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Research Paper

Uniform, uninformed or misinformed?: The lingering challenge of minimally informative priors in data-limited Bayesian stock assessments

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ABSTRACT

A Bayesian approach to parameter estimation in fisheries stock assessment is often preferred over maximum likelihood estimates, and fisheries management guidelines also sometimes specify that one or the other paradigm be used. However, important issues remain unresolved for the Bayesian approach to stock assessment despite over 25 years of research, development, and application. Here, we explore the consequence of a common practice in Bayesian assessment models: assigning a uniform prior to the logarithm of the parameter representing population scale (log-carrying capacity for biomass-dynamics models, or log-unfished recruits for age-structured models). First, we explain why the value chosen for the upper bound of this prior will affect parameter estimates and fisheries management advice given two properties that are met for many data-poor stock assessment models. Next, we use three case studies and a simulation experiment to show a substantial impact of this decision for data-limited assessments off the US West Coast. We end by discussing four methods for generating an informative prior on the population scale parameter, but conclude that these will not be suitable for many assessments. In these cases, we advocate that maximum likelihood estimation is a simple way to avoid the use of Bayesian priors that are excessively informative.

1. Introduction

For at least 60 years, statistical and theoretical models have been used in fisheries science to estimate biological parameters (e.g., population productivity), justify management targets (e.g., maximum sustainable yield), and predict outcomes from different management actions (e.g., expected fishery yield). Bayesian statistics have been used for more than 25 of those years to estimate population dynamics parameters and uncertainty about their values (Collie and Walters, 1991), and Bayesian parameter estimation remains widely used in stock assessment (Maunder, 2003). Bayesian parameter estimation requires specifying a prior probability distribution for all model parameters. The analyst then calculates a posterior distribution for parameters as the product of their prior probability and the probability of data having arisen given these values (termed the "model likelihood"). Finally, the analyst generally uses numerical techniques to sample parameter values from this posterior distribution, and then summarizes these samples by reporting the posterior mean, median, and/or credible intervals for a given parameter or derived quantity.

In recent years, Bayesian assessment methods have become central to the assessment and management of "data-limited" stocks (which we define as stocks with little or uninformative data, insufficient institutional capacity for analysing data, or otherwise having impediments to a conventional stock assessment). Scientific advice is increasingly important for the large proportion of stocks worldwide that do not have existing stock assessments (Costello et al., 2012; Thorson et al., 2012), and stock reduction analysis (SRA) methods (Kimura and Tagart, 1982) are increasingly used to estimate allowable catches for these stocks (Cope, 2013; Dick and MacCall, 2011; MacCall, 2009; Martell and Froese, 2013; Walters et al., 2006). SRA models estimate population size using a specified value or distribution for the ratio of final biomass relative to initial biomass, termed the "final biomass ratio" (or less frequently by specifying a distribution *a priori* on some other parameter that is correlated with population scale). SRA models generally have little information to update the value or distribution for the final biomass ratio, so the value/distribution for the final biomass ratio strongly determines the resulting estimates of allowable catch (Wetzel and Punt, 2011). Ongoing research has expanded Bayesian SRA to include abundance indices (Punt and Butterworth, 1997; Cope et al., 2015; Froese et al., 2016), and these methods will generally have little information to estimate the absolute size of the population (e.g., Cope et al., 2015). As we will see, these extended SRAs are often highly sensitive to decisions about the prior distribution for the parameter determining population size.

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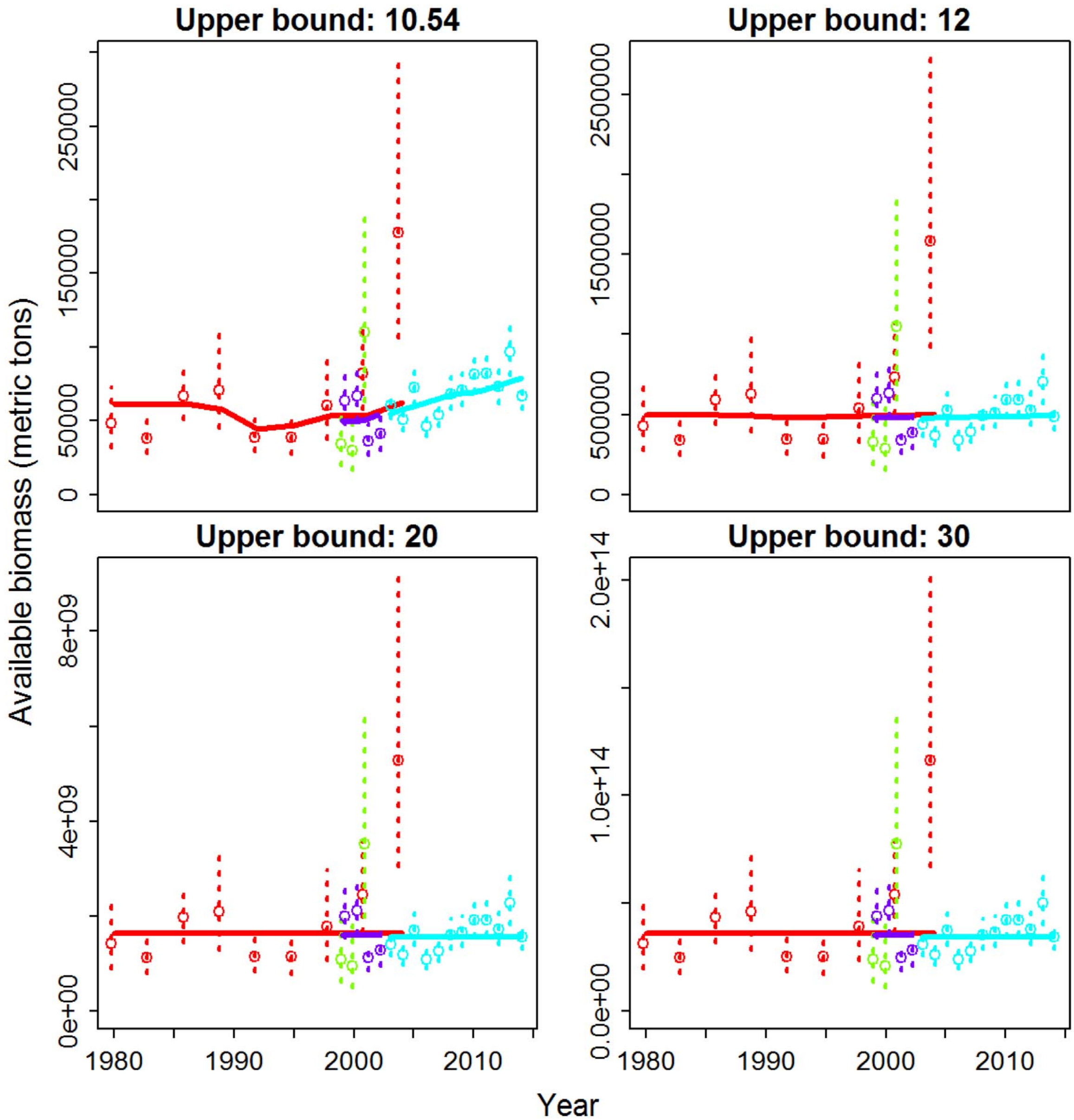

Fig. 1. Laplace approximation to the posterior density (top panel) and the ratio of population biomass in 2015 relative to average unfished biomass (bottom panel) across a wide range for the population scale parameter, $\ln(R_0)$, for a stock assessment model for arrowtooth flounder in US federal waters off Oregon, Washington, and California.

Despite its wide use for both data-rich and data-limited stock assessments, Bayesian parameter estimation in stock assessment models poses important challenges that have not been solved. In the early days of Bayesian assessment modelling, Punt and Hilborn (1997) noted the difficulty of specifying prior distributions for model parameters. As one example, they observed that (almost) all stock assessment models must estimate the population scale (carrying capacity K in surplus production, or average unfished recruits R_0 in age-structured models). Punt and Hilborn (1997, Fig. 1) show that integrating across a seemingly "uninformative" prior on population scale (a uniform prior on unfished biomass) results in an implied prior on the final biomass ratio that is strongly informative. Difficulties also arise when integrating across multiple informative priors on different model parameters (Brandon et al., 2007), and when eliciting priors from experts and scientists (Haapasaari et al., 2013).

As an alternative to Bayesian parameter estimation, stock assessment scientists have frequently used maximum likelihood (ML) estimation. ML does not require integrating across model parameters, and prior information when available can be included by specifying informative "penalties" on parameters (Maunder, 2003), e.g., based on meta-analytic information regarding the stock-recruitment relationship (Dorn, 2002). By using informative penalties without integrating across parameters, ML avoids the influence of the tail of the prior distributions on stock assessment results. ML techniques are also available for estimating parameter uncertainty either with or without parametric assumptions (i.e., asymptotic standard errors and likelihood profiles, respectively), and perform comparably to Bayesian methods for this task (Magnusson et al., 2013) although care must be given to parameters whose estimates are highly skewed (Stewart et al., 2013). ML is generally less computationally demanding than Bayesian estimation, so using ML estimation is often useful for complicated models where full Bayesian estimation is infeasible. Model selection and model-averaging techniques have previously been developed and tested for both Bayesian and ML modelling (Burnham and Anderson, 2002; Hooten and Hobbs, 2015; Ward, 2008).

Despite these similarities between ML and Bayesian approaches to parameter estimation, we note that assessment reviewers and management authorities have at times approved the use of only one or the