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William Harford, Meaghan Bryan, Elizabeth A. Babcock

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Probabilistic assessment of fishery status using data-limited methods

William Harford[1], Meaghan Bryan[2], Elizabeth A. Babcock[3]

[1]Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, FL, 33149; [2]NOAA Southeast Fisheries Science Center, Sustainable Fisheries Division Miami, FL, 33149; [3] Department of Marine Biology and Ecology, University of Miami, Miami, FL 33149

Introduction

Within United States fishery management, National Standard Guidelines direct harvest decisions based upon reference points that denote whether overfishing is occurring and whether the stock is considered to be overfished. Science has a key role in effectively communicating uncertainty in stock status determination in relation to fisheries management reference points. Uncertainties arise in indicators of stock status and in delineation of management reference points. Reference points are often calculated from estimates of growth, survival, and productivity parameters using per-recruit models. These parameters are obtained through statistical modeling or through expert judgment. Where statistical estimation is concerned, several sources of uncertainty affect parameter estimation. Process uncertainty arises from natural biological variation and observation uncertainty arises from sampling and measurement error. Both of these types of uncertainties contribute to residual error between observed and predicted values. Parameter estimation uncertainty is a consequence of sampling and measurement error and a consequence of model misspecification (Francis and Shotton 1997; Haddon 2011; Mangel 2006; Peterman 2004; Peterman and Peters 1998). Like management reference points, indicators of stock status, including length-based mortality estimators, also rely on uncertain growth and survival parameters (Ault et al. 2005; Beverton and Holt 1957; Gedamke and Hoenig 2006).

A general approach to probabilistic assessment should propagate uncertainty in life history parameters to estimation of stock status indicators, to reference points, and to conclusions about the exploitation status of the fishery (Jiao et al. 2005; Prager et al. 2003). The Bayesian approach offers one such method for moving beyond point-estimates to making probability statements about management quantities. This approach utilizes a Markov chain Monte Carlo method to numerically sample posterior distributions of life history parameters. Statistical models of life history characters (e.g. growth, maturity, length-weight conversion) are fit concurrently, but with separate likelihood functions. Through an iterative process, samples from posterior distributions are obtained. Uncertainty in life history parameters is then propagated to estimation of per-recruit-based reference points and data-limited indicators of stock status, like length-based mortality estimators. Probabilistic statements about stock status are then made by calculating probabilities associated with status indicators (e.g. current fishing mortality or catch) exceeding reference points (e.g. F_{lim} or MSY) via MCMC simulation. Implementing a Bayesian approach provides a unified numerical framework for linking parameter estimation uncertainty to reference point and status indicator uncertainty and to probabilistic measures of stock status. The Bayesian framework can also be used to represent uncertainty as informative prior distributions for parameters that are difficult to measure, like natural mortality and stock-recruitment productivity.

Our objective is to demonstrate that data-limited stock assessment is amenable to probability-based assessment of stock status. Data-limited methods that rely on per-recruit reference points and that rely on relatively simple stock status indicators enable straightforward demonstration of the role of uncertainty in determining stock status without the unwieldy complexity of data-rich assessment modeling. A step-by-step example is constructed using a simulated dataset. This example yields probabilistic distributions of management reference points, probabilistic estimates of current total mortality calculated from length composition data, and an estimate of *MSY*. Kobe plots are then constructed to represent probability-space of current fishery status. The hypothetical example demonstrates this methodology. Management advisory statements derived from this approach can better reflect several types of uncertainty than the use of point-estimates. Consequently, this approach is a starting point for aligning the use of data-limited assessments with the matter of risk assessment and risk tolerance (Jiao et al. 2010).

Method summary

To demonstrate how probabilistic statements about fishery status can be made, data sampling was simulated from an age-structured fish stock with somatic growth following the von Bertalanffy growth function (von Bertalanffy 1938), allometric length-weight function ($W_i = a_W L_i^{b_W}$), and maturation at age 1. Data sets of (1) length-age pairings, (2) length-weight pairings, (3) mean lengths in catches during a period of stable catches, and (4) mean annual catch in biomass were available to the estimation procedure. A Bayesian approach is used to fit life history functions using the software OpenBUGS (Lunn et al. 2009). Diffuse priors are specified for estimated parameters and for error variances of growth and length-weight functions. Parameter chains are evaluated to determine whether the Markov chain Monte Carlo algorithms converged on their target distributions. Convergence is checked for all model parameters against Gelman-Rubin convergence criteria (Gelman et al. 2004).

The estimation procedure consists of five steps that occur concurrently. In the first step, posterior distributions of growth parameters are estimated. (Fig 1).

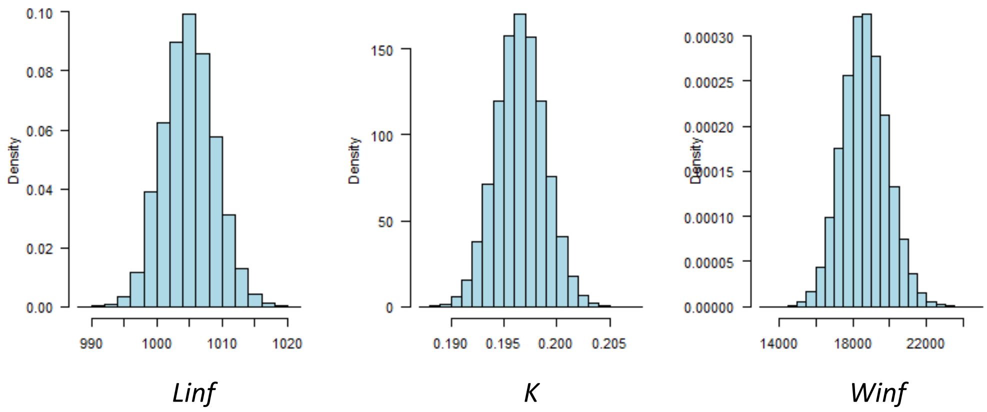

Figure 1. Posterior distributions of von Bertalanffy parameters K and Linf, and Winf parameter.

In the second step, priors are specified for natural mortality (*M*) and stock-recruitment curve shape (i.e. steepness; *h;* Fig. 2). To inform priors for steepness, meta-analytic approaches and life history correlates are useful (Hamel 2014; Shertzer and Conn 2012).

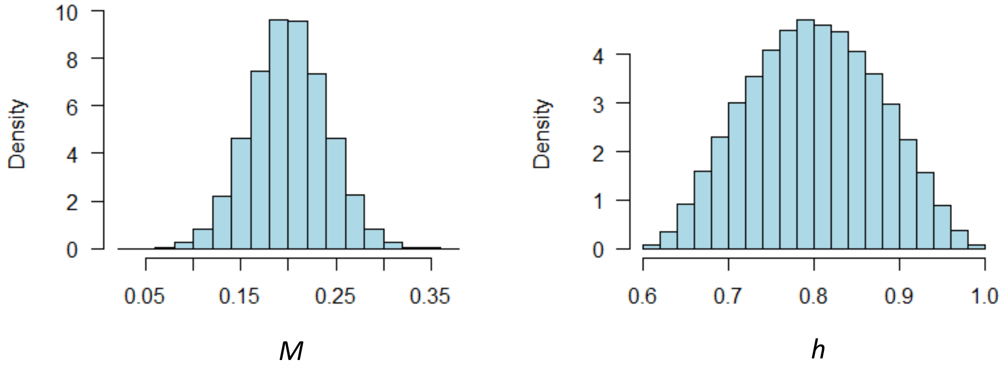

Figure 2. Example priors for natural mortality (*M*) and stock-recruitment steepness (*h*)

In step three, fishing mortality is estimated using mean lengths in catches and the Beverton-Holt mean length Z estimator. The posterior distribution of *Z* incorporates uncertainty in growth parameters and sampling error associated with mean lengths in catches. Calculation of current fishing mortality *F* is calculated as *F=Z-M*, which incorporates uncertainty in *Z* and *M*. Spawning biomass as a fraction of the unfished state can be calculated using per-recruit metrics and equation (1) in Hordyk et al. (2015), thus, reflecting uncertainty in *M*, *F*, and *h* (Fig. 3).

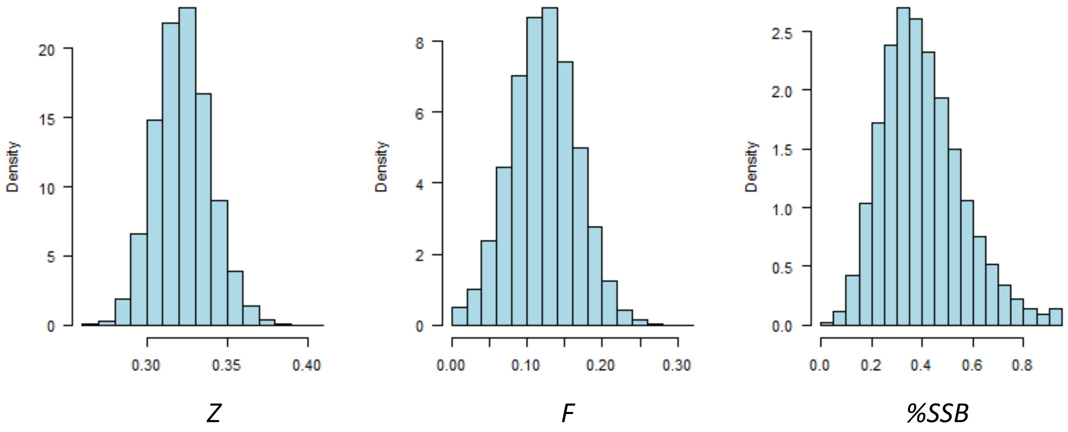

Figure 3. Status indicators of total mortality (*Z*), fishing mortality (F), and spawning biomass as a fraction of the unfished state (%SSB).

In step four, per-recruit calculations are used to specify reference points, including those like F SPR 30% that can serve as proxies for *Fmsy*. Given total mortality estimation from the previous step, per-recruit curves can also be scaled to total catches, thus provided estimates of other relevant management quantities like maximum sustainable yield (Fig. 4).

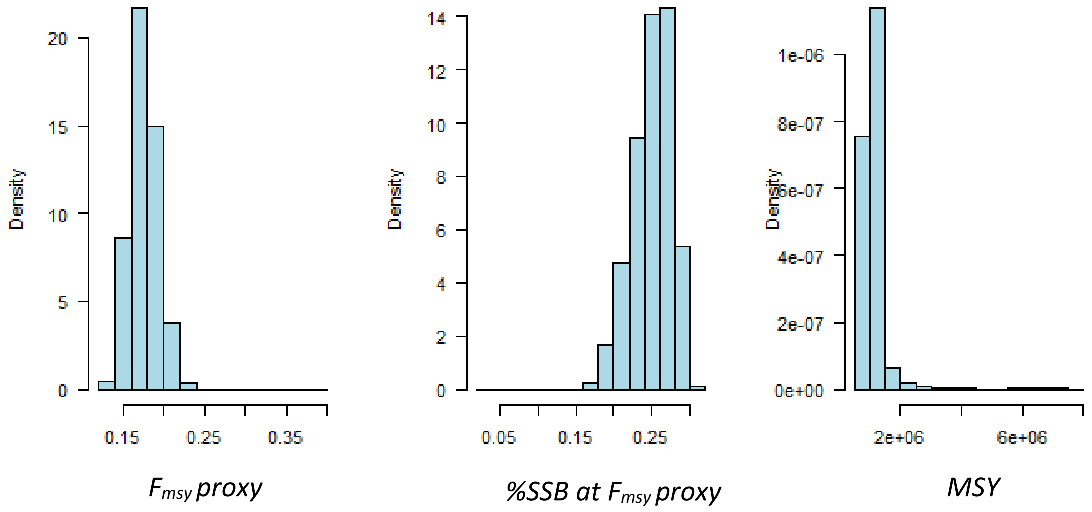

Figure 4. Management reference points.

Finally, uncertainty in status indicators and in reference points are utilized to make probabilistic statements about the state of resource. For instance, the probability of current fishing mortality exceeding F_{msy} is approximated by the function $D_j = \begin{Bmatrix} 1, \text{ if } F > F_{msy} \\ 0, \text{ otherwise} \end{Bmatrix}$, where D_j is an indicator function that is calculated for T total MCMC iterations, and $\Pr(F > F_{msy}) = {\sum_{j=1}^{T} D_j} \big/ T$. Kobe plots are generated that reflect fishery status and its uncertainty (Fig. 5). Consequently, management advice is reflects degree of belief in alternative resource states.

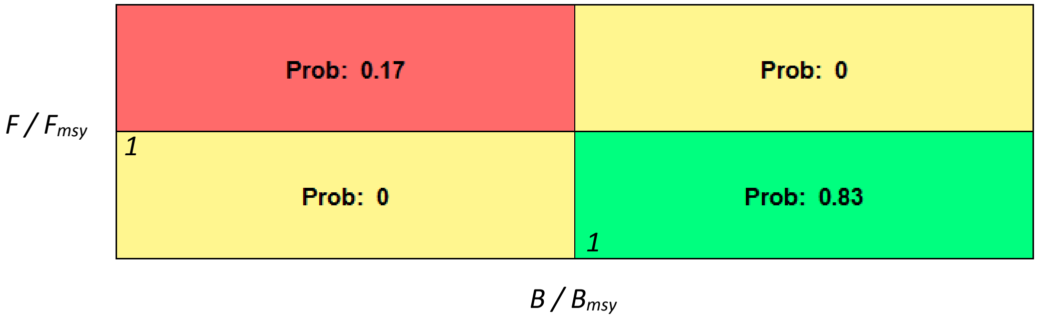

Figure 5. Kobe plot describing resource state in probabilistic terms that reflect uncertainty in data used in analysis and in stock productivity.

References

Ault J.S., Smith S.G., Bohnsack J.A., 2005, Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. ICES J Mar Sci 62, 417–423.

Beverton R.J.H., Holt S.J., 1957, On the dynamics of exploited fish populations. London UK, Chapman and Hall.

Francis R., Shotton R., 1997, “Risk” in fisheries management: a review. Can. J. Fish. Aquat. Sci. 54, 1699–1715.

Gedamke T., Hoenig J.M., 2006, Estimating Mortality from Mean Length Data in Nonequilibrium Situations, with Application to the Assessment of Goosefish. Trans. Am. Fish. Soc. 135, 476–487.

Gelman A., Carlin J.B., Stern H.S., Rubin D.B., 2004, Bayesian data analysis, Second Edition. London, U.K., Chapman and Hall/CRC.

Haddon M., 2011, Modelling and Quantitative Methods in Fisheries, Second Edition. Second edition, Chapman and Hall/CRC.

Hamel O.S., 2014, A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES J. Mar. Sci. J. Cons. fsu131.

Hordyk A.R., Loneragan N.R., Prince J.D., 2015, An evaluation of an iterative harvest strategy for data-poor fisheries using the length-based spawning potential ratio assessment methodology. Fish. Res.

Jiao Y., Chen Y., Wroblewski J., 2005, An application of the composite risk assessment method in assessing fisheries stock status. Fish. Res. 72, 173–183.

Jiao Y., Reid K., Nudds T., 2010, Consideration of uncertainty in the design and use of harvest control rules. Sci. Mar. 74, 371–384.

Lunn D., Spiegelhalter D., Thomas A., Best N., 2009, The BUGS project: evolution, critique and future directions (with discussion). Stat Med 28, 3049–3082.

Mangel M., 2006, Commentary: accounting for uncertainty in marine reserve design. Ecol Lett 9, 11–12.

Peterman R.M., 2004, Possible solutions to some challenges facing fisheries scientists and managers. ICES J Mar Sci 61, 1331–1343.

Peterman R.M., Peters C.N., 1998, Decision analysis: taking uncertainties into account in forest resource management. In: V S., Taylor B. (Eds.), Statistical Methods for Adaptive Management Studies, Handbook No. 42. Victoria, British Columbia, British Columbia Ministry of Forestry.

Prager M.H., Porch C.E., Shertzer K.W., Caddy J.F., 2003, Targets and Limits for Management of Fisheries: A Simple Probability-Based Approach. North Am. J. Fish. Manag. 23, 349–361.

Shertzer K.W., Conn P.B., 2012, Spawner-Recruit Relationships of Demersal Marine Fishes: Prior Distribution of Steepness. Bull. Mar. Sci. 88, 39–50.

von Bertalanffy L., 1938, A quantitative theory of organic growth (Inquiries on growth laws II). Hum. Biol 10, 181–213.