Estimating the probability density function of the Overfishing Limit for crab stocks

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Alaska Fisheries Science Center, Seattle WA

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1 Introduction

A workgroup was convened in summer 2011 (informally by email) to provide guidance to the crab stock assessment authors on appropriate ways to estimate probability density functions (pdfs[1]) for the OFL given that the Crab FMP now contains maxABC control rules by tier. These rules are explicitly linked to the estimated extent of uncertainty in the OFL. Consistency in how the pdf for the OFL is determined is necessary so that there is consistency in maxABC specifications for crab stocks. However, there are also implications for how this pdf is determined for groundfish stocks because uncertainty in ABC control rules is presently being analyzed. A public meeting was held to facilitate further discussion and recommendations in conjunction with the Crab Modeling Workshop at the Alaska Fisheries Science Center (and by Webex) on January 10th. This meeting included biologists working on groundfish stock assessments in addition to the key members of the CPT and SSC (a summary is reported separately for Council presentation). Participants in the meeting (as well as the members of the workgroup) are listed in Appendix 1.

The meeting reviewed the methods employed in the past by the Crab Plan Team to calculate the pdf for the OFL, compared these methods with how ABCs are determined for groundfish stocks, and focused on the practicalities of alternative estimators (from assessments) for this pdf. Presently, only for Tier 1 groundfish stocks does the relationship between the OFL and the ABC relate to a pdf, whereas for crab stocks, Tiers 1-4 (as described in Box 1) account for uncertainties. The Tier 1 stocks for groundfish rely on estimates of pdfs for F_{msy} . For crab stocks, a "P*" approach was developed, which gives an ABC that has a specified level of probability of exceeding the "true" OFL.

Discussion at this meeting focused upon three main topics:

a) distinctions between the estimated OFL used in management which may be adjusted by control rules, the estimate of OFL without the control rule and the true, but unknown OFL.
b) calculation of the variance of the OFL and the probability of exceeding *OFL*, including risk-neutral assumptions (i.e., avoid specifying precautionary assessment model assumptions) inherent in the OFL; and
c) how to handle sources of uncertainty not captured in the stock assessment, including the implied assumption that OFL estimates are derived from "risk neutral" methods (e.g., the uncertainty for proxies of F_{msy}).

[1] Note that the strict definition of the function describing the probability density (PDF) may not necessarily apply and that what was discussed and meant were probability density estimates (which may involve simulation algorithms rather than analytical functions)

2 Summary

The meeting reviewed the methods employed by the crab Plan Team and that for groundfish, with focus on the practicalities of alternative estimators (from assessments) for OFL. At the outset, participants wished to clarify some of the goals and terminologies that are used when referring to an "OFL pdf". It was noted that the term "OFL" is sometimes used to represent the actual value that is specified for management (typically by applying a control rule and typically published in the Federal Register). The *specified* OFL is a fixed value, in contrast to the *true-but-unknown* OFL, which is a random variable. Since the true-but-unknown OFL is a random variable, it has a probability density function that can be computed from the stock assessment. The pdf for the true-but-unknown OFL allows probability statements to be made about the relationship between candidate ABC values and the true OFL (e.g., a value of *x* will have *y* probability of being larger than the true-but-unknown OFL). Since the pdf cannot be observed, estimators—either parametric or non-parametric-- are required. For example, if the pdf is approximately normal, the mean can be approximated by the mode of the posterior density and the variance can be approximated by inverting the Hessian matrix (or some proxy such as squaring the product of the posterior mode and the survey biomass CV).

The meeting clarified that inferences from these estimators are implicitly treated as Bayesian due to the probability statements that are required[2].

For the Tier 1 groundfish stocks, since the pdf of F_{msy} is required to be reliable, the computations can be done straightforwardly from the Hessian approximation to the posterior density (Box 2). The meeting noted that, in practice, Tier 1 assessments sometimes result in a relatively small buffer between OFL and ABC and that this is counter-intuitive given the difficulty of accurately measuring abundances and the typical variability observed between the outcomes of alternative (but equally plausible) model specifications. Presently, management strategy evaluations are underway with various post-docs and research projects which aim to quantify the size of this effect, and identify alternative risk-averse approaches that are suitable for groundfish stocks in other Tiers (in addition to Tier 1).

The meeting suggested that one approach to evaluate whether existing proxies are appropriate and existing control rules are consistent would be to apply lower tier control rules to higher tier (and perhaps simulated) stocks. This might prove useful for both crab and groundfish OFL/ABC specification systems.

For crab, the focus was on methods for computing pdfs for stocks in Tiers 3 and 4. A procedure was outlined which (for both tiers) involves extensive, but straightforward simulations. These are (revised slightly from previous methods) shown in Box 3. As outlined, computing OFL pdfs for Tier 3 crab stocks involves summarizing output from MCMC (as a representation of the posterior probability density). Provided these have "converged" (i.e., form a reliable estimate of the posterior density function), then the MCMC method has several advantages including 1) distributional assumptions for computing the pdf for the OFL are unnecessary; 2) marginal distributions will account appropriately for "curvature" in the posterior surface; and 3) application of control rules for each individual "draw" from the posterior distribution can be done straightforwardly. A drawback of using MCMC is that obtaining the maxABC for a single model run can be time consuming and can detract from explorations of alternative model specifications/options (which may play a larger role in illustrating model sensitivity/uncertainty). Another is that both achieving and demonstrating convergence are difficult problems. The use of the Hessian approximation to the joint posterior density was considered potentially satisfactory since the

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[2] A frequentist approach would address a statement such as "there is a 95% probability that the μ_{OFL} is contained within $\hat{X}_{OFL} \pm 1.96\hat{S}_{OFL}$ (for a normally distributed random variable)"

calculations involved are much faster. However, the meeting noted that comparisons between Hessian-based estimates of the distribution for the OFL and those from MCMC analyses should be undertaken.

For Tier 4 crab stocks, using a truncated normal (as opposed to a log-normal) distribution for Tier 4 stocks (see Box 3) was noted as a potential concern. There was some indication that this formulation avoided some pathologies in which previous approaches led to distributions of the OFL with medians that were substantially different from the 'best' estimates.

Regarding the issue of what to use when uncertainty in some quantities is unavailable, the meeting discussed alternative estimates of variability. For example, scientists working with west coast groundfish proposed an inverse method to specify probabilities of different stock sizes based on sensitivity tests. Specifically, the steps for that method are:

1. identify a low ending biomass (or OFL) considered half as likely as the base ending biomass (expert judgment on the part of the CPT);
2. assume these represent the 0.5 and 0.125 points along a log-normal distribution (given that they are supposed to represent 50% and 25% of the probability distribution); and
3. take the natural log of the ratio of ending biomass in base state to that in the low state. Divide by 1.15 to get an estimate of standard error of the logarithm of the OFL.

An advantage of this method is that it is transparent and can be used to account for extra-model uncertainty in obtaining the low biomass scenario. The meeting noted that there would be difficulty in subjectively identifying a low ending biomass (or OFL) that is considered "*half as likely*" as the base ending biomass and that it may be easier and just as intuitive to specify the variance of the OFL directly.

For crab stocks, a distinguishing characteristic relative to groundfish is that the OFL is computed using control rules instead of being based on direct consideration of F_{msy}. For example, it can be argued that μ_{OFL} (or $\hat{X}_{OFL}$ as the estimator) should be based directly on F_{msy} (i.e., $\hat{X}_{OFL} = f\left(\hat{F}_{msy}\right)$ and that then catch limits based on a control rule (call it OFL') be used for evaluation purposes. Quantities such as the probability of OFL' and any relevant ABCs exceeding $\hat{X}_{OFL}$ would then be relative to actual overfishing (which could be interpreted as exceeding F_{msy}[3]) rather than the probability of exceeding a specific FMP definition of the OFL control rule. This was an aside from the task of following the present definitions of OFL control rules. However, it reflects the discussion the meeting had on the added complexity of the calculations for crab, especially for Tier 3 and 4 stocks for which the OFL follows a sloping control rule.

3 Recommendations:

Shorter term considerations

1. Make clear distinctions between regulatory values (OFL and ABC), true but unknown values (μ_{OFL}), and estimators (e.g., $\hat{X}_{OFL}$)
2. Calculate the pdf of the OFL using pragmatic approaches such as using point estimates of OFL and variances from the uncertainty estimates either from the Hessian or MCMC.
3. Simulation approaches as outlined above for crab Tier 3 and 4 should be implemented in a standard software package with clear documentation Note that there is potential for lack of

[3] The actual MSFCMA's definition reads, "The terms 'overfishing' and 'overfished' mean a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce the maximum sustainable yield on a continuing basis."

transparency because since the simulation procedure is complex it may detract from other fundamental issues related to the probability that F_{msy} will be exceeded.

Longer-term broader considerations for both groundfish and crab control rules:

4. Alternative candidate pdf estimators for OFL-ABC determinations might best be evaluated relative to F_{msy} instead of relative to legally-defined OFL control rules (which have explicitly been designed to avoid exceeding F_{msy}, when biomass is estimated to be below B_{msy})
5. Evaluate/reconsider the utility of computing probabilities of proxies:
    a. Do they accurately reflect the uncertainty in actual F_{msy} estimates?
    b. Should post-control rule computation of uncertainties (i.e., computing probabilities of exceeding control rule outputs rather than of F_{msy}) be avoided?
    c. What is the latitude for legal definitions of OFL (via a pre-specified control rule) versus OFL= $f\left(F_{msy}\right)$?
6. Evaluate the consequences of applying control rules from lower tiers to higher-tier stocks to understand general consistency (in terms of risk aversion) and conditions where they vary
7. For crab examine method applied in 2010 to compute OFL pdfs for Tier 4 to a range of stocks including uncertainty in B_{msy} (proxy) and consider bootstrapping to generate uncertainty similar to Tier 3 estimates (using MCMC). It may be difficult to predict how distributional assumptions will compare (e.g., log-normal vs normal since with larger variances more "samples" will be truncated/omitted).
8. Quantify the impact of each source of uncertainty for pdf estimates based on multiple sources of uncertainty (e.g. the Tier 4 OFL control rule). For example, for Tier 4 stocks, what is the contribution to the variance for the OFL from the assumed level of uncertainty associated with natural mortality compared to that related to stock size and the B_{msy} (proxy)? This could be done by successively turning off each source of uncertainty to evaluate the relative impact on results. This has been done in the Crab ACL analysis in conjunction with σ_B values.
9. Examine model-based uncertainty compared to survey-based values. Uncertainty may be underestimated for data-poor stocks for which the assessment pre-specifies many parameters. For Alaska crab and groundfish, survey CVs may provide a consistent treatment across tier levels commensurate with the reliability of stock size estimates as observed in surveys. In general, the stock size and associated reference points of a stock with a high survey CV is considered more uncertain and in need of a larger buffer, then a stock with a low survey CV. However, assuming the uncertainty of the estimate of OFL is primarily due to survey CVs assumes uncertainty in biological rates plays a minor role, and that both survey catchability and selectivity is reasonably high.
10. The size of the buffer between the OFL and the ABC for crab stock is small because of the specification P* = 0.49. Perhaps a comprehensive reconsideration of the Crab Tier system including both the OFL and ABC control rules should be pursued.

    There should be a "risk neutral" treatment of uncertainty and other measures inherent in current specifications process. For example, MMB as a measure of spawning biomass and treatment of 'total catch' when control rules currently applied to MMB (only) and females added in afterwards and B_{msy} includes only males and yet the MSST should conceptually include females. CPT to discuss progress towards using an alternative (and more appropriate) measure of effective spawning biomass/reproductive potential for crab stocks in May.

11. Identifying additional uncertainty in OFL distribution
    a. σ_B,
    b. asymmetry of the uncertainty (if assessment and OFL estimates are not "risk neutral")

c. The impact of pre-specifying rather than estimating parameters. For example, in stocks where fishery availability may change significantly from year to year due to spatial targeting of strong recruitments, more data would be needed to account for this process and model appropriately. In low data situations, the assessment would (typically) assume constant selectivity and hence likely overestimate the precision of abundance and mortalities.

Tiers 1 through 3

For Tiers 1 through 3, reliable estimates of B, B_{MSY}, and F_{MSY}, or their respective proxy values, are available. Tiers 1 and 2 are for stocks with a reliable estimate of the spawner/recruit relationship, thereby enabling the estimation of the limit reference points B_{MSY} and F_{MSY}.

- Tier 1 is for stocks with assessment models in which the probability density function (pdf) of F_{MSY} is estimated.
- Tier 2 is for stocks with assessment models in which a reliable point estimate, but not the pdf, of F_{MSY} is made.
- Tier 3 is for stocks where reliable estimates of the spawner/recruit relationship are not available, but proxies for F_{MSY} and B_{MSY} can be estimated.

For Tier 3 stocks, maturity and other essential life-history information are available to estimate proxy limit reference points. For Tier 3, a designation of the form "F_X" refers to the fishing mortality rate associated with an equilibrium level of fertilized egg production (or its proxy such as mature male biomass at mating) per recruit equal to X% of the equilibrium level in the absence of any fishing.

The OFL and ABC calculation accounts for all losses to the stock not attributable to natural mortality. The OFL and ACL are total catch limits comprised of three catch components: (1) non-directed fishery discard losses; (2) directed fishery discard losses; and (3) directed fishery retained catch. To determine the discard losses, the handling mortality rate is multiplied by bycatch discards in each fishery. Overfishing would occur if, in any year, the sum of all three catch components exceeds the OFL.

Tier 4

Tier 4 is for stocks where essential life-history, recruitment information, and understanding are insufficient to achieve Tier 3. Therefore, it is not possible to estimate the spawner-recruit relationship. However, there is sufficient information for simulation modeling that captures the essential population dynamics of the stock as well as the performance of the fisheries. The simulation modeling approach employed in the derivation of the annual OFLs captures the historical performance of the fisheries as seen in observer data from the early 1990s to present and thus borrows information from other stocks as necessary to estimate biological parameters such as γ.

In Tier 4, a default value of natural mortality rate (M) or an M proxy, and a scalar, γ, are used in the calculation of the F_{OFL}. Explicit to Tier 4 are reliable estimates of current survey biomass and the instantaneous M. The proxy B_{MSY} is the average biomass over a specified time period, with the understanding that the Council's Scientific and Statistical Committee may recommend a different value for a specific stock or stock complex as merited by the best available scientific information. A scalar, γ, is multiplied by M to estimate the F_{OFL} for stocks at status levels **"**a**"** and **"**b,**"** and γ is allowed to be less than or greater than unity. Use of the scalar γ is intended to allow adjustments in the overfishing definitions to account for differences in biomass measures. A default value of γ is set at 1.0, with the understanding that the Council's Scientific and Statistical Committee may recommend a different value for a specific stock or stock complex as merited by the best available scientific information.

If the information necessary to determine total catch OFLs and ACLs is available for a Tier 4 stock, then the OFL and ACL will be total catch limits comprised of three catch components: (1) non-directed fishery discard losses; (2) directed fishery discard losses; and (3) directed fishery retained catch. If the information necessary to determine total catch OFLs and ACLs is not available for a Tier 4 stock, then the OFL and ACL are determined for retained catch. In the future, as information improves, data would be available for some stocks to allow the formulation and use of selectivity curves for the discard fisheries (directed and non-directed losses) as well as the directed fishery (retained catch) in the models. The resulting OFL and ACL from this approach, therefore, would be the total catch OFL and ACL.

Tier 5

Tier 5 stocks have no reliable estimates of biomass and only historical catch data is available. For Tier 5 stocks, the OFL is set equal to the average catch from a time period determined to be representative of the production potential of the stock, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information. The ABC control rule sets the maximum ABC at less than or equal to 90 percent of the OFL and the ACL equals the ABC.

For Tier 5 stocks where only retained catch information is available, the OFL and ACL will be set for the retained catch portion only, with the corresponding limits applying to the retained catch only. For Tier 5 stocks where information on bycatch mortality is available, the OFL and ACL calculations could include discard losses, at which point the OFL and ACL would be applied to the retained catch plus the discard losses from directed and non-directed fisheries.

Box 1. Description of the Tier system in place for crab stocks.

Under Amendment 56, the SSC determines if a stock qualifies under Tier 1. This determination is based on if "reliable" estimates of F_{msy} and its pdf are available. A short background comes from Thompson (1996) where risk averse and risk neutral approximations can be provided given these estimates.

The Tier 1 harvest level is calculated as the product of the harmonic mean of F_{msy} and the geometric mean of the projected biomass estimate: $B_{GM} = \exp\left(\ln \hat{B} - 0.5CV^2\right)$ where $\hat{B}$ is the point estimate (highest posterior density; HPD) of the projected biomass and CV^2 is the coefficient of variation of the point estimate.

For ABC determinations the harmonic mean of F_{msy} is computed as $F_{HM} = \exp\left(\ln \hat{F}_{msy} - 0.5\sigma^2_{\ln F_{msy}}\right)$, where $\ln \hat{F}_{msy}$ is the HPD of log-F_{msy} and $\sigma^2_{\ln F_{msy}}$ is the estimated variance. For both B_{GM} and F_{HM} the CV^2 and $\sigma^2_{\ln F_{msy}}$ are approximated by the Hessian matrix which is the critical part of deriving estimates of the PDF of F_{msy}. Thus simply $ABC = F_{HM} B_{GM}$.

OFL for Tier 1 groundfish is similarly computed as: $OFL = F_{AM} B_{GM}$ where $F_{AM} = \exp\left(\ln \hat{F}_{msy} + 0.5\sigma^2_{\ln F_{msy}}\right)$.

For EBS pollock, the exploitation-rate type value that corresponds to the F_{msy} level was applied to the "fishable" biomass for computing ABC levels. For a future year, the fishable biomass is defined as the sum over ages of predicted begin-year numbers multiplied by age specific fishery selectivity (normalized to the value at age 6) and mean body mass (10-year average). For northern rock sole and yellowfin sole, the biomass is defined as being greater than age 5.

Box 2. Specification of OFL (and ABC) for groundfish

Tier 3 crab stocks

Form a cumulative distribution for the OFL from the MCMC sample. Find the median of the distribution. Using normal quantiles to rescale the distribution so that the median is equal to the OFL (similar to a bias-corrected bootstrap). Alternatively use the variance from the MCMC sample (or Hessian approximation) to form the cumulative distribution.

Tier 4 crab stocks

Calculation of a distribution for the OFL for Tier 4 stocks involves repeating four steps (detailed below). The aim is to have the median of the distribution for the OFL equal the point estimate (so that P*=0.5 implies that the ABC equals to the point estimate of the OFL). The proposed steps are:

(a) Sample current MMB from a normal distribution with mean given by the point estimate of current MMB and CV equal to the sampling CV.

(b) The B_{MSY} proxy is the average MMB over a pre-specified set of years. Uncertainty in the B_{MSY} proxy only accounts for uncertainty in MMB for the years for which it is assumed the stock was "at B_{MSY}" and not uncertainty in the years concerned. For each of the years used when defining the B_{MSY} proxy, sample MMB from a distribution with mean given by its point estimate and CV equal to the sampling CV. The pseudo B_{MSY} proxy is then the average of the samples values.

(c) Sample M from a normal distribution with mean equal to the assumed M and CV equal to an assumed CV (e.g. 0.2).

(d) Compute the OFL.

Form a cumulative distribution for the OFL from the sampled values. Find the median of this distribution. Using normal quantiles to rescale the distribution so that the median equals the OFL (similar to a bias-corrected bootstrap).

Box 3. Proposed OFL PDF methods for Tier 3 and Tier 4 crab stocks.

Appendix 1: List of OFL workshop participants

Jim Ianelli	AFSC Seattle (Chair)
Diana Stram	NPFMC
Robert Foy	AFSC Kodiak
Ginny Eckert	UAF Juneau
Siddeek Shareef	ADFG Juneau
Paul Starr	New Zealand
André Punt	UW (PFMC SSC member)
Jason Gasper	NMFS RO Juneau
Lou Rugolo	AFSC Seattle
Jack Turnock	AFSC Seattle
Doug Pengilly	ADFG Kodiak
Jack Tagart	BSFRF
Doug Woodby	ADFG Juneau (NPFMC SSC member)
Martin Dorn	AFSC Seattle (PFMC SSC member)
Pat Livingston	AFSC Seattle (NPFMC SSC chair)
Jie Zheng	ADFG Juneau
Steve Martell	UBC
Grant Thompson	AFSC Seat`tle
Dana Hanselman	AFSC Juneau
Buck Stockhausen	AFSC Seattle
Bill Gaeman	ADFG Juneau
Denby Lloyd	
Dave Somerton	AFSC Seattle
Edward Poulson	
Hamachan Hamazaki	ADFG Anchorage