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Applications of a Bayesian surplus production model to New Zealand fish stocks

New Zealand Fisheries Assessment Report 2016/52

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We applied a generalised surplus production model to a range of stocks in New Zealand, representing both well assessed stocks and those that do not currently have an accepted quantitative assessment. All the stocks examined had an accepted abundance index, but with varying degrees of information in the data. Estimation was achieved within a state-space Bayesian framework using a Sampling-Importance-Resampling (SIR) procedure. This incorporated both observation error and annual process error deviates from model predictions, and an informative prior on the intrinsic growth rate based on available life history data. In some cases, an informative prior on the constant of proportionality for fishery independent abundance indices was also used. Fixed values for process error and observation error variances were applied. This report details the process of application and outcomes for a range of case-studies. For most of the instances in which the Bayesian surplus production model (BSP) has been fitted to the same abundance index data to which CASAL had previously been fitted, stock status, stock trend, and projection results were remarkably similar between BSP and CASAL. This was especially so for stock status and projection results for hoki East, hoki West, bluenose, and Chatham hake and despite the fact that the CASAL models fitted were fully age-structured and in all instances fitted to more types of data than the BSP. In a few instances however, results from the two approaches differed. For example, for the SPO 7 rig stock the stock trend data obtained could not be explained by the catch biomass time series provided and the BSP gave uninformative results. This is in contrast to an earlier assessment of the same stock in which the CASAL model fitted to both abundance index data and fishery length frequency data provided informative estimates of stock trends. Also, fits of the BSP model to an aggregate of Chatham Rise East orange roughy stock trend data (both fishery and fishery independent indices) provided good fits and informative estimates of stock size and depletion. This is in contrast to an attempt in 2006 to fit CASAL to abundance index and catch at length data for the same stock, which at that point wasn't able to fit the trend data. A more recent stock assessment in 2014 was more successful in fitting the stock trend data, however the results are not comparable with the current BSP application, due to different assumptions concerning the stock structure and the use of only fishery independent abundance indices. By providing a wide range of such case-study examples, this work represents a first step towards the application of surplus production models for formal stock assessments in New Zealand. The potential use of this approach, alongside suggestions for further work, are discussed.

1. INTRODUCTION

In the 2008 Harvest Strategy Standard (HSS) and associated Operational Guidelines it states that New Zealand fish stocks within the Quota Management System should be managed according to “MSY-compatible reference points or better” (Ministry of Fisheries, 2008, 2011). To help achieve this the Fishery Assessment Working Groups convened by the Ministry for Primary Industries (MPI) have terms of reference that include a requirement “to assess, based on scientific information, the status of fisheries and fish stocks relative to MSY-compatible reference points and other relevant indicators of stock status” (Ministry of Fisheries, 2011). Furthermore they may be required to define the projected consequences of different TAC implementations, thereby providing guidance for management.

As part of the working group process stock assessments are characterised according to the following levels of complexity:

1. ***Full Quantitative Stock Assessment***: There is a reliable index of abundance and an assessment indicating status in relation to targets and limits.
2. ***Partial Quantitative Stock Assessment***: An evaluation of agreed abundance indices (e.g. standardised CPUE) or other appropriate fishery indicators that have not been used in a full quantitative stock assessment to estimate stock or fishery status in relation to reference points.
3. ***Qualitative Evaluation***: A fishery characterisation with evaluation of fishery trends (e.g. catch, effort, unstandardised CPUE, or length-frequency information) has been conducted but there is no agreed index of abundance.
4. ***Low information evaluation***: There are only data on catch with no other fishery indicators.

These are differentiated largely on the basis of a) whether or not a reliable abundance index is available; and b) whether the resource is valuable enough to spend time conducting an assessment. Only for Level 1 assessments are both of these criteria true, making it possible to deliver estimates of biomass relative to established reference points. These correspond to about 20% of New Zealand stocks by number. For the remaining stocks, more tenuous methods have been used to ensure that management conforms to legislative requirements. This includes in particular the use of a reference abundance index or total catch, taken from an historical period of assumed stability, as proxy indicators of B_{msy} and MSY respectively.

Proxy reference points provided by a catch or catch rate are a practical interim solution, but there is nevertheless a need to develop more quantitatively rigorous approaches. In the work presented here we illustrate application of a surplus production model to stocks currently subjected to a Level 2 assessment. These are predominantly the less valuable stocks. An abundance index is available, but they generally do not warrant the time required for a full quantitative assessment. A surplus production model can however be easily implemented within an appropriately short timeframe, whilst still providing outputs that would bring conditional management into full alignment with the HSS.

The objective of this work is therefore to illustrate the potential utility of a surplus production model in New Zealand stock assessments. To achieve this we apply the model to a variety of stocks, some of which are already assessed, and draw conclusions concerning the utility of model outputs.

2. METHODS

Cohort-aggregated surplus production models are able to represent changes in exploited biomass over time in response to a particular harvest regime. In fisheries stock assessment they are usually written in discrete form (Equation 1a), where *B* is the total exploitable biomass, *C* is the catch and *g(.)* is the surplus production function. For this study we assume the generalised production function described by McAllister et al. (2000), which is a hybrid model that combines the well-known logistic function introduced to fisheries by Schaefer (1954, 1957), with the Fletcher (1978) model (Equation 1b). This has three parameters *r*, *K* and *n*, which can be interpreted respectively as the maximum intrinsic growth rate, the arithmetic mean biomass at unexploited equilibrium (or carrying capacity) and a "shape" parameter which defines the inflection point of the production function relative to *K*.

$$B_{t+1} = B_t + g(B_t) - C_t \qquad \text{(Equation 1a)}$$

$$g(B_t) = \begin{cases} rB_t\left(1 - \frac{B_t}{2B_{msy}}\right) & B_t \le B_{msy} \\ \gamma m\left(\frac{B_t}{K} - \left(\frac{B_t}{K}\right)^n\right) & B_t > B_{msy} \end{cases} \qquad \text{(Equation 1b)}$$

$$\gamma = \frac{n^{(n/(n-1))}}{n-1}$$

$$m = MSY$$

The model has a number of useful reference points associated with it, which can be obtained directly from the parameter estimates (Equation 2). These correspond to MSY and the associated biomass.

$$MSY = \frac{rB_{msy}}{2} \qquad \text{(Equation 2a)}$$

$$B_{msy} = K\left(\frac{1}{n}\right)^{1/(n-1)} \qquad \text{(Equation 2b)}$$

The shape parameter therefore determines the value of B_{msy}/K, and is most intuitively understood via the parameter $\varphi = B_{msy}/K$. For example, a symmetric production function corresponds to $n = 2$ and $\varphi = 0.5$. This is usually inconsistent with predictions made by age structured models, which are based on a stock-recruitment function that often predicts $\varphi < 0.5$. Through changes in φ, the generalised form described above is able to provide a close approximation to the shape of the production function assumed by cohort-based models.

2.1 Estimation framework

Parameters of the surplus production model were estimated within a Bayesian state-space framework (Equation 3). This re-formulates the process equation to include a time-dependent error term (the process error, ε^p) and a parallel observation process that relates an abundance index *I* to the unobserved biomass state with some degree of error (the observation error, ε^o), according to an estimated catchability scalar *q*.

$$B_{t+1} = [B_t + g(B_t) - C_t].\varepsilon_t^p \qquad \text{(Equation 3a)}$$

$$I_{it} = [q_i B_t].\varepsilon_{it}^{o} \qquad \text{(Equation 3b)}$$

The advantage of this class of models is that they allow both process and observation error to be represented simultaneously, which is important for precautionary or risk based management (Harwood & Stokes, 2003). A parameter for the ratio of initial stock biomass B_{init} to the carrying capacity K, must also be estimated and is referred to as the parameter $a = B_{init}/K$.

The parameter φ was fixed on input; r, K, B_{init}, q for each index and the error terms were estimated. The large number of parameters necessitates a Bayesian approach with appropriate priors (Equation 4). Parametric distributional assumptions for ε^p and ε^o are required, and we assumed them to follow a log-normal distribution with an expectation of one.

Due to there being relatively few types of data typically available for BSP model fitting, it is often not possible to estimate simultaneously observation error and process error variance in BSP type models. In the estimation approach taken in this report and other recent applications (e.g. Stanley et al., 2009, McAllister & Duplisea, 2012, Yamanaka et al., 2012), the value for process error standard deviation, σ_p, was fixed and the value for the additive component of observation error variance for the abundance indices was obtained through iterative reweighting in which the empirical estimates of the observation error variance conditional on the posterior modal fit was used to update initially assumed values until the inputted observation error standard deviations, σ_o, for each index were about 10–20% larger than the empirical values obtained at the posterior mode. This was to allow for parameter uncertainty about the posterior mode. Also a minimum bound was subjectively set in which $\sigma_o \geq 0.15$.

The value inputted for process error variance however was set based on experience with age structured-models that have included stochastic recruitment. For example, simulation of stochastic age-structured models for a range of life history types suggests that the coefficient of variation in between-year stochastic variation in stock biomass is typically much less than about 0.15 and this sets an upper bound for σ_p for all but the shortest-lived and most variable stocks. The range of process error standard deviation was set such that $0.15 \geq \sigma_p \geq 0.05$. Unless otherwise stated we assumed values of $\sigma_p = 0.05$. The reference case prior distributions for estimated parameters were as follows.

$$r \sim LN(\mu_r, \sigma_r^2) \qquad \text{(Equation 4a)}$$

$$\ln(K) \sim U(.,.) \qquad \text{(Equation 4b)}$$

$$\ln(q) \sim U(.,.) \qquad \text{(Equation 4c)}$$

$$\varepsilon_{.}^{p} \sim LN\left(-\sigma_p^2/2, \sigma_p^2\right) \qquad \text{(Equation 4d)}$$

$$\varepsilon_{..}^{o} \sim LN(0, \sigma_o^2) \qquad \text{(Equation 4e)}$$

$$B_{init}/K \sim LN(-\sigma_a^2/2, \sigma_a^2) \qquad \text{(Equation 4f)}$$

The r and K parameters of the logistic model are highly correlated, and their estimation is helped through the use of an informative prior or priors. Since there is no established conventional practice for the most appropriate form for a non-informative prior for K, we assumed two different forms of uninformative prior for K: 1) the subjectively intuitive log-uniform prior for K for eight of the case studies, and 2) the more common uninform on K prior for the other two case studies (i.e., LIN 3&4 and Chatham Rise East Orange roughy). However, an informative log-normal prior for *r* was applied in all case studies The expectation and variance for the prior on intrinsic growth, with $E[r] = \exp(\mu_r + \sigma_r^2/2)$, was constructed from available life-history data using methods described in McAllister et al. (2001). These are detailed below.

We assumed an uniform prior on the natural logarithm of catchability q, which gives $\pi(q) \propto 1/q$. Catchability was treated as a nuisance parameter and integrated out of the joint posterior density function. A shortcut procedure was used to achieve this (Equation 5), similar in approach to that proposed by Ludwig & Walters (1985). In each Bayesian Monte Carlo iteration (see below), q was computed analytically using the closed-form maximum likelihood estimate (MLE) of q for each abundance index conditional on the model predicted values for stock biomass, *B*. The MLE allowed for the standard deviation for each index *I*, σ_o, to differ between years:

$$\hat{q} = exp\left[\frac{\sum_{i=1}^{n} ln\left(\frac{I_i}{B_i}\right)/\sigma_{o,i}^2}{\sum_{i=1}^{n} 1/\sigma_{o,i}^2}\right] \qquad \text{(Equation 5)}$$

This shortcut approach is analytically equivalent to treating q as a free parameter and integrating it from the joint posterior density function when computing the marginal posterior density functions for quantities of interest. For some case studies a survey abundance index was available with an associated informative prior for q that had been obtained mainly through expert judgment. Bayesian estimation of parameters was achieved using the Sampling Importance Resampling (SIR) algorithm implemented in the Visual Basic package BSP (McAllister, 2013b).

2.2 Development of a prior for the intrinsic growth rate

This involves the estimation of *r* numerically as the solution to the Euler-Lotka equation (Equation 6), which states that the maximum intrinsic growth reflects the net balance of survivorship *s*, and unconstrained fecundity *f*, averaged over all age classes (McAllister et al., 2001).

$$\sum_{a=0}^{\infty} s_a f_a e^{-ar} = 1 \qquad \text{(Equation 6)}$$

$$s_a = e^{-aM}$$

$$f_a = \alpha m_a w_a$$

Survivorship and fecundity are calculated using available life history data. Survivorship is a simple function of the natural mortality *M*, which is assumed constant across ages. Fecundity is the product of female maturity *m*, weight *w*, and the recruits per spawner *α*. Recruits per spawner is itself a function of steepness *h*, and the female spawning biomass per recruit *ρ*, in this case assuming a Beverton-Holt stock recruitment relationship. The relevant functional forms are given in Equations 7a (maturity-at-age), 7b (length-at-age), 7c (weight-at-age) and 7d (recruits per spawner).

$$m_a = \left(1 + 19^{(a_{50}-a)/a_{95}}\right)^{-1} \quad \text{(Equation 7a)}$$

$$l_a = l_\infty \left(1 - exp\left(-k(a - t_0)\right)\right) \quad \text{(Equation 7b)}$$

$$w_a = a{l_a}^b \quad \text{(Equation 7c)}$$

$$\alpha = \frac{4h}{\rho(1-h)} \quad \text{(Equation 7d)}$$

The particular life-history data used, and the dependent prior for *r* are given for each case study listed in the results section.

2.3 Model comparison

To compare the credibility of each stock assessment model run when the model in each run was fitted to the same abundance index data, we computed Bayes factors (Stanley et al. 2012). Bayes factors were computed for a reference run and for each of the related sensitivity runs. Bayes factors account for both the goodness of fit of each model to the data and the parsimony of the two compared models. They are calculated as the ratio of the marginal probability of the data for one model to that for a second model. We used the mean value for the importance weights from a given model run as an approximation of the probability of the data given the model (McAllister & Kirchner 2002). Providing that one can get importance sampling to work for each model, this is known to be a numerically stable approximation for the probability of the data, given the model and approximations obtained through importance sampling. For example, the coefficient of variation (CV) in the natural logarithm in the mean importance weight was less than 0.05 after a few hundred thousand draws from the importance function. In all instances, the Bayes factor was computed in relation to the reference case (or base case) model settings. In other words, the probability of the data for the reference case model was placed in the denominator and that for the model run to which it was compared in the numerator. It is commonly held that the Bayes factor must depart substantially from 1.0 for anything to be inferred from the exercise but even fairly large departures in Bayes factors can result from random chance in the data and/or misspecification of probability models. Intermediate values for Bayes factor (e.g., between about 0.01 and 100) should be interpreted with caution. For example, models with Bayes factors of between 0.1 and 0.01 could be interpreted as unlikely but not discredited. When the Bayes factor for a model is less than 0.001, the model could be viewed as highly unlikely relative to the other.

2.4 Study outline and objectives

The objective of this investigation was to review preliminary applications of the BSP package to different New Zealand fish stocks, in an attempt to assess utility of the approach in providing a simplified stock assessment process. A generalised surplus production model is easier to apply than a cohort-based integrated assessment, being faster to run and requiring fewer data and fewer decisions about model settings to apply. In particular the method might be useful for data-moderate (Level 2) stock assessments, for which only catch and abundance data are available.

We detail case-study applications of BSP, split into stocks that are currently unassessed, and those for which an accepted CASAL stock assessment is already in place. These are summarised in Table 2. For each case study a range of applications have been attempted, with an intention of illustrating the performance of the model under different situations. Since the applications were intended to be illustrative, this was an *ad hoc* rather than systematic approach. In particular we may assume different values for φ, and for ease of reference use the notation BSP(φ) to refer to the particular parameterisation assumed. Typically we applied the models BSP(φ=0.5), to replicate the logistic (symmetric) production function, and BSP(φ=0.25), to provide a closer match to the productivity assumptions of an age-structured model. For each model application we return estimates for the intrinsic and derived parameters listed in Table 1.

Table 1: Table of definition of terms in results tables.

Variable	Definition
r	Maximum rate of population increase
K	Average unfished exploitable biomass
MSY	Maximum sustainable yield
B_{msy}	Exploitable stock biomass at MSY
B_{init}	Stock biomass at the beginning of the time series
B_{cur}	Stock biomass in the current, i.e., most recent historical year with a catch record
B_{cur}/B_{msy}	Ratio of stock biomass in the current year to stock biomass at MSY
B_{cur}/B_{init}	Ratio of stock biomass in the current year to initial stock biomass
B_{cur}/K	Ratio of current stock biomass to average unfished biomass
F_{msy}	Fishing mortality rate at MSY
F_{cur}	Current year fishing mortality rate
F_{cur}/F_{msy}	Ratio of current year fishing mortality rate to fishing mortality rate at MSY
RepY_{cur}	Current year replacement yield, i.e., the catch biomass that results in no population change
$\mathrm{Catch}_{cur}/\mathrm{RepY}_{cur}$	The ratio of current year catch biomass to current year replacement yield
$\mathrm{P}(B_{cur} > 0.4B_{msy})$	The probability that current year stock biomass exceeds 40% of stock biomass at MSY
$\mathrm{P}(B_{cur} > 0.8B_{msy})$	The probability that current year stock biomass exceeds 80% of stock biomass at MSY
$\mathrm{P}(B_{cur} > B_{msy})$	The probability that current year stock biomass exceeds stock biomass at MSY
$\mathrm{P}(\mathrm{F}_{cur} < F_{msy})$	The probability that current year fishing mortality rate is less than MSY fishing mortality rate

Table 2: Summary of species and analyses conducted for this report.

Species	Stock	Assessment level	Data characteristics	Summary of analyses
Jack mackerel (*Trachurus declivis*)	JMD 7	2	Abundance indices do not respond to changes in catch and therefore appear uninformative.	BSP(φ=0.5) and BSP(φ=0.25) model applications. Examined posterior updates of PMPD distributions to evaluate whether data are informative.
Jack mackerel (*Trachurus novaezelandiae*)	JMN 7	2	Abundance indices are responsive to the catch and therefore likely to be informative.	BSP(φ=0.5) and BSP(φ=0.25) model applications. Examined posterior updates of PMPD distributions to evaluate whether data are informative.
Elephant fish (*Callorhinchus milii*)	ELE 3	2	Catch history is uncertain, and there may have been a shift in productivity due to changing fishing patterns	Tested whether historical underreporting of catch may have occurred. Applied BSP(φ=0.5) model with revised estimates of historical catch.
Rig (*Mustelus lenticulatus*)	SPO 7	2	Abundance indices do not respond to changes in catch and therefore appear uninformative.	BSP(φ=0.5) model applied with and without informative priors on q, to evaluate value of a prior on q for estimating stock status.
Hoki (*Macruronus novaezelandiae*)	HOK 1 East	1	Responsive indices with both depletion and recovery should provide information for BSP model fit.	Evaluated alternative assumptions regarding process error and catchability priors for BSP(φ=0.5) and BSP(φ=0.25) model outputs. Comparison of BSP and CASAL estimates of status.

Hoki (*Macruronus novaezelandiae*)	HOK 1 West	1	Abundance estimates suggest rapid depletion and recovery which may be problematic for the BSP model.	Evaluated alternative assumptions regarding process error and catchability priors for BSP(φ=0.5) and BSP(φ=0.25) model outputs.
Hake (*Merluccius australis*)	HAK 3	1	Responsive indices with both depletion and recovery should provide information for BSP model fit.	BSP(φ=0.5) model fit and comparison with CASAL outputs.
Ling (*Genypterus blacodes*)	LIN 3&4	1	Apparent conflict between survey and CPUE abundance indices.	Evaluated alternative assumptions regarding process error and catchability priors for BSP(φ=0.5) and BSP(φ=0.2) model outputs. Comparison of BSP and CASAL estimates of status.
Bluenose (*Hyperoglyphe antarctica*)	BNS	1	Uncertainty in historical catches.	Evaluated alternative assumptions regarding historical catches for BSP(φ=0.5) and BSP(φ=0.3) model outputs. Comparison of BSP and CASAL estimates of status.
Orange roughy (*Hoplostethus atlanticus*)	ORH 3B East	1	Multiple indices which appear to show little evidence of stock recovery and therefore contradict CASAL model outputs.	Application of BSP(φ=0.5) model and evaluation of whether it is consistent with most recent abundance data.

3. CASE STUDY APPLICATIONS AND RESULTS

3.1 Unassessed Stocks

Four assessments were carried out on stocks that do not currently have a model-based assessment of status. These are intended to be illustrative of how a generalised production model can be applied in a variety of novel situations, and should not be considered formal attempts to assess status. We are able to demonstrate versatility of the approach in accommodating problematic and uninformative data through simple modifications of the model assumptions, which could provide direction for further work on these stocks.

A key issue with these low information data is how diagnostics should be formulated and interpreted to determine whether any useful management advice could be derived from the posterior results (McAllister & Edwards, 2014). From an empiricist viewpoint, it could be argued that there would need to be an appreciable update in the priors from fitting the model to the data for the results to be considered to be empirically-based. While this could be assessed in viewing the marginal posterior for carrying capacity, it is more relevant to investigate how distributions for key quantities such as depletion would be updated from their prior distributions. A “quasi” prior distribution for model variable such as depletion can be obtained by running the stock assessment model with the priors and the inputted catch records but without fitting the model to the abundance index data. The resulting model output distributions are thus conditioned only on the model structure, priors and catch record inputs. These output distributions are termed “post model, pre-data” (PMPD) distributions and serve as a reference against which posterior updates for derived quantities can be checked.

To show how catch data and priors combine with model structure before the model is fitted to abundance index data, we have thus computed PMPD distributions for several quantities, including depletion, and presented these for each case study. To judge whether the fit of the model to the abundance index data leads to posterior distributions that are informed by the abundance index data, we will plot the posterior distributions and where appropriate the prior distributions for model quantities together with the PMPD distributions. We propose that the posterior precision for key quantities such as depletion should be higher than the precision in the PMPD distribution if the posterior results are useable for management purposes. Further work beyond the scope of the current report is required to formulate quantitative criteria that could be used to judge whether any given posterior update of the PMPD is sufficient. In addition to this criterion, the marginal posterior distribution for scalar quantities such as carrying capacity and current stock biomass should not have thick positive tails, as this would indicate that carrying capacity is poorly resolved by the model fit.

Jack Mackerel – JMD 7

Background

Jack mackerel JMD 7 (Table 3) has proven difficult to assess due to uncertainty in catch records and the lack of any apparent responses in the abundance indices to historical variation in exploitation (McKenzie, 2009). The catch history and CPUE indices (Figure 1) are derived from species proportions estimates, and since the abundance indices do not appear to show responses to historical variations in the catch biomass time series, it is not expected that the application of BSP would provide an informative assessment of stock status.

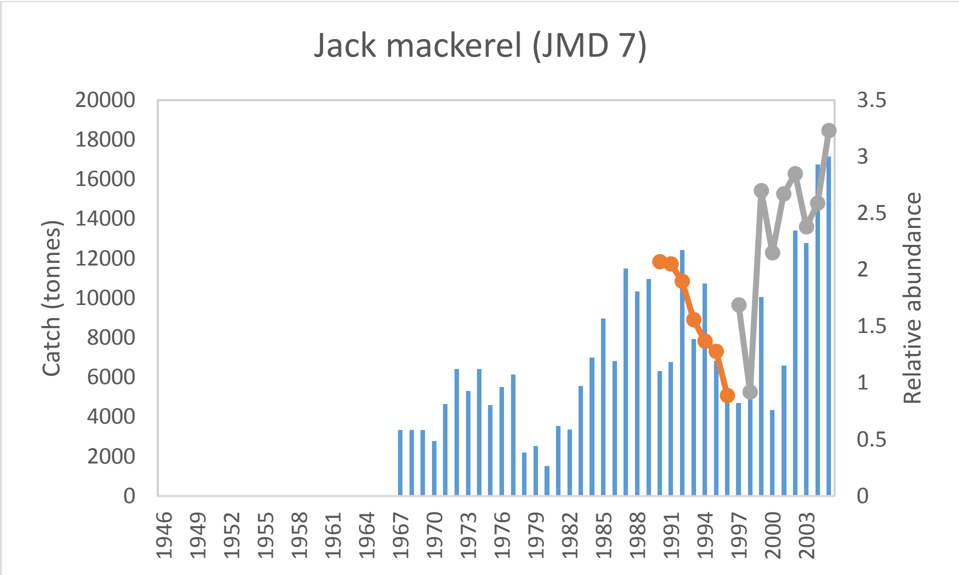

Figure 1: Catch and abundance data for JMD 7. Catches are shown as vertical bars. Relative abundance indices are shown as lines.

Table 3: Life-history data and prior on intrinsic growth for JMD 7.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	M	per year	0.18	0.25
Fraction mature at age	a_{50}	year	3	0.10
	$d_{50\text{-}95}$		6	0.10
Growth	k		0.28	0.10
	L_{inf}	cm	46	0.05
	t_0	year	-0.4	0.25
Length-to-weight	a		2.3E-05	0.001
	b		2.84	0.001
Recruitment	h		0.90	0.055
Intrinsic growth	r		0.688	0.31

Analyses performed

The BSP(φ=0.5) model was fitted to two standardised CPUE indices, between 1990–1996 and 1997–2005. The catch time series extends back to 1946. Since the CPUE data tend to track the trends in the catch biomass records, it appeared that there was relatively little information in the data for model-based estimation of productivity. The sensitivity of results to applying a production function more similar to that obtained from an age structured model was evaluated using a BSP(φ=0.25) model. For the two different surplus production functions considered, PMPD were computed to evaluate the direction and degree of update provided by fitting the model to the abundance index data.

Results

For the BSP(φ=0.5) run, the posterior median for stock biomass showed relatively little change over the time series except for a slight drop in the late-1990s when the first index dropped, and then a recovery to the same levels following that (Figure 2a). The change in abundance was accommodated by a period of negative process error deviates, since the catch records during this period could not explain these variations in the abundance indices (Figure 2b).

There were slight updates in the PMPD distribution for depletion, carrying capacity and current stock biomass (Figure 3). The ratio of posterior precision to PMPD precision (using the coefficients of variation) were 3.0, 1.4 and 1.5, respectively. Most significantly, the posterior mean for depletion (0.95) was updated to a larger value than the PMPD mean value (0.83). The posterior distributions for replacement yield and F/F_{msy} in the current year (2005) are also updated from the PMPDs to suggest that the stock is lightly fished (Figure 3). However, the tail of the marginal posterior distribution for carrying capacity was still relatively thick at very high levels (e.g., at 2 million). The posterior interval for the ratio of fishing mortality rate to fishing mortality rate at MSY remained less than 0.8 for all years but became wider in the final two decades (Figure 3). The posterior median value for this ratio remained less than about 0.2 for all years and was about 0.14 in the final year, 2005 (Table 4).

The results for BSP(φ=0.25) showed similar though slightly less pronounced updates to the priors and PMPDs. Of note, the PMPD for B_{cur}/K was lower under the Fletcher-Schaefer model (0.625) than with the Schaefer model (0.84) (Table 5). Apart from having a much higher estimate of B_{cur}/B_{msy} for BSP(φ=0.25), the posterior for B_{cur}/K and most of the other stock status indicators was centred at slightly less optimistic values than those for BSP(φ=0.5) (Table 5). Bayes factor favoured BSP(φ=0.25) by a factor of 6.7.

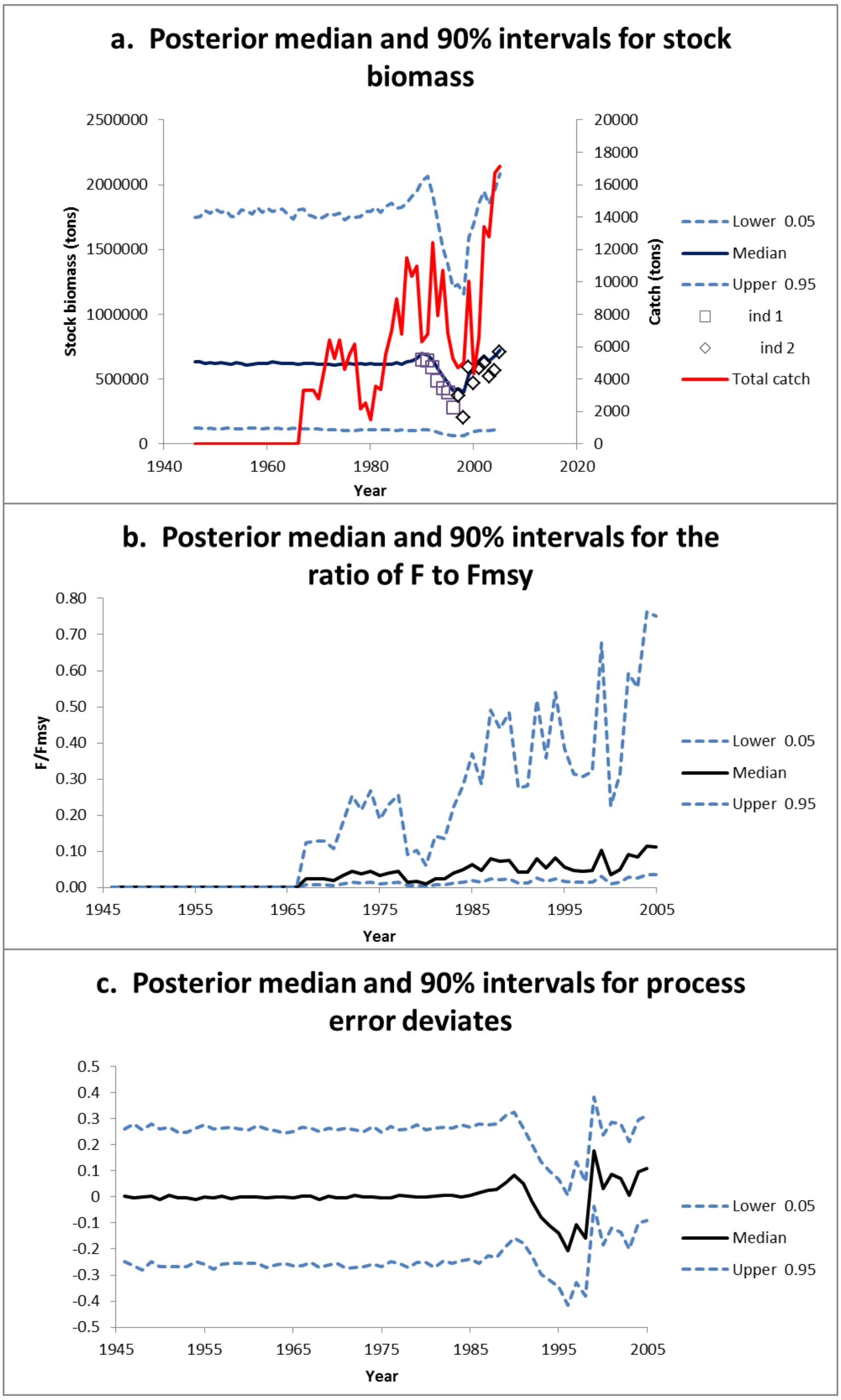

Figure 2: Posterior median and 90% intervals for a. stock biomass, b. the ratio of the annual fishing mortality rate to F_{msy} and c. process error deviates for the BSP(φ=0.5) model fit for JMD 7.

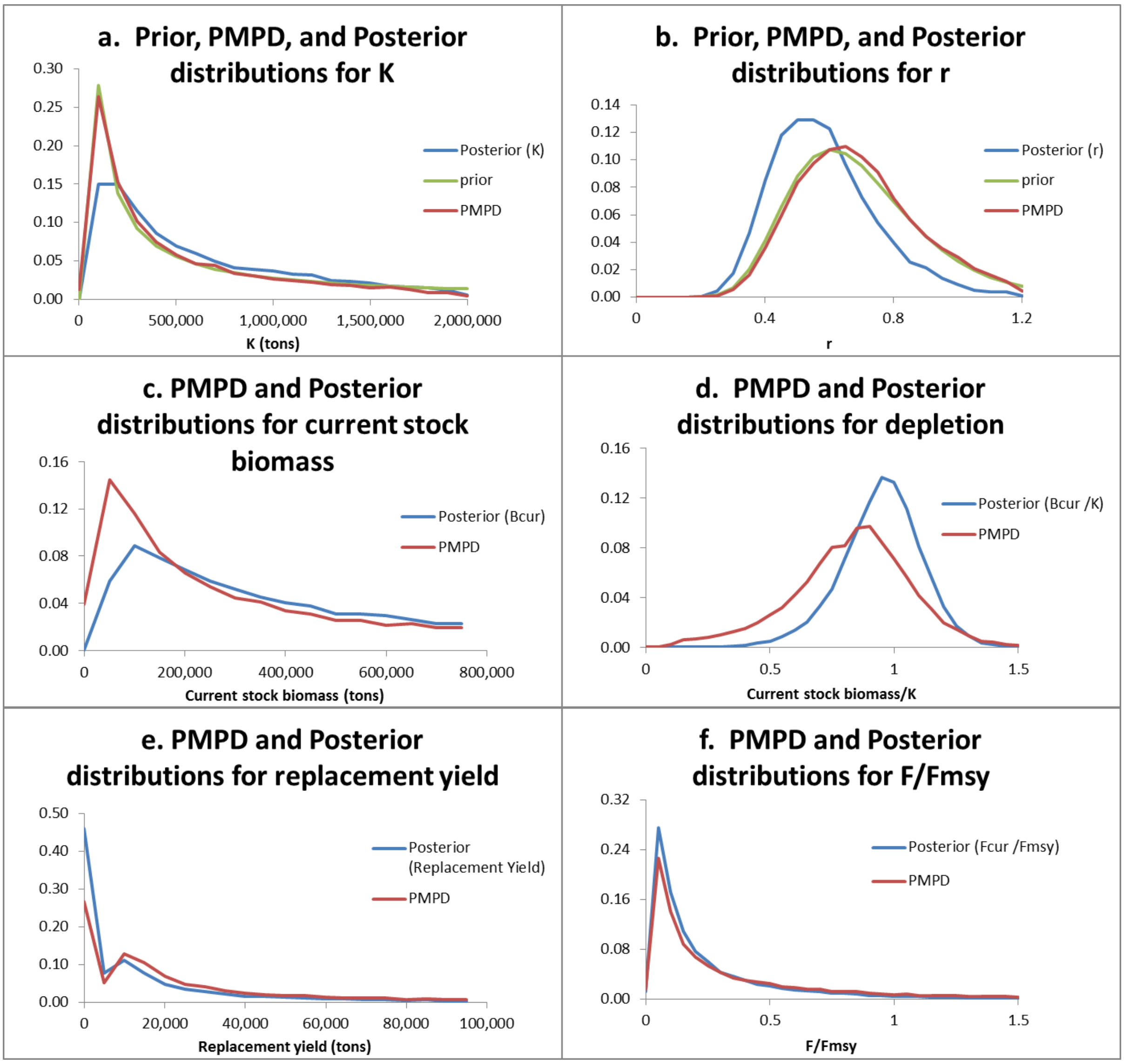

Figure 3: Prior, PMPD and posterior distributions for a) carrying capacity, b) intrinsic growth, c) current stock biomass, d) depletion, e) replacement yield in the current year (2005), and f) F/F_{msy} in the current year for the BSP(φ=0.5) model fit for JMD 7.

Table 4: Posterior mean, standard deviation, coefficient of variation, median and 90% intervals for quantities of interest for the BSP(φ=0.5) model fit for JMD 7.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.607	0.165	0.272	0.374	0.588	0.921
K	618130	488856	0.791	99341	459436	1638519
MSY	92672	79499	0.858	14417	66139	257024
B_{msy}	309065	244428	0.791	49671	229718	819259
B_{init}	607688	480903	0.791	88806	445794	1658790
B_{cur}	621374	529991	0.853	82708	480239	1916845
B_{cur}/B_{msy}	1.919	0.362	0.189	1.313	1.927	2.514
B_{cur}/B_{init}	1.004	0.284	0.283	0.587	0.975	1.514
B_{cur}/K	0.959	0.181	0.189	0.657	0.964	1.257
F_{msy}	0.303	0.0826	0.272	0.187	0.294	0.461
F_{cur}	0.069	0.0815	1.184	0.010	0.039	0.232
$\mathrm{F}_{cur}/\mathrm{F}_{msy}$	0.239	0.2869	1.198	0.032	0.132	0.798
RepY_{cur}	18793	32744.4	1.742	0	4057	90308
$\mathrm{Catch}_{cur}/\mathrm{RepY}_{cur}$	0.3439	0.7063	2.054	0	0	1.741
$\mathrm{P}(B_{cur} > 0.4B_{msy})$	1					
$\mathrm{P}(B_{cur} > 0.8B_{msy})$	0.998					
$\mathrm{P}(B_{cur} > B_{msy})$	0.989					
$\mathrm{P}(\mathrm{F}_{cur} < F_{msy})$	0.969					

Conclusions

We conclude that there was an update in the posterior distributions relative to the priors and PMPD distributions for both versions of BSP that were considered for JMD 7, and a moderate amount of information in the data to update the priors, although not by very much. The limited amount of information in the data about stock size is mainly reflected in the relative thick tails in the posterior distributions at large values for carrying capacity and stock biomass. There appears to be mild support for the hypothesis that the stock remains lightly exploited since the posterior mean for depletion was at a higher value than the PMPD assumption: the current depletion was estimated to be 0.95 for BSP(φ=0.5), whereas the PMPD value was 0.83. Moreover, the posterior distribution for F/F_{msy} also suggested that the stock was lightly fished since the 90% interval was for BSP(φ=0.5), less than 0.8 for the entire time series. It could be expected that if the abundance index has a fairly low CV and shows little change over the periods of highest exploitation, that the stock has remained lightly fished. Under such circumstances, a stock reduction analysis such as the ones performed here could be expected to yield little update in the prior distributions, and the posteriors for carrying capacity and stock biomass could be expected to maintain fairly thick right-hand tails, as seen here for JMD 7.

It is important to note that for both production functions considered, the direction of the update to the PMPD was the same, i.e., pointing to a lightly exploited stock. However, the magnitude of the update was for most quantities less well pronounced for the BSP(φ=0.25) model. It is also important to note that this was favoured by a Bayes factor of 6.7 over BSP(φ=0.5).

It is important to identify diagnostics from BSP results that correctly indicate that a stock is lightly fished when it is truly lightly fished. This is important since it would be a serious misdiagnosis to consistently conclude that there were insufficient data available to assess the status of a stock, when in fact more careful inspection of model outputs could reliably reveal that a stock was lightly fished. Such a misdiagnosis could in some circumstances create unnecessary constraints and costs on industry for example if the onus was put on industry to pay for further surveying and research to enable more precise assessments of resource status.

Table 5: Posterior and PMPD median and 90% interval results for evaluations of the sensitivity of BSP results for JMD 7 to different input settings.

Run	r			B_{msy}			B_{cur}			$RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
$\varphi=0.5$ Posterior	0.374	0.588	0.921	49671	229718	819259	82708	480239	1916845	0	4057	90308
$\varphi=0.5$ PMPD	0.411	0.675	1.026	32905	162627	791781	25470	277291	1568803	0	14728	140418
$\varphi=0.25$ Posterior	0.415	0.648	1.007	29703	113994	418448	47584	402088	1854506	0	7989	52938
$\varphi=0.25$ PMPD	0.42	0.673	1.018	28667	102119	399794	28097	281590	1577262	0	13339	73553

Run	B_{cur}/B_{msy}			B_{cur}/K			F_{cur}/F_{msy}			$Catch_{cur}/RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
$\varphi=0.5$ Posterior	1.313	1.927	2.514	0.656	0.964	1.257	0.032	0.132	0.798	0	0	1.741
$\varphi=0.5$ PMPD	0.759	1.686	2.384	0.380	0.843	1.192	0.033	0.188	1.81	0	0.211	1.932
$\varphi=0.25$ Posterior	1.346	3.257	6.443	0.336	0.814	1.61	0.026	0.135	1.161	0	0.367	3.304
$\varphi=0.25$ PMPD	0.792	2.499	5.944	0.198	0.625	1.486	0.031	0.183	1.812	0	0.611	2.6

Jack Mackerel – JMN 7

Background

As noted above for JMD 7, there remains uncertainty in the reliability of the catch records and CPUE time series (Figure 4) for JMN 7 (Table 6) due to uncertainties in the splitting of catches into the two different jack mackerel species (McKenzie, 2009). The uncertainties in the species proportions estimates are not accounted for in the catch and CPUE time series derived for the jack mackerel stocks. As yet, there has been no successful attempt at assessing the status of this stock and the sustainability of the fishery for it.

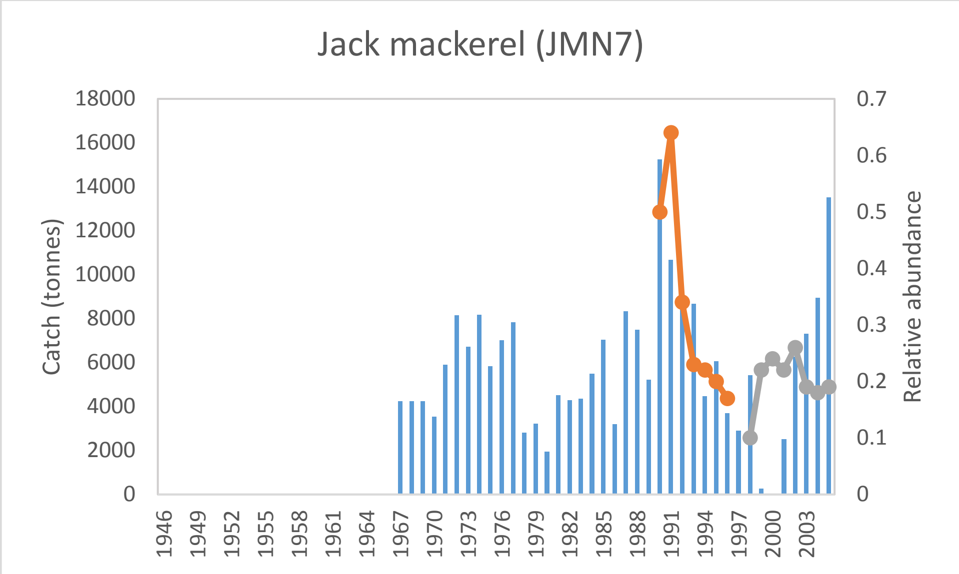

Figure 4: Catch and abundance data for JMN 7. Catches are shown as vertical bars. Relative abundance indices are shown as lines.

Analyses performed

In contrast to the case with JMD 7, the CPUE indices for JMN 7 show depletion responses to variation in the catch biomass records. It therefore appears that there is information in the data for parameter and abundance estimation. As for JMD 7, both BSP(φ=0.5) and BSP(φ=0.25) models were applied.

Results

All posterior results show marked updates in the priors for K and marked updates in the PMPD distributions for estimated variables for both the model versions. For BSP(φ=0.5), the results are shown in Figure 5 and Figure 6 and For both BSP(φ=0.5) and BSP(φ=0.25) the stock appears to be close to the B_{msy} level in the final year with posterior medians for B_{cur}/B_{msy} at close to one under both models (Tables 7 and 8). For BSP(φ=0.5) the 90% posterior interval for B_{cur}/B_{msy} ranged from 0.6 to 1.3, and from 0.4 to 2.7 for BSP(φ=0.25). The posterior median for the ratio of fishing mortality rate to F_{msy} in the final year (2005) is very close to 2 in both models and suggests that the most recent fishing mortality rate is not sustainable. The depletion relative to K differs between the two models, with the posterior median at 0.49 for BSP(φ=0.5) and 0.26 for BSP(φ=0.25). The Bayes factor was 1.8 times in favour of the BSP(φ=0.25) model. This relatively small ratio for the probability of the data in favour of the BSP(φ=0.25) model indicates that the difference could easily be due to random sampling error variation in the abundance index data.

Conclusions

This case study shows an instance of moderately informative data. For JMN 7, the abundance index series shows depletion and recovery responses to periods with higher and lower catches. These updates of the priors and PMPDs, suggest that the stock is close to the B_{msy} under the two different settings for φ. However, the estimate of the ratio of F to F_{msy} in the current year (2005) under both hypotheses is very high and possibly unsustainable (Table 8).

Table 6: Life-history data and prior on intrinsic growth for JMN 7.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	M	per year	0.18	0.25
Fraction mature at age	a_{50}	year	3	0.10
	$d_{50\text{-}95}$	Year	3	0.10
Growth	k		0.3	0.2
	L_{inf}	cm	36	0.1
	t_0	year	-0.65	0.5
Length-to-weight	a		0.028	0.1
	b		2.84	0.1
Recruitment	h		0.9	0.055
Intrinsic growth	r		0.72	0.31

Table 7: Posterior mean, standard deviation, coefficient of variation, median and 90% intervals for quantities of interest for the BSP(φ=0.5) model for JMN 7.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.67	0.173	0.257	0.410	0.654	0.976
K	51168	85682	1.675	30651	42894	65149
MSY	8017	12737	1.589	5986	7086	8284
B_{msy}	25584	42841	1.675	15325	21447	32574
B_{init}	51406	83479	1.624	27951	41982	70281
B_{cur}	27581	85671	3.106	10685	17759	29746
B_{cur}/B_{msy}	0.971	0.24	0.247	0.585	0.971	1.333
B_{cur}/B_{init}	0.505	0.16	0.316	0.286	0.489	0.781
B_{cur}/K	0.485	0.12	0.247	0.2923	0.486	0.666
F_{msy}	0.335	0.086	0.257	0.205	0.327	0.488
F_{cur}	0.681	0.180	0.265	0.431	0.670	0.985
F_{cur}/F_{msy}	2.129	0.712	0.335	1.322	1.98	3.504
RepY_{cur}	6661	3432	0.515	5083	6588	7721
$\text{Catch}_{cur}/\text{RepY}_{cur}$	2.089	0.398	0.191	1.737	2.046	2.616
$P(B_{cur} > 0.4B_{msy})$	0.998					
$P(B_{cur} > 0.8B_{msy})$	0.763					
$P(B_{cur} > B_{msy})$	0.455					
$P(F_{cur} < F_{msy})$	0.015					

Table 8: Posterior and PMPD median and 90% interval results for evaluations of the sensitivity of BSP results for JMN 7 to different input settings.

Run	r			B_{msy}			B_{cur}			$RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
$\varphi=0.5$ Posterior	0.411	0.654	0.976	15325	21447	32574	10685	17759	29746	5083	6588	7721
$\varphi=0.5$ PMPD	0.423	0.697	1.056	23864	116580	748056	27625	216353	1452516	0	7598	79307
$\varphi=0.25$ Posterior	0.4	0.634	0.955	14085	19820	40683	7728	19708	95120	4212	5720	7324
$\varphi=0.25$ PMPD	0.422	0.684	1.056	19653	86714	395375	30719	292284	1544567	0	6080	37359

Run	B_{cur}/B_{msy}			B_{cur}/K			F_{cur}/F_{msy}			$Catch_{cur}/RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
$\varphi=0.5$ Posterior	0.585	0.971	1.333	0.292	0.486	0.667	1.322	1.983	3.504	1.737	2.047	2.616
$\varphi=0.5$ PMPD	1.248	1.815	2.163	0.624	0.908	1.082	0.025	0.182	1.266	0	0	2.577
$\varphi=0.25$ Posterior	0.402	1.045	2.685	0.101	0.261	0.671	0.424	2.104	6.156	1.71	2.347	3.071
$\varphi=0.25$ PMPD	1.46	3.241	4.956	0.365	0.810	1.239	0.024	0.134	1.307	0	0.75	3.897

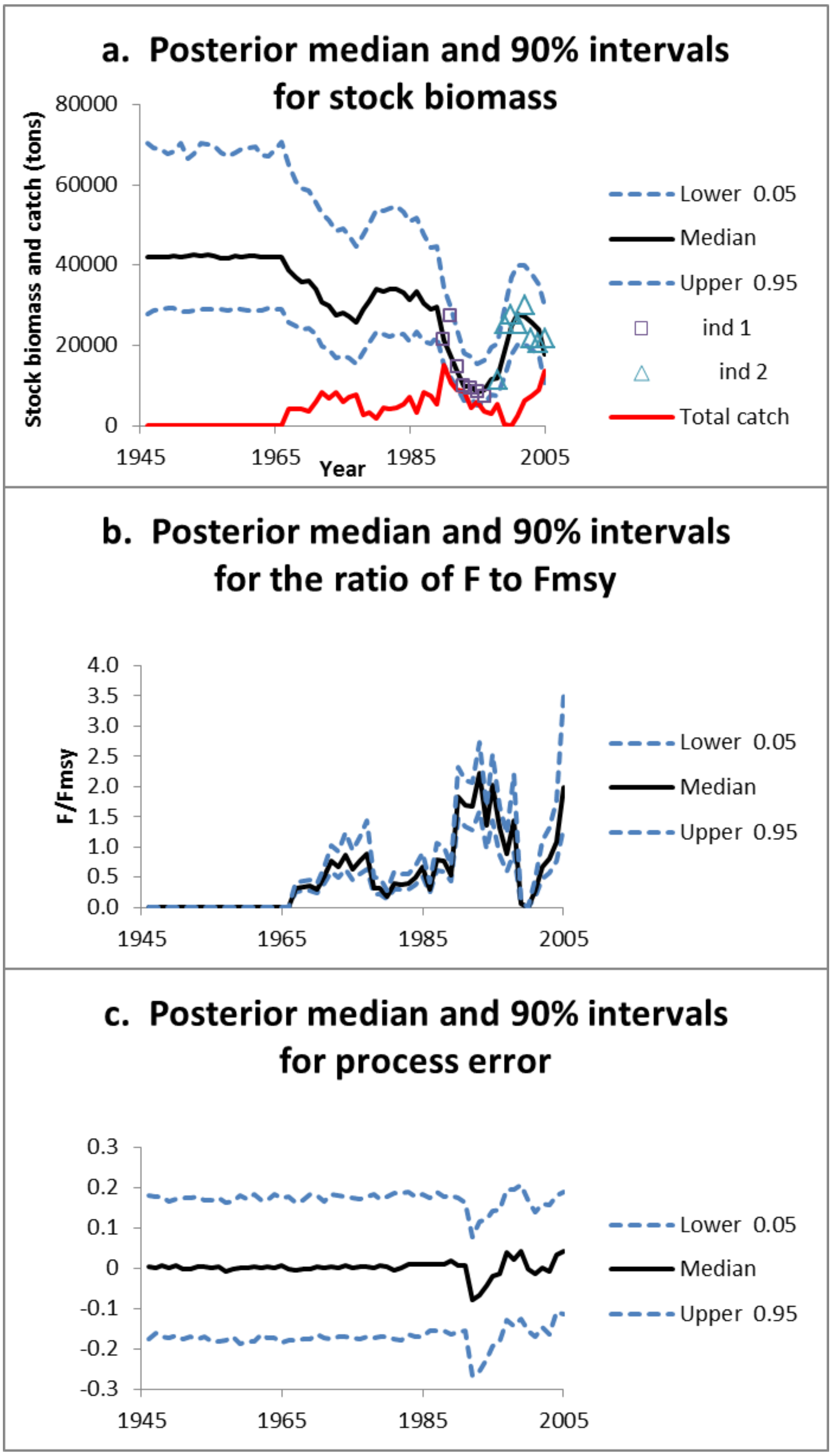

Figure 5: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. process error deviates for the BSP(φ=0.5) model for JMN 7.

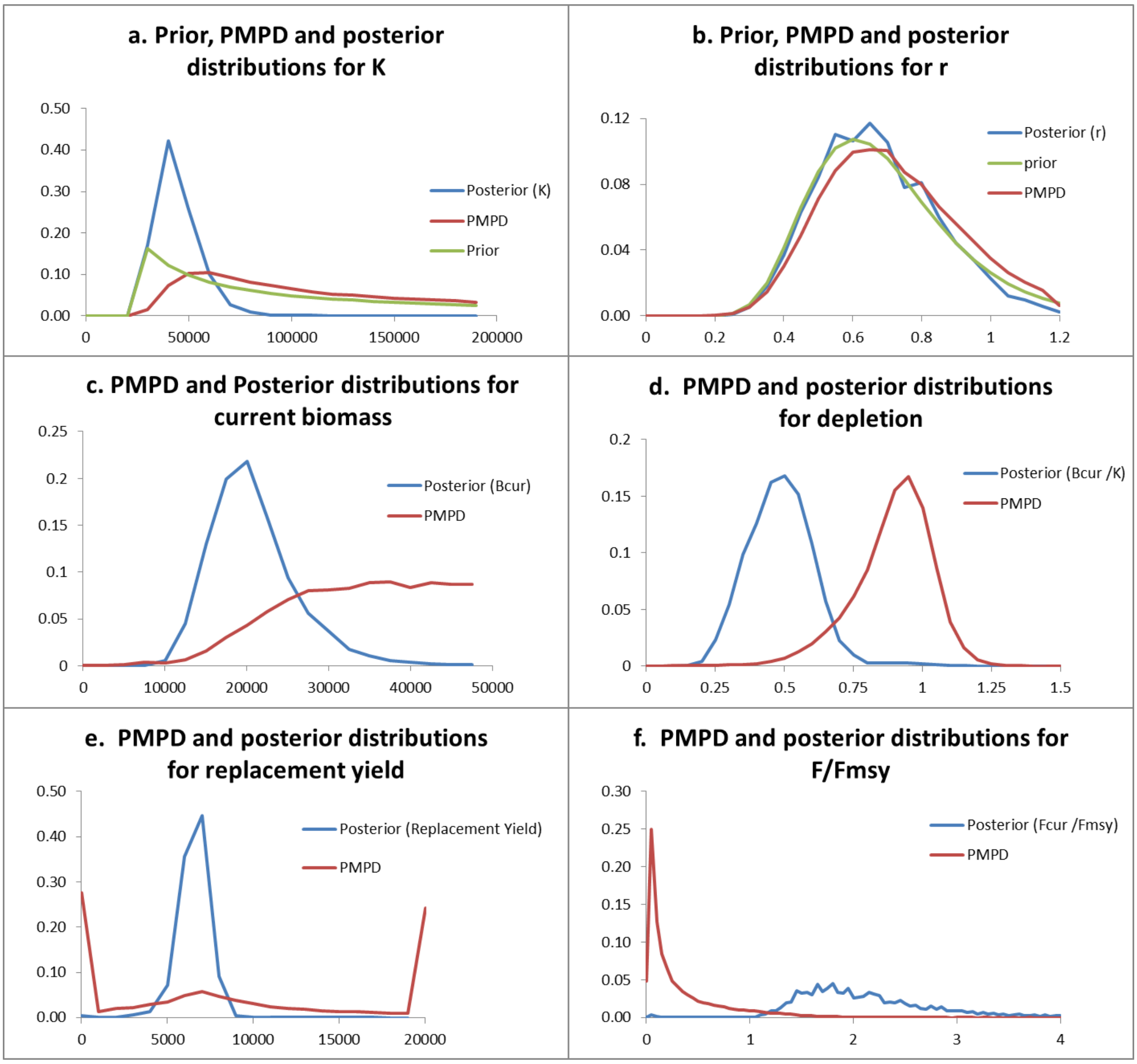

Figure 6: Prior, posterior and PMPD distributions for a) carrying capacity, b) r, c) current stock biomass, d) depletion, e) replacement yield and e) F_{cur}/F_{msy} for the BSP(φ=0.5) model for JMN 7.

Elephant fish – ELE 3

Background

The ELE 3 (Table 9) stock has an uncertain catch history, but has undergone a notable recovery over the time period for which abundance data have been collected (Figure 7). This has led to assertions that there may have been a regime shift in productivity, due to changing spatial fishing patterns. However it has also been hypothesised that there had been systematic underreporting of the catch prior to 1983.

Stock trend indices have been formulated based on standardisation of commercial bottom trawl catch per unit effort data (Starr & Kendrick, 2013). Preliminary applications of BSP that used catch records from 1936–2012 could not fit the abundance index data, except through estimation of strong systematic variations in process error deviates (McAllister, 2013a). For the current application, we evaluated the hypothesis that catch had been under-reported, which produced a more convincing assessment.

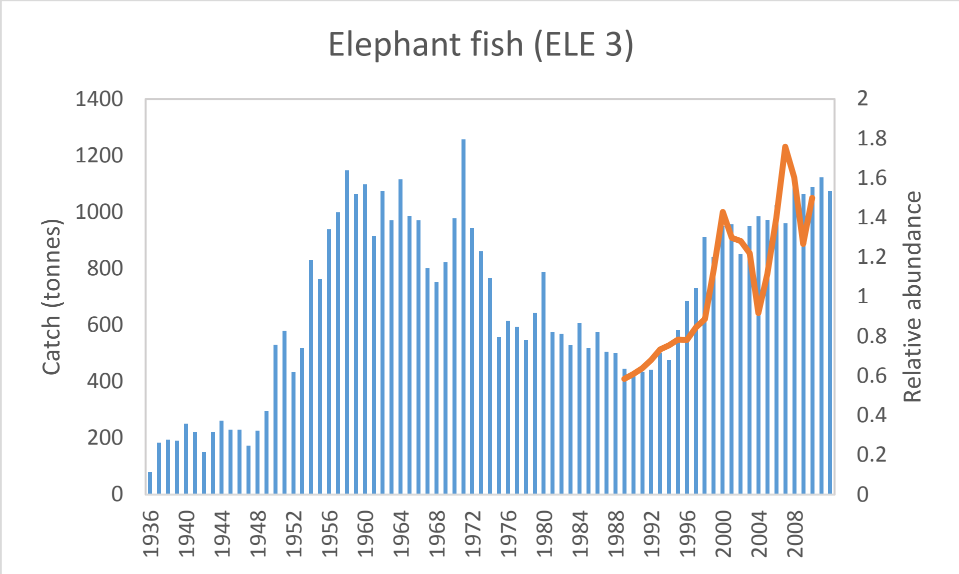

Figure 7: Catch and abundance data for ELE 3. Catches are shown as vertical bars. The relative abundance index is shown as a line.

Table 9: Life-history data and prior on intrinsic growth for ELE 3.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	*M*	per year	0.35	0.25
Growth	*k*		0.224	0.1
	Linf	cm	94.1	0.05
	t0	year	-0.69	0.25
Fraction mature at age	a_{50}	years	5	0.05
	$d_{50\text{-}95}$		0.5	0.05
length-to-weight	*a*		9.1E-06	0.05
	b		3.02	0.05
Recruitment	*h*		0.70	0.15
Intrinsic growth	*r*		0.29	0.2771

Analyses performed

We first estimated the degree of historical under-reporting of the catch by including a catch multiplier for catches prior to 1983, and finding the maximum posterior density (MPD) estimate. The catch multiplier for year 1936–1982 was estimated to be 1.399, and this led to a marked improvement in the ability of the model to fit the recent upward trend in the abundance index. Keeping the estimated catch multiplier fixed, we were then able to fit the model using a fully Bayesian estimation framework. Two BSP(φ=0.5) applications were carried out, the first with the catches adjusted by the MPD estimate of the early catch adjustment, and the second using the historical catch records for all years as provided. For both of these runs PMPD distributions were produced.

Results

When a fixed bias-correction factor was applied to the catch records for 1936–1982 informative posterior results were obtained with clear updates in the priors and PMPDs (Figures 8 and 9). Process error deviates showed a relatively small amount of systematic variation in years subsequent to 1985 to account for the two brief periods of systematic variation in the CPUE index in this period (Figure 8). When no bias correction factor was applied to the historical catch records, the posterior intervals were very wide and showed relatively little update from the PMPDs (Figures 10 and 11). The process error deviates showed much more pronounced systematic trends to account for the strong increase in the abundance indices in the mid-1980s to 2000s, since the historical catch records could not explain this increase seen in the abundance index. The posterior for K in this run showed some update from the prior and PMPD. However the posteriors for depletion and F/F_{msy} retained one of the posterior modes centred still on the PMPDs (Figure 11). This suggests that without a bias correction factor applied to the early catch records, the trend patterns in the abundance index data and catch records are relatively uninformative about the key parameters and stock status. The posterior results should therefore not be used in management decision making. Consistent with these results, the Bayes factor was 7.3 in support of the model run in which the bias correction factor was applied to the historical catch records from 1936–1982.

Conclusions

It appears to be plausible that historical catch records for ELE 3 from 1936–1982 could be underreported. Maximum posterior density analysis suggested that these records would need to be adjusted by a factor of about 1.4 to enable the abundance index trends since 1986 to be accounted for. When this factor was applied to the historical catch records, informative posterior results were obtained. However, some further sensitivity analysis on the bias correction factor would be required before results from this BSP application could be used to provide information on current stock status and management advice for ELE 3.

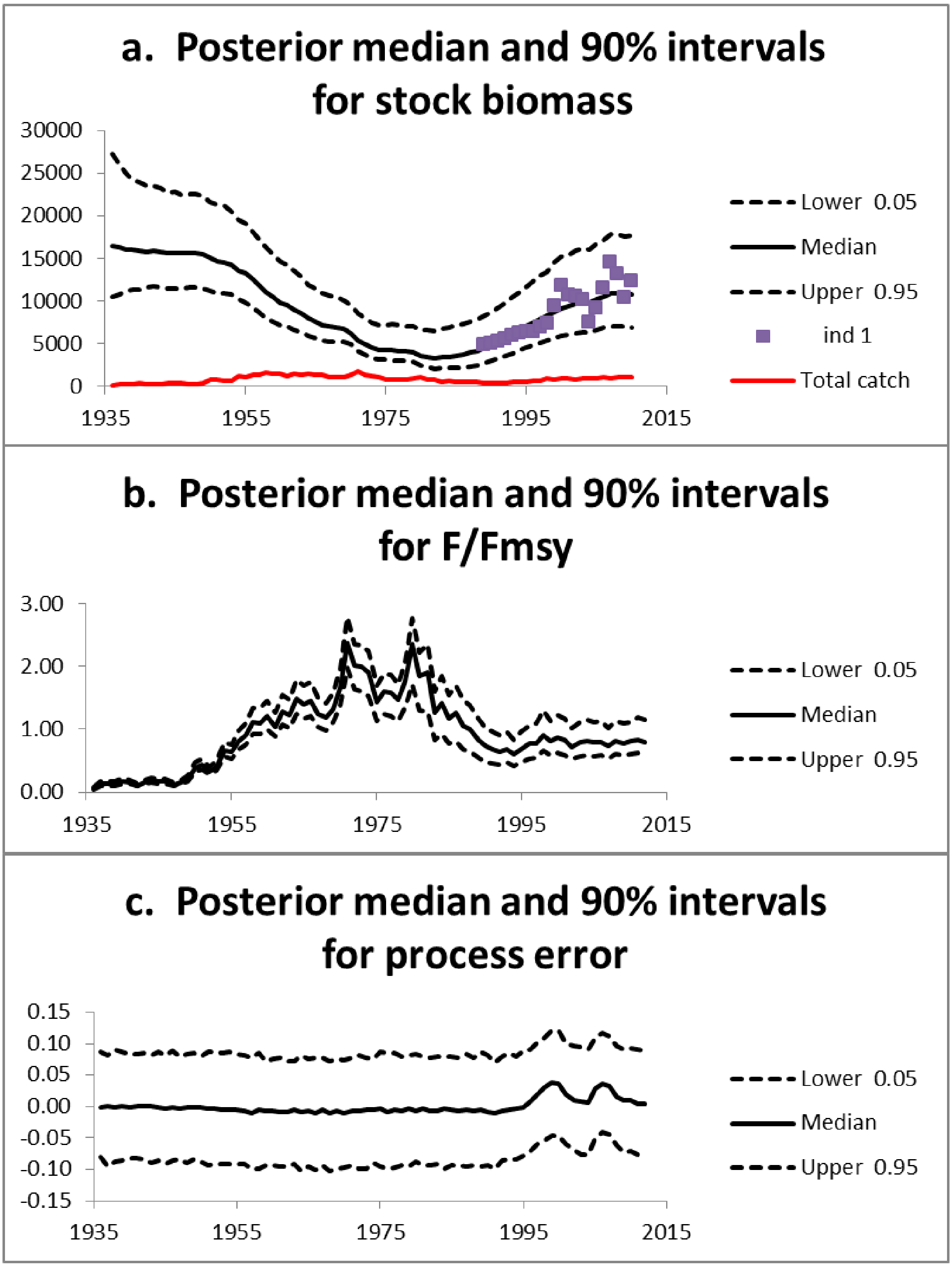

Figure 8: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. B/B_{msy} deviates for the BSP(φ=0.5) model for ELE 3 when a catch bias correction factor is applied to the catch records from 1936–1982.

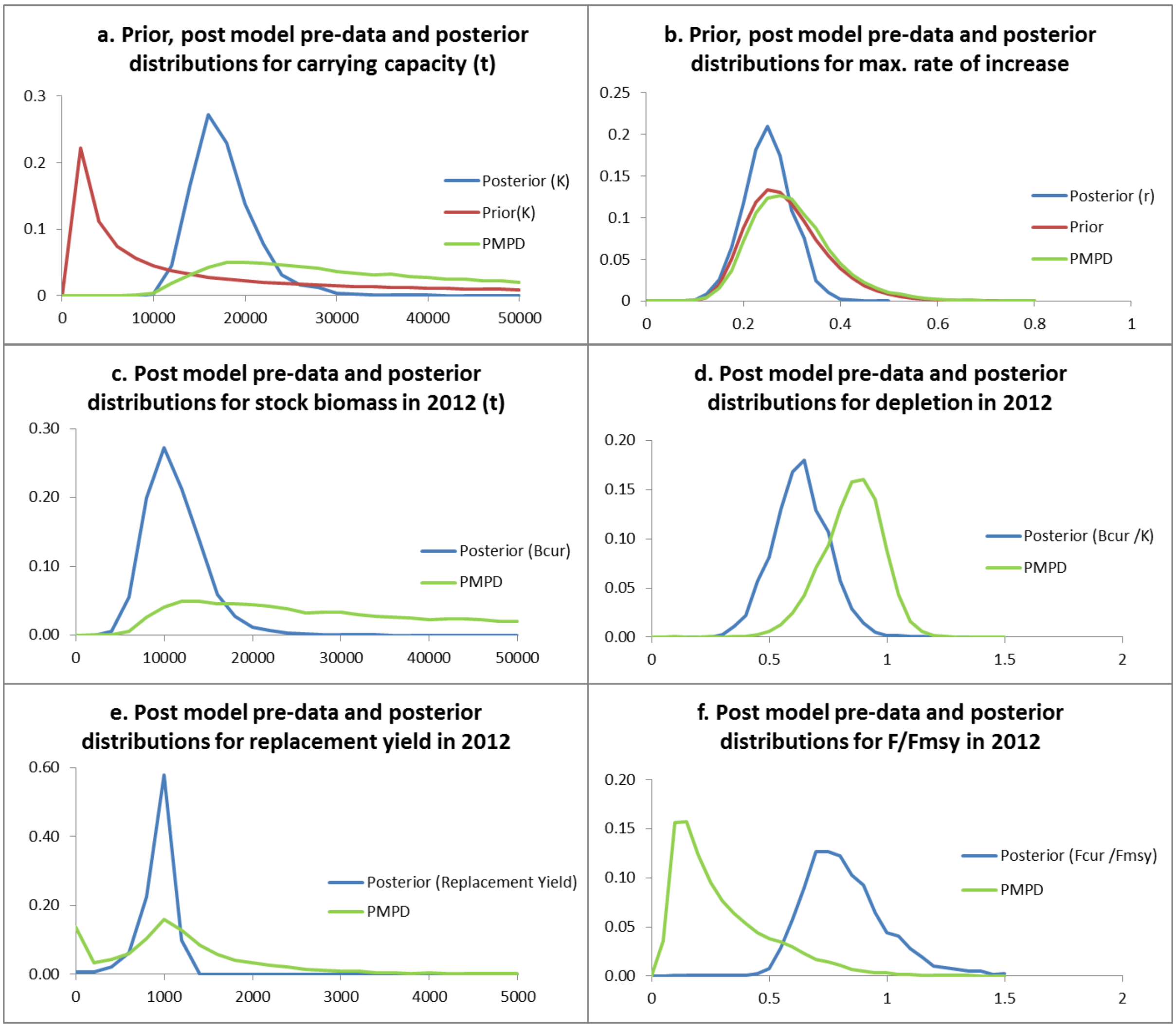

Figure 9: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. B/B_{msy} deviates for the BSP(φ=0.5) model for ELE 3 when a catch bias correction factor is applied to the catch records from 1936–1982.

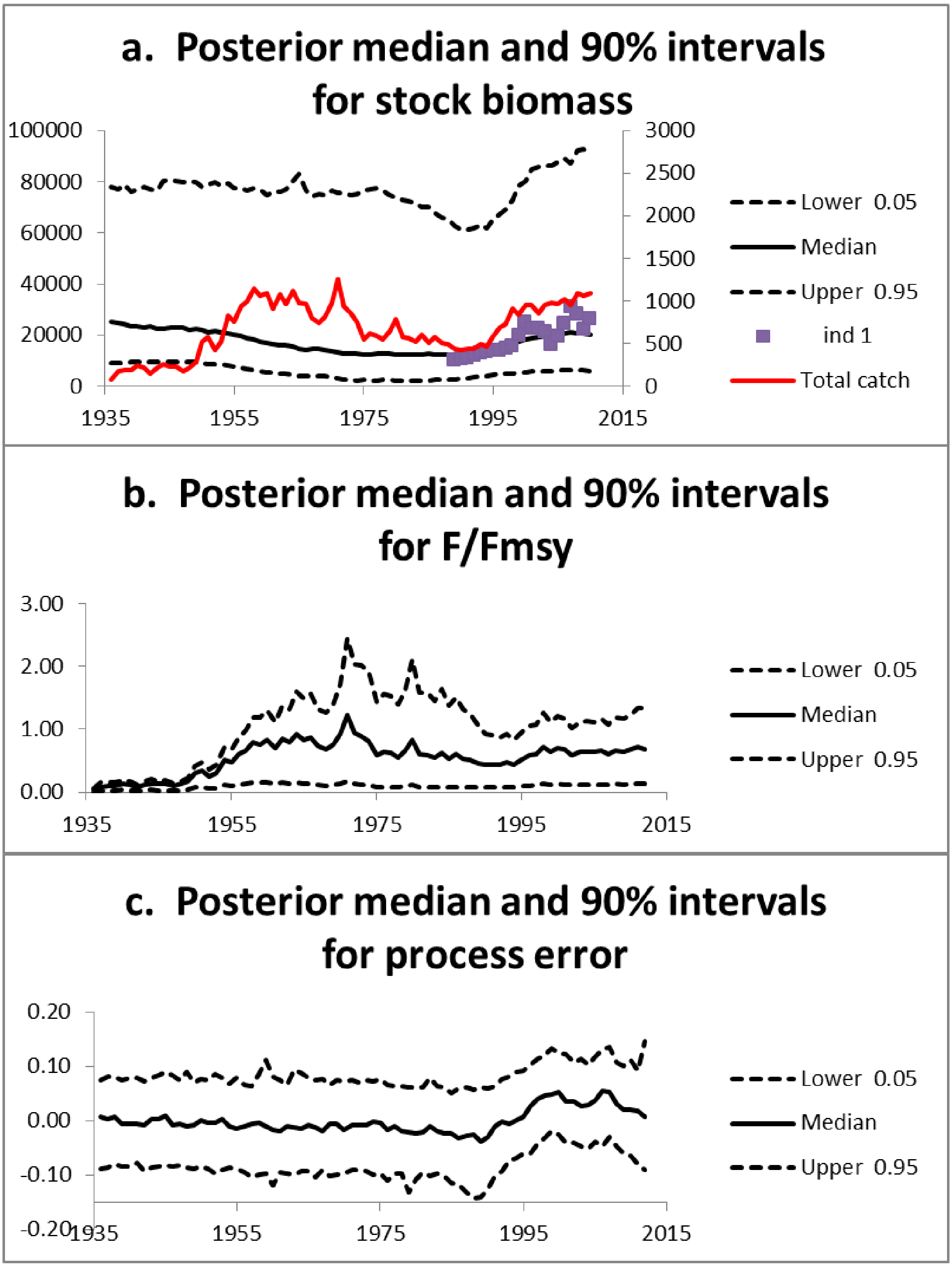

Figure 10: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. B/B_{msy} deviates for the BSP(φ=0.5) model for ELE 3 when no catch bias correction factor is applied to the catch records from 1936–1982.

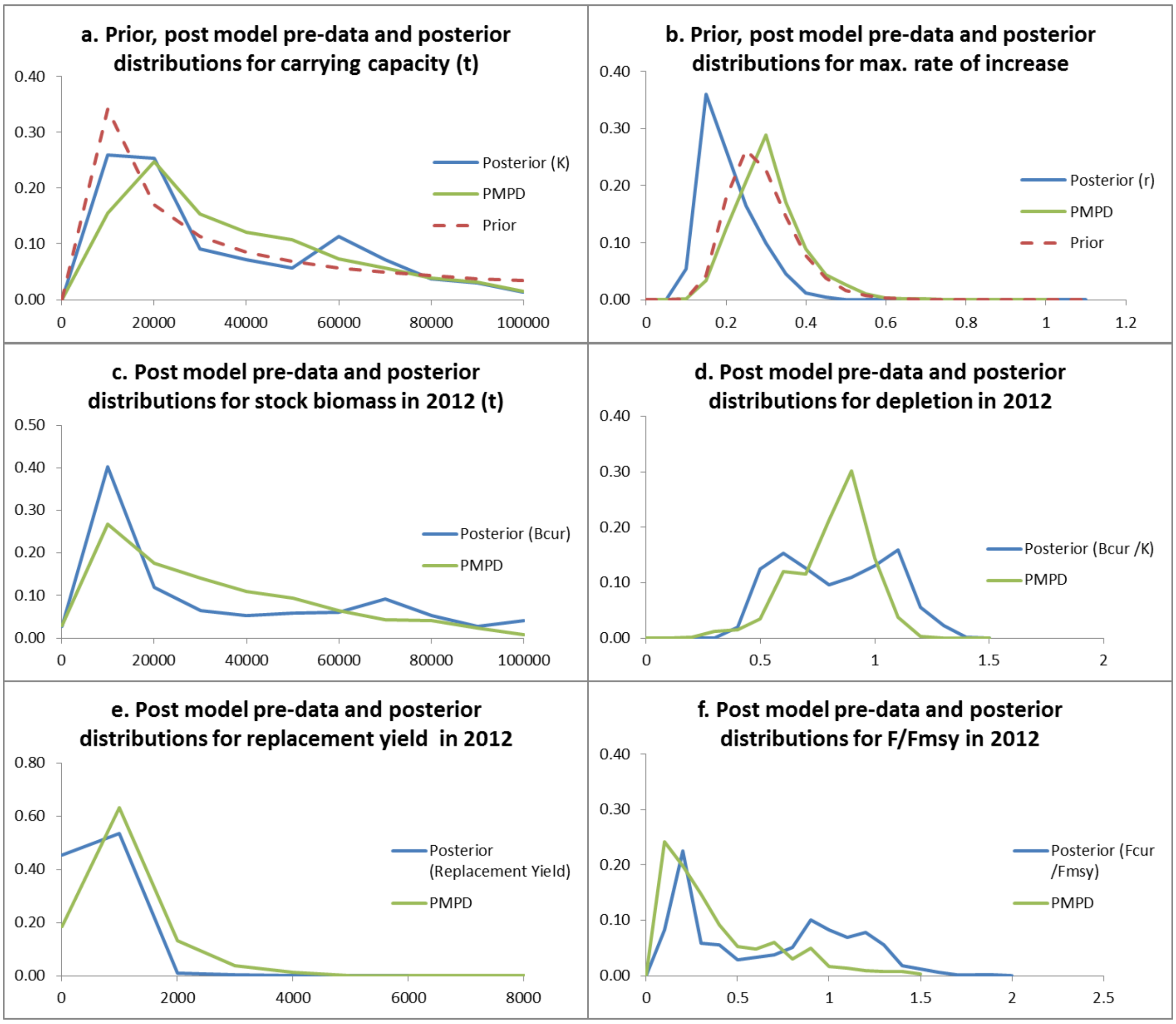

Figure 11: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. B/B_{msy} deviates for the Schaefer model for ELE 3 when no catch bias correction factor is applied to the catch records from 1936-1982.

Rig – SPO 7

Background

In 2006, an age-structured implementation of CASAL was fitted to two setnet commercial CPUE indices from two areas and the West coast South Island (WCSI) survey biomass index for SPO 7 (Table 10). Based on this analysis it was concluded that it was highly likely that the stock was below its B_{msy} level (Ministry for Primary Industries, 2013). In 2013 another assessment of stock status was performed but this consisted of an analysis of trends in standardised CPUE data and the WCSI trawl survey index for this stock. No stock assessment modelling was carried out.

The standardised setnet CPUE index (038) and WCSI trawl survey index were considered in the 2013 assessment to more reliably track abundance trends than the other available indices (Ministry for Primary Industries, 2013). However the variations in these indices do not appear to be uniquely explained by the variations in historical catch records. For example, the CPUE index declines most steeply when catches are at a low point relative to subsequent years and then the CPUE index increases in the last decade of the time series when catches are not much different or a little higher. The trawl survey index shows a similar pattern but is more variable between years and is only available once every few years. This relatively poor correspondence between the abundance indices and catch (Figure 12) suggest that a stock assessment based on a fit of a stock assessment model to these data would not be expected to produce very informative results on stock status.

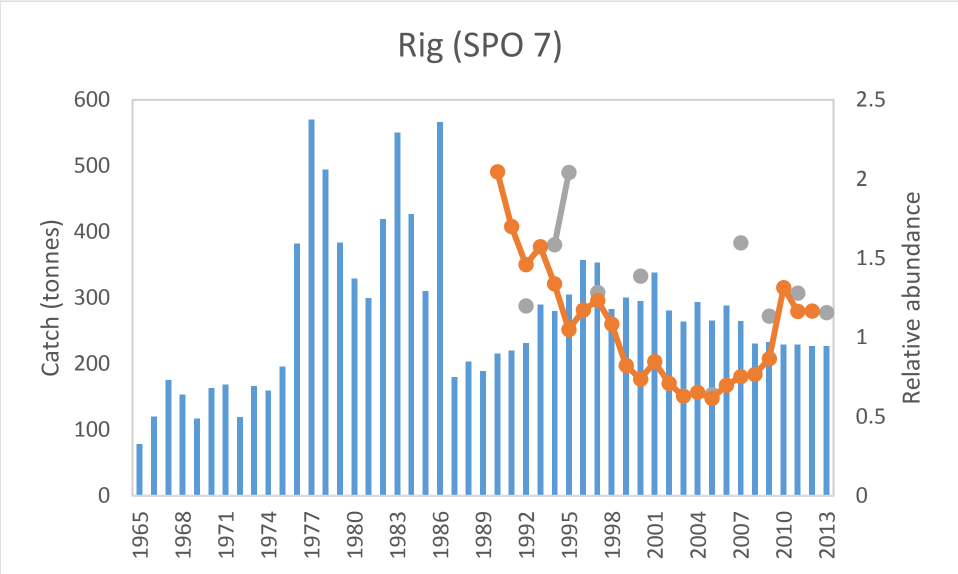

Figure 12: Catch and abundance data for SPO 7. Catches are shown as vertical bars. Relative abundance indices are shown as lines.

Table 10: Life-history data and prior on intrinsic growth for SPO 7.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	*M*	per year	0.25	0.25
Fraction mature at age	a_{50}		7.5	0.10
	d_{50-95}		2.0	0.10
Growth	*k*		0.119	0.1
	L_{inf}	cm	147.2	0.05
	t_0	year	-2.35	0.25
Length-to-weight	*a*		0.000986	0.01
	b		3.32	0.01
Recruitment	*h*		0.50	0.14
Intrinsic growth	*r*		0.12	0.25

Analyses performed

Two runs of the BSP(φ=0.5) model were implemented. The first run included non-informative priors for the constants of proportionality *q*. An informative prior for *q* has not yet been formulated for the WCSI trawl survey for SPO 7. In second run therefore, we evaluated how this could influence performance of the assessment model by including an informative prior for the trawl survey constant of proportionality, with a median *q* set at 0.1 and the prior coefficient of variation set at 0.6. This prior was arbitrary, but allowed us to evaluate the potential usefulness of an informative prior for the trawl survey constant of proportionality in providing informative stock assessment results.

Results

When non-informative priors for the constants of proportionality were applied, the posterior intervals were very wide (Figures 13 and 15) and the posterior distributions, especially for B_{cur}/K and F_{cur}/ F_{msy}, showed relatively little update from the PMPDs. This indicates that the data are uninformative. For example, the posterior for depletion appeared to retain considerable mass in the region of the PMPD distribution, showing that the data did not suggest a significant update from the PMPD. When an informative prior for the trawl survey *q* was applied, the posterior results showed a marked update from the priors and PMPDs (Figures 14 and 15). The informative *q* prior for the trawl index however was arbitrary and the results provided are for illustrative purposes only. The chief mechanism to explain the decline and then increase in the relative abundance data for both runs was through systematic trends in the process error deviates that mirrored the trend in the abundance index data. No tabulated posterior results are shown for stock status since it is concluded that the posterior results from the analysis which used non-informative priors did not show sufficient updates from the prior and PMPD results for key quantities of interest.

Conclusions

The posterior results from fitting the BSP to the abundance index data show that the data were not sufficiently informative to provide stock assessment results that were determined by the data. Posterior distributions for example for depletion and the ratio of current F to F_{msy} had considerable mass in the vicinity of the PMPD and the stock assessment data were thus ambiguous about stock status. This case study thus illustrates a situation in which results from a BSP model should not be applied in assessing stock status and evaluating the potential consequences of different management options. The results also show considerable potential benefits of formulating an informative prior distribution for the constant of proportionality for trawl survey indices.

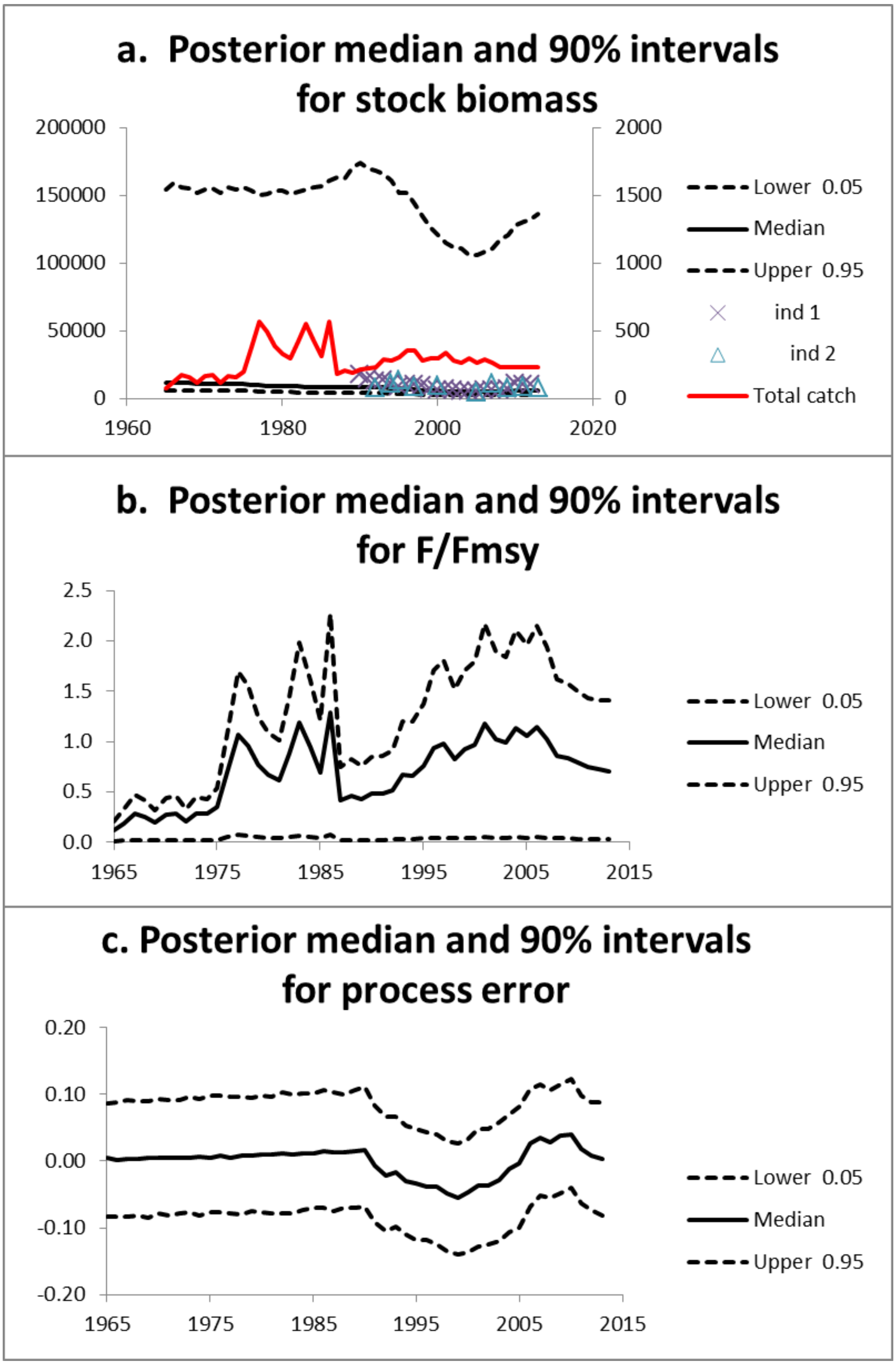

Figure 13: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. B/B_{msy} deviates for the BSP(φ=0.5) model for SPO 7 when non-informative priors are used for the constants of proportionality for the abundance indices.

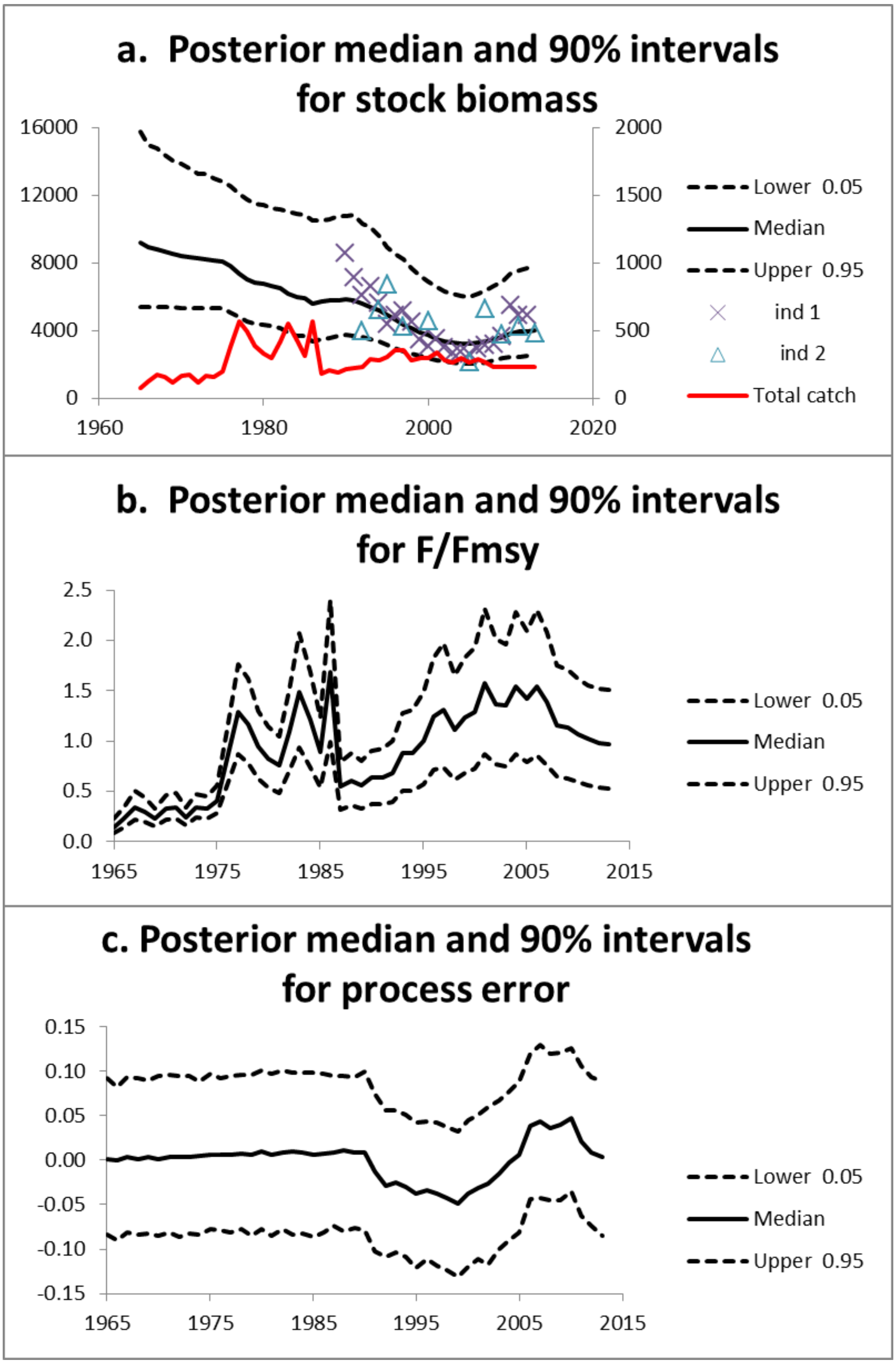

Figure 14: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. B/B_{msy} deviates for the BSP(φ=0.5) model for SPO 7 when an informative prior was used for the constant of proportionality for the WCSI abundance index.

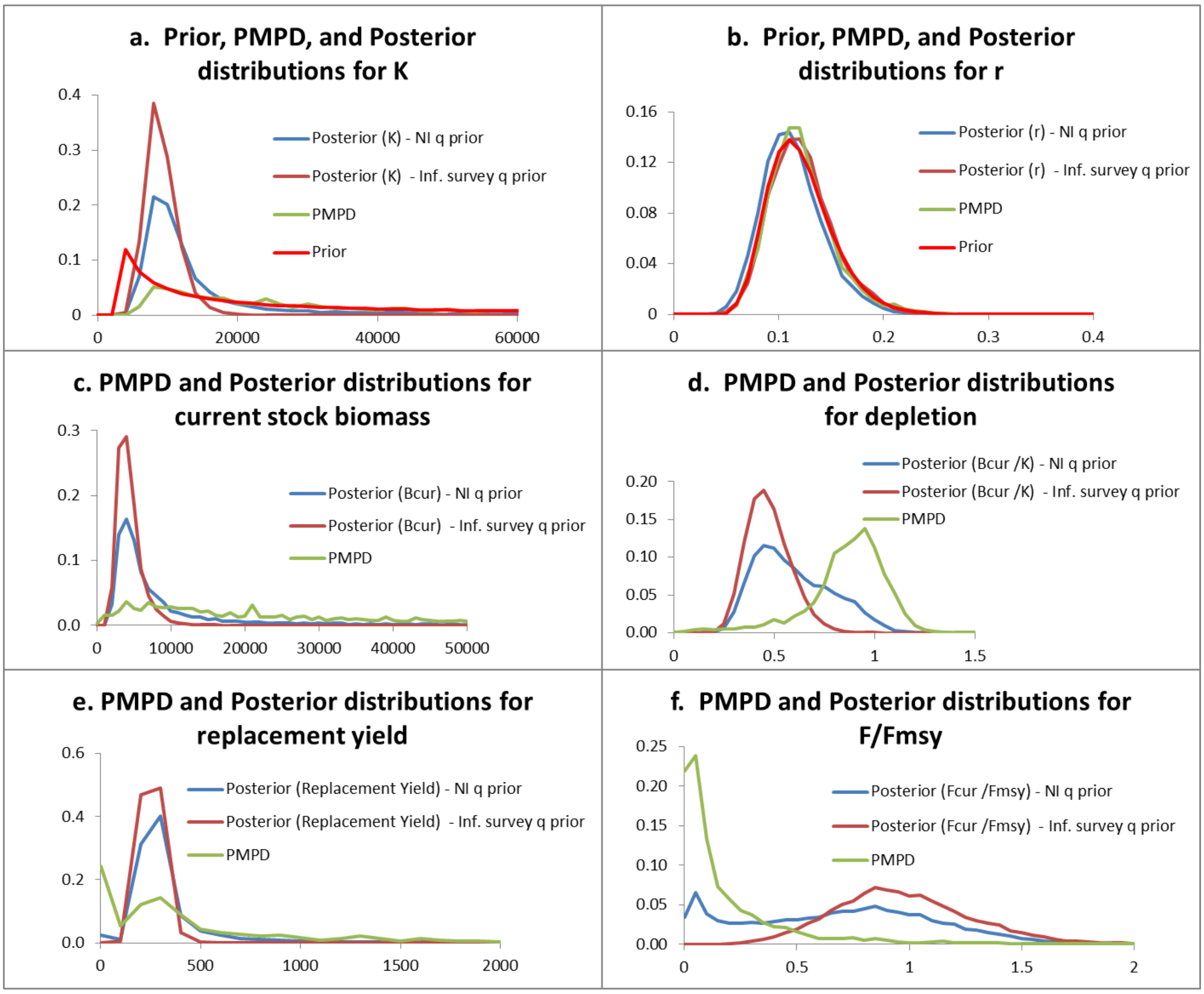

Figure 15: Prior, posterior and PMPD distributions for a) carrying capacity, b) intrinsic growth rate, c) current stock biomass, d) depletion, e) replacement yield in the current year, and f) F/F_{msy} in the current year, for SPO 7. Results are shown for runs in which non-informative priors are applied to all the constants of proportionality for the abundance indices (non-informative *q* prior) and for when an informative prior is applied for the trawl survey *q* (informative survey *q* prior).

3.2 Assessed Stocks

In this section we apply BSP to New Zealand stocks that have already been assessed using CASAL. These typically have more informative abundance data, allowing an easier model fit. As well as providing a further illustration of the application of a surplus production modelling approach, performance of BSP relative to CASAL also presents an interesting evaluation of whether a production model can provide comparable results.

Hoki – HOK 1 East

Background

The Western and Eastern stocks of hoki in the HOK 1 management area have been assessed as two separate stocks since 1989 (McKenzie, 2013). A two-stock version of CASAL has been applied since 1998 to simultaneously assess both the Eastern and Western stocks of hoki. While they are treated as separate breeding populations, they are assessed together in the same model due to stock mixing on some fishing grounds. For the current investigation, the Eastern and Western stocks are examined separately using BSP.

Both trawl and acoustic survey indices of abundance have been available since the early 1990s, although not in every year (Figure 16). For the Eastern stock, acoustic surveys have been carried out on the spawning ground in Cook Strait and trawl surveys have been carried out on the Chatham Rise to the East of the South Island.

The objectives of the present analyses include the following:

1) Evaluation of the extent of differences in the assessment of absolute abundance, trends in abundance, and depletion with respect to average unfished stock size (*K* in the BSP which is analogous to B_0 in CASAL) between BSP and CASAL.
2) Evaluation of the extent of differences in projections of abundance of the different constant catch policy options between BSP and CASAL.
3) Evaluation of the influence on abundance estimates and stock status of the standard deviation in process error deviates assumed and the informative priors for the constant of proportionality for the fishery independent indices of abundance in the BSP model implementations.

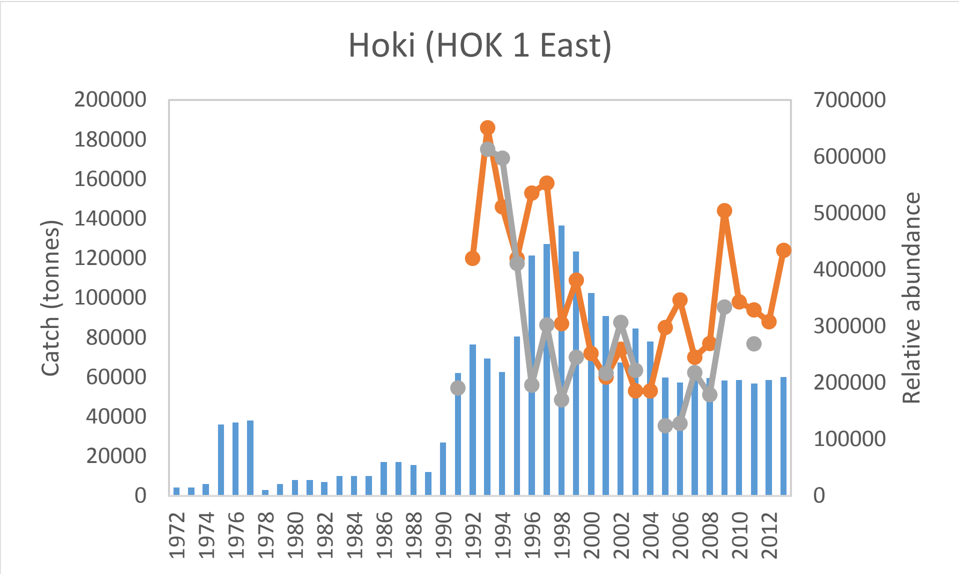

Figure 16: Catch and abundance data for HOK 1 East. Catches are shown as vertical bars. Relative abundance indices are shown as lines.

Input settings

Observation error was defined per year, using the coefficients of variation for the Chatham Rise Trawl Survey index and the Cook Strait acoustic survey index reported as "total CV" by McKenzie (2013).

The reference case was chosen to be as similar as possible to the CASAL assessment in 2012 (McKenzie, 2013). The BSP application thus used informative priors for catchability for both Cook Strait and Chatham Rise indices, the BSP(φ=0.25) Fletcher-Schaefer generalised production model, the process error standard deviation σ_p = 0.10, and the informative prior for *r* as specified in Table 11.

The BSP model distinguishes only the stock biomass recruited to the commercial fishery in predicting the stock biomass indices. Should a prior for *q* in a BSP model be applied, the prior should scale the abundance index to the exploitable biomass. However in the CASAL stock assessment informative priors for *q* were used that scaled the survey indices to the biomass of fish recruited to the survey. As such, it should be noted that either one or both of the informative priors for *q* formulated for the CASAL model may be inappropriately scaled for the biomass component modelled in BSP.

The apparent composition of the stock biomass represented by the informative survey *q* priors is different between the Cook Strait and Chatham Rise index time series. When the indices in each year are divided by the prior median values for *q*, the ratio of implied stock biomass on the Chatham Rise is approximately twice the implied stock biomass surveyed in the Cook Strait. This could be explained by there being on average a smaller biomass of spawners in the Cook Strait each year compared to the surveyed stock on the Chatham Rise, which includes both mature and immature fish. Therefore it may not be appropriate to apply both priors at the same time within the BSP model since BSP models only the stock biomass recruited to the commercial fishery and doesn't distinguish between different portions of the stock represented by each survey. An attempt could be made to adjust the survey *q* priors to be more consistently scaled to the BSP modelled biomass. However this was not done here since the applications were for exploratory and comparative purposes only. Moreover, given that the prior CVs for the two survey *q*'s are quite large, specifically 0.65 and 0.77 for the Cook Strait and Chatham Rise surveys, the credibility distributions for the implied stock biomass values by year would still be overlapping and not necessarily problematic for the estimation. Because of this overlap and the attempt to make input settings as similar as possible to the CASAL assessment, the reference case BSP model included informative priors for *q* for both surveys.

Table 11: Life-history data and prior on intrinsic growth for HOK 1 East.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	M	per year	0.298	0.153
Fraction mature at age	a_{50}		4	0.1
	$d_{50\text{-}95}$		2	0.1
Growth	k		0.161	0.1
	L_{inf}	cm	101.8	0.05
	t_0	year	-2.18	0.25
Length-to-weight	a		0.00479	0.01
	b		2.89	0.01
Recruitment	h		0.75	0.079
Intrinsic growth	r		0.378	0.176

Analyses performed

As noted above, the value chosen for the process error standard deviation was somewhat arbitrary. It is therefore important to evaluate the sensitivity of BSP results to different possible values for the process error standard deviation and where possible to compute Bayes factors to evaluate the empirical credibility of different values applied for the process error standard deviation. While this type of sensitivity analysis has been often performed in BSP assessments (e.g. Stanley et al., 2012, McAllister, 2013c), the sensitivity of results may depend on other BSP model settings such as whether informative or non-informative priors for q are applied and the value presumed for φ.

The reference case input settings described above were thus modified to represent a range of sensitivity tests. Several different model runs were performed. These were aimed at evaluating the sensitivity of results to 1) different levels of process error standard deviation under different settings for the BSP model, e.g., when different values for φ were assumed and when either informative or non-informative priors for q were assumed, and 2) the use of informative versus uninformative priors for q when the abundance index data were already fairly informative. The first set of analyses, referred to as set A, were performed using non-informative priors for the constant of proportionality, and were aimed at evaluating the effect of applying different levels of process error standard deviation. The second set of analyses, set B, were aimed at evaluating the effect of applying potentially inconsistent priors for survey q within the BSP(φ=0.5) model. Here different model runs were conducted in which informative and non-informative q priors were applied under the same model. A third set of analyses, set C, were performed to evaluate performance of the BSP(φ=0.25) model. Within this set, informative and non-informative priors for the survey q were also evaluated. A fourth and fifth set of analyses (D and E) were performed using the BSP(φ=0.25) model in which the process error SD was set at smaller and larger values, where the priors for q were first non-informative (D), and then informative (E). The settings for these different runs are listed in Table 12. The final set of analyses includes PMPD runs for the BSP(φ=0.5) and BSP(φ=0.25) models (F). These PMPD runs had a process error standard deviation σ_p = 0.10 but non-informative *q* priors. They could therefore be used to determine the information content of the indices with and without the informative *q* priors.

Results

Reference case

The BSP model offered good fits to both relative abundance indices (Figure 17) and provides considerable updates to the priors and modelled variables under the post model, pre-data distributions (Figure 18). The BSP results suggest that the stock declined in the 1990s and was at a low point in 2003 at about 34% of *K* (Figure 17). Since then the stock has recovered. The posterior median for stock biomass was 52% of *K* in 2013 (Table 13). This is the same value as estimated by the CASAL assessment in three of five runs for the Eastern stock (table 21 in McKenzie, 2013). The 90% posterior intervals for B_{cur}/K are fairly wide: 33%–81%; and wider than the 95% intervals reported for the five different runs by McKenzie (2013), in which intervals were widest for run 1.9 at 37–70% (table 21 in McKenzie, 2013). Fishing mortality rates were highest between 1996 and 2004 with *F* approaching F_{msy} in 1998 and 1999 (Figure 17). There was no significant trend in process error deviates with the 90% interval overlapping zero in all years (Figure 17c). There was however a non-significant negative trend in the 1990s and then a positive trend in process error deviates 2002–2008.

The PMPD distributions for BSP(φ=0.25) in general had less optimistic central tendencies for the stock status variables than with the BSP(φ=0.5) model (Table 14). For example, the PMPD for B_{cur}/K was centred at about 0.55, in contrast to 0.84 with the BSP(φ=0.5) model implementation. This pattern was also true for the jack mackerel stocks (Tables 5 and 8).

The marginal posteriors show considerable update from the PMPD distributions for all quantities except for *r* (Figure 18). There was however a slight update in the posterior for *r*, with the posterior median shifted slightly to the right. The projection results from BSP(φ=0.25) with a catch set at a value close to the 2012 catch (60 000 tons) show no net change in stock size up to 2020 (Figure 19). This result is very similar to that obtained in the CASAL implementation, for which future catches were set at the 2012 value and assuming a consistent long-term pattern in stock-recruit deviates (McKenzie, 2013).

Table 12: Summary of sensitivity test runs for HOK 1 East.

Code	Category Description	Code	Run Description
Ref	Reference run	Ref	BSP(φ=0.25) reference run with σ_p = 0.10 and informative priors for both survey *q*'s
A	Process error variants with non-informative *q* priors for BSP(φ=0.5).	A.1	σ_p = 0.005
		A.2	σ_p = 0.05
		A.3	σ_p = 0.10
		A.4	σ_p = 0.15
B	Effects of priors for *q* under the BSP(φ=0.5) model	B.1	σ_p = 0.10, informative prior for Cook Strait Acoustic *q*
		B.2	σ_p = 0.10, informative prior for Chatham Rise Trawl *q*
		B.3	σ_p = 0.10, informative prior for both survey *q*'s
C	Effects of priors for *q* under the BSP(φ=0.25) model	C.1	σ_p = 0.10, non-informative survey *q* priors
		C.2	σ_p = 0.10, informative prior for Cook Strait Acoustic *q*
		C.3	σ_p = 0.10, informative prior for Chatham Rise Trawl *q*
D	Process error variants with non-informative *q* priors under the under the BSP(φ=0.25) model	D.1	σ_p = 0.005
		D.2	σ_p = 0.05
		D.3	σ_p = 0.15
E	Process error variants with informative *q* priors under the under the BSP(φ=0.25) model	E.1	σ_p = 0.005
		E.2	σ_p = 0.05
		E.3	σ_p = 0.15
F	PMPD analysis	F.1	σ_p = 0.10, non-informative survey *q* priors, φ = 0.5
		F.2	σ_p = 0.10, non-informative survey *q* priors, φ = 0.25

Sensitivity analysis

Category A, D and E runs: Different assumptions about the standard deviation in process error under different B_{msy} /K ratios and informative vs. informative q priors. In run category A, the Schaefer BSP(φ=0.5) model was applied with non-informative priors for *q* and low to high values for the process error standard deviation, σ_p The most common implementation of BSP during stock assessment assumes the Schaefer model with non-informative priors for *q* and relatively small values for the standard deviation in process error, particularly for long-lived species. For example, BSP rockfish assessments have assumed values of σ_p of either 0.05 or 0.10 (McAllister & Duplisea, 2012). The effect of different values for σ_p could be expected to be more pronounced when priors for *q* are non-informative. Bayes factors were computed separately for the Category A, D and E runs to allow comparisons within each of these sets of runs. Within each of these categories, the Bayes factor was computed relative to the run with the smallest value for σ_p, i.e., $\sigma_p = 0.005$.

When the process error SD was set very low ($\sigma_p = 0.005$; run A.1), the model was practically deterministic. This scenario gave considerably more precise and more pessimistic results than the other category A runs, which had higher values for the process error SD (Table 14). With σ_p set at 0.005 the posterior median for the stock biomass in 2013 was a little over half of that when σ_p was set at 0.15 (run A.4) and the 90% posterior interval was far narrower (350 000 – 586 000 compared to 370 000 – 2.5 million tonnes). Bayes factors favoured slightly more the deterministic run A.1, e.g., with this run having a Bayes factor about five times that of run A.4 where σ_p was set at 0.15 (Table 15).

In run category D, $\varphi = 0.25$ and non-informative priors for *q* were applied. The stock biomass estimates tended to become less certain here also when σ_p was increased. The stock biomass values were also considerably larger in these runs than in category A runs where $\varphi = 0.5$, giving slightly more optimistic assessment results when status is measured relative to the MSY reference points. In contrast to the Schaefer model run, Bayes factors favoured the run with $\sigma_p = 0.1$, e.g., by a factor of about 8 compared to the deterministic run (Table 15).

Runs in category E were the same as those in category D, except that informative priors for *q* were applied. The effect of the informative priors was to considerably reduce uncertainty in quantities of interest and reduce the tendency for uncertainty in stock biomass to increase as σ_p was increased. Bayes factors favoured the runs E.2 and Ref. with σ_p set at 0.05 and 0.1 by factors of about 3 compared to the deterministic run (Table 15).

Category B and C runs: using non-informative and informative priors for survey constants of proportionality under different B_{msy}/K ratios

The use of informative priors for *q*, even though they were relatively imprecise, increased the posterior precision in nearly all of the quantities estimated. Bayes factors were computed separately for Categories B and C. In each of these sets of runs Bayes factors were computed relative to the run with noninformative priors (i.e., run A.3 for runs B, and C.1. for runs C). Even without the informative priors for *q*, the posteriors were quite strongly informed by the abundance index and catch data (runs A.3 and C.1, Table 14). The informative *q* priors in run categories B and C increased the central tendencies of the posterior distributions for stock biomass and when applied together made them narrower than for comparable scenarios (A.3 and C.1). For example, run B.3 with informative priors for both of the survey qs had a slightly higher median current biomass but slightly narrower 90% interval than run A.3 which also had a σ_p of 0.1 but noninformative priors. As noted when comparing runs A, D and E, lowering the value for B_{msy}/K when going from runs B to C, from 0.5 to 0.25 increased the stock biomass estimates (Table 13).

In contrast to the Jack Mackerel results, Bayes factor was equivocal about the two different values applied for B_{msy}/K, (φ). With informative q priors Bayes factors were 1.0 and 0.8 for runs B.3 and the Reference run where φ was set at 0.5 and 0.25, respectively (Table 14).

Table 13: Posterior mean, standard deviation, coefficient of variation, median and 90% intervals for quantities of interest for HOK 1 East, reference case run.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.401	0.069	0.172	0.2968	0.395	0.5234
K	1688245	408953	0.242	1153141	1617939	2468355
MSY	83025	18461	0.222	58876	80028	118031
B_{msy}	422061	102238	0.242	288285	404485	617089
B_{init}	1699320	605251	0.356	916044	1584647	2844180
B_{cur}	919694	359442	0.391	475478	848125	1615576
B_{cur}/B_{msy}	2.169	0.601	0.277	1.325	2.089	3.257
B_{cur}/B_{init}	0.579	0.224	0.386	0.289	0.547	0.993
B_{cur}/K	0.542	0.15	0.277	0.3311	0.5223	0.8141
F_{msy}	0.2004	0.0345	0.172	0.1484	0.1975	0.2617
F_{cur}	0.0747	0.0274	0.366	0.0371	0.0707	0.1262
F_{cur}/F_{msy}	0.3797	0.1434	0.378	0.1856	0.3567	0.6415
RepY_{cur}	63393.7	18064.1	0.285	33938	63351.1	92795.7
$\mathrm{Catch}_{cur}/\mathrm{RepY}_{cur}$	0.9962	0.4034	0.405	0.6095	0.9345	1.5889
$P(B_{cur} > 0.4B_{msy})$	1					
$P(B_{cur} > 0.8B_{msy})$	0.999					
$P(B_{cur} > B_{msy})$	0.996					
$P(F_{cur} < F_{msy})$	0.999					

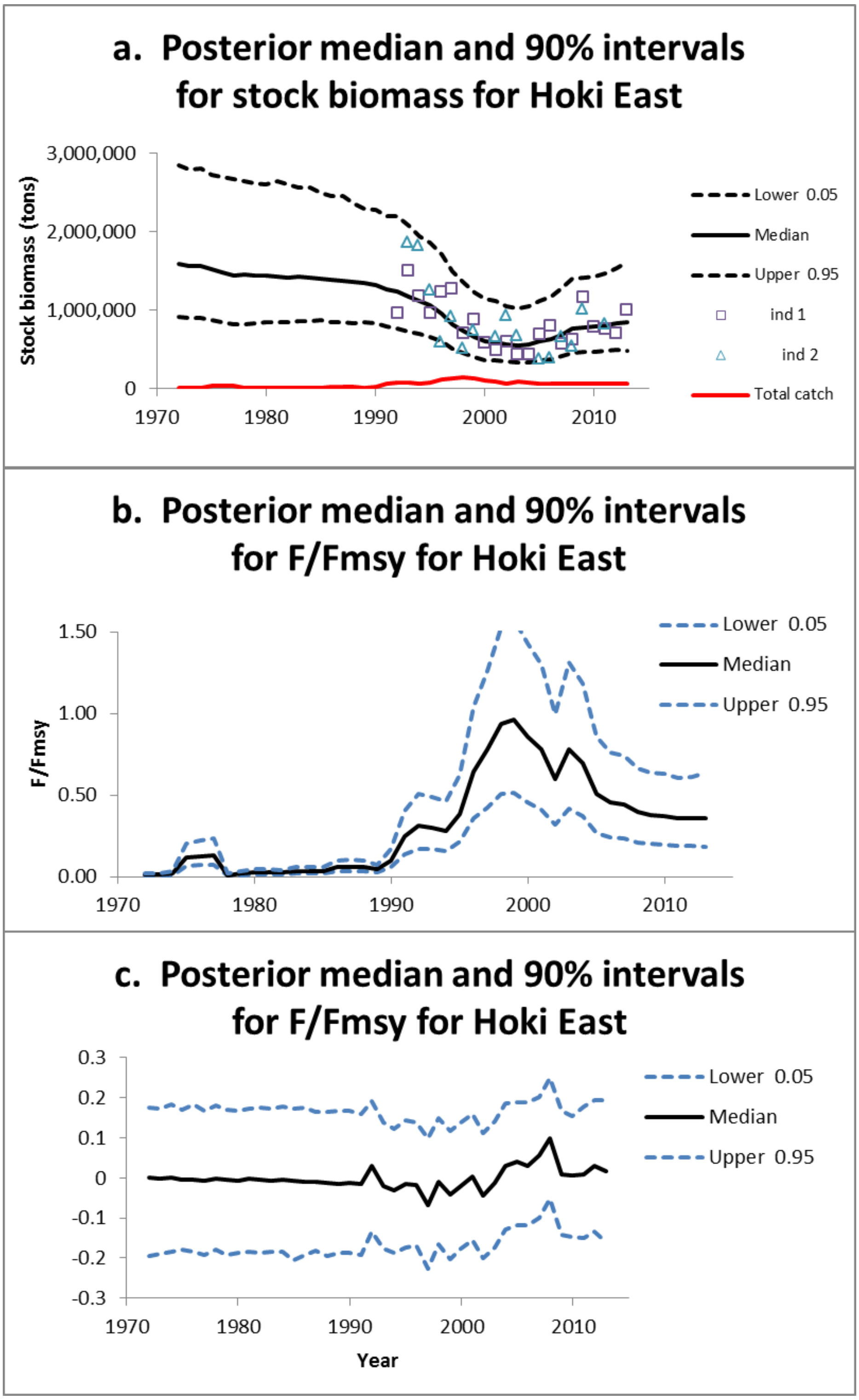

Figure 17: Posterior median and 90% intervals for a. stock biomass, b. the ratio of the annual fishing mortality rate to F_{msy} and c. process error deviates for HOK 1 East, reference case run.

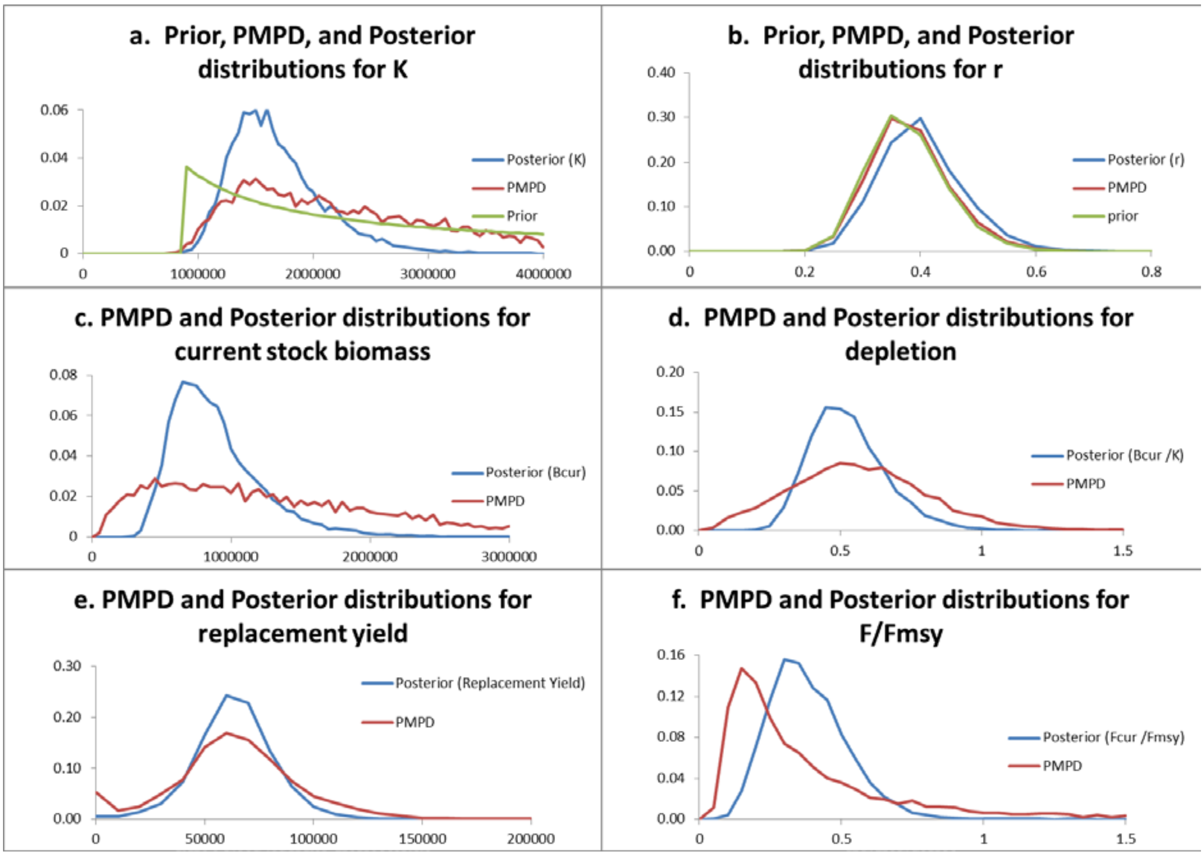

Figure 18: Prior, PMPD and posterior distributions for a) carrying capacity, b) r, c) current stock biomass, d) depletion, e) replacement yield in the current year (2005), and f) F/F_{msy} in the current year, for the HOK 1 East reference case run.

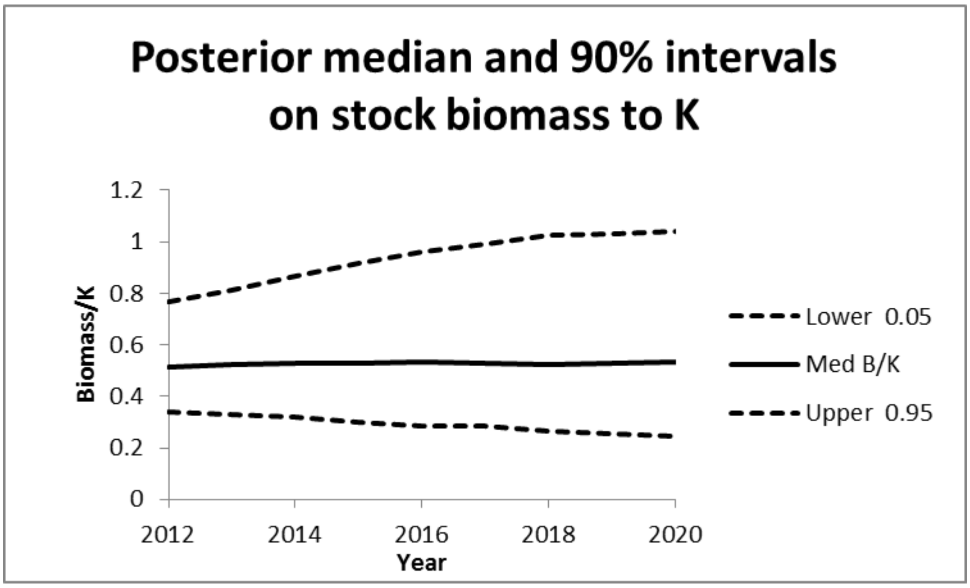

Figure 19: Posterior median and 90% intervals for the ratio of stock biomass to carrying capacity for HOK 1 East under the reference case run with a constant catch policy of 60 000 tons per year.

Table 14: Posterior and post-model-pre-data median and 90% interval results for evaluations of the sensitivity of BSP results for HOK 1 East to different input settings.

Run	r			B_{msy}			B_{cur}			$RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
Ref	0.297	0.395	0.523	288285	404485	617089	475478	848125	1615576	33938	63351	92796
A.1	0.308	0.392	0.493	323252	388349	475794	349069	441686	585888	70216	74124	77842
A.2	0.29	0.382	0.494	322765	407379	533596	344302	476496	708348	63905	74873	83381
A.3	0.285	0.373	0.489	327697	454248	700942	345580	557956	1107171	50375	77162	101788
A.4	0.279	0.37	0.49	346082	559850	1386913	373571	769503	2520631	7309	83727	158474
B.1	0.277	0.362	0.47	348983	479856	812348	380593	618705	1322514	45430	77010	106669
B.2	0.289	0.376	0.487	330498	443439	656204	346319	541255	989466	53015	76783	98704
B.3	0.276	0.364	0.471	348290	465373	714228	375921	584200	1098345	49548	77272	102354
C.1	0.291	0.387	0.513	308877	485992	974180	530404	1172195	3261566	6151.7	63159	109796
C.2	0.295	0.391	0.518	303863	440322	719363	516883	991333	2117726	27456	63113	97858
C.3	0.299	0.399	0.528	289317	407151	649842	465935	850015	1832240	30509	63442	93046
D.1	0.338	0.453	0.598	271049	352342	492745	485412	715457	1217176	60085	64845	67620
D.2	0.307	0.413	0.549	289429	396256	644930	505767	852154	1795752	45545	63076	78621
D.3	0.287	0.386	0.51	308448	526669	896211	510693	1289084	3145305	0	64874	124210
E.1	0.351	0.467	0.606	267159	338364	443174	482868	677108	1030091	60596	65071	67758
E.2	0.319	0.424	0.561	281253	367632	506408	491886	748256	1260371	48296	63155	76163
E.3	0.293	0.387	0.516	287346	430997	705395	453326	905620	1859779	21587	66829	110416
F.1	0.281	0.375	0.499	408102	843135	1753907	410557	1442654	3404112	0	74269	188697
F.2	0.284	0.375	0.504	280356	515501	904934	232842	1170604	3089769	5739	62940	113568

Run	B_{cur}/B_{msy}			B_{cur}/K			F_{cur}/F_{msy}			$Catch_{cur}/RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
Ref	1.325	2.089	3.257	0.331	0.522	0.814	0.186	0.357	0.641	0.61	0.935	1.589
A.1	0.932	1.132	1.327	0.466	0.566	0.664	0.563	0.697	0.888	0.771	0.809	0.854
A.2	0.916	1.159	1.433	0.458	0.580	0.717	0.497	0.667	0.886	0.719	0.801	0.938
A.3	0.876	1.227	1.672	0.438	0.614	0.836	0.312	0.591	0.891	0.57	0.774	1.107
A.4	0.861	1.352	1.949	0.431	0.676	0.975	0.142	0.446	0.849	0	0.664	1.11
B.1	0.915	1.28	1.722	0.458	0.640	0.861	0.269	0.551	0.86	0.499	0.769	1.118
B.2	0.871	1.207	1.636	0.434	0.604	0.814	0.358	0.601	0.902	0.587	0.779	1.091
B.3	0.898	1.248	1.67	0.449	0.624	0.835	0.33	0.576	0.869	0.562	0.772	1.121
C.1	1.454	2.41	4.048	0.363	0.602	1.012	0.093	0.266	0.577	0	0.875	1.705
C.2	1.383	2.251	3.568	0.346	0.563	0.892	0.145	0.31	0.592	0.48	0.919	1.732
C.3	1.289	2.112	3.434	0.322	0.528	0.859	0.163	0.35	0.66	0.58	0.926	1.59
D.1	1.667	2.06	2.56	0.417	0.515	0.64	0.234	0.367	0.518	0.887	0.925	0.999
D.2	1.561	2.176	3.024	0.39	0.544	0.756	0.172	0.341	0.55	0.754	0.949	1.291
D.3	1.263	2.439	4.666	0.316	0.61	1.167	0.094	0.244	0.609	0	0.763	1.814
E.1	1.654	2.019	2.432	0.413	0.505	0.608	0.262	0.378	0.526	0.885	0.922	0.990
E.2	1.516	2.062	2.738	0.379	0.516	0.684	0.228	0.375	0.575	0.787	0.950	1.241
E.3	1.15	2.082	3.863	0.287	0.521	0.966	0.158	0.343	0.695	0.000	0.842	1.640
F.1	0.942	1.679	2.13	0.471	0.840	1.065	0.091	0.224	0.819	0	0.463	1.144
F.2	0.745	2.221	3.973	0.186	0.555	0.993	0.097	0.271	1.429	0	0.867	1.823

Table 15: Bayes Factors for different model runs for HOK 1 East. Bayes factors are computed referenced to the first run in the set of compared model runs. ln(av wt) is the natural logarithm of the average importance ratio for each run. σ_p is the standard deviation in process error.

Run	q priors	σ_p	B_{msy}/K	ln(av wt)	Bayes factor
A.1	uninformative q priors	0.005	0.5	54.68008	1.0
A.2	uninformative q priors	0.05	0.5	54.453	0.8
A.3	uninformative q priors	0.1	0.5	53.8593	0.4
A.4	uninformative q priors	0.15	0.5	53.02422	0.2
B.1	informative prior for Cook Strait Acoustic q	0.1	0.5	51.66258	0.11
B.2	informative prior for Chatham Rise Trawl q	0.1	0.5	51.8805	0.14
B.3	informative prior for both survey qs	0.1	0.5	46.69881	0.001
C.1	uninformative survey q priors	0.1	0.25	54.60252	1.0
C.2	informative prior for Cook Strait Acoustic q	0.1	0.25	51.75721	0.058
C.3	informative prior for Chatham Rise Trawl q	0.1	0.25	51.41686	0.041
Ref.	informative q priors for both surveys	0.1	0.25	46.43853	0.0003
D.1	uninformative q priors	0.005	0.25	52.50059	1.0
D.2	uninformative q priors	0.05	0.25	53.60216	3.0
C.1	uninformative q priors	0.1	0.25	54.60252	8.2
D.3	uninformative q priors	0.15	0.25	53.01109	1.7
E.1	informative q priors	0.005	0.25	45.39213	1.0
E.2	informative q priors	0.05	0.25	46.39882	2.7
Ref	informative q priors	0.1	0.25	46.43853	2.8
E.3	informative q priors	0.15	0.25	45.48513	1.1
B.3	informative q priors	0.1	0.5	46.69881	1.0
Ref	informative q priors	0.1	0.25	46.43853	0.8
F.1	non-informative survey q priors	0.1	0.5	59.74606	1.0
F.2	non-informative survey q priors	0.1	0.25	59.77299	1.0

Conclusions

For HOK 1 East, the stock depletion and stock biomass estimates were sensitive to a number of different BSP settings including the ratio set for B_{msy} to K, the process error standard deviation and the use of informative versus non-informative priors for the survey index q's. A smaller ratio of B_{msy} to K gave smaller values for current depletion, as did using lower values for process error SD. The informative priors for survey q, reduced uncertainty in estimates of stock biomass related quantities. The relative support for different process error standard deviations depended on whether a Schaefer versus a Fletcher-Schaefer model was applied. Under the Schaefer model, the version close to a deterministic model was favoured. Under the Fletcher-Schaefer model BSP(φ=0.25), intermediate values for the process error SD of 0.05 and 0.10 were favoured.

Hoki – HOK 1 West

Background

The abundance indices for HOK 1 West (Table 16 and Figure 20) show a sharper drop in the late 1990s and early 2000s and a sharper recovery in the late 2000s than those for the Eastern hoki stock. The fast depletion and recovery may be difficult for simple stock assessment models with minimal complexity to track, and could be accounted for by a combination of larger process error and observation error deviates during this period. These data could also lead to a strong update in the prior for *r* that may be spurious, should the strong decline and then increase be due partly to a drop and then increase in catchability of the stock over this period. Thus, of particular interest is how the production model will fit the abundance index data, the strength of the pattern in observation error and process error deviates, the extent of update in the prior for *r*, and the degree of similarity between the BSP predictions and CASAL predictions of stock status in the most recent and future years.

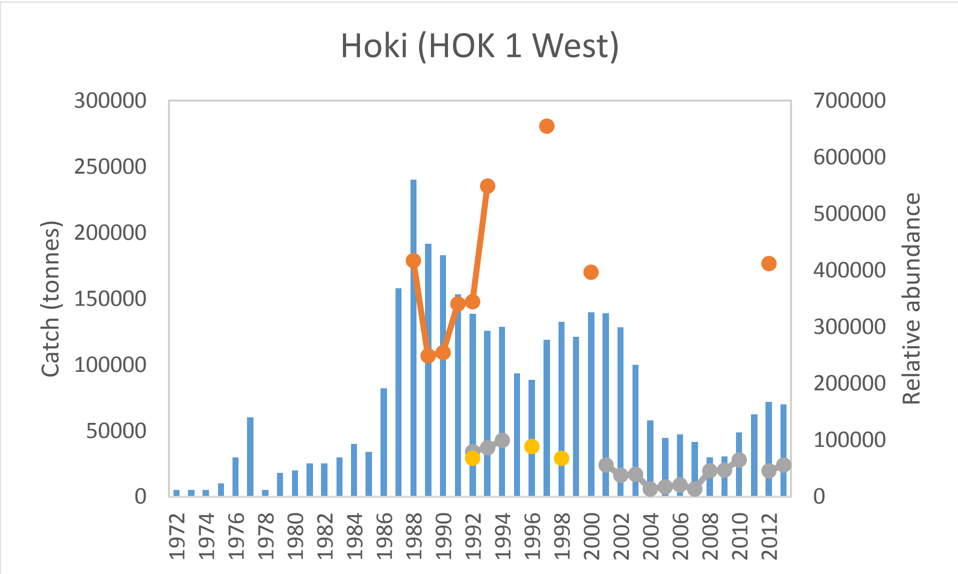

Figure 20: Catch and abundance data for HOK 1 West. Catches are shown as vertical bars. Relative abundance indices are shown as lines.

Table 16: Life-history data and prior on intrinsic growth for HOK 1 West.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	M	per year	0.295	0.15
Fraction mature at age	a_{50}	years	4	0.1
	d_{50-95}	years	3	0.1
Growth	k		0.213	0.05
	L_{inf}	cm	104	0.213
	t_0	year	-0.6	0.15
Length-to-weight	a		0.00479	0.01
	b		2.89	0.01
Recruitment	h		0.75	0.079
Intrinsic growth	r		0.370	0.173

Analyses performed

As for the Eastern stock of hoki, the prior distributions for the constants of proportionality (q) – for the acoustic index of abundance from the west coast and the trawl survey indices of abundance from the sub-Antarctic plateau – implied consistently different stock biomass values. When the prior median q was applied to the acoustic and trawl indices, the average ratio of stock biomass values implied by each survey, for nearest years (within plus or minus one year), was about two. Should the indices be considered to represent the same stock biomass as in a BSP model application, the priors for q are thus somewhat inconsistent. To evaluate the sensitivity of BSP results to different assumptions about the survey q's, different permutations of applying non-informative and informative priors for the q parameters were therefore considered (Table 17). The effects on estimates of stock biomass and status of halving or doubling the prior medians for the survey q's were also evaluated (Table 17).

Table 17: Summary of sensitivity test runs for HOK 1 West.

Code	Category Description	Code	Run Description
Ref	Reference run	Ref	Reference run (σ_p = 0.10, non-informative priors for all survey *q*'s, and φ = 0.5)
A	Effects of priors for *q* under the BSP(φ=0.5) model	A.1	informative prior for West Coast acoustic *q*
		A.2	informative prior for sub-Antarctic trawl *q*'s
		A.3	informative prior for all survey *q*'s
B	Effects of adjustments to priors for *q*	B.1	trawl survey *q* prior / 2
		B.2	acoustic survey *q* prior median x 2
C	BSP(φ=0.25) model	C.1	σ_p = 0.10, non-informative priors for all survey *q*'s
D	PMPD analysis	D.1	φ = 0.5
		D.2	φ = 0.25

Results

The BSP(φ=0.5) model showed a fairly good fit to the abundance index data, with the decline in the late 1990s and early 2000s and subsequent increase in the indices tracked quite closely (Figure 21). The 90% posterior intervals for the process error deviates overlapped with zero in all years. As with the Eastern stock, the deviates showed a slight decline from the mid-1990s to the mid-2000s and then an increase in the mid to late 2000s (Figure 21).

The abundance index data were moderately informative and gave considerable updates from the post model pre-data distributions for all quantities, except for the prior and PMPD for *r* (Figure 22). The BSP analyses, including the sensitivity runs, all suggest that the stock is moderately depleted relative to carrying capacity, with posterior medians ranging between about 0.31 and 0.41 (Table 19). The stock was at a minimum in 2005, being 16% of unfished stock biomass under the reference case (Figure 21a). The fishing mortality rate values were their highest in 2002 and 2003 when the posterior median was at about 2.5 times the value for F_{msy} (Figure 21b). The posterior median for this ratio reduced to about 0.90 in 2013 (Table 18).

Run category A showed that whether non-informative priors, or different combinations of the informative priors for the survey *q*'s, were applied, made relatively little difference to stock status and abundance estimates (Table 19). But as expected, when informative priors were applied for either the acoustic or trawl (runs A.1 and A.2) survey *q*'s or all of the survey *q*'s (run A.3), the posterior results became slightly more certain compared to the Ref run. In run category B, posterior results were moderately sensitive when the prior medians for *q* were made consistent by halving the trawl survey q prior median (run B.1) or doubling the acoustic survey *q* prior median (run B.2) (Table 19). For example the posterior median for depletion was lower at 0.35 when the West coast acoustic survey *q* prior median was multiplied by two (B.2) and the largest at 0.41 when the trawl survey *q* prior median was halved (B.1).

Applying a Fletcher-Schaefer model with φ = 0.25 but keeping non-informative q priors (run C.1) gave results slightly more pessimistic than the BSP(φ=0.5) model (Ref) with the posterior median for depletion being 0.31 (Table 19). This is partly due to the PMPD distribution with φ = 0.25 (D.2) favouring a considerably lower depletion than the BSP(φ=0.5) model (D.1). For example, the median PMPD for depletion was 0.85 under the BSP(φ=0.5) model (D.2), and 0.50 under the BSP(φ=0.25) model (D.1). The Fletcher-Schaefer surplus production function is less productive over the upper range of stock sizes than the Schaefer model, and with the same catches and priors for *r* and *K* gives a lower depletion level. However the Bayes factor for the BSP(φ=0.25) model was only 1.2 in favour of this model.

Table 18: Posterior mean, standard deviation, coefficient of variation, median and 90% intervals for quantities of interest for HOK 1 West, reference case run.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.37	0.06	0.17	0.26	0.37	0.48
K	1218403	256942	0.211	915361	1176342	1631152
MSY	109221	17191	0.157	87810	107501	132793
B_{msy}	609201	128471	0.211	457680	588171	815576
B_{init}	1228894	415582	0.338	732338	1146353	1844749
B_{cur}	481550	264260	0.549	253327	441623	900366
B_{cur}/B_{msy}	0.775	0.26	0.336	0.452	0.728	1.25
B_{cur}/B_{init}	0.408	0.167	0.411	0.209	0.376	0.72
B_{cur}/K	0.387	0.13	0.336	0.226	0.364	0.625
F_{msy}	0.184	0.032	0.173	0.131	0.183	0.238
F_{cur}	0.170	0.058	0.342	0.081	0.164	0.273
F_{cur}/F_{msy}	0.928	0.287	0.309	0.498	0.904	1.424
RepY_{cur}	94360	15504	0.164	71394.8	94328	118221
$\mathrm{Catch}_{cur}/\mathrm{RepY}_{cur}$	0.749	0.135	0.180	0.584	0.740	0.966
$P(B_{cur} > 0.4B_{msy})$	0.985					
$P(B_{cur} > 0.8B_{msy})$	0.372					
$P(B_{cur} > B_{msy})$	0.145					
$P(F_{cur} < F_{msy})$	0.642					

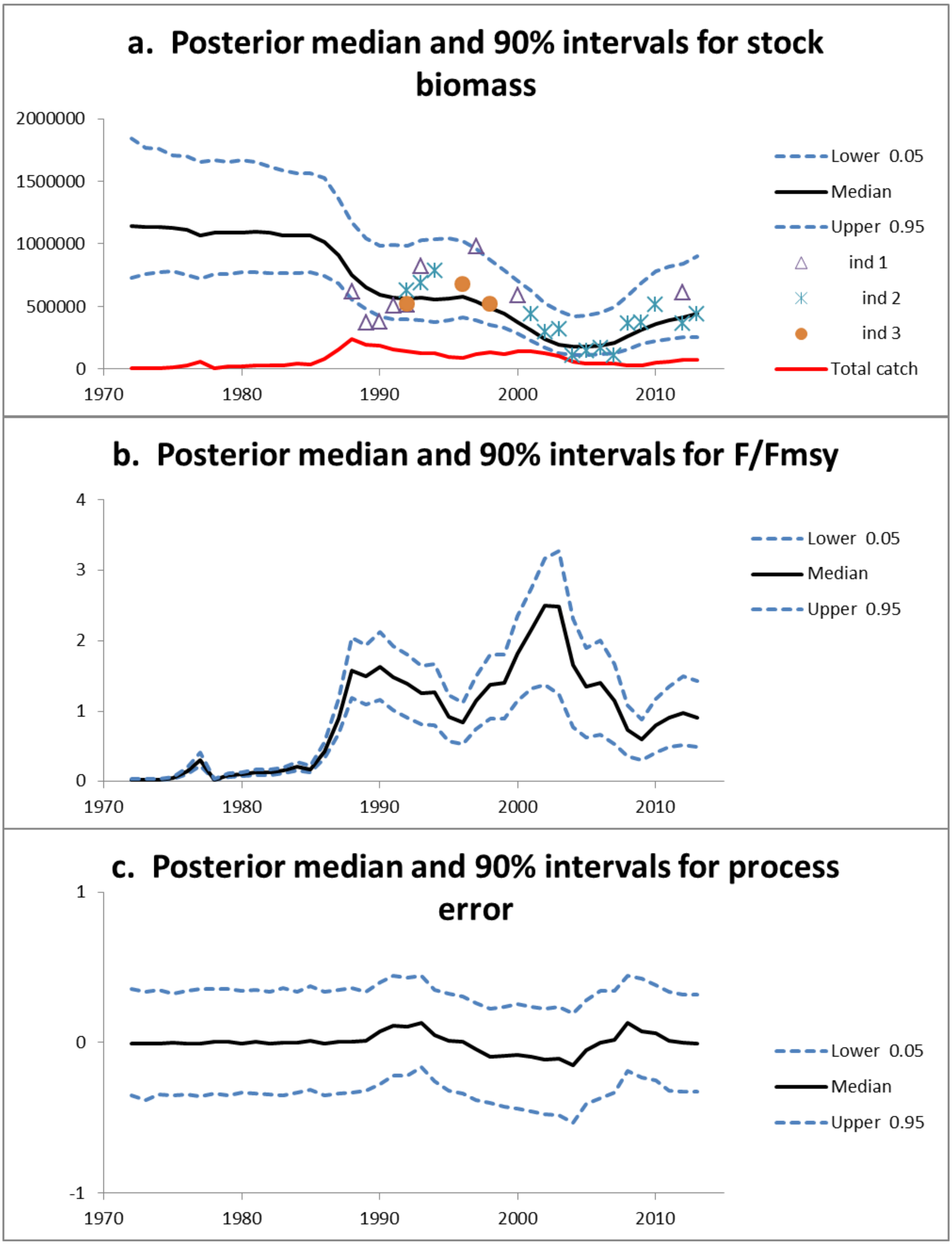

Figure 21: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. process error deviates for the BSP(φ=0.5) model for HOK 1 West.

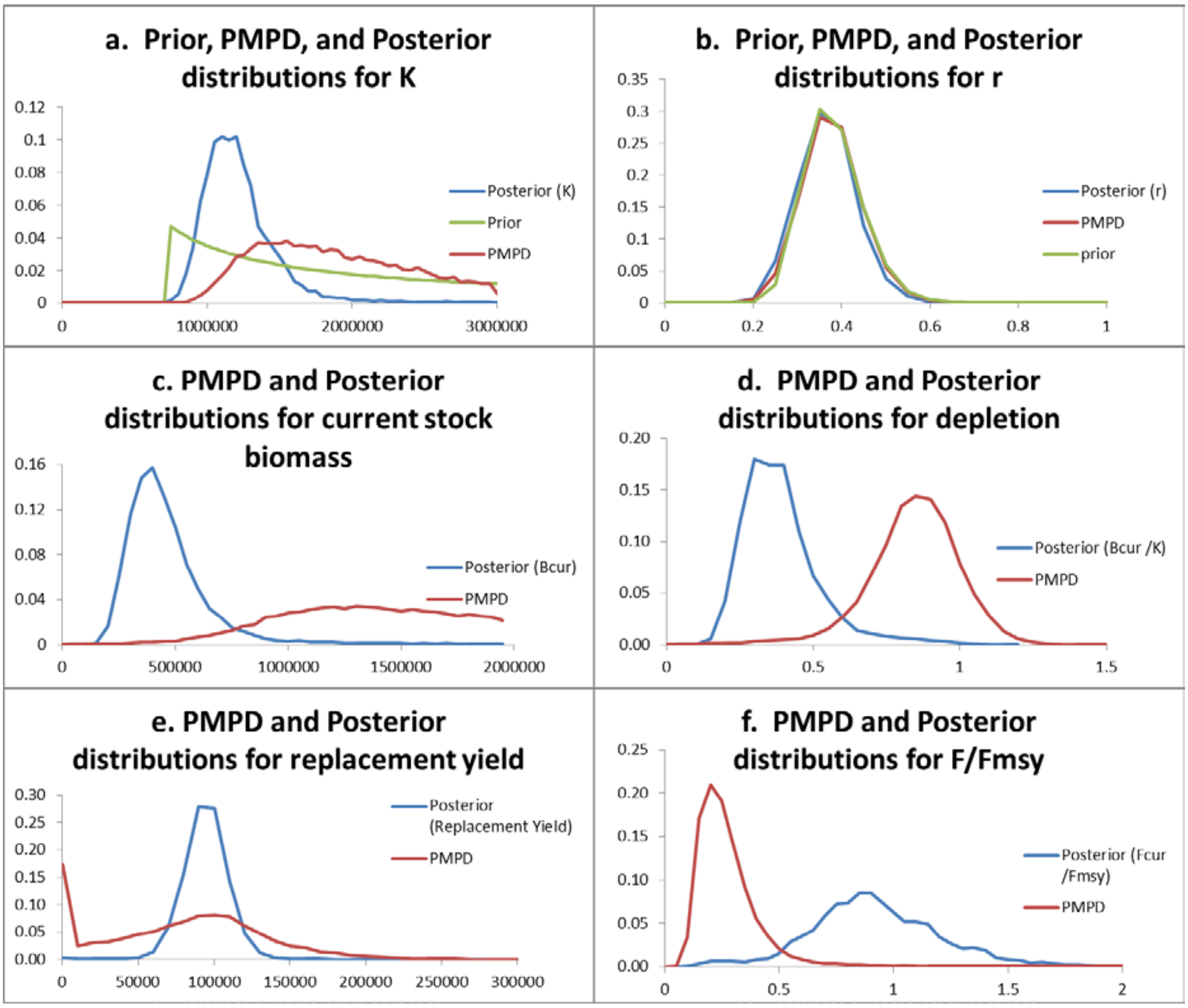

Figure 22: Prior, posterior and PMPD distributions for a) carrying capacity, b) intrinsic growth, c) current stock biomass, d) depletion, e) replacement yield and f) F_{cur}/F_{msy} for the reference case BSP(φ=0.5) model for HOK 1 West.

Conclusions

Taken in combination, the stock assessment data were moderately informative about carrying capacity, stock biomass and stock status for the Western stock of hoki. When informative priors for all of the three survey *q*'s were applied and made consistent with the west coast acoustic *q* prior (run B.1), the estimated depletion was 41%, which is identical to two of the five estimates of depletion from the CASAL stock assessment runs from the 2012 stock assessment of hoki (table 21 in McKenzie, 2013). When other combinations of informative and non-informative priors were applied, the results were slightly more pessimistic than the CASAL results for the Western stock.

Table 19: Posterior and PMPD median and 90% interval results for evaluations of the sensitivity of BSP results for HOK 1 West to different input settings. See Table 17 for information on the settings for the different runs.

Run	r			B_{msy}			B_{cur}			$RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
Ref	0.261	0.366	0.475	457680	588171	815576	253327	441623	900366	71395	94328	118221
A.1	0.270	0.360	0.467	460900	591629	832729	266080	444967	864230	72679	95280	118141
A.2	0.285	0.370	0.473	456835	577616	762491	257923	417990	687019	73203	94362	116546
A.3	0.279	0.363	0.464	460784	584643	775345	267334	429483	719466	73440	94985	116096
B.1	0.257	0.339	0.430	489060	626735	848224	301925	525942	1008411	73696	96437	119723
B.2	0.287	0.376	0.474	451392	572946	734281	258567	408464	662405	74612	94025	115441
C.1	0.302	0.390	0.505	341011	442051	589764	329779	544669	915792	63744	83758	104041
D.1	0.276	0.377	0.490	568263	903524	1404624	713010	1538356	2727925	0	82975	166206
D.2	0.284	0.375	0.507	394472	550034	720039	355654	1098847	2305934	24444	79213	110922

Run	B_{cur}/B_{msy}			B_{cur}/K			F_{cur}/F_{msy}			$Catch_{cur}/RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
Ref	0.452	0.728	1.250	0.226	0.364	0.625	0.498	0.904	1.424	0.584	0.740	0.966
A.1	0.466	0.745	1.241	0.233	0.372	0.621	0.512	0.887	1.392	0.589	0.733	0.952
A.2	0.449	0.704	1.084	0.225	0.352	0.542	0.601	0.930	1.433	0.601	0.742	0.955
A.3	0.467	0.718	1.109	0.234	0.359	0.555	0.588	0.921	1.404	0.602	0.737	0.953
B.1	0.497	0.828	1.402	0.249	0.414	0.701	0.436	0.803	1.334	0.583	0.725	0.945
B.2	0.444	0.699	1.071	0.222	0.350	0.535	0.614	0.933	1.418	0.606	0.744	0.938
C.1	0.739	1.228	1.983	0.185	0.307	0.496	0.385	0.659	1.120	0.672	0.836	1.096
D.1	1.142	1.704	2.163	0.571	0.852	1.082	0.132	0.243	0.534	0.000	0.524	1.092
D.2	0.765	2.018	3.588	0.191	0.505	0.897	0.143	0.340	1.181	0.455	0.859	1.692

Chatham Rise Hake – HAK 3

Background

The HAK 3 stock (Table 20) had only two relative indices of abundance, which showed a depletion and then recovery (Figure 23). Because of this contrast, and apparent reaction of the indices to changes in catch, it is expected that the data will be moderately informative about stock status.

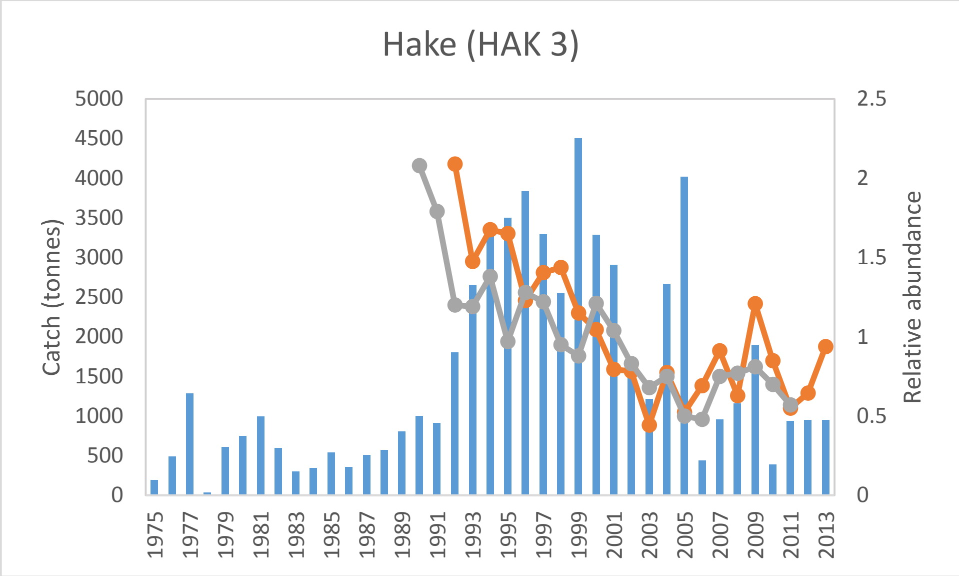

Figure 23: Catch and abundance for HAK 3. Catches are shown as vertical bars. Relative abundance indices are shown as lines.

Analyses performed

Only the BSP(φ=0.5) model was applied for Chatham Rise Hake. A PMPD run was also carried out to evaluate the update in estimates for quantities of interest.

Table 20: Life-history data and prior on intrinsic growth for HAK 3.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	M	per year	0.19	0.25
Fraction mature at age	a_{50}	years	7	0.1
	$d_{50\text{-}95}$		3	0.1
Growth	k		0.229	0.1
	L_{inf}	cm	106.5	0.05
	t_0	year	-0.01	0.32
Length-to-weight	a	g to mm	0.00188	0.01
	b		3.305	0.01
Recruitment	h		0.90	0.08
Intrinsic growth	r		0.3786	0.30

Results

We noted that the commercial CPUE index may be hyperstable (Appendix 1), but did not explore this further here. The posterior median for stock biomass shows a close fit to both time series of abundance indices (Figure 25a). The posterior median process error by year is not significantly different from zero, although it shows some non-significant systematic variation in the early and late 2000s (Figure 25c). This suggests also that the BSP(φ=0.5) model explains the abundance index data fairly well given the historical catch records.

All posterior results show a strong update from the prior and PMPD distributions, including those for the parameter *r* (Figure 24). The posterior for *r* is much narrower and has a lower central tendency (posterior median and CV of 0.21 and 0.19) than the prior (prior median and CV of 0.37 and 0.30). This is largely because of the marked depletion and then recovery in both abundance indices in response to the larger catches in the 1990s and subsequent drop in catches from 2006 onwards. The posterior mean for *r* is lower than the prior since the abundance indices increase more slowly than predicted by the prior after catches are reduced. The residual error variance in the abundance indices is also relatively low with a total BSP model fit CV of 0.23 and 0.19 for the trawl survey and standardised commercial catch per unit effort indices.

The BSP model suggests that the stock is at about 43% of unfished stock size (posterior median) with a 90% posterior interval of 0.33, 0.54 (Table 21).

Table 21: Posterior mean, standard deviation, coefficient of variation, median and 90% intervals for quantities of interest for HAK 3.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.217	0.041	0.189	0.153	0.214	0.289
K	34427	5707	0.166	26544	33711	44646
MSY	1817	195	0.107	1496	1812	2139
B_{msy}	17213	2853	0.166	13272	16855	22323
B_{init}	35507	12100	0.341	20820	33413	52748
B_{cur}	14750	3210	0.218	10602	14701	21257
B_{cur}/B_{msy}	0.859	0.127	0.147	0.666	0.852	1.085
B_{cur}/B_{init}	0.448	0.13	0.29	0.273	0.430	0.674
B_{cur}/K	0.429	0.063	0.147	0.333	0.426	0.543
F_{msy}	0.108	0.0205	0.189	0.076	0.107	0.144
F_{cur}	0.067	0.014	0.2	0.046	0.067	0.090
F_{cur}/F_{msy}	0.631	0.127	0.201	0.447	0.617	0.857
RepY_{cur}	1741	209	0.12	1401	1742	2092
$\mathrm{Catch}_{cur}/\mathrm{RepY}_{cur}$	0.554	0.069	0.124	0.454	0.546	0.678
$P(B_{cur} > 0.4B_{msy})$	1					
$P(B_{cur} > 0.8B_{msy})$	0.654					
$P(B_{cur} > B_{msy})$	0.134					
$P(F_{cur} < F_{msy})$	0.991					

Conclusions

The application to Chatham Rise hake demonstrates that marked updates in the priors for leading parameters of surplus production models can occur when catch and abundance index are informative and the abundance index data have relatively little residual error variability. However a correlation analysis of the trawl survey index and commercial catch per unit index suggests that the cpue may be hyperstable with a hyperstability coefficient of about 0.5 (Appendix 1). This suggests that further exploration of potential hyperstability in New Zealand commercial catch rate data is prudent and that stock assessments that use commercial CPUE should evaluate the sensitivity of results to different scenarios for hyperstability.

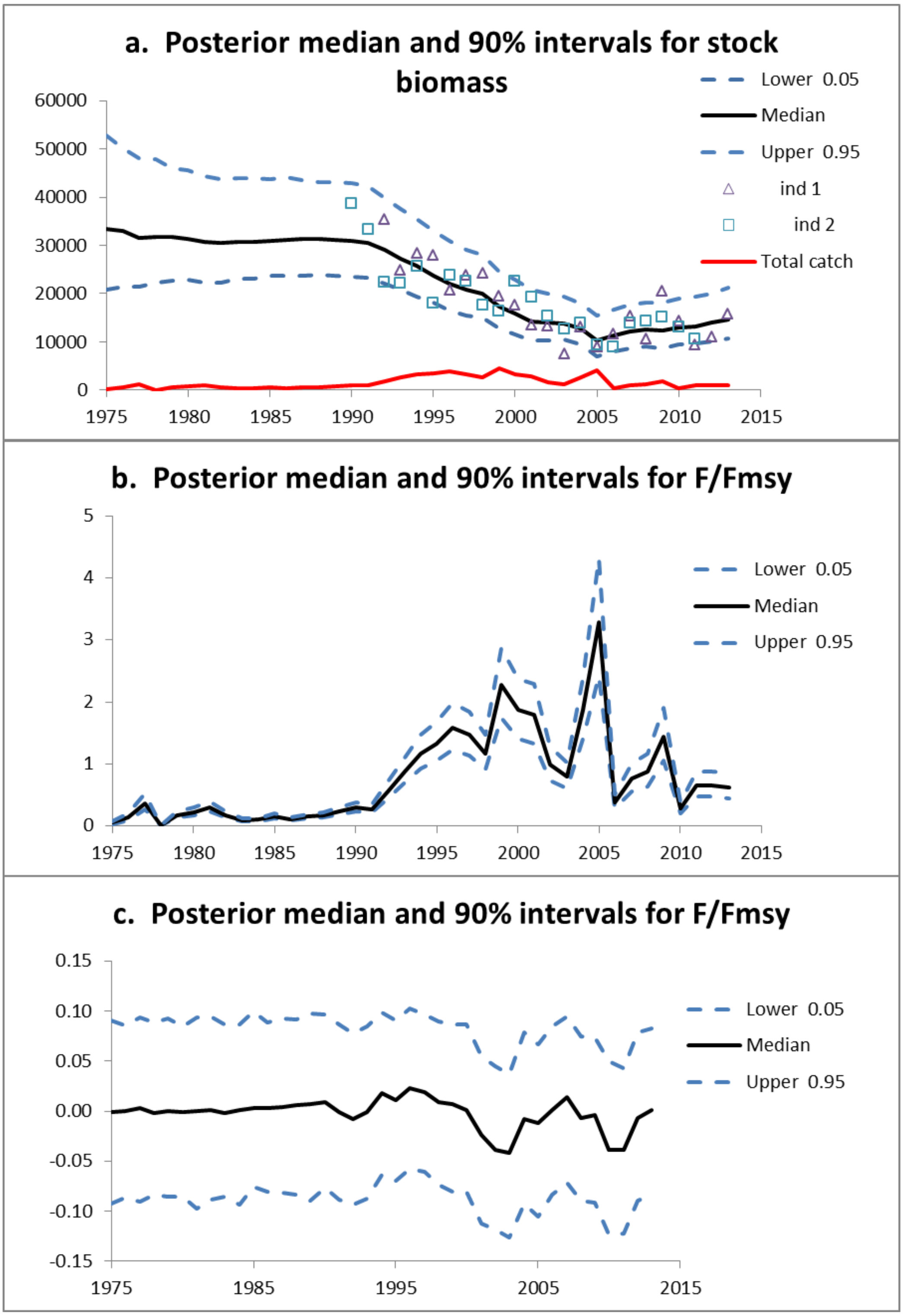

Figure 24: Posterior median and 90% intervals for a. stock biomass, b. the ratio of the annual fishing mortality rate to F_{msy} and c. process error deviates for HAK 3. ind 1 represents the trawl survey index, ind 2 represents standardised commercial catch rate.

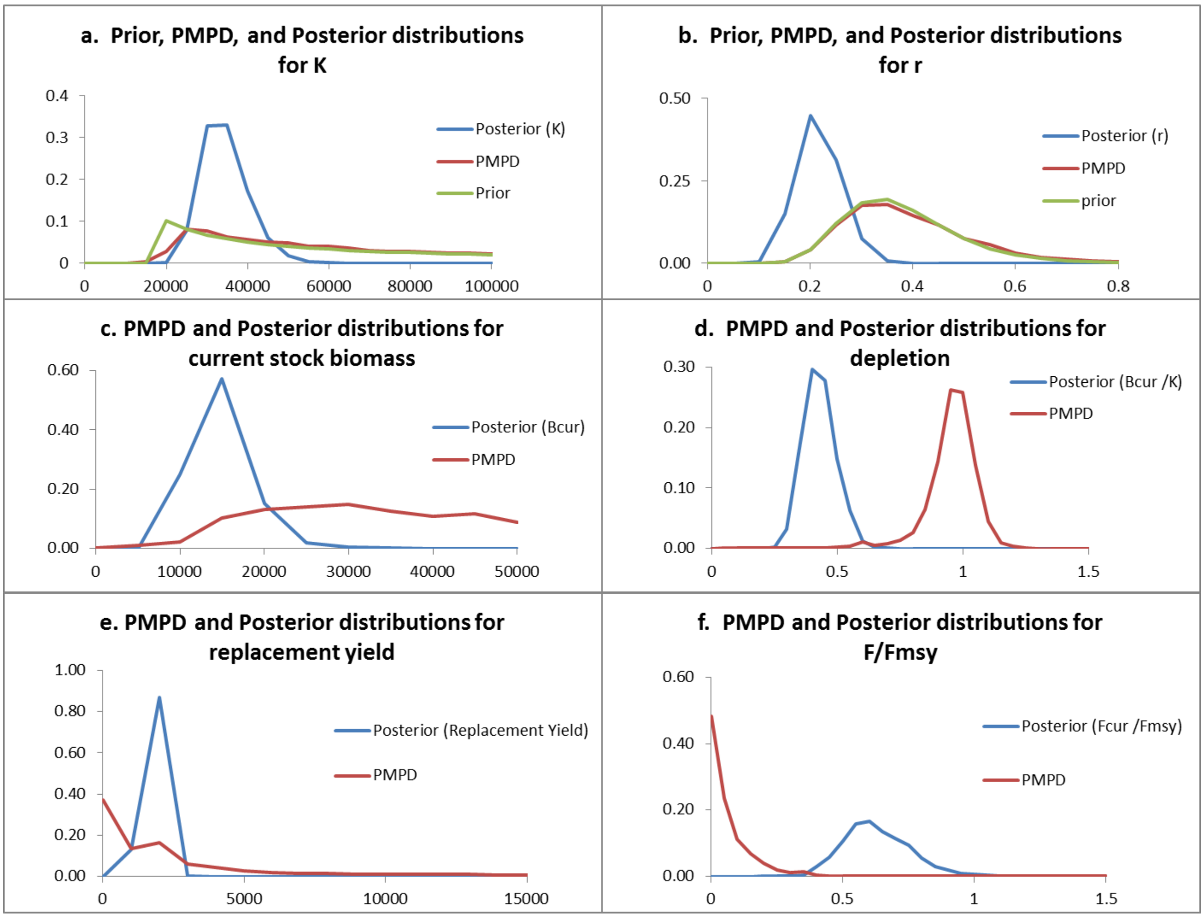

Figure 25: Prior, posterior and PMPD distributions for a) carrying capacity, b) intrinsic growth, c) current stock biomass, d) depletion, e) replacement yield in the current year, and f) F/F_{msy} in the current year, reference case run for HAK 3.

Chatham Rise Ling – LIN 3&4

Background

The LIN 3&4 stock (Table 22) was assessed in 2012 using CASAL fitted to standardised commercial longline catch per unit indices (CPUE) and Tangaroa trawl survey biomass indices (Horn et al., 2013). The abundance index data appear to be in a slight conflict because the CPUE index shows a depletion but the trawl survey index does not (Figure 26). The trawl survey index may have considerably more interannual sampling error variation, but it is uncertain why the trawl survey index fails to show the decline seen in the CPUE index. An informative prior for the trawl survey constant of proportionality was formulated in the stock assessment and this helps to provide some indication of absolute abundance when a stock assessment model is fitted to these indices. This therefore offers some marginal advantage to having the trawl survey index included in the stock assessment. The prior for carrying capacity for all runs performed was uniform over *K*, rather than uniform over the natural logarithm of *K*.

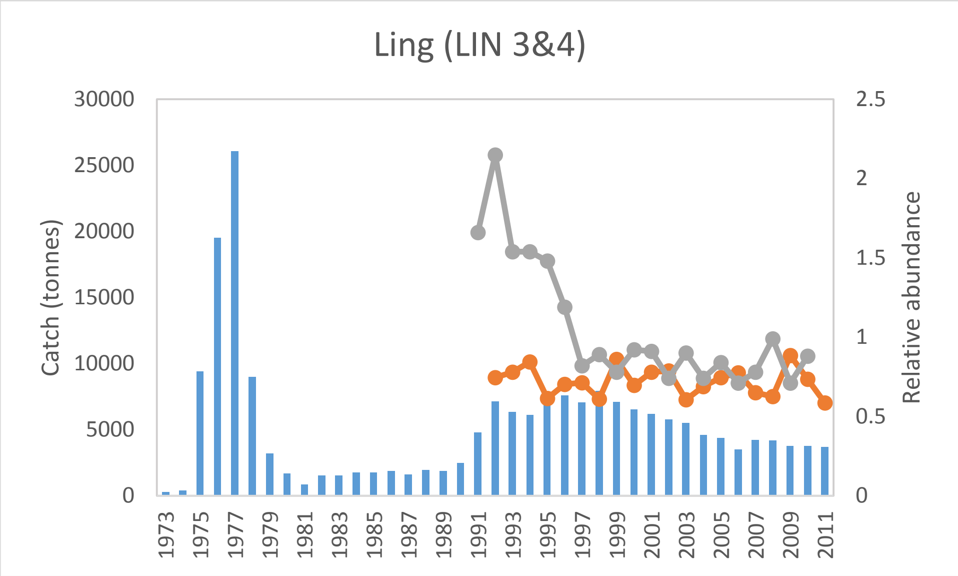

Figure 26: Catch and abundance for LIN 3&4. Catches are shown as vertical bars. Relative abundance indices are shown as lines.

Table 22: Life-history data and prior on intrinsic growth for LIN 3&4.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	M	per year	0.14	0.25
Fraction mature at age	a_{50}		12	0.1
	$d_{50\text{-}95}$		2	0.1
Growth	k		0.083	
	L_{inf}	cm	156.4	
	t_0	year	-0.74	
Length-to-weight	a	cm to g	0.00114	0.1
	b		3.318	0.1
Recruitment	h		0.887	0.08
Intrinsic growth	r		0.2559	0.34

Analyses performed

As mentioned above, an informative prior for the trawl survey q was available. The influence of this informative prior on providing informative stock assessment results was evaluated. Also, the sensitivity of results to different settings for the standard deviation in process error deviates and in φ were also evaluated.

Table 23: Summary of sensitivity test runs for LIN 3&4.

Code	Category Description	Code	Run Description
Ref	Reference run	Ref	Reference run (σ_p = 0.05, informative prior for the trawl survey *q*, and φ = 0.5)
A	Non-informative *q* prior		Non-informative trawl *q* prior
B	Effects of different hypotheses for process error variance	B.1	σ_p = 0.005
		B.2	σ_p = 0.15
C	BSP(φ = 0.2) model	C.1	informative trawl *q* prior
		C.2	non-informative trawl *q* prior
D	PMPD analysis	D.1	φ = 0.5
		D.2	φ = 0.2

Results

Results for the reference case run are listed in Table 24. The trawl survey index shows relatively little trend compared to the CPUE and may be hyperstable. The PMPD distributions gave relatively high values for the median depletion with values of 0.95 and 0.75 when B_{msy} to *K* ratios were set at 0.5 and 0.2, respectively. Fitting the BSP model to both indices and giving them similar weight with model fit CVs of 0.25 shows that the model fits neither very well and instead goes midway through the observations in the first half of the time series (Figure 27). Process error deviates show no pronounced pattern over the time series but the fishing mortality rate shows a spike in the late 1970s when catches spiked upwards (Figure 27). The marginal PMPD distributions for *K* and stock biomass show the effect of presuming a uniform prior for *K*, i.e., the right hand tails are flat for both marginal PMPD distributions (Figure 28). In contrast, the right-hand tails of the *K* and stock biomass PMPD distributions thinned in the other case studies in which a uniform on log *K* prior was applied. The reference case run that uses the informative prior for *q* yielded considerable updates to the PMPD distributions (Figure 28) and a minor update in the prior for *r*. The stock status indicators in the most recent year show that the stock is relatively lightly depleted, with the posterior median values for depletion ranging from about 0.48 to 0.72 for the different scenarios considered (Table 25).

The informative prior for the trawl survey *q* (Ref and C.1) ties down the estimation of absolute biomass and gave tighter credibility intervals for biomass quantities than the run with an uninformative prior for *q* (C.2) (Table 25). Running the model with a lower (B.1) versus higher (B.2) process error variance tightened versus inflated the posterior intervals for most estimated quantities and made stock status indicators less versus more optimistic (Table 25). The run with the highest process error standard deviation of 0.15 (B.2) had a Bayes factor of 0.1 compared to the reference case run where it was set at 0.05. Applying the BSP(φ=0.2) model (C.1) tended to give lower depletion relative to unfished biomass and lower current replacement yield estimates, but considerably higher ratios for current stock biomass to B_{msy} (Table 25). Bayes factor for the BSP(φ=0.2) run (C.1) was 2.9 compared to the reference case run, providing nonsignificant support for a lower B_{msy} to K ratio than given in the Schaefer model.

Table 24: Posterior mean, standard deviation, coefficient of variation, median and 90% intervals for quantities of interest for LIN 3&4, reference case run.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.225	0.05	0.22	0.153	0.220	0.316
K	124937	48168	0.386	76359	111792	219911
MSY	6873	2856	0.416	4507	5972	12245
B_{msy}	62468	24084	0.386	38179	55896	109956
B_{init}	132910	60953	0.459	71663	115916	237578
B_{cur}	83174	46528	0.559	38484	69782	178739
B_{cur}/B_{msy}	1.281	0.256	0.2	0.875	1.274	1.716
B_{cur}/B_{init}	0.638	0.201	0.314	0.365	0.609	1.01
B_{cur}/K	0.64	0.128	0.2	0.438	0.637	0.858
F_{msy}	0.113	0.025	0.22	0.077	0.110	0.158
F_{cur}	0.055	0.0228	0.414	0.0206	0.0529	0.096
F_{cur}/F_{msy}	0.505	0.219	0.433	0.181	0.492	0.893
RepY$_{cur}$	5599	1399	0.25	4011	5357	8002
Catch$_{cur}$/RepY$_{cur}$	0.674	0.162	0.241	0.432	0.687	0.904
P(B_{cur}> 0.4B_{msy})	1					
P(B_{cur}> 0.8B_{msy})	0.976					
P(B_{cur}> B_{msy})	0.854					
P(F_{cur}< F_{msy})	0.978					

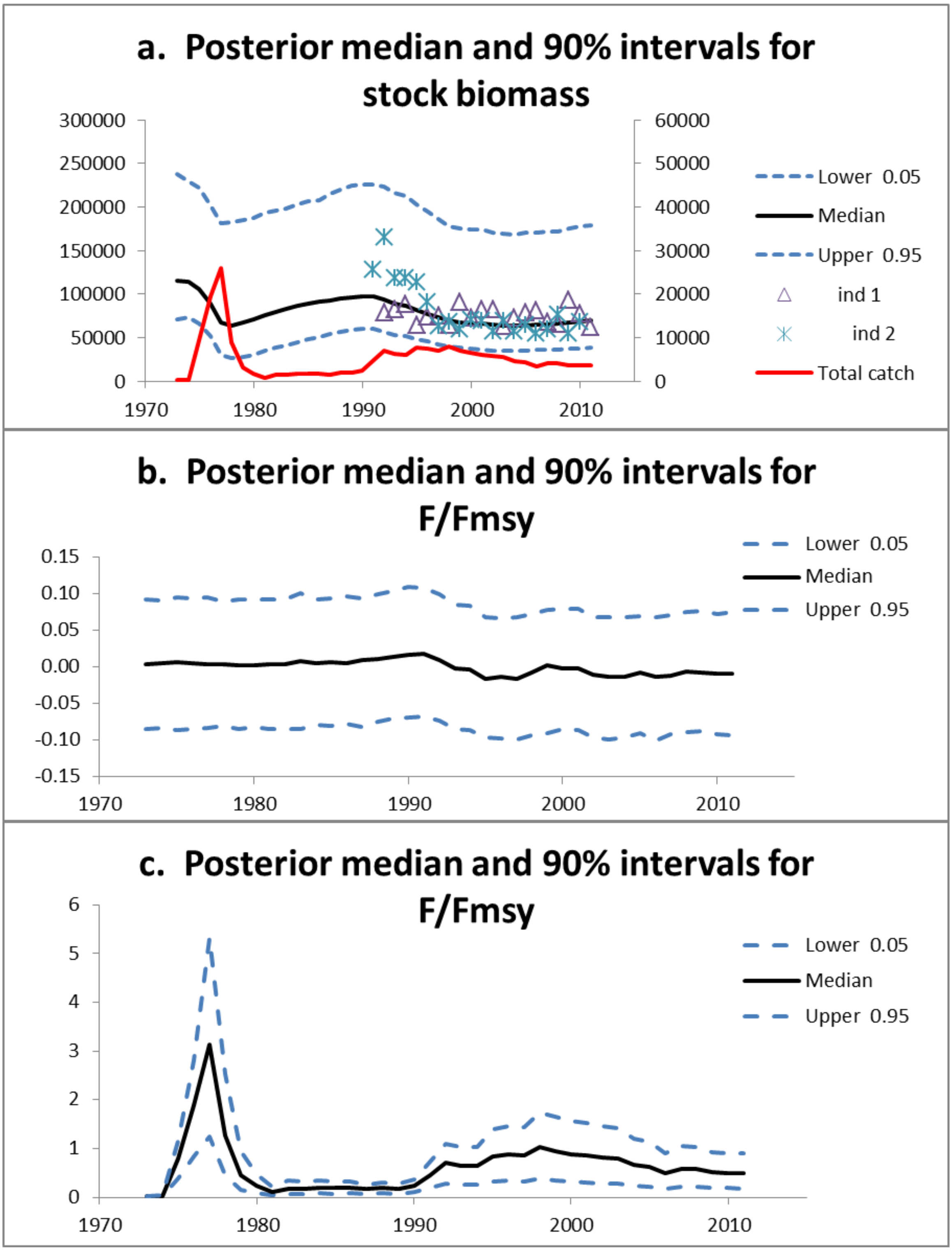

Figure 27: Posterior median and 90% intervals for a. stock biomass, b. the ratio of the annual fishing mortality rate to F_{msy} and c. process error deviates for LIN 3&4, reference case run. ind 1 represents the trawl survey index, ind 2 represents standardised commercial catch rate.

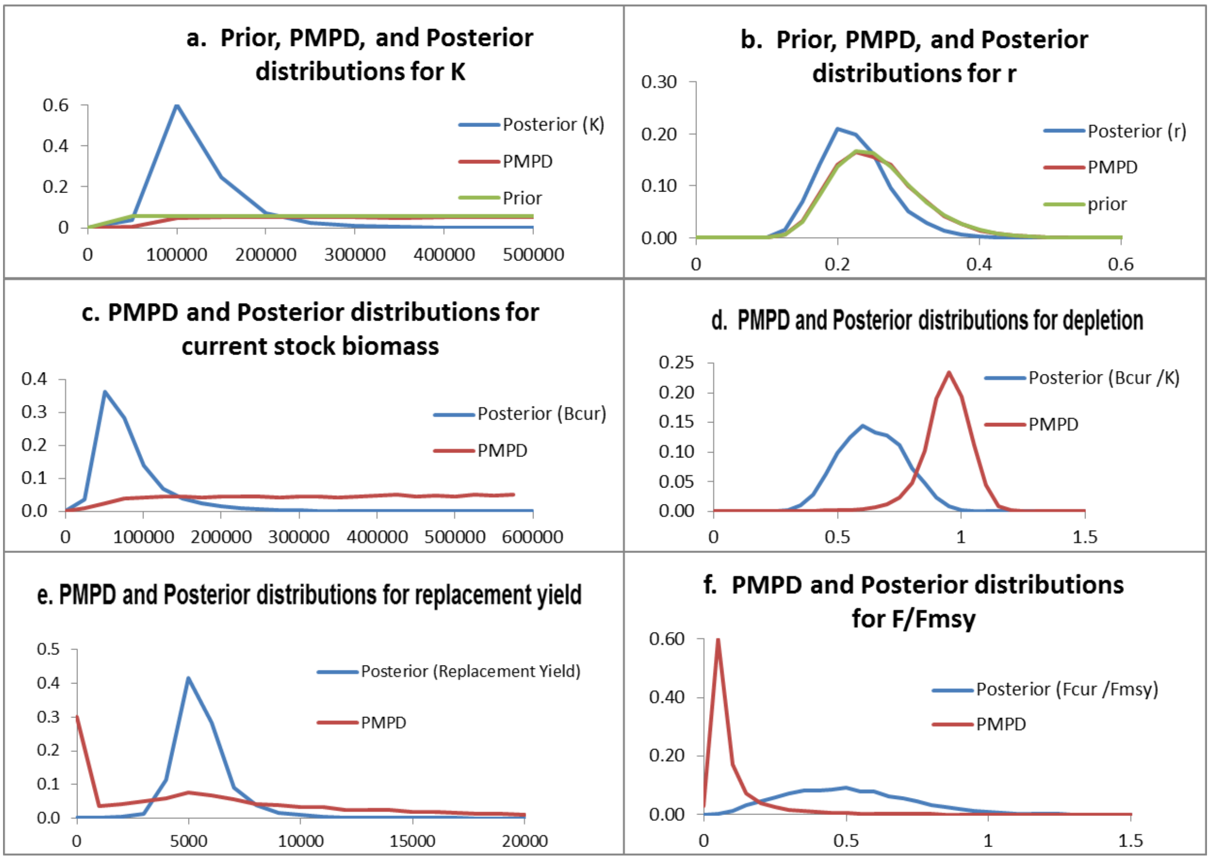

Figure 28: Prior, post-model, pre-data distributions for a) carrying capacity, b) intrinsic growth, c) current stock biomass, d) depletion, e) replacement yield in the current year, and f) F/F_{msy} in the current year, reference case run for LIN 3&4.

Conclusions

The combination of using a commercial catch rate index that showed some response to higher extractions, and a trawl survey abundance index with an informative prior for *q*, yielded informative stock assessment results for LIN 3&4. The fit to the abundance indices was not satisfactory since the implied abundance trends were different between indices for the early part of the time series and the posterior median stock biomass trajectory fitted neither index very well. Further evaluation of the sensitivity of results to fitting the model to these different stock trend indices would be advisable to produce a reliable stock assessment. It is likely that stock status could be considerably worse should the model be fitted to the longline CPUE data compared to that obtained by fitting the model to the trawl survey indices only.

The computation of Bayes factors showed that larger values for the process error standard deviation of 0.15 were less credible than lower values of either 0.05 or 0.005. Also, Bayes factors tended to only slightly favour the BSP(φ=0.2) model (Table 26).

Table 25: Posterior and post-model-pre-data median and 90% interval results for evaluations of the sensitivity of BSP results for LIN 3&4 to different input settings. See Table 23 for information on the settings for the different runs.

Run	r			B_{msy}			B_{cur}			$RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
Ref	0.153	0.22	0.316	38179	55896	109956	38484	69782	178739	4011	5357	8002
A.1	0.155	0.222	0.323	38393	69729	413351	37931	98097	730825	3391	5716	19532
B.1	0.149	0.208	0.286	37495	48545	68840	38010	55416	99385	4295	4830	5095
B.2	0.161	0.239	0.356	44450	85151	197319	41567	102239	268923	3288	8181	20252
C.1	0.169	0.253	0.369	28957	42553	74573	52626	101026	239364	2513	4214	6275
C.2	0.165	0.247	0.363	31180	62201	160970	60708	186648	627584	1703	4531	9687
D.1	0.166	0.247	0.37	59460	276805	474238	91885	524378	956650	0	5109	21777
D.2	0.168	0.248	0.371	33506	103447	185963	59846	405512	867998	0	4156	10076

Run	B_{cur}/B_{msy}			B_{cur}/K			F_{cur}/F_{msy}			$Catch_{cur}/RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
Ref	0.875	1.274	1.716	0.438	0.637	0.858	0.181	0.492	0.893	0.432	0.687	0.904
A.1	0.881	1.445	1.915	0.441	0.723	0.957	0.043	0.342	0.866	0	0.61	0.855
B.1	0.863	1.148	1.539	0.431	0.574	0.770	0.358	0.652	0.949	0.725	0.766	0.86
B.2	0.719	1.279	1.827	0.359	0.639	0.914	0.105	0.291	0.749	0	0.419	0.849
C.1	1.533	2.401	3.638	0.307	0.480	0.728	0.12	0.292	0.576	0.58	0.876	1.446
C.2	1.716	2.999	4.519	0.343	0.600	0.904	0.046	0.162	0.498	0	0.779	1.499
D.1	1.495	1.891	2.156	0.748	0.946	1.078	0.027	0.059	0.33	0	0	0.733
D.2	1.702	3.771	5.525	0.340	0.754	1.105	0.031	0.075	0.526	0	0.625	1.531

Table 26: Bayes factors for model runs with different values for process error variance and ratios for B_{msy} to K.

Run	Model run	Bayes Factor
Ref.	$\sigma_p = 0.05$	1.0
A.1	$\sigma_p = 0.005$	1.2
A.2	$\sigma_p = 0.15$	0.1
Ref	$\varphi = 0.5$	1.0
C.2	$\varphi = 0.2$	2.9

Bluenose – BNS

Background

A CASAL assessment was applied to BNS (Table 27) in 2012 (Cordue & Pomarede, 2012). The abundance index data show a classical one-way trip (Figure 29), which makes it difficult for the model to identify a unique combination of the productivity parameter *r*, and the carrying capacity *K*.

For this stock, the population that has recruited to the fishery appears to be different from the component of the population that is mature. This could thus give rise to some differences in results between age-aggregated and age-disaggregated models.

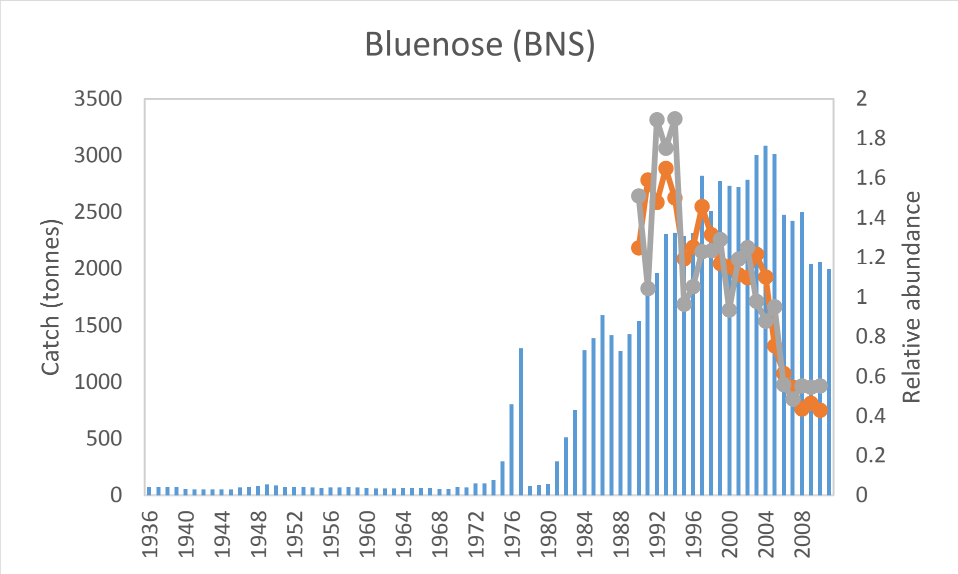

Figure 29: Catch and abundance for BNS. Catches are shown as vertical bars. Relative abundance indices are shown as lines.

Table 27: Life-history data and prior on intrinsic growth for BNS.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	M	per year	0.083	0.25
Fraction mature at age	a_{50}			
	$d_{50\text{-}95}$			
Growth	k		0.071	0.2
	L_{inf}	cm	92.5	0.1
	t_0	year	-0.5	0.5
Length-to-weight	a		0.00963	0.05
	b		3.173	0.05
Recruitment	h		0.75	0.13
Intrinsic growth	r		0.1005	0.334

Analyses performed

A BSP(φ=0.5) model was applied as the reference case run. As there was some uncertainty in the historical catch levels, low, medium and high scenarios for the catch biomass series were evaluated. Under the low catch scenario catches prior to 1975 were assumed to be zero and catches between 1975 and 1984 were considerably lower than the reference catches in most of these years. Under the high catch scenario, catches were set at about double the base case for years prior to 1981. The effects of uncertainty in the rate of natural mortality and steepness on the prior for *r* and stock assessment results was also evaluated. These different sensitivity runs are listed in Table 28.

Results

The BSP(φ=0.5) model provides a fairly good fit to the CPUE data and predicts a marked decline in biomass from the mid-1990s onwards (Figure 30a). The reference case, and all other model runs fitted to the data, indicate that the stock is at about a quarter of the unfished stock size (Tables 29 and 31, and Figure 31). The posterior median fishing mortality rate in 2011 was 2.2 to 3 times the MSY level, depending on the run and the posterior median replacement yield for 2011 was 1000-1300 tonnes (Tables 29 and 31). The posterior results were relatively insensitive to the low and high catch scenarios (B.1 and B.2, Table 31). The posterior results were sensitive to the prior for *r* (lower and higher prior median C.1 and C.2) as there was very little productivity information in the data (Table 31). The Bayes factors for the different runs were fairly similar between the different runs, indicating that the data were not informative about the different input assumptions (Table 30).

Table 28: Summary of sensitivity test runs for BNS.

Code	Category Description	Code	Run Description
Ref	Reference run	Ref	$\sigma_p = 0.10$ and $\varphi = 0.5$
A	BSP($\varphi = 0.3$) model	A.1	
B	Effects of uncertainty in historical catch records	B.1	low catch scenario
		B.2	high catch scenario
C	Effects of uncertainty in the prior for *r*	C.1	low *r* prior (prior mean = 0.089)
		C.2	high *r* prior (prior mean = 0.173)
D	PMPD analysis	D.1	$\varphi = 0.5$
		D.2	$\varphi = 0.3$

Table 29: Posterior mean, standard deviation, coefficient of variation, median and 90% intervals for quantities of interest for the BSP(φ=0.5) model for BNS.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.101	0.037	0.363	0.0528	0.0961	0.163
K	71394	41073	0.575	36620	59558	146905
MSY	1696	979	0.577	783	1487	3178
B_{msy}	35697	20537	0.575	18310	29779	73452
B_{init}	71036	41424	0.583	32025	59512	149811
B_{cur}	19419	18115	0.933	6323	13890	48876
B_{cur}/B_{msy}	0.518	0.187	0.36	0.261	0.49	0.845
B_{cur}/B_{init}	0.27	0.115	0.426	0.122	0.245	0.49
B_{cur}/K	0.259	0.093	0.360	0.130	0.245	0.423
F_{msy}	0.0504	0.0183	0.363	0.0264	0.0481	0.0815
F_{cur}	0.149	0.075	0.504	0.040	0.140	0.284
F_{cur}/F_{msy}	3.182	1.789	0.562	0.861	2.944	6.246
RepY$_{cur}$	1296	949	0.732	556	1049	2951
Catch$_{cur}$/RepY$_{cur}$	1.998	0.877	0.439	0.677	1.906	3.591
P(B_{cur}> 0.4B_{msy})	0.72					
P(B_{cur}> 0.8B_{msy})	0.08					

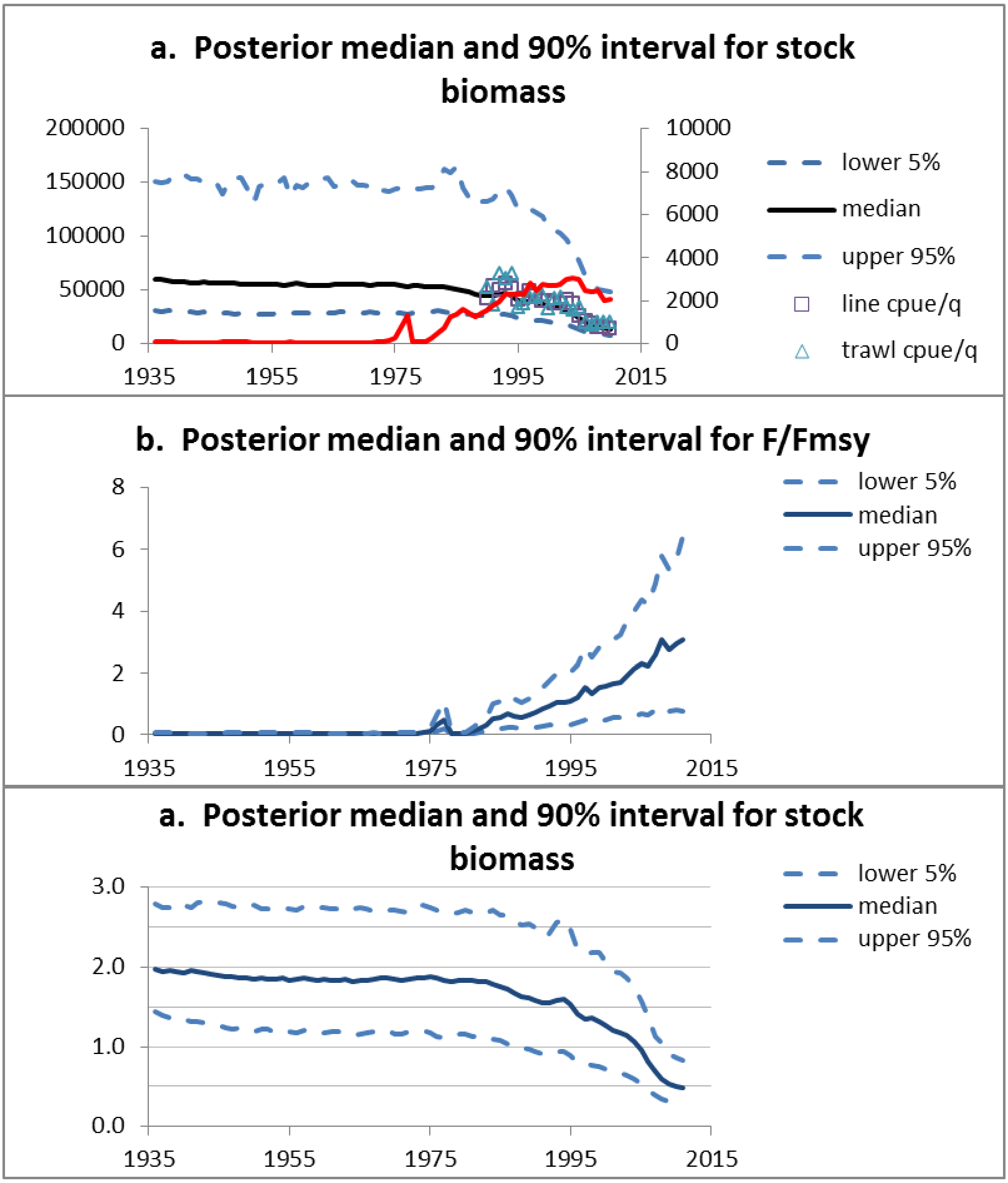

Figure 30: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. B/B_{msy} deviates for the reference case BSP(φ=0.5) model for BNS.

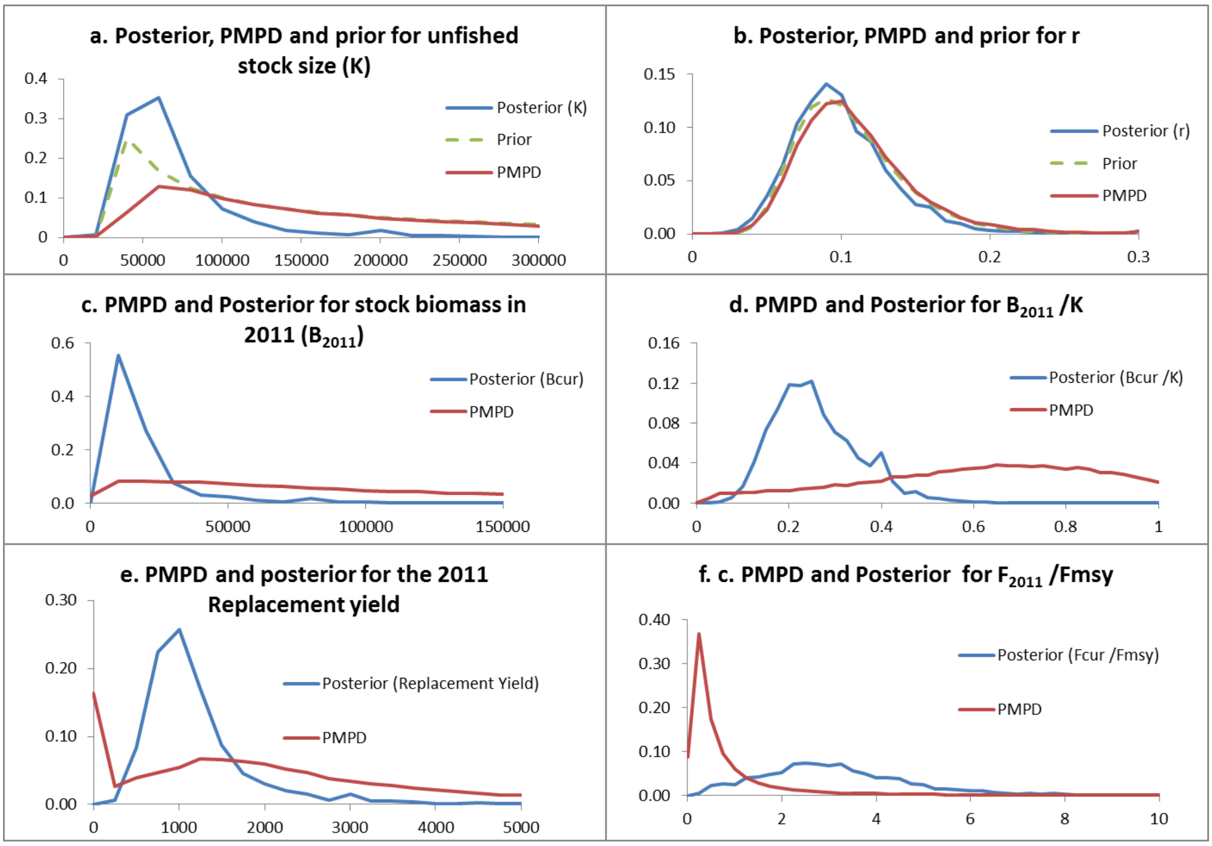

Figure 31: Prior, post-model, pre-data distributions for a) carrying capacity, b) r, c) current stock biomass, d) depletion, e) replacement yield and e) F_{cur}/F_{msy} for the Schaefer model for BNS.

Table 30: Bayes factors for different model runs for bluenose.

Run	Description	Bayes factor
Ref	φ = 0.5	1.0
A.1	φ = 0.3	1.6
B.1	low catch	1.0
B.2	high catch	1.0
C.1	low *r*	1.1
C.2	high *r*	0.8

Conclusions

The one way trip abundance index data suggested a strong decline in abundance from the mid-1990s to 2011. The informative prior for *r* allowed for a fairly strong update to the prior distributions when the model was fitted to data. Results were sensitive to the different priors for *r* that were applied due to the one-way trip abundance index data but relatively insensitive to historical catch uncertainty since the uncertainty was applied only for years in the remote past, i.e., mostly prior to 1980 when catches were considerably lower than those in subsequent years.

Table 31: Posterior and post-model-pre-data median and 90% interval results for evaluations of the sensitivity of BSP results for BNS to different input settings. See Table 28 for information on the settings for the different runs.

Run	r			B_{msy}			B_{cur}			$RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
Ref	0.053	0.096	0.163	18310	29779	73452	6323	13890	48876	556	1049	2951
A.1	0.049	0.099	0.192	12505	22482	51383	6368	15514	62749	407	1009	2436
B.1	0.053	0.096	0.171	17665	29158	75309	6504	13840	54911	545	1062	3561
B.2	0.055	0.097	0.169	18054	29677	76514	6369	13446	56111	579	1061	3045
C.1	0.041	0.086	0.168	17261	31592	108696	5812	14405	81458	438	988	4245
C.2	0.068	0.158	0.315	12646	21684	57339	3975	9770	41076	649	1274	3087
D.1	0.059	0.103	0.18	23759	64759	171343	8566	91399	329309	0	1831	6666
D.2	0.06	0.104	0.188	14548	30823	54776	5165	47039	176728	0	1060	2666

Run	B_{cur}/B_{msy}			B_{cur}/K			F_{cur}/F_{msy}			$Catch_{cur}/RepY_{cur}$		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
Ref	0.261	0.49	0.845	0.130	0.245	0.423	0.86	2.944	6.246	0.677	1.906	3.591
A.1	0.287	0.751	1.674	0.086	0.225	0.502	0.567	2.622	7.56	0.816	1.974	4.735
B.1	0.277	0.511	0.877	0.139	0.255	0.438	0.684	2.849	6.161	0.559	1.883	3.669
B.2	0.266	0.488	0.854	0.133	0.244	0.427	0.734	2.863	5.988	0.654	1.882	3.45
C.1	0.218	0.489	0.954	0.109	0.244	0.477	0.51	3.101	8.132	0.471	2.024	4.565
C.2	0.256	0.481	0.864	0.128	0.240	0.432	0.742	2.452	5.508	0.645	1.57	3.067
D.1	0.32	1.374	2.365	0.160	0.687	1.183	0.109	0.429	4.462	0	0.657	2.844
D.2	0.242	1.531	4.227	0.073	0.459	1.268	0.183	0.809	8.154	0	1.453	5.202

East Chatham Rise Orange roughy – ORH 3B East

Background

Chatham Rise and other New Zealand orange roughy stocks (Table 32 and Figure 32) were assessed using CASAL in 2006 (Dunn, 2007) and 2014 (Cordue, 2014). In the former instance, the model was unable to fit the continued lack of stock recovery in most indices after catches had been reduced in the mid-1990s. In the latter instance the model was fitted to a few years of catch-at-age or catch-at-length data and a number of years of fishery independent abundance index data. Strongly informative priors for the constant of proportionality for these indices were applied which tended to make them function as absolute abundance estimates within the stock assessment. The models were not fit to any of the commercial catch rate indices that were available for some of the stocks. The stocks were all found to be depleted relative to unfished conditions, though a few appeared to be at or near the target stock sizes relative to unfished conditions. The CASAL model for all stocks tended to predict that the stock should be increasing within the last decade, even though the abundance index data in this period were quite sparse for all stocks. The fits tended to suggest that in the decades prior to the development of the fishery recruitment deviations from the long-term predicted levels were very high.

One advantage in applying a BSP model to these data are that it is much simpler to apply and fit to the abundance index data. The BSP model was applied to abundance index available for the East Chatham Rise orange roughy stock in 2013 (McAllister et al., 2013). This stock is part of the larger ORH 3B. Up until then, it had been a number of years since there had been an attempt to assess New Zealand orange roughy stocks using stock assessment models. In 2006, there had been a concerted effort to fit an earlier version of CASAL to the orange roughy data (Dunn, 2007). However, in this effort, most attempts predicted an increase in stock abundance when catches were considerably reduced in the mid-1990s. This is contrary to changes in the abundance indices, which do not increase, and is mainly because the age structured models suggested that the average expected recruitment from the start of the fishery in the 1980s should remain at about virgin levels and remain that way for about 30 years, i.e., until about 2020. The fishery targets spawning aggregations and the median age at maturity and recruitment to the spawning aggregations is about 30 to 40 years. It was thus seen to be peculiar that the abundance indices did not start to increase when the catches were reduced in the 1990s.

The BSP model has no such presumptions about age of maturity or age of recruitment to the fishery, except that the prior for *r* uses the estimated maturity ogive for the fish stock of interest. It is thus of interest to evaluate whether a BSP model can fit the available abundance indices for the Chatham Rise East orange roughy stock, which is part of ORH 3B. The prior for carrying capacity for all runs performed was uniform over *K*, rather than uniform over the natural logarithm of *K*.

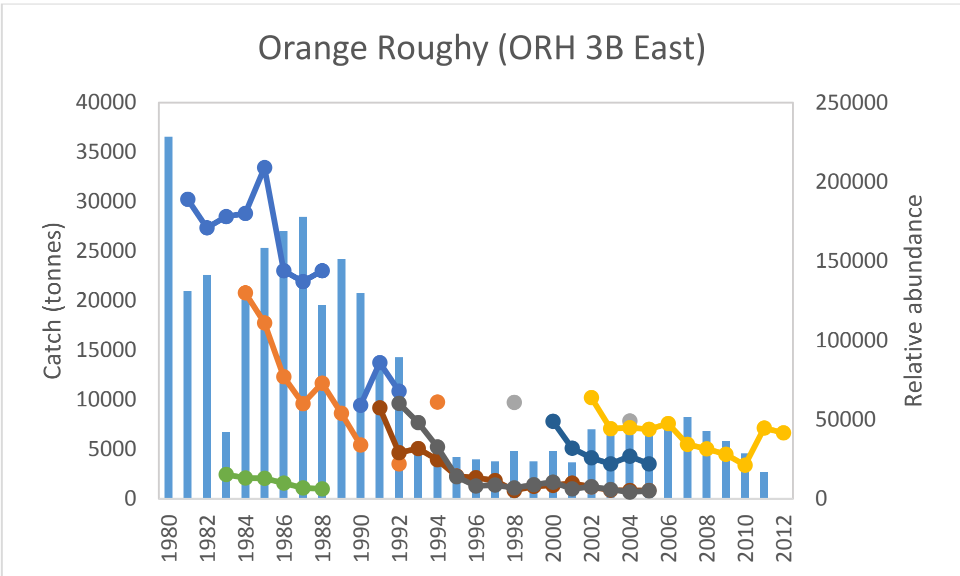

Figure 32: Catch and abundance for ORH 3B East. Catches are shown as vertical bars. Relative abundance indices are shown as lines.

Table 32: Life-history data and prior on intrinsic growth for ORH 3B East.

	Parameter	Units	Value	Coefficient of variation
Natural mortality	M	per year	0.045	0.25
Fraction mature at age	a_{50} d_{50-95}		35.67	4.56
Growth	k		0.059	0.2
	L_{inf}	cm	37.78	0.1
	t_0	year	-0.491	0.5
Length-to-weight	a		0.08	0.05
	b		2.75	0.05
Recruitment	h		0.75	0.13
Intrinsic growth	r		0.0456	0.264

Analyses performed

Three different runs were performed. These were aimed at evaluating whether the BSP model could fit the abundance index data available to Dunn (2007), predict the subsequent data to 2011 based on the fit to data to 2005, fit all of the data available to 2011 and the sensitivity of results to fitting data only to 2005 versus 2011. In the first run, the model was thus run to 2005 and fitted to data available to that point, as in Dunn (2007). In the second run, the model was fitted to 2005 but projected to 2011 using catch records available to 2011. The model projected stock biomass for years to 2011 was then compared to the abundance index data available from 2006 to 2011. In the third run, the model was run and fitted to abundance index data to 2011. This enabled the comparison of model results predicted by data to 2005 with those obtained by fitting the model to data up to 2011.

Results

The BSP(φ=0.5) model provided a fairly good fit of the model to the abundance index data to 2005 (Figure 33). The prior for K was strongly updated and the prior for r was slightly updated and shifted to the left (Figure 36). The marginal PMPD distributions for K and stock biomass here also show the effect of presuming a uniform prior for K, i.e., unlike when a uniform on log K prior is applied, the right-hand tails are flat for these marginal PMPD distributions (Figure 36). All posterior distributions were quite informative for the quantities of interest (Figure 36). The model suggests that the stock is heavily depleted and continuing to decline up to 2011 (Figure 35 and Table 33). When the model was fitted to data to 2005 and then projected using the catch records to 2012, the model predicted biomass corresponded fairly closely to the acoustic indices divided by the posterior mean estimate of q (Figure 34). The fit of the model to the different abundance indices changed relatively little when the model was fitted to the full time series to 2011 (Figure 35).

Table 33: Posterior mean, median, standard deviation (SD), coefficient of variation (CV), 80% interval for ORH 3B East when the BSP(φ=0.5) model was fitted to abundance index data up to 2011.

Variable	Mean	SD	CV	10th percentile	Median	90th percentile
r	0.045	0.012	0.257	0.0322	0.0434	0.0605
K	526643	179297	0.34	338357	489154	751529
MSY	5790	1989	0.344	3621	5410	8507
B_{msy}	263322	89648	0.34	169178	244577	375765
B_{init}	517974	156716	0.303	321068	451690	667261
B_{cur}	41236	21615	0.524	22435	37279	68304
B_{cur}/B_{msy}	0.164	0.074	0.45	0.089	0.15	0.249
B_{cur}/B_{init}	0.084	0.033	0.396	0.049	0.078	0.126
B_{cur}/K	0.082	0.037	0.45	0.0443	0.0752	0.1244
F_{msy}	0.0226	0.0058	0.257	0.0161	0.0217	0.0302
F_{cur}	0.079	0.032	0.396	0.041	0.077	0.122
F_{cur}/F_{msy}	3.68	1.63	0.44	1.88	3.42	5.90
RepY$_{cur}$	1672	794	0.475	907	1501	2596
Catch$_{cur}$/RepY$_{cur}$	1.94	0.78	0.40	1.05	1.82	3.01
P(B_{cur} > 0.2B0)	0.014					
P(B_{cur} > 0.8B0)	0					

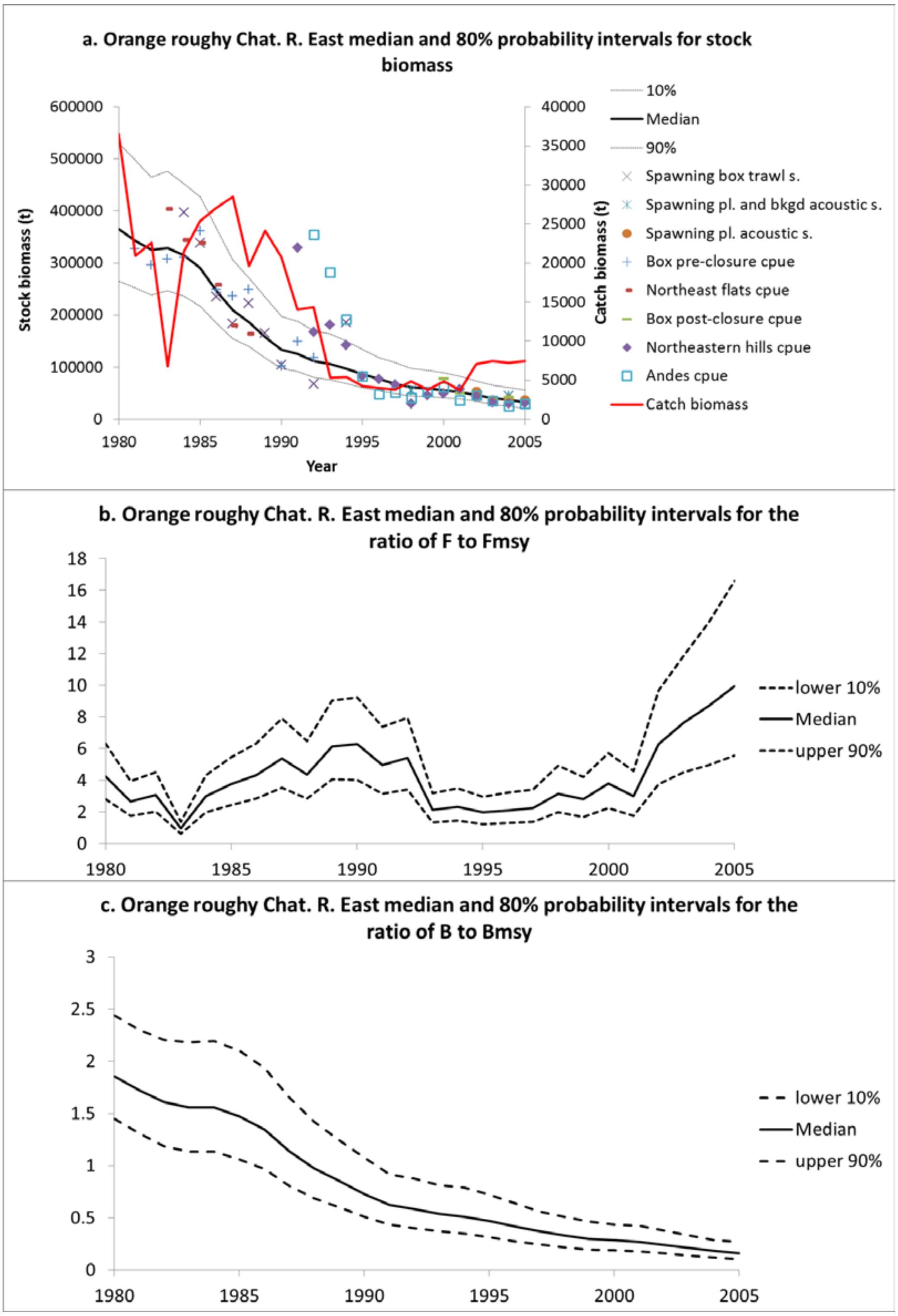

Figure 33: Posterior median and 90% intervals for a. stock biomass, b. F/F_{msy} and c. B/B_{msy} deviates for the BSP(φ=0.5) model ORH 3B East.

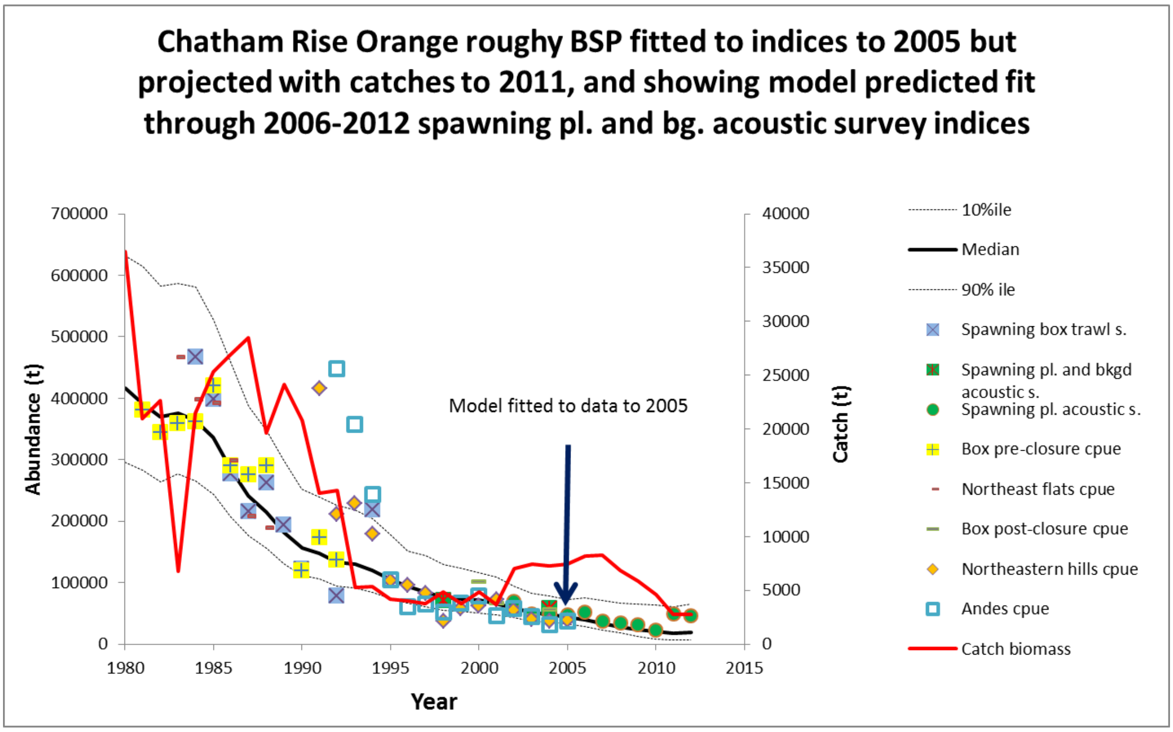

Figure 34: Posterior median and 90% intervals for stock biomass for the BSP(φ=0.5) model for ORH 3B East. The model was fitted to data to 2005 and then projected using catch records from 2006–2012 to show how the model predicted biomass trajectory relates to the observed indices divided by their posterior median *q*.

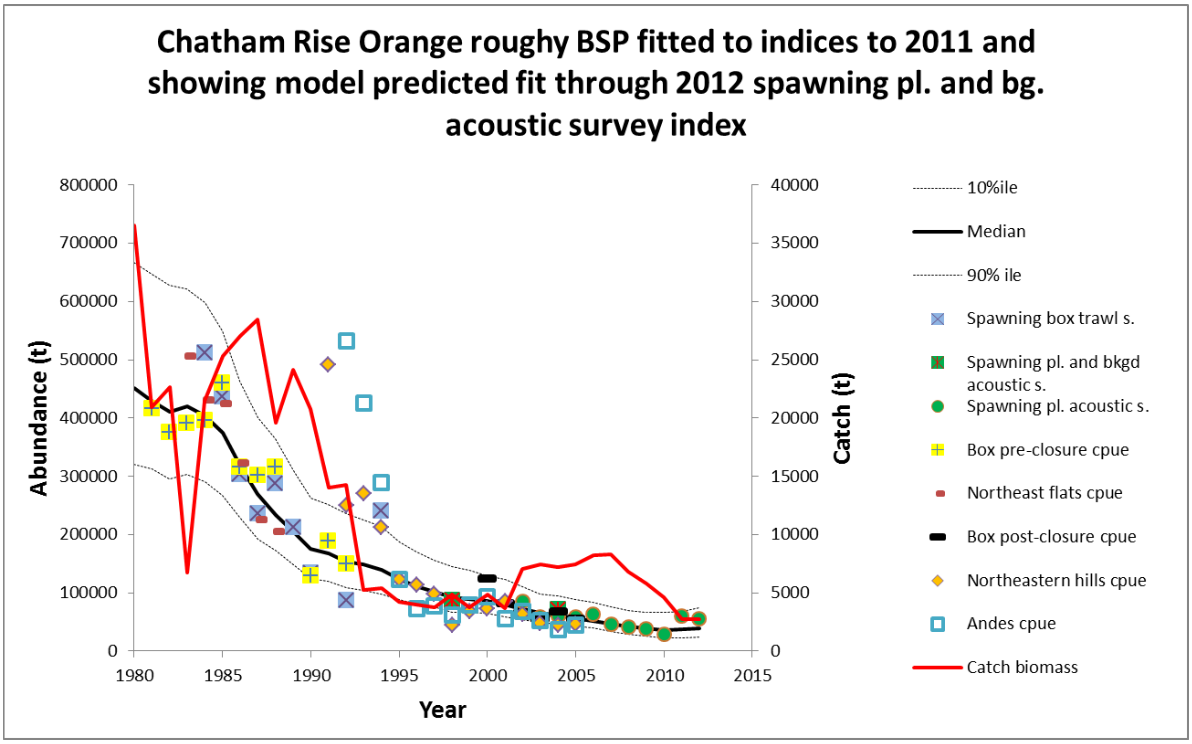

Figure 35: Posterior median and 90% intervals for stock biomass for the BSP(φ=0.5) model for ORH 3B East. The model was fitted to data to 2011.

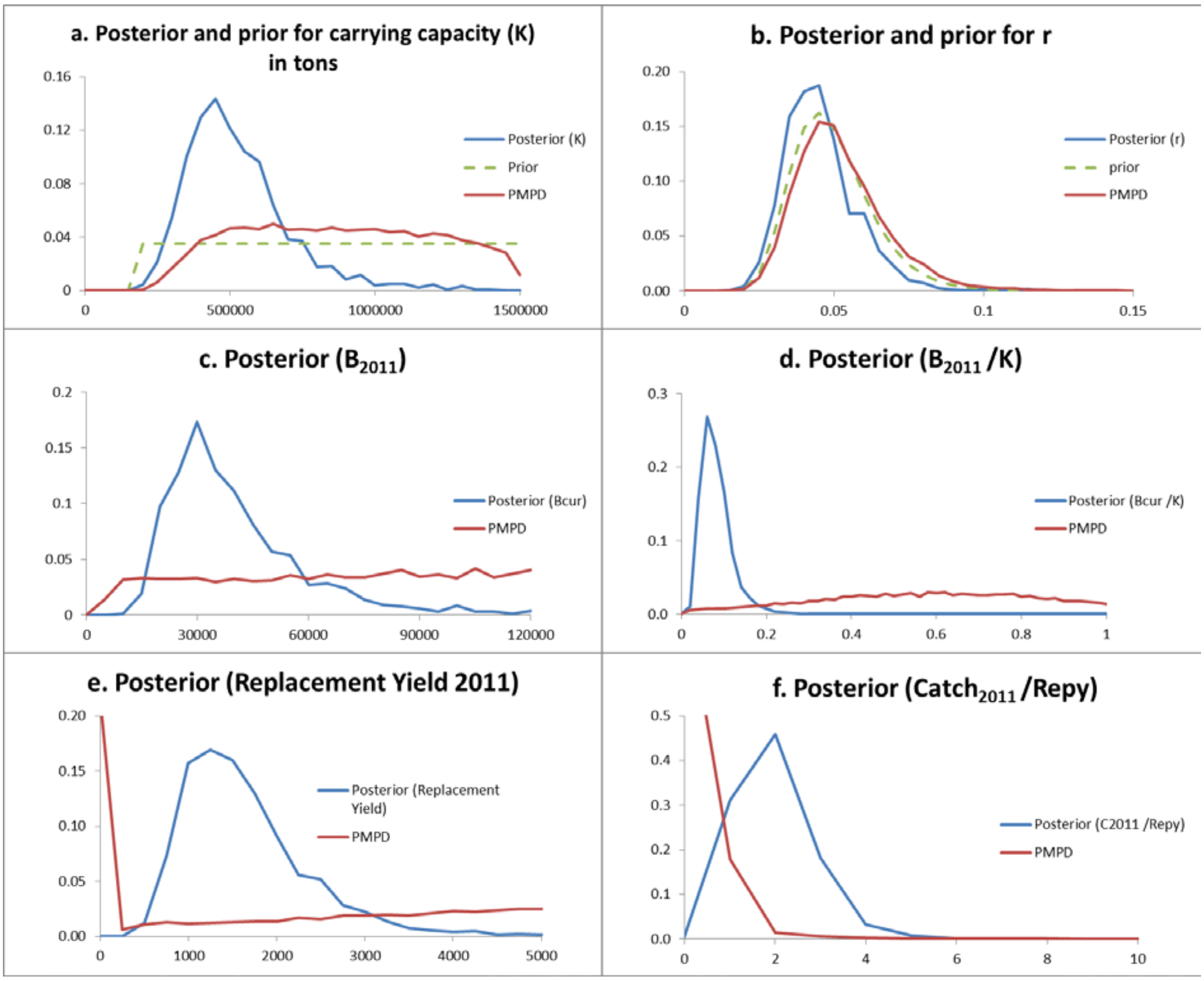

Figure 36: Prior, post-model, pre-data distributions for a) carrying capacity, b) intrinsic growth, c) current stock biomass, d) depletion, e) RepY$_{cur}$ and f) Catch$_{cur}$/ RepY$_{cur}$ for the BSP(φ=0.5) model for ORH 3B East.

Conclusions

The BSP model was able to fit the abundance index data through to 2012 for ORH 3B East fairly well. The model was also able to predict the subsequent acoustic index data from 2006–2012 when the model was fitted to data to 2005 and then projected through to 2012 using catch records from 2006 to 2011. However, the acoustic indices for 2011 and 2012 were markedly higher than those in the previous years and the model under predicted those values both when fitted to data to only 2005 but also when fitted to data to 2011. This suggests that the BSP model could be expected to reliably predict stock trajectories for at least three to four years into the future for catch scenarios that do not depart much from recent years.

These results stand in contrast to results of an attempt in 2006 to fit CASAL to abundance index and catch-at-length data for Chatham Rise east orange roughy. That attempt was unable to provide informative results since the age-structured model mostly predicted recovery after catches declined due to the expected supply of recruitment from average unfished conditions up to about 30 years after the fishery started. The BSP, however, predicted surplus production from a surplus production function that had no such lag built in and with the low prior median for the maximum rate of increase was able to predict the continuation of low stock biomass following the period of heavy depletion. Results more recently obtained from a successful CASAL application to Chatham Rise orange roughy are not comparable with those from the BSP model, since this more recent application was to a number of disaggregated stock units. CASAL was fitted to shorter abundance index time series for each of the stock units and unlike this BSP application excluded all fishery dependent abundance indices.

4. CONCLUSIONS AND FURTHER WORK

For eight of the ten stocks considered in this report, the BSP model provided an informative analysis of the available catch and abundance index data. The computation of post-model, pre-data distributions (PMPDs) was essential to diagnosing whether the stock assessment data were sufficient to provide information about stock status. This was especially the case for instances in which stocks appeared to be lightly fished. An update in the posterior over to the right of the PMPD distribution for depletion appeared to be reasonably indicative of a stock being lightly fished. This still left a posterior distribution for K and stock biomass that had thick tails. The latter could be expected for instances in which data suggest a lightly fished stock, since depletion needs to occur to be informative about the upper bound for K and stock biomass.

It is important to be able to diagnose when model outputs suggest that there is insufficient information in the data to reliably assess stock status. Such a condition could occur as a result of particular configurations in the data; for example, when an abundance index shows no pronounced trend and does not overlap with the period in which the heaviest exploitation occurred. A lack of information could be potentially diagnosed from comparisons between the posterior and PMPD distributions, which may show considerable overlap. The two instances in which the data were judged to be insufficiently informative for stock assessment had bimodal posterior distributions for depletion and F_{last}/F_{msy} and the posterior retained higher densities near the main mode of the PMPD distribution. It is recommended that simulation modelling be applied to characterise how abundance index series interact with production models to produce posteriors for depletion under a range of scenarios for actual stock depletion. This type of analysis could help to formulate reliable diagnostics about when data are truly informative about different scenarios for depletion.

Where informative priors were available for constants of proportionality (q) for fishery independent abundance indices, this helped considerably to provide informative estimates of stock status. However, the formulation of informative priors for q for fishery independent abundance indices needs to be done carefully to avoid inconsistencies in the stock biomass implied by the indices in combination with the informative q priors. The q priors for the acoustic and trawl surveys developed in the 2013 CASAL assessment for the western stock of hoki for example implied considerably different stock biomass values. This may be fine for an age structured model which can represent the different stock components measured by the different surveys. However, the q-priors for different abundance indices fitted in age-aggregated models such as BSP would need to be adjusted so that they applied only to the vulnerable stock biomass component being modelled.

An informative prior for q was however not always sufficient to provide informative results on stock status, even in combination with an informative prior for r. Over the catch time series there had to be at least some depletion response in the abundance indices for the BSP implementation to provide informative results about stock status.

Where a generalised version of the Schaefer production model was considered, e.g., the Fletcher-Schaefer model with the ratio for B_{msy} to K set at values well below 0.5, fits to the data were as good as with the Schaefer model. Also, Bayes factors tended slightly to favour the Fletcher-Schaefer model for those stocks in which both models were considered. Bayes factors were useful in indicating which model runs had stronger support from the data when different model runs were fitted to the same set of abundance indices. This is particularly useful when different runs can indicate different interpretations of current stock status and suggest different management actions.

Where comparisons were carried out between BSP results and CASAL results, stock status results and projection results tended to be quite similar, suggesting that the primary information about stock status in assessments with several different types of data comes from historical catch records and abundance index data. Further work is required to more systematically compare BSP results with those from implementations of CASAL to the same stocks. This will be useful for finding those conditions in which results could be expected to be similar versus situations where they could be expected to be different. For example, differences in estimates of depletion between CASAL and BSP could result when an abundance index is derived from spawning aggregations when the fishery targets both immature and mature fish. This work should also focus on comparisons of estimates of stock status as well as stock trajectories under different quota policy options.

As found in other applications of BSP, larger assumed values for process error variance resulted in higher estimates of stock size. In all of the case studies where different process error standard deviations were tried, Bayes factors favoured least the model runs with the highest process error standard deviation (0.15) and favoured most the runs with the smaller process error SDs (0.005 or 0.05). Further work is required to develop biologically justifiable assumptions about the base case value assumed for the standard deviation in process error deviates for different life history types. This could be achieved via further exploratory simulation modelling with an age-structured model that applies different levels of standard deviation for recruitment deviates and also exploratory modelling for stocks with a lot of reliable catch-age data.

It is expected that the BSP model could offer reliable assessments of stock status and evaluations of fishery management options when the full time series of catch biomass values from the start of the fishery is available and at least one stock trend index is available that can be explained by variation in the catch biomass time series, i.e., the stock trend index shows the most depletion when catches were highest and a recovery following the reduction in catches following a period of high catches. It is expected that the approach will also work well for short-lived to long-lived fishes with at least a three-year average age at maturity. It is expected that the method could fail for very short-lived species with considerable recruitment variability, since trends in stock size may be more strongly influenced by environmental conditions that affect recruitment success. The approach will also work best when estimates of life history parameters and a range of plausible values for the recruitment steepness parameter are available for the formulation of a prior for r. Without the availability of such information, the methodology would then need to rely on there being informative variation in the catch and abundance index data. It is also advantageous to implement a constrained state-space modelling approach in which the process error variance is set at some base case plausible value and the observation error variance is treated as a fixed parameter but determined through an iterative fitting process. From accumulated experience in applying the BSP model, it appears that for most iteroparous fish stocks, the base case values for the process error standard deviation could be set in the range of 0.05–0.10, with larger values applied for shorter-lived species that are believed to have considerable interannual variation in recruitment.

Further work is also recommended to characterise conditions in which hyperstability versus hyperdepletion in abundance indices could be expected. For example, for LIN 3&4 it is plausible that hyperdepletion could have occurred in the commercial long line index due to a change in selectivity from very large-sized ling to smaller sized ling in later years. Further research is required to develop reasonable approaches to more accurately interpret fishery dependent abundance indices when hyperstability versus hyperdepletion may have occurred.

Finally further work is recommended for the development of base-case specifications for the BSP model in future stock assessments and also the formulation of a short-list of recommended types of sensitivity tests to apply in future stock assessments using BSP.

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APPENDIX 1: Hyperstability in commercial catch rate data for HAK 3

A plot of the standardised commercial catch rate data versus trawl survey index indicates pronounced hyperstability in the commercial catch rate index (Figure 24). Estimates of the hyperstability coefficient are considerably less than one: with the fitted model constrained to go through the origin the least squares estimate is 0.53. The R-squared for a linear model constrained to go through zero was about 22% whereas that for a hyperstability model was about 62%. This suggests that it may be prudent to consider further exploration of hyperstability in New Zealand commercial catch rate data, at least for this species, where some fishery independent index of abundance is also available. In the analyses conducted in this report however, we ignore the hyperstability hypothesis.

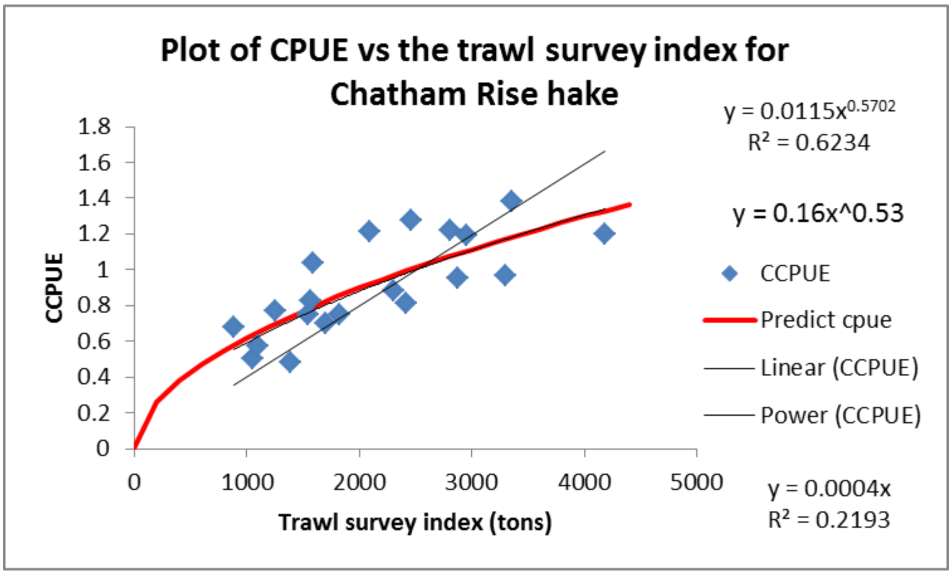

Figure 37: Plot of standardised commercial catch rate versus the trawl survey index for Chatham Rise hake (HAK 3).