureau of Resource Sciences, Australian Government Print Service, Canberra. 360 p.

Tzeng, T.D., Lin D.R. and S.Y. Yeh. 2002. Comparison on growth characteristics of southern east china sea's lizard fish (*Saurida tumbil*) between 1970s and 1990s. *Acta Oceanographica Taiwan* 40(1):93–105.

Ursin, E. 1963. On the seasonal variation of growth rate and growth parameters in Norway pout (*Gadus esmarkii*) in the Skagerrak. *Meddelelser fra Danmarks Fiskeri-Og Havundersogelser* 4(12):17–29.

van der Elst, R. 1981. A guide to the common sea fishes of southern Africa. C. Struik, Cape Town. 367 p.

van der Elst, R.P. and F. Adkin. 1991. Marine linefish: priority species and research objectives in southern Africa. Oceanographic Research Institute, Special Publication No.1. 132 p.

Van Dijk, H.K., Hop, J.P. and A.S. Louter. 1987. An algorithm for the computation of posterior moments and densities using simple importance sampling. *The Statistician* 36: 83–90.

Vaughan, D.S. 1987. Stock Assessment of the Gulf Menhaden, *Brevoortia patronus*, Fishery. NOAA Technical Report NMFS 58.

Vaughan, D.S. 1990. Assessment of the status of the Atlantic menhaden stock with reference to internal waters processing. NOAA Technical Report NMFS 262.

Vaughan, D.S., Huntsman, G.R., Manooch, III C.S., Rohde, F.C. and G.F. Ulrich. 1992. Population characteristics of the red porgy, *Pagrus pagrus*, stock off the Carolinas. *Bulletin of Marine Science* Vol. 50: 1–20.

Vazquez, A., Avila de Melo, A., Alpoim, R., de Cardenas E. and L. Motos. 1997. An assessment of the cod stock in NAFO division 3M. NAFO SCR Doc. 97/50. 10 p.

Vignaux, M. 1994. Catch per unit effort (CPUE) analysis of west coast South Island Cook Strait spawning hoki fisheries, 1987-93. *New Zealand Fisheries Assessment Research Document* 94/11.

Wada, T. 1988. Population dynamics on Japanese sardine, *Sardinops melanostictus* caught by the domestic purse seine fishery in the waters off the coast of Southeastern Hokkaido. Bulletin of the Hokkaido Regional Fisheries Research Laboratory 52.

Wakabayashi, K. 1984. Estimations of biomass and yield for yellowfin sole in the Eastern Bering Sea, and stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 1992, November 1991. *International North Pacific Fisheries Commission Bulletin* 42: 65–72.

Waldron, D.E., Showell M.A. and G. Harrison. 1991. Status of the Scotian shelf silver hake (whiting) population in 1990. NAFO SCR Doc. 91/42: 34 p.

Walker, T.I., Taylor, B.L., Hudson, R.J. and J.P. Cottier. 1998. The phenomenon of apparent change of growth rate in gummy shark (*Mustelus antarcticus*) harvested off southern Australia. *Fisheries Research* 39: 139–163.

Walters, C. and A. Punt. 1994. Placing odds on sustainable catch virtual population analysis and survey data. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 946–958.

Walton, C.J. 1987. Parent-progeny relationship for established population of anadromous alewives in a Maine lake. *American Fisheries Society Symposium* 1: 451–454.

Walters, C.[J.] and D. Ludwig. 1994. Calculation of Bayes posterior probability distributions for key population parameters. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 713–722.

Wang, C.H. and S. Tanaka. 1988. Development of a multi-cohort analysis method and its application to the Indian Ocean yellowfin tuna length composition. *Far Seas Fisheries Research Laboratories* 25: 1–73.

Warburton, K. 1982. Sandeels - the elusive species. *Scottish Fishery Bulletin* 47: 22–27.

Ware, D.M. and G.A. McFarlane. 1989. Fisheries production domains in the Northeast Pacific Ocean. p. 359–379. in R.J. Beamish and G.A. McFarlane, editors. Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. *Canadian Special Publication of Fisheries and Aquatic Sciences* 108.

Watanabe, T. 1973. The recent trend in the stock size of the Pacific population of the common mackeral off Honshu, Japan, as viewed from egg abundance. Canadian Fisheries Research Board. Translation Series. 2451. 13 p.

Webb, B.F. (1979). Preliminary data on the fishery for deepsea trevalla. *Tasmanian Fisheries Research* 22: 18–29.

Wilkins, M.E. 1980. Size composition, age composition and growth of chilepepper, *Sebastes goodei*, and bocaccio, *S. paucipinis* from the 1977 rockfish survey. *Marine Fisheries Review* Mar.-Apr.: 48–53.

Winters, G.H., and J.P. Wheeler. 1987. Recruitment dynamics of spring-spawning herring in the Northwest Atlantic. *Canadian Journal of Fisheries and Aquatic Sciences* 44: 882–900.

Wismer, D.A. 1980. The impact of thermal effluents on smallmouth bass reproductive success at Baie du Dore, Lake Huron. Master thesis, University of Toronto, Toronto, Ontario.

Witherell, D. 1996. Groundfish of the Bering Sea and Aleutian Islands area: a species profile. North Pacific Fishery Management Council, Alaska. 15 p.

Wolfert, D.R. 1981. The commercial fishery for walleyes in New York waters of Lake Erie, 1959-1978. *North American Journal of Fisheries Management* 1: 112–126.

Wu, H., Cheng, G. Zhou J. and J. Wang. 1985. Study of the growth of the hairtails, *Trichiurus haumela* (Forskål). *Oceanologia et Limnologia Sinica* 16: 156–167.

Yabuta, Y., Yukinawa M. and Y. Warashina. 1960. Growth and age of yellowfin tuna. 2. Age determination (scale method). *Report of the Nankai Regional Fisheries Research Laboratory* (12): 63–74.

Yang, R., Hiyama, Y. and Y. Nose. 1964. On the parent-progeny relationship, considering the variation of geographical distributions of Hokkaido Herring (*Clumea pallasii*). *Bulletin of the Japanese Society of Scientific Fisheries* 30: 239–242.

Yasuda, H. 1950. Growth of Japanese principal fish. III. *Taius tumifrons*. *Bulletin of the Japanese Society of Scientific Fisheries* 16(6): 39–43.

Yimin, Y. and A.A. Rosenberg. 1991. A study of the dynamics and management of the hairtail fishery, *Trichiurus haumela*, in the East China Sea. *Aquatic Living Resources* 4: 65–75.

Yukinawa, M. 1970. Age and growth of southern bluefin tuna Thunnus maccoyii by use of scale. *Bulletin of the Far East Fisheries Research Laboratory* (3): 229–257.

Zwanenburg, K. and P. Comeau. 1991. Haddock on the Eastern Scotian Shelf 1991. CAFSAC Research Document 91/47: 43 p.

Zwanenburg, K., and P. Fanning. 1988. Assessment of haddock in 4TVW -- population status and catch projections for 1989. CAFSAC Res. Doc. 88/76: 34 p.

Zwanenburg, K. and P.C.F. Hurley. 1987. Redfish (*Sebastes* spp.) in management unit 4VWX: an assessment of present stock status. CAFSAC Research Document 87/35: 34 p.

Appendix 1: Intellectual Property

No intellectual property has arisen from the project that is likely to lead to significant commercial benefits, patents or licences. Any intellectual property associated with this project will be shared between the Fisheries Research and Development Corporation, PIRVic and the University of Washington.

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