AGENDA D-2(a)
OCTOBER 2009

MEMORANDUM

TO: Council, SSC and AP Members

FROM: Chris Oliver
Executive Director

DATE: September 24, 2009

SUBJECT: Management Issues

ESTIMATED TIME
4 HOURS
All D-2 Items

ACTION REQUIRED

Review Progress on ACL Requirements

BACKGROUND

In June 2009 the Council tasked staff to begin analyses necessary to bring FMPs into compliance with new annual catch limit (ACL) and accountability measure (AM) requirements for ending overfishing of federal fisheries under the revised guidelines for National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act (MSA).

Compliance with ACL requirements for Alaska Scallop and BSAI Crab FMPs will require substantive changes to those FMPs primarily in order to incorporate an ABC control rule into the annual specifications process for both FMPs. Action plans for these analyses are attached as Item D-2(a)(1) for crab and Item D-2(a)(2) for scallop. Technical analyses to provide alternative ABC control rule formulations for BSAI Crab Stocks were completed this summer and are attached as Item D-2(a)(3) and Item D-2(a)(4) in conjunction with analyses of the Groundfish Tier system uncertainty evaluations (attached as Item D-2(a)(5)). These were presented at the Joint meeting of the Crab Plan Team and Groundfish Plan Teams on September 16th (see Joint CPT/Groundfish Plan Team report under agenda item C-5(c) of briefing books). The Crab Plan Team recommended alternative approaches for formulation of uncertainty-based buffer approaches to ABC control rules for BSAI crab stocks (contained in the report attached under C-5(c)). These alternatives will be discussed at this meeting in conjunction with the timeframe for this analysis as well as alternative formulations for establishing ABCs (and ACLs) for weathervane scallop. Statutory deadlines of October 2011 and June 2011 for the crab and scallop FMP amendments require Council final action in 2010.

The Council also adopted an interim action plan for amending the two groundfish FMPs in June (Item D-2(a)(6)), pending scientific recommendations on which groundfish species may be candidates for a new, voluntary FMP category for ecosystem components (Item D-2(a)(7)). The main proposed action is to define which species: 1) are "in the fishery," 2) may be included in this new "EC" category (e.g., forage fish), and/or 3) may be removed from the FMP (e.g., non-specified species). Other FMP text changes will be proposed to document compliance with the guidelines on other management issues.

The Council is scheduled to revise the draft action plan at this meeting to provide a suite of alternatives for beginning the draft environmental assessment. The Council tasked the Non-Target Species Committee with recommending revisions to the alternatives to begin the analysis. The committee convened on September 15, 2009, but a lack of clarity in the guidelines did not allow the committee to provide recommendations at this time. The committee requests another meeting to review responses to a series of questions it generated, at which time it expects to be able to recommend revised alternatives for analysis (Item D-2(a)(8)). A joint response from staffs of NOAA General Counsel, NMFS Headquarters, NMFS Alaska Region, and the Council is provided under Item D-2(a)(9)).

Council staff will be prepared to present an inclusive list of possible alternatives for analysis based on the AFSC vulnerability analysis and committee discussions from which the Council may select its range of alternatives at this meeting, or redirect the staff list to the committee for another meeting of the Non-Target Species Committee meeting. The timeline for Council action is short, however, and the Council is encouraged to streamline the alternatives to address only those FMP amendments that are required to meet the revised guidelines. Final action should be scheduled no later than April 2010 for implementation to occur by January 1, 2011.

AGENDA D-2(a)(1)
OCTOBER 2009

DRAFT ACTION PLAN FOR ANNUAL CATCH LIMIT AMENDMENTS TO THE BSAI KING AND TANNER CRAB FMP

September 17, 2009

PROPOSED ACTION Amend the BSAI King and Tanner Crab FMP to comply with the Magnuson-Stevens Reauthorization Act (MSRA). The FMP will be revised to address the following requirements:

1. An ABC control rule which articulates how ABC will be set compared to the OFL based on the scientific knowledge about the stock or stock complex and the scientific uncertainty in the estimate of OFL and any other scientific uncertainty. The ABC must be recommended to the Council by the SSC,

   Action: Amend FMP to include an ABC control rule, define ACL as ABC, and include a process for recommending this ABC annually to the Council by the SSC. Multiple alternatives may be considered in evaluating an appropriate ABC which explicitly considers uncertainty for crab stocks. Alternative ABC control rule and the means by which they consider explicitly scientific uncertainty are being developed by analysts following discussion at the ACL Workshop May 21-22. Review of comparative control rule strategies occurred at the September 16 Joint Groundfish-Crab Plan Team meeting. The SSC review process for recommending specifications to the Council must also be modified (both in scope and timing) to meet these requirements. Options for doing this are currently under consideration and may require changes to the current timing for TAC-setting by the State of Alaska. Tasked to NPFMC/AKRO/AFSC/ADFG staff.

2. Councils must build into the reference points and control rules appropriate consideration of risk, taking into account uncertainties in estimating harvest, stock conditions, life history parameters, or the effects of environmental factors.

   Action: Explicit consideration of uncertainties will be evaluated in conjunction with alternative ABC control rule strategies under Action 1. Tasked to NPFMC/AKRO/AFSC/ADFG staff.

3. Catch from all sources must be counted against the OY. Accountability measures (AMs) that are triggered if an ACL (i.e., the ABC) is exceeded.

   Action: Amendment to FMP to include explicit directive that the total not exceed the established ACL, describe AMs that are triggered if an ABC is exceeded; reference the current in-season management system and provisions for annually calculating all catch and comparing against the ACL. Bycatch mortality must be taken into account when evaluating the status of stocks. This is being done in conjunction with the annual assessments and reference in FMP could be made specifically to annual SAFE reports production. Tasked to NPFMC/AFSC/AKRO/ADFG staff.

4. Include estimate of OY and MSY and provide specification analysis.

   Action: Explicit consideration of uncertainties will be evaluated in conjunction with alternative ABC control rule strategies under Action 1. Tasked to NPFMC/AFSC/AKRO/ADFG staff.

PROBLEM STATEMENT/OBJECTIVE On January 16, 2009, NMFS issued final guidelines for National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act (MSA). They provide guidance on how to comply with new annual catch limit (ACL) and accountability measure (AM) requirements for ending overfishing of fisheries managed by federal fishery management plans. Annual catch limits are amounts of fish allowed to be caught in a year. A legal review of the BSAI King and Tanner Crab FMP found there were inadequacies in the FMP texts that need to be addressed. Several work groups (e.g., ABC/ACT Control Rules, Vulnerability Evaluations) have been created to produce reports on how to carry out the more technical components of the NS 1 guidelines. Statutory deadlines require compliance with the MSA by the start of the 2011 fisheries although these reports have not been finalized.

Prepared by Diana Stram

This action is necessary to facilitate compliance with requirements of the MSA to end and prevent overfishing, rebuild overfished stocks and achieve optimum yield. **ANALYSIS** An EA[1] for amendment to the BSAI King and Tanner Crab FMP is required.

RANGE OF ALTERNATIVES

Alternative 1.	No Action
Alternative 2.	Amend the BSAI King and Tanner Crab FMP to comply with annual catch limit and accountability requirements pursuant to revised guidelines for National Standard 1.

Note Alternative 2 may contain multiple options for ABC control rules.

APPLICABLE LAWS NEPA, MSA

STAFF RESOURCES

NPFMC	Diana Stram
ADF&G	Doug Pengilly, Shareef Siddeek, Forrest Bowers, Jie Zheng
NOAA AKR	Sue Salveson, SeanBob Kelly, Gretchen Harrington, Ben Muse
NOAA AFSC	Anne Hollowed, Jack Turnock, Bob Foy, Lou Rugolo
NOAA Habitat	No habitat implications
NOAA PR	No protected resource implications
NOAA GCAK	Clayton Jernigan
HQ	Galen Tromble, Rick Methot, Mark Milliken, Mark Nelson

TIMELINE TO IMPLEMENTATION

January 2009	*NMFS HQ issues final guidelines for National Standard 1.*
April 2009	*NMFS HQ issues draft working group reports (e.g., ABC/ACT Control Rules, Vulnerability Evaluations) on how to carry out the technical components of the guidelines.*
April/May	*Interagency staffs meet numerous times to coordinate NPFMC response.*
May 2009	*Annual Catch Limit Work Shop at AFSC coordinates SSC and Groundfish Plan Teams response(s).*
June 2009	*Council approves draft action and tasks staff with preparation of analysis*
Summer 2009	*ADF&G and AFSC Staff prepares analyses of alternative control rule strategies*
September 2009	*Crab Plan Team reviews alternative ABC control rule strategies and make recommendations for alternatives to include in analysis*
October 2009	SSC reviews CPT recommendations and analyses of draft ABC control rules and provides recommendations for alternative to include in analysis
March 2010	CPT special meeting to review draft assessments including alternative control rule applications, make 'mock' ABC recommendations by stock for analysis
April/May 2010	Staff completes draft EA incorporating impact analysis of ABC recommendations
June 2010	Initial review of EA
Oct/Dec 2010	Final action-Council selects preferred alternative
Early 2011	Council staff submits EA to NMFS for Secretarial review; NMFS publishes NOA (and proposed rule if necessary) to implement ACL amendments
September 2011	CPT reviews assessments, recommends ABCs for 2011/12 fishing year
October 2011	SSC reviews assessments, reviews CPT recommendations, recommends ABCs for 2011/12 fishing year
October 2011	Crab fisheries begin under new specification process

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[1] AKRO staff will advise if regulatory amendment(s) is required; an RIR/IRFA would be prepared if necessary

MAJOR ISSUES

- The Council and NMFS should place this amendment (along with Scallop and Groundfish FMP amendments) among its highest priorities for action. Statutory deadline of June, 2011 for implementation of ACL/AM requirements for scallop requires final action no later than October 2010.
- Need to resolve timing issue of CPT and SSC ability to make ABC recommendations prior to TAC setting.

AGENDA D-2(a)(2)
OCTOBER 2009

DRAFT ACTION PLAN FOR ANNUAL CATCH LIMIT AMENDMENTS TO THE ALASKA SCALLOP FMP

September 17, 2009

PROPOSED ACTION Amend the Alaska Scallop FMP to comply with the Magnuson-Stevens Reauthorization Act (MSRA). The FMP will be revised to address the following requirements:

1. An ABC control rule which articulates how ABC will be set compared to the OFL based on the scientific knowledge about the stock or stock complex and the scientific uncertainty in the estimate of OFL and any other scientific uncertainty. The ABC must be recommended to the Council by the SSC,

   Action: Amend FMP to include an ABC control rule, define ACL as ABC, and include a process for recommending this ABC annually to the Council by the SSC. Multiple alternatives may be considered in evaluating an appropriate ABC for scallop stocks including reconsideration of the existing MSY, currency for evaluation of stock status (meat weight versus individual scallops), region-specific ABCs, and statewide ABCs. Tasked to NPFMC/AKRO/ADFG staff.

2. Catch from all sources must be counted against the OY. Accountability measures (AMs) that are triggered if an ACL (i.e., the ABC) is exceeded.

   Action: Amendment to FMP to include explicit directive that the GHR not exceed the established ACL, describe AMs that are triggered if an ABC is exceeded; reference the current in-season management system and provisions for annually calculating all catch and comparing against the ACL. Bycatch mortality must be taken into account when evaluating the status of stocks. This could be done in conjunction with the annual SAFE report production for the previous fishing year. Tasked to AKRO/NPFMC staff.

3. Define the stocks in the fishery.

   Action: Amendment to remove non-target scallop stocks (pink scallops, spiny scallops, rock scallops) from the FMP and redefine as a weathervane scallop FMP. Tasked to AKRO/NPFMC staff.

4. Councils must build into the reference points and control rules appropriate consideration of risk, taking into account uncertainties in estimating harvest, stock conditions, life history parameters, or the effects of environmental factors.

   Action: Explicit consideration of uncertainties will be evaluated in conjunction with alternative ABC control rule strategies under Action 1. Tasked to NPFMC/AKRO/ADFG staff.

PROBLEM STATEMENT/OBJECTIVE On January 16, 2009, NMFS issued final guidelines for National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act (MSA). They provide guidance on how to comply with new annual catch limit (ACL) and accountability measure (AM) requirements for ending overfishing of fisheries managed by federal fishery management plans. Annual catch limits are amounts of fish allowed to be caught in a year. A legal review of the Alaskan Scallop FMP found there were inadequacies in the FMP texts that need to be addressed. Several work groups (e.g., ABC/ACT Control Rules, Vulnerability Evaluations) have been created to produce reports on how to carry out the more technical components of the NS 1 guidelines. Statutory deadlines require compliance with the MSA by the start of the 2011 fisheries although these reports have not been finalized.

This action is necessary to facilitate compliance with requirements of the MSA to end and prevent overfishing, rebuild overfished stocks and achieve optimum yield.

ANALYSIS An EA[1] for amendment to the Scallop FMP is required.

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[1] AKRO staff will advise if regulatory amendment(s) is required; an RIR/IRFA would be prepared if necessary

Prepared by Diana Stram

RANGE OF ALTERNATIVES

Alternative 1.	No Action
Alternative 2.	Amend the Alaskan Scallop FMP to comply with annual catch limit and accountability requirements pursuant to revised guidelines for National Standard 1.

Note Alternative 2 will contain several options for MSY and ABC control rules.

APPLICABLE LAWS NEPA, MSA

STAFF RESOURCES

NPFMC	Diana Stram
ADF&G	Gregg Rosenkrantz
NOAA AKR	Sue Salveson, SeanBob Kelly, Gretchen Harrington, Scott Miller
NOAA AFSC	TBD
NOAA Habitat	No habitat implications
NOAA PR	No protected resource implications
NOAA GCAK	Clayton Jernigan
HQ	Galen Tromble, Rick Methot, Mark Milliken, Mark Nelson

TIMELINE TO IMPLEMENTATION

January 2009	NMFS HQ issues final guidelines for National Standard 1.
April 2009	NMFS HQ issues draft working group reports (e.g., ABC/ACT Control Rules, Vulnerability Evaluations) on how to carry out the technical components of the guidelines.
April/May	Interagency staffs meet numerous times to coordinate NPFMC response.
May 2009	Annual Catch Limit Work Shop at AFSC coordinates SSC and Groundfish Plan Teams response(s).
June 2009	Council approves draft action and tasks staff with preparation of analysis
Summer/Fall 2009	Staff prepares analysis
March 2010	Staff prepares draft EA for Scallop Plan Team review and recommendations
March-May 2010	Staff incorporates SPT revisions as applicable
June 2010	SSC/Council initial review of EA
October 2010	Council recommends preferred alternative
Late 2010	Council staff submits EA to NMFS for Secretarial review; NMFS publishes NOA (and proposed rule if necessary) to implement ACL amendments
February 2011	Scallop Plan Team recommends ABCs for 2011 fishing year
April 2011	SSC reviews Scallop SAFE report, SPT recommendations and recommends ABCs for 2011 fishing year
June 2011	Scallop fishery begins under new specification process

MAJOR ISSUES

- The Council and NMFS should place this amendment (along with Crab and Groundfish FMP amendments) among its highest priorities for action. Statutory deadline of June, 2011 for implementation of ACL/AM requirements for scallop requires final action no later than October 2010.
- Need to identify whether any changes to federal regulations will result which would require a Regulatory Impact Review (RIR) and Regulatory Flexibility Analyses (IRFA/FRFA)
- Consideration must be given to annual SAFE report changes to enable informed recommendations of annual ABCs (ACLs).

A Note Regarding ACLs for BSAI Crab Stocks

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ABSTRACT

Two methods for calculating ACLs ("Pstar" and "decision theoretic") are outlined, along with the details needed to implement these methods for the BSAI crab stocks in tier 3 (stocks which are assessed using population dynamics models), and tier 4 (stocks which are assessed using survey data). The two methods are then applied for illustrative purposes to data for Bristol Bay red king crab, St Matthews Island blue king crab, and Norton Sound red king crab.

Introduction

Annual Catch Limits (ACLs) need to be implemented for the Bering Sea and Aleutian Islands (BSAI) crab stocks by 2010. While methods exist for specifying Overfishing Levels (OFLs) for these stocks (NPFMC, 2007), no process currently exists for setting ACLs. Moreover, unlike groundfish stocks in the BSAI, Acceptable Biological Catches (ABCs) are not set annually for the BSAI crab stocks and there is no ABC control rule for BSAI crab. Thus, the process for developing ACLs for crab stocks is likely to impact how ABCs are specified for these stocks.

ACLs differ from OFLs in that account is taken of "scientific uncertainty" when computing ACLs (i.e. the difference between the OFL and the ACL will be greater when there is more "scientific uncertainty"). However, what "scientific uncertainty" is and how it should be quantified and used to adjust OFLs to compute ACLs is not well-defined. A variety of methods for setting ACLs for crab stocks were identified during the 21-22 May 2009 workshop at the Alaska Fisheries Science Center (AFSC) Seattle. Seattle. These methods included three approaches to assess scientific uncertainty in stock assessments: 1) a qualitative approach, 2) a probability only (PO) or "Pstar" approach, and 3) a decision theoretic (DT) approach. The North Pacific Fishery Management Council (NPMFC) Scientific and Statistical Committee (SSC) noted that "*the PO and DT approaches were highly technical and we did not have sufficient lead time to review the methodology and were therefore unable to make recommendations on a preferred analytical approach to assessing uncertainty.*" Thus further exploration of these technical approaches, "Pstar" (Caddy and McGarvey 1996; Prager *et al.*, 2003; Shertzer *et al.*, 2008; Hanselman, 2009) and "decision theoretic" (Thompson, 2009) was requested for assessing their potential application to BSAI crab stocks.

This note outlines the two methods and provides technical details on how they could be implemented for the BSAI crab stocks. The results of preliminary applications of these methods to three of the BSAI crab stocks (Bristol Bay red king crab BBRKC, St Matthews Island blue king crab SMIBKC, and Norton Sound red king crab NSRKC) are provided for illustrative purposes. These three stocks differ in several ways: (a) BBRKC is relatively data-rich while SMIBKC and NSRKC are fairly data-poor, (b) BBRKC is a tier 3 stock (i.e. $F_{35\%}$ can be estimated) while SMIBKC and NSRKC are tier 4 stocks (the proxy for F_{MSY} is set to γM, where for these stocks γ is currently assumed to be 1), (c) OFLs are only computed for males for SMIBKC and NSRKC while the OFL for BBRKC includes catches of both sexes, and (d) the assessment for BBRKC includes bycatch by the trawl fleet, bycatch in the directed fishery, and bycatch in the directed fishery for Tanner crab.

METHODS

The Pstar method

The Pstar method as it is implemented here involves constructing a distribution for the OFL given the uncertainty captured within the stock assessment (and perhaps additional uncertainty – see below) and selecting the ACL so that the probability that the "true" OFL will be exceeded is not greater than a (pre-specified) probability P* (see the left panel of Fig. 1). The value of the ACL can also be obtained by constructing a cumulative distribution for the OFL and reading off the value of the ACL corresponding to the given P* (in this case of Fig. 1, P*=0.0789)

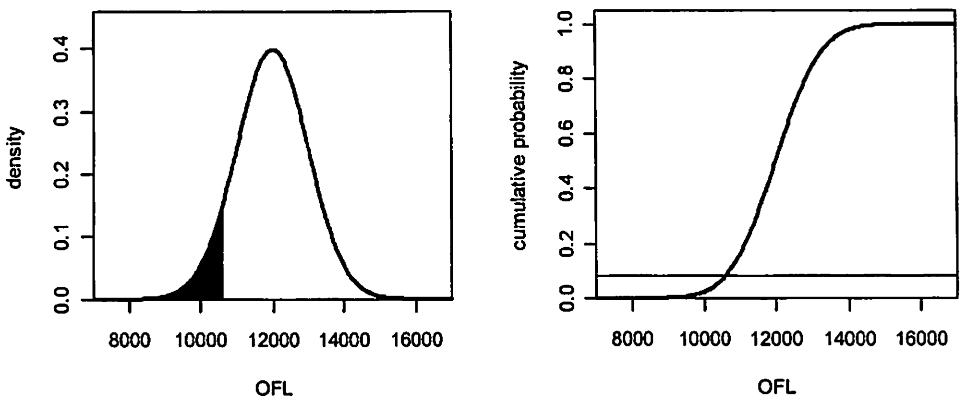

Figure 1. Application of the P* method for the case in which the distribution of the ACL is normal.

The P* method is relatively straightforward to implement for crab stock assessments, assuming that uncertainty can be quantified. The fishing mortality used to compute the OFL for year y, $F_{OFL,y}$, is computed as follows (NPFMC, 2007):

A. If $MMB(F)_y$ [1], is less than βB_{MSY} [2] when F=0, then $F_{OFL,y}$=0.

B. If $MMB(F)_y$ is larger than B_{MSY} when $F=F_{\text{MSY\_prox}}$ [3], then $F_{OFL,y}$ is $F_{\text{MSY\_prox}}$.

C. If neither A nor B is true, $F_{OFL,y}$ is selected to satisfy the equation $F = F_{\text{MSY}} \dfrac{MMB(F)_{2010} / B_{MSY} - \alpha}{1-\alpha}$ (this equation needs to be solved iteratively, but it converges quickly).

Note that the actual ACL depends on the value selected for P*. The value for this quantity is a policy decision although plots such as the right panel of Fig. 1 provide the trade-off between P* and the ACL.

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[1] $MMB(F)_y$ is the mature male biomass (at the time of mating) [MMB] in year y as a function of the exploitation rate during year y, F.

[2] B_{MSY} is the biomass at which MSY is achieved (or a proxy thereof).

[3] The proxy for F_{MSY} differs among tier levels ($F_{35\%}$ for stocks in tier 3 and γM for stocks in tier 4).

The decision theoretic method

The decision theoretic method determines the buffer between the OFL and the ACL (in this paper the buffer is the ratio, *f*, of the fishing mortality on which the ACL is based relative to that on which the OFL is based) to maximize an order mean of antilog relative yield, i.e. exp(yield/reference yield). Thompson (2009) suggests that appropriate objective is to find *f* to maximize the function:

$$\iiint \left(\frac{1-\exp(-ara.rw)}{\exp(ara)-1} \right) p_{rw}(rw\,|\,\boldsymbol{\alpha},f).p_{\alpha}(\boldsymbol{\alpha}).d\boldsymbol{\alpha}.drw \qquad (1)$$

where rw is the ratio of the expected catch under a harvest strategy which calculates an F based on the OFL control rule but sets the catch limit (TAC) based on $f.F$, relative to the expected catch under a reference harvest strategy (in this case setting the TAC based on the OFL control rule[4]),

ara is the (pre-specified) extent of absolute risk aversion,

$p_{rw}(rw\,|\,\boldsymbol{\alpha},f)$ is the probability density function for rw (which depends on the value of f and the parameters $\boldsymbol{\alpha}$), and

$p_{\alpha}(\boldsymbol{\alpha})$ is the "prior" distribution (actually the posterior distribution from the stock assessment) for the parameters of the stock assessments, $\boldsymbol{\alpha}$.

For the purposes of the implementations of the decision theoretic method, *rw* is defined as the average catch over the last 50 years of a 100 projection period when the catch is based on a fishing mortality which is *f* multiplied by $F_{OFL,y}$, divided by the average catch over the last 50 years of a 100 projection period when the catch is based on a fishing mortality of $F_{OFL,y}$[5]. Given a sample from a posterior distribution (which accounts for the parameter uncertainty component of $\boldsymbol{\alpha}$), Equation 1 involves computing *rw* and hence $\frac{1-\exp(ara.rw)}{\exp(ara)-1}$ for each draw from the posterior and averaging over draws.

Parameter uncertainty is only one source of uncertainty. Two other key sources of uncertainty are random fluctuations in recruitment about the underlying stock-recruitment relationship and estimation uncertainty. These two sources of uncertainty are addressed as follows:

- Recruitment uncertainty. Future recruitment is assumed to be log-normally distributed about a Beverton-Holt stock-recruitment relationship[6] characterized so that MSY occurs at the value of $F_{\mathrm{MSY\_prox}}$ computed from the maximum likelihood (actually maximum posterior density) estimates for the

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[4] Alternative reference harvest strategies could be selected but the results *should* be insensitive to this choice (within limits).

[5] To more adequately account for uncertainty, the F_{MSY} proxy used to calculate $F_{OFL,y}$ is always set to that calculated from the maximum likelihood estimates for the parameters.

[6] The analyses of this report are based on the Beverton-Holt stock-recruitment relationship but could have been based on any plausible stock-recruitment (such as Ricker), and could, in principle at least, include uncertainty regarding the form of the stock-recruitment relationship in the parameter vector $\boldsymbol{\alpha}$.

parameter of the model, and a pre-specified value for the extent of variation about the stock-recruitment relationship, σ_R.

- Estimation uncertainty. In principle, this should be accounted for by simulating the data on which the stock assessment is based and applying the stock assessment method for each year of the projection period, draw from the posterior, and value for *f*. However, this is computationally infeasible. Therefore, an approximate method is applied here. This involves (for each combination of future year and draw) generating a log-normal variate with mean 1 and CV σ_η and multiplying all of the population size-related inputs needed to calculate the OFL (historical numbers-at-size) by this variate. This implicitly assumes that estimation uncertainty primarily impacts the estimates of the scale of the population.

The application of the above algorithm requires that the values for the parameters for a Beverton-Holt stock-recruitment relationship are available. However, reliable stock-recruitment relationships are not available for any of the BSAI crab stocks and assuming steepness=1 can lead to counter-intuitive results (the ACL should be based on fishing mortalities which exceed $F_{\text{MSY\_prox}}$). Therefore, the value of the steepness parameter has been selected here so that the (deterministic) long-term yield is maximized when fishing mortality is $F_{\text{MSY\_prox}}$. For computational ease, the same steepness parameter is assumed for all draws from the posterior distribution. However, the value for R_0, the recruitment at the average unfished level, is computed for each draw from the posterior under the assumption that the average recruitment produced over the years used to define the B_{MSY} proxy arose (deterministically) from the stock recruitment relationship, i.e. let $\{y_1, y_2, ..., y_n\}$ be the set of years on which B_{MSY} is based then $B_{\text{MSY\_prox}} = \frac{1}{n}\sum_{y=y_1}^{y_2} MMB_y$ and $R_{\text{MSY\_prox}} = \frac{1}{n}\sum_{y=y_1}^{y_n} R_{y+L}$ where L is the (assumed) lag between spawning and recruitment to the model. Now, the Beverton-Holt stock-recruitment parameterized in terms of steepness (h), R_0, and the spawner-biomass-per-recruit in the absence of fishing (φ_0) is:

$$R = \frac{4hR_0 B}{(1-h)R_0\varphi_0 + (5h-1)B} \tag{2}$$

Substituting $R_{\text{MSY\_prox}}$ for R and $B_{\text{MSY\_prox}}$ for B and solving for R_0 leads to:

$$R_0 = \frac{R_{\text{MSY\_prox}}(5h-1)}{4h-(1-h)\varphi_0 R_{\text{MSY\_prox}} / B_{\text{MSY\_prox}}} \tag{3}$$

Extensions to fixed parameters

The above algorithms for the two methods only address uncertainty arising from sources included in the stock assessment (although they also partially address estimation uncertainty). Unfortunately, there are a variety of sources of uncertainty which are not addressed in the BSAI stock assessments. One key source of additional uncertainty relates to parameters whose values are fixed during the assessment (often natural mortality M and survey catchability q). Although it is possible, in principle at least, to estimate these parameters, doing so often leads to unrealistic results. The uncertainty associated with these parameters (and steepness) can be addressed when computing ACLs by selecting a range of fixed values for these parameters and applying the above approaches for each combination of fixed parameters and then pooling the resultant sets of results, giving each combination a (pre-specified) weight.

Specific implementation issues

As noted above, each assessment is based on a different set of assumptions, different population dynamics models, and (in particular) takes account of catches by different fleets. The following sections outline the specific assumptions made when computing OFLs for each stock (some of these lead to areas where further work may be required; see Table 1):

Bristol Bay red king crab

The OFL for this stock includes catches of males by the directed fishery, discards (of males and females) by the directed fishery, and catches of males and females by the trawl and Tanner crab fisheries. F_{OFL} is the fishing mortality rate on fully-selected males during the directed fishery. The future fully-selected fishing mortality rates for the trawl and Tanner crab fisheries are set to the average values over the most recent five years of the assessment period. The future fully-selected fishing mortality rate for male discards is computed by multiplying F_{OFL} by the ratio of the sum of the fishing mortality rates for male discards over the most recent five years of the assessment period to the sum of the fishing mortality rates for directed male fishery over the same period. The future fully-selected fishing mortality rate for female discards is defined analogously. The future selectivity patterns for the directed fishery, the trawl fishery and the Tanner crab fishery are assumed to be same as those for the most recent year of the assessment period. The timings for the directed and Tanner crab fisheries are set to those for the most recent year of the assessment period. Future recruitment is set to the average recruitment over the most recent five years (moving average for projections several years into the future).

Norton Sound red king crab

The OFL for this stock pertains only to males and is computed in numbers (rather than weight). The OFL includes contributions from three fisheries: (a) a summer fishery, (b) a winter fishery, and (c) a subsistence fishery. F_{OFL} is the exploitation rate on fully-selected animals during the summer fishery. The future exploitation rate for the winter fishery is calculated by multiplying F_{OFL} by the ratio of the sum of the exploitation rates for the winter fishery for the most recent five years of the assessment period to the sum of the exploitation rates for the summer fishery over the same period. The future exploitation rates for the subsistence fishery are defined analogously. The future selectivity pattern for the summer fishery is assumed to equal that for the most recent year of the assessment period (the selectivity patterns for the winter and subsistence fisheries are time-invariant). The timing for the future summer fishery is set to that for the most recent year of the assessment period. Future recruitment is set to the average recruitment over the most recent five years (moving average for projections several years into the future).

St Mathew Island blue king crab

The OFL for this stock pertains only to males. The catch of discarded males is computed when calculating the OFL, but is not currently included in the reported OFL. The future moulting probability for stage 1 and 2 animals is set equal to the average moulting probability for these animals over the last 10 years of the assessment period and recruitment to stage 1 is set equal to the average recruitment over the last five years [moving average] (the stage 1 recruitment does not impact the OFL because the OFL does not include contributions from stage 1 and 2 animals). F_{OFL} pertains to fully-selected recruits and adults. The timing for the future fisheries is set to that for the most recent year of the assessment period.

RESULTS AND DISCUSSION

The Pstar method

Figure 2 shows the results of applying the Pstar method to develop a distribution for the OFL (no attempt is made to select an OFL using the results in Fig. 2 because that process depends on the value selected for P*, which is a policy and not scientific choice). The analyses are based on drawing 800 parameter vectors from the posterior distributions for each assessment. These samples were based on 1,000,000 cycles of the Markov chain Monte Carlo algorithm where the first 200,000 cycles were ignored as a burn-in and the chain was thinned each 1,000th cycle. In addition to distributions for OFL, Figure 2 also shows the distribution for $F_{35\%}$ (the $F_{\rm MSY}$ proxy) for Bristol Bay red king crab because, unlike the case for the other two stocks, the $F_{\rm MSY}$ proxy for Bristol Bay red king crab is subject to uncertainty.

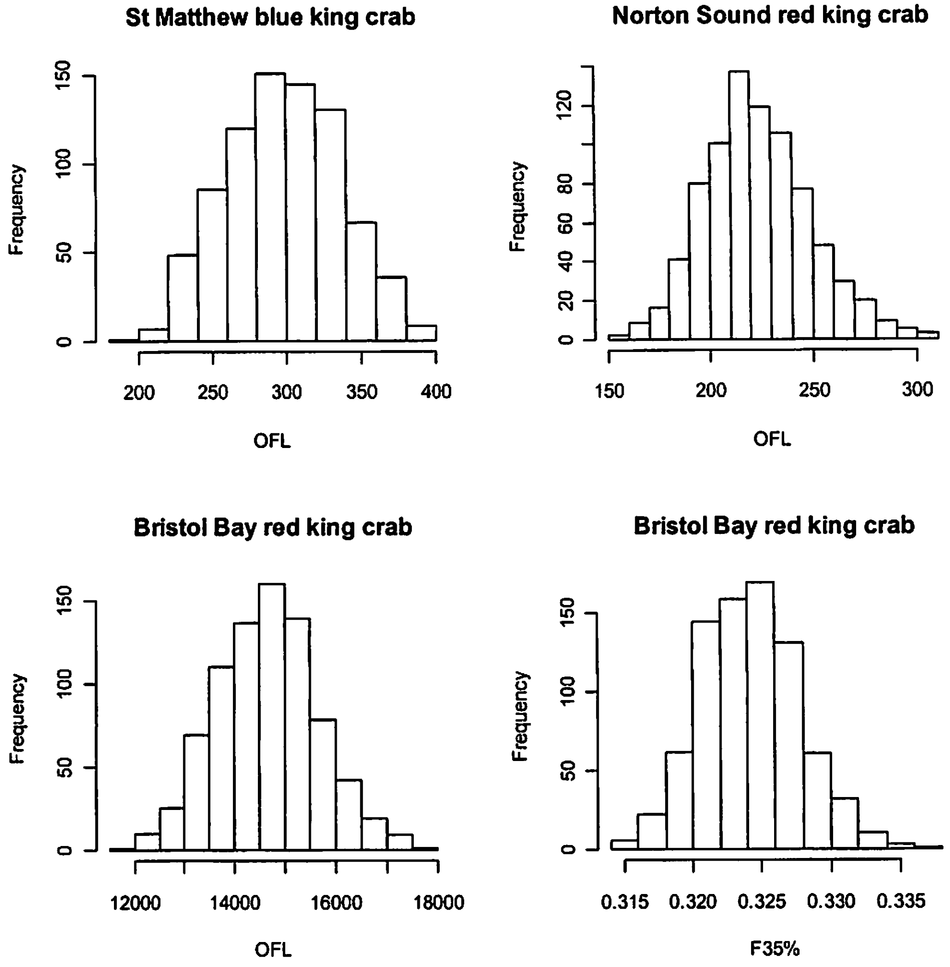

Figure 2. Distributions for the OFL for the three example stocks (upper two panels and lower left panel) and the distribution for $F_{35\%}$ for the Bristol Bay red king crab.

Figure 2 can be used to determine the ACL given a specified value for the P*. Use of Figure 2 would imply that the buffer between the ACL and the OFL would change annually depending on the uncertainty in the assessment. An alternative way to compute the ACL would be to pre-specify P* and compute a fixed value for ACL/OFL (which would not change between years). Graphs which could be used to compute this buffer based on the data from the most recent stock assessments are shown in Figure 3.

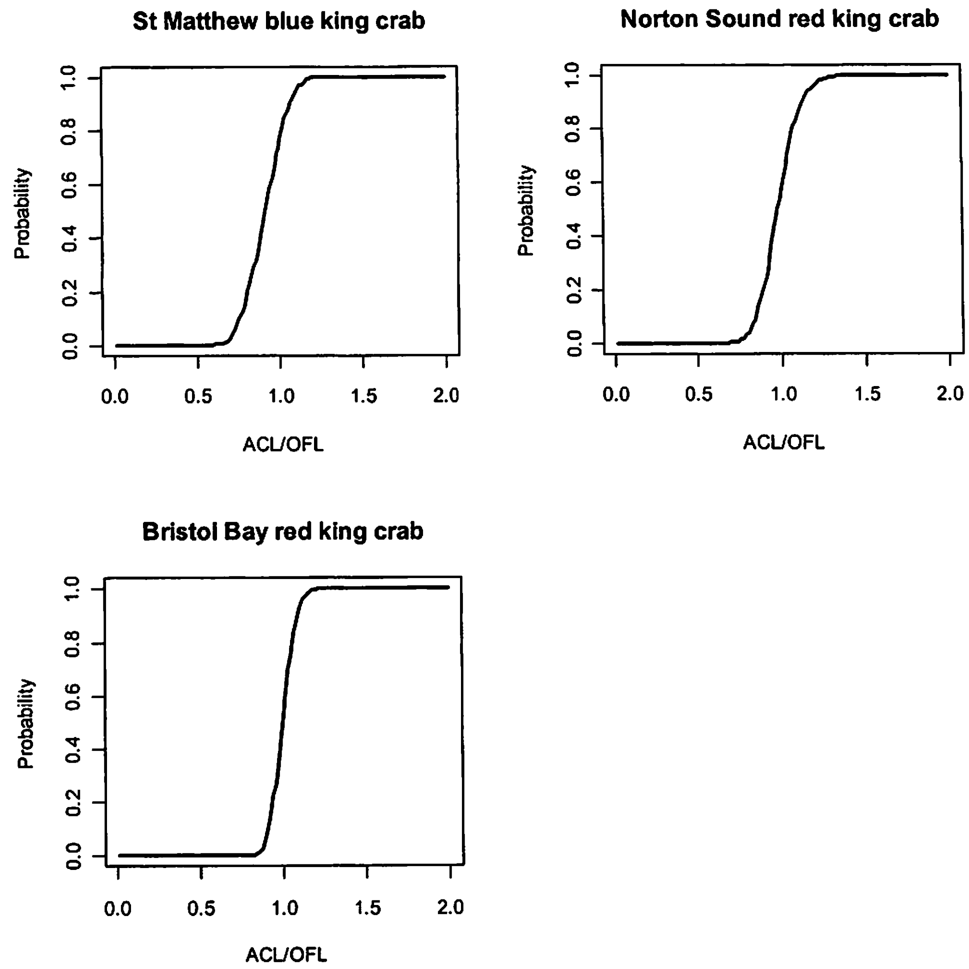

Figure 3. Probability of the ACL exceeding the OFL as a function of the multiplicative buffer between the ACL and OFL for the three example stocks.

As noted above, the F_{MSY} proxies for NSRKC and SMIBKC are not subject to uncertainty (they are set to *M* which is a fixed parameter in the assessment). Analyses were conducted for SMIBKC based on $M = 0.16\text{yr}^{-1}$, 0.18yr^{-1}, and 0.2yr^{-1} to examine this source of uncertainty and to illustrate the application of the method for accounting for uncertainty in fixed parameters. The final distribution for the OFL is based on giving the three choices for *M* (0.16yr^{-1}, 0.18yr^{-1} and 0.2yr^{-1}) prior weights (probabilities) of 0.25, 0.5 and 0.25. As expected, Figure 4 shows that the distribution for the OFL differs depending on the value assumed for *M*. Also, the combined distribution for the OFL (which accounts for uncertainty in *M*) is broader (more uncertain) than the individual distributions. For example, the standard deviation for the OFL for SMIRKC in Figure 2 is 38.1 while the standard deviation for the OFL for SMIRKC for the "combined" analysis in Figure 4 is 56.9. These standard deviations correspond to CVs of 0.13 and 0.18.

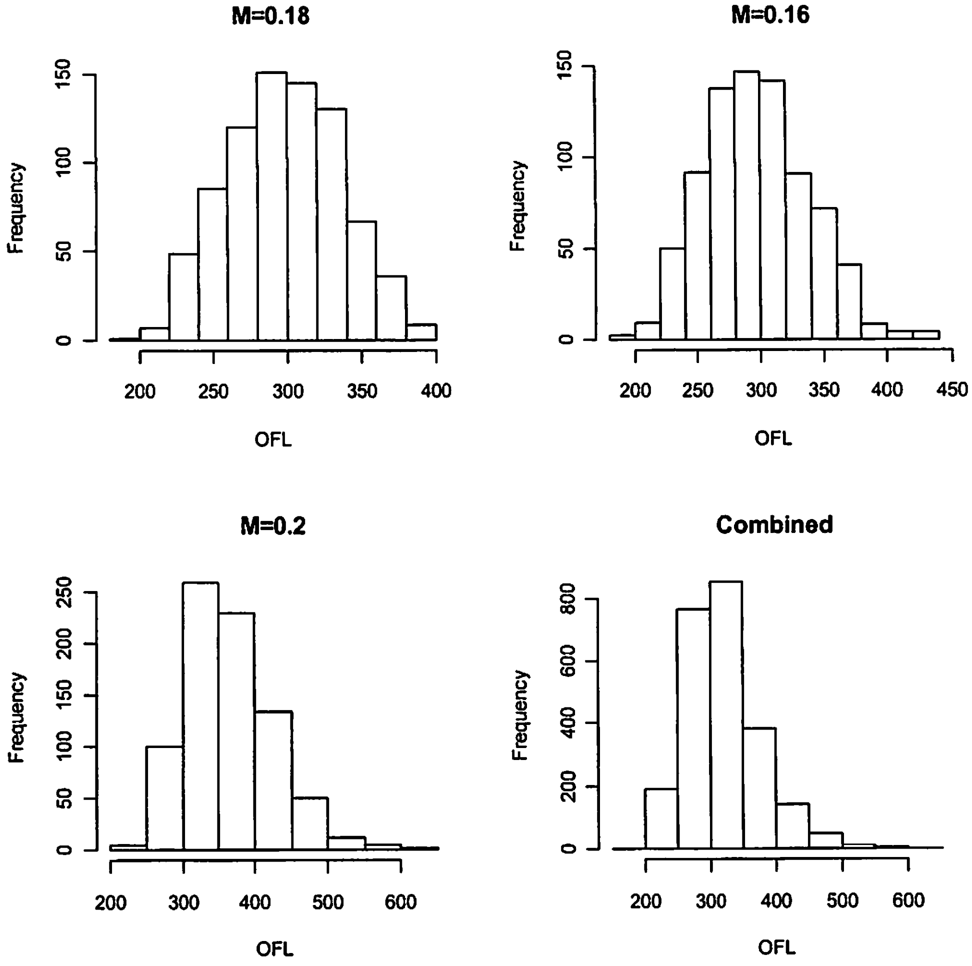

Figure 4. Distributions for the OFL for St Matthew Island blue king crab for three values for *M* and when the distributions for different values for *M* are combined.

The decision theoretic method

The decision theoretic method requires specifications for the steepness of the stock-recruitment relationship and the extent of variation in recruitment. Steepness was calculated as outlined above (so that MSY occurs deterministically at the F_{MSY} proxy) with resultant values of 0.7, 0.405 and 0.53 respectively for BBRKC, NSRKC, and SMIRKC. The extent of variation in recruitment was arbitrarily set to 0.5 for all three species. Figure 5 illustrates the relationship between yield and fishing mortality (expressed relative to the F_{MSY} proxy) for BBRKC. The decision theoretic method also requires value for the parameter *ara*. Unlike the Pstar method, it is not possible to apply the decision theoretical method without specifying a value for *ara*. Here, we select three values for *ara* 0.1, 0.5 and 0.9. The extent of uncertainty of assessment model outputs has been modelled by assuming that numbers-at-length and MMB are estimated subject to log-normal error with a CV of 0.2 (independent among years).

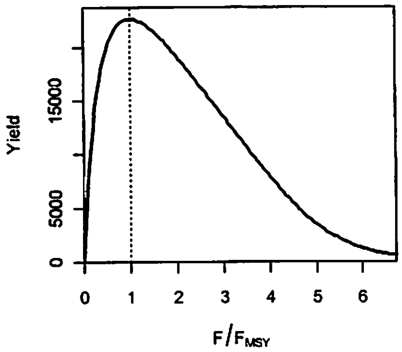

Figure 5. Example yield curve for Bristol Bay red king crab.

Figure 6 shows the value of Equation 1 for each of three stocks as a function of the buffer size, *f*. Figure 6 is based on values for *f* from 0.5 to 1.15 in steps of 0.05 owing to computational demands; finer steps could be used if greater precision is needed.

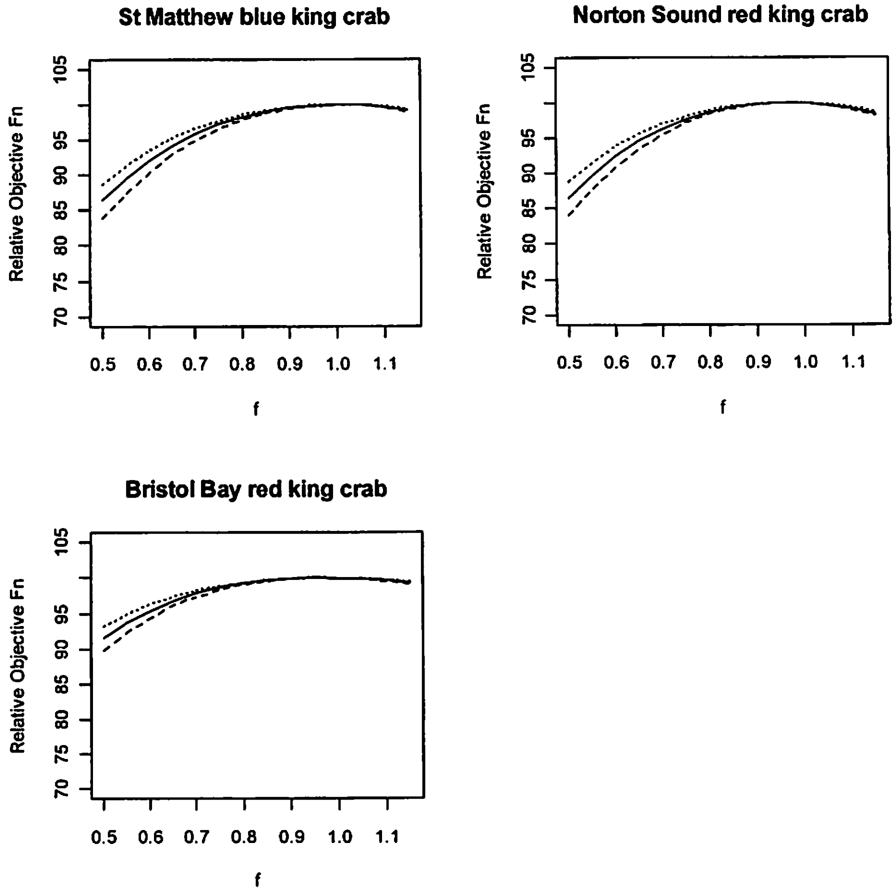

Figure 6. Relationship between the value of Equation 1 and *f* for three different choices for *ara*.

The curves in Figure 6 are maximized at f=1 (i.e. no buffer between the ACL and the OFL) for St Mathew Island blue king crab and at f=0.95 (i.e. a ratio of F_{MSY}/F_{OFL} of 0.95) for the other stocks. However, Equation 1 is relatively constant close to its maximum across a fairly wide range of values for f. It should be noted that the selection of f does not explicitly refer to how often overfishing occurs, but rather on how yield should be maximized given a pre-specified extent of risk aversion.

Final remarks

Both of the methods identified by the SSC can be implemented for the BSAI crab stocks. The Pstar method is the simplest (conceptually and computationally) and its key policy parameter (P*) is easily understood. In contrast, the meaning of the key policy parameter for the decision theoretic method (*ara*) is more opaque even for members of the stock assessment community. Furthermore, the decision theoretical method requires that not only does uncertainty need to be quantified (as for the Pstar method) but also that a stock-recruitment relationship be defined (not doing so leads to unrealistic results for the stocks considered in this note), the extent of variation in recruitment must be specified and (future) estimation uncertainty modelled. While this note outlines ***plausible*** ways to address each of these issues (and the approach outlined to deal with fixed parameters can be used to address uncertainty in, for example steepness, the extent of variation in recruitment, and the extent of uncertainty in future assessments), these solutions necessarily involve more assumptions which need to be justified.

Finally, and as illustrated in Figure 4, the extent of uncertainty in the OFL depends on which uncertainty are included in the calculations. While some sources of uncertainty can be accounted for as outlined above, this approach cannot (easily) be extended to other sources of uncertainty (such as uncertainty about stock structure). In addition, application of the approach for dealing with uncertainty about fixed parameter values requires the specification of prior weights, which can be a very difficult exercise (Butterworth *et al.*, 1996).

ACKNOWLEDGEMENTS

Dana Hanselman and Grant Thompson are thanked for useful discussions on the Pstar and decision theoretic methods. Doug Woodby is thanked for comments on an earlier version of this document.

REFERENCES

Butterworth, D.S., Punt, A.E., and A.D.M. Smith. 1996. On plausible hypotheses and their weighting, with implications for selection between variants of the Revised Management Procedure. *Rep. int. Whal. Commn* 46: 637–640.

Caddy, J.F. and R. McGarvey. 1996. Targets or limits for management of fisheries? *N. Am. J .Fish. Manage.* 16:479-487.

Hanselman, D. 2009. A general method to adjust catch limits / targets with survey uncertainty. Draft document submitted to the 21-22 May 2009 ACL workshop. 17pp.

North Pacific Fishery Management Council (NPFMC). 2007. Initial Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. North Pacific Fishery Management Council, Anchorage.

Prager, M.H., Porch, C.E. Shertzer, K.W. and J.F. Caddy. 2003. Targets and limits for management of fisheries: a simple probability-based approach. *N. Am. J. Fish. Manage.* 23:349-361.

Shertzer, C.E., Prager, M.H. and E.H. Williams. 2008. A probability-based approach to setting annual catch levels. *Fish. Bull.* 106:225-232.

Thompson, G.G. 2009. A decision-theoretic approach to setting buffers between fishery management targets and limits. Draft document submitted to the 21-22 May 2009 ACL workshop. 32pp.

Table 1. Issues that need to be addressed to compute OFLs and ACLs for BSAI crab stocks.

Stock	**Issue**
SMIBKC	Compute OFL (ACL) including discards
SMIBKC	Compute OFL (ACL) including females
NSRKC	Compute OFL (ACL) including discards and females
NSRKC	Compute OFL (ACL) in weight

AGENDA D-2(a)(4)
OCTOBER 2009

Tier 4 ACL analysis for BSAI crab stocks with no assessment model

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National Marine Fisheries Service
September 18, 2009

This analysis uses the P* method and uncertainty estimated for crab tier 4 stocks with no stock assessment models. The OFL control rule is,

$$F = \begin{cases} Bycatch \quad only \ , Directed \quad F = 0, & if \ \dfrac{B_t}{B_{REF}} < \beta \\ \dfrac{F_{REF}\left[\dfrac{B_t}{B_{REF}} - \alpha\right]}{(1-\alpha)} & if \ \beta < \dfrac{B_t}{B_{REF}} < 1 \\ F_{REF} & if \ B_t \geq B_{REF} \end{cases}$$

B_t	survey mature male biomass at time of mating in year t,
B_{REF}	average survey mature male biomass at time of mating over some time period,
F_{REF}	gamma*M, gamma assumed = 1,
α	fraction of B_{REF} where the harvest control rule intersects the x-axis if extended below β,

β fraction of B_{REF} below which directed fishing mortality is 0.

The total catch OFL is where F above is the Fofl,

OFL = (1-exp(-Fofl))*MMB at fishery.

Current biomass was assumed to have a lognormal distribution and M a normal distribution. The biomass values for the appropriate time period were resampled with replacement (nonparametric bootstrap) to estimate uncertainty in the biomass reference point. Additional uncertainty was added to M to approximate uncertainty in total catch. Results here are from estimating the OFL 1000 times.

Bering Sea Tanner Crab Tier 4 ACL analysis

Eastern Bering sea Tanner crab cv (S.E./mean) on M was assumed 0.2 (Figure 2)and cv of current survey biomass was 0.15 (last three years cv of survey biomass, 2006-2008, 0.14, 0.37, 0.15) (Figure 1). The 2008 survey mature male biomass was 143 mill lbs, which results in MMB at mating taking out the OFL of 127 million lbs. Bref was the average MMB at mating for 1969 to 1980 (189.9 mill lbs) (Figure 3).

The resulting cv on estimated mean catch OFL about 0.41 (Figure 4). The ratio of ACL/OFL would need to be 92% to achieve a 50% probability of exceeding the OFL(Figure 5). At 75% ACL/OFL the probability of exceeding the OFL is about 30% (Table 1).

The CV on current biomass has been quite variable for Tanner crab. If the CV = 0.25 on current biomass then buffers would need to be increased to get the same level of risk as with a lower CV (Figure 6).

Discard (0% mortality) averages about 68% of the total catch for Tanner crab, 52% when assumed 50% mortality on discards. A range of 25% discard mortality to 100% discard mortality results in variability of the total catch by about +- 20-30%. The CV on M was increased to 0.4 to account for the uncertainty in M and total catch. With CV =0.4 on M the CV on catch OFL is about 0.51 compared to 0.41 with CV = 0.2 on M. This would result in a 95%CI about +-20% more on the OFL to account for uncertainty in discard mortality. While the ratio at 50% probability of exceeding the OFL is similar to the lower CV = 0.2 on M (ACL at 92% the OFL), the probability of exceeding the OFL is higher with the higher CV on M, for lower ACL/OFL ratios (Figure 7, Table 1).

Analysis of groundfish buffers and P* values indicate that the use of F40 to F35 results in an ACL/OFL ratio of 81% to 87%, with a resulting P* of 0.03 to 0.22 using uncertainty in current survey biomass alone. However, these results do not incorporate uncertainty in M (Fref), the biomass reference point (Bref), or catch. The average P* for the groundfish analysis was 0.12. If the average P* of 0.12 is applied to Tanner crab (CV=0.2 on M) the ratio of ACL to OFL would need to be 0.55 (Table 2). However, this is taking into account uncertainty in reference points (M, Bref) as well as current biomass. When uncertainty in catch is included, the ratio of ACL to OFL would need to be 0.45 to obtain a P* = 0.12 (Table 2).

If only uncertainty in current biomass is used for tanner crab to compare with the groundfish analysis, then an ACL/OFL of about 0.68 would result in a P* = 0.12 (Table 2). This lower value of ACL/OFL than for groundfish may result due to the use of the sloping control rule and that current biomass for Tanner crab is below Bref resulting in more variability in the OFL than if biomass was above Bref. If MMB was above the Bref then the ACL/OFL is about 0.84 to get a P*=0.12, which is similar to the F40/F35 ratio for groundfish tier 3 stocks.

Pribilof Blue King crab Tier 4 ACL Analysis

This analysis was conducted the same as for Bering sea Tanner crab. CV on M was 0.20 with an assumed normal distribution and mean M=0.18. CV on current survey mature male biomass at time of survey was 0.8 (average of 2006-2008) using a lognormal distribution. A nonparametric bootstrap was used for Bref.

At the present time current biomass is at a low level that would result in OFL = 0 and the ACL = 0. To illustrate buffer sizes if biomass were at a level where a fishery would occur, a current mature male biomass at survey was assumed at 5.6 million lbs, which results in a mean MMB at mating of about 4.6 million lbs, at 50% Bref (Bref = 9.28 million lbs).

The resulting distributions on MMB, Fref (=M) and Bref are shown in Figures 9-11.

Due to the high uncertainty in survey biomass for Pribilof blue king crab, the ACL would need to be less than 40% of the OFL(a 60% buffer) for the probability of exceeding the OFL to be less than 50% (Figures 12 and 13). The lowest probability that can be achieved in this case is about 25% of exceeding the OFL, even at an ACL approaching zero (Tables 1 and 2). This result occurs because a high number of OFL values are zero, due to the high level of uncertainty in survey biomass.

If current biomass is lower (at 25% of Bref) then the probability of exceeding the OFL does not go below about 60% even when ACL approaches zero (Figure 14) (Table 1).

Pribilof Red king crab Tier 4 ACL Analysis

This analysis was conducted the same as for Bering sea Tanner crab. Cv on M was 0.20 with an assumed normal distribution and mean M=0.18 (Figure 17). A nonparametric bootstrap was used for Bref (Figure 16). Bref is the mean of 1991 to 2007 MMB (8.66 mill lbs). Current biomass is 12.5 million lbs (2008 mature male biomass at survey) with a cv = 0.4 (mean cv of 2006-2008). The mean MMB at mating is 8.95 mill lbs, just above Bref (Figure 15).

The ACL would need to be below 90% of the OFL to get a probability of less than 50% of the ACL exceeding the OFL (Figure 18 and 19). At an ACL of 75% OFL the probability of exceeding the OFL would be 0.38 (Table 1). A 20% probability of exceeding the OFL would result in an ACL at 50% OFL.

Conclusions

This analysis indicates that ACL/OFL declines for a given P* as the stock status declines relative to Bref, due to higher variability in Fref determined from the sloping control rule. When only uncertainty in current biomass is accounted for, and the stock is above Bmsy, then P* and ACL/OFL results are similar to groundfish analysis. However, of the three tier 4 stocks evaluated here, one was at 67% of Bref, one well below 25% Bref and the other nearly equal to Bref, thus the sloping control rule has an effect on the OFL distribution.

This analysis considered four sources of uncertainty, Fref, Bref, current biomass and catch. The P* values estimated are higher for tier 4 crab stocks than those estimated for groundfish stocks due to more sources of uncertainty being incorporated. Also, for some stocks, current biomass CV is very high, which results in relatively low ACL/OFL values, and in some cases would result in ACL=0 at values where the OFL would still be greater than zero.

Table 1. P* estimated for three tier 4 crab stocks at a fixed ACL/OFL of 0.75, compared to groundfish assessment results.

	2008					
Stock	B/Bmsy	CV Bio	CV M	ACL/OFL	P*	
Tanner	0.67	0.15	0.2	0.75	0.3	
Tanner	0.67	0.15	0.4	0.75	0.35	
Prib Blue	0.5	0.8	0.2	0.75	0.65	
Prib Blue	0.25	0.8	0.2	0.75	0.7	
Prib Red	1.0	0.4	0.2	0.75	0.38	
Groundfish	Varies	varies	none	0.81-0.87	mean 0.12, range 0.03-0.22	

Table 2. ACL/OFL estimated for three tier 4 crab stocks at a fixed P* = 0.12.

		Uncertainty in B, M and Bref	Additional Catch uncertainty	Uncertainty in Biomass only	Uncertainty in B only and B/Bmsy>1.0
	P*	ACL/OFL	ACL/OFL	ACL/OFL	
Tanner	0.12	0.55	0.45	0.68	0.84
Pribilof Blue (B/Bmsy=0.5)	0.12	<0.05			
Pribilof Blue (B/Bmsy=0.25)	Min P* =0.25	<0.05			
Pribilof Red	0.12	0.30			

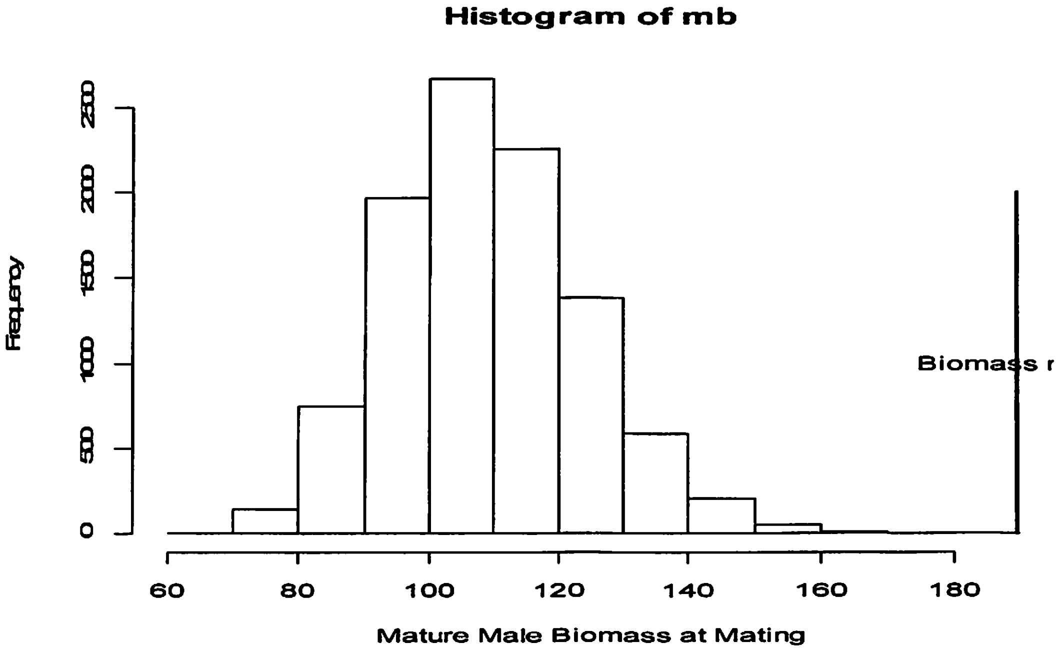

Figure 1. Distribution of MMB at mating with Bref (189.9 mill lbs).

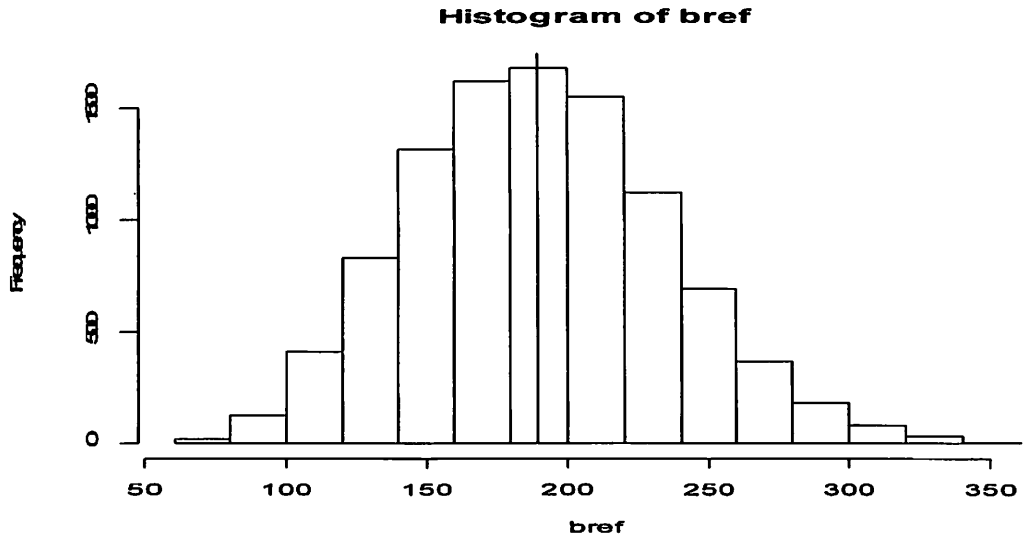

Figure 2. Distribution of Bref from nonparametric bootstrap.

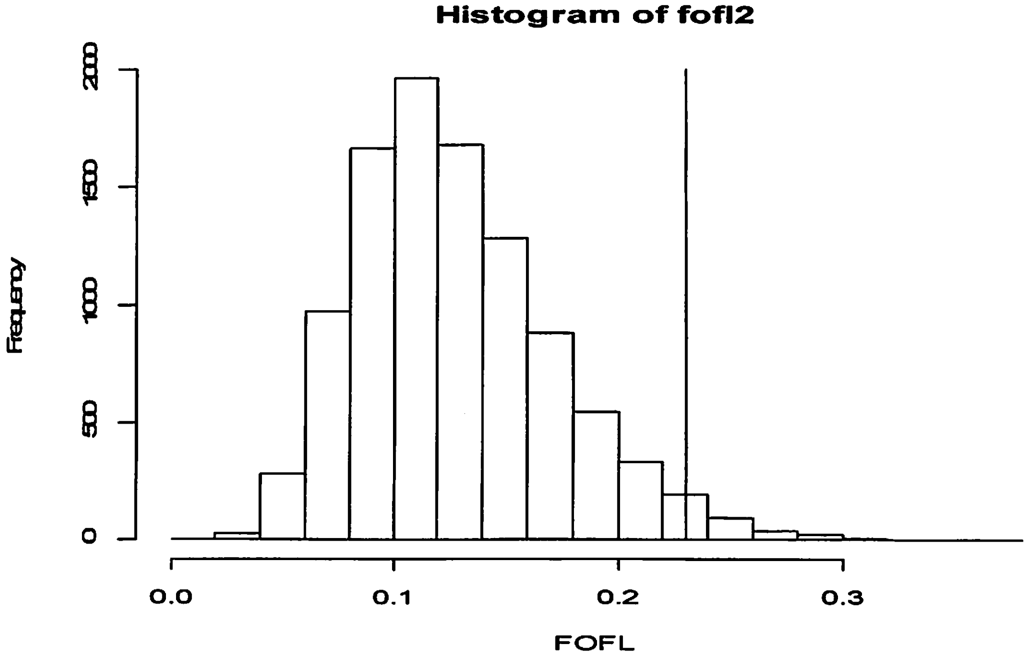

Figure 3. Distribution of Fofl from the control rule. Vertical line is Fref = M = 0.23.

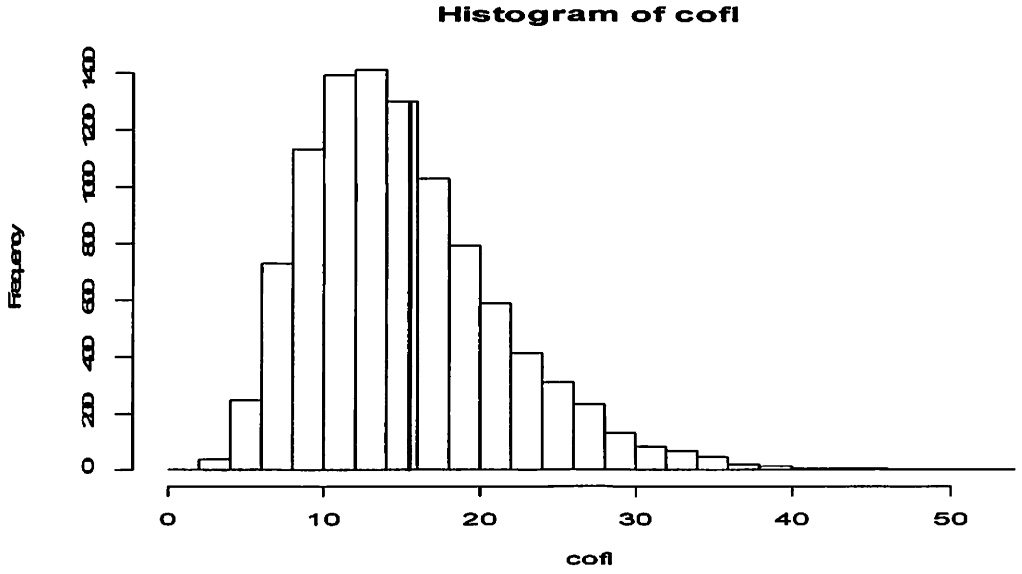

Figure 4. Distribution of catch OFL. Vertical line is the mean OFL for 2008/09 season. CV = 0.41.

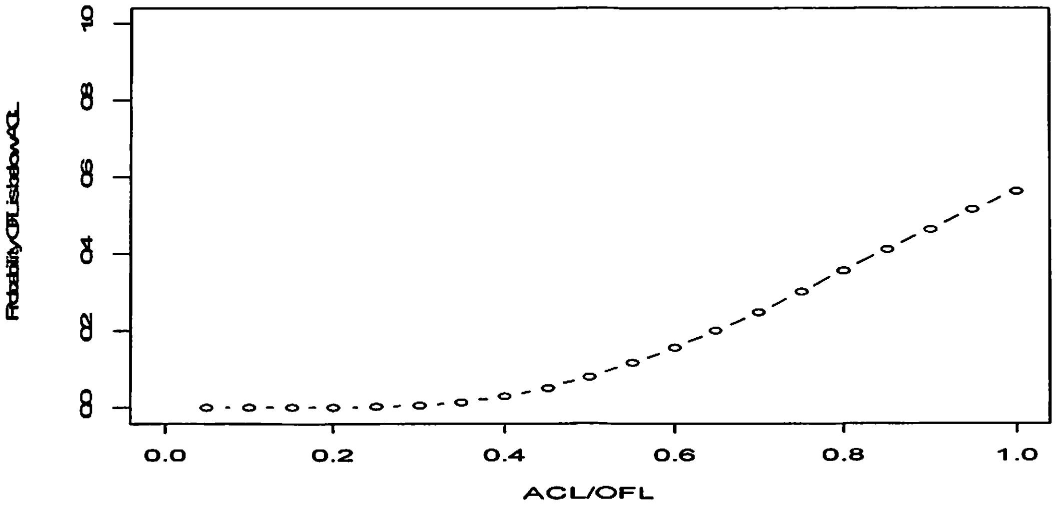

Figure 5. Probability of exceeding the OFL for ratios of ACL/OFL from 0 to 1.0 for Bering sea Tanner crab. Cv current biomass 0.15, cv = 0.2 M. At about 92% OFL there is a 50% probability of exceeding the OFL. At 65% OFL gives about 20% probability of exceeding OFL. 75% OFL gives probability of exceeding of 30%.

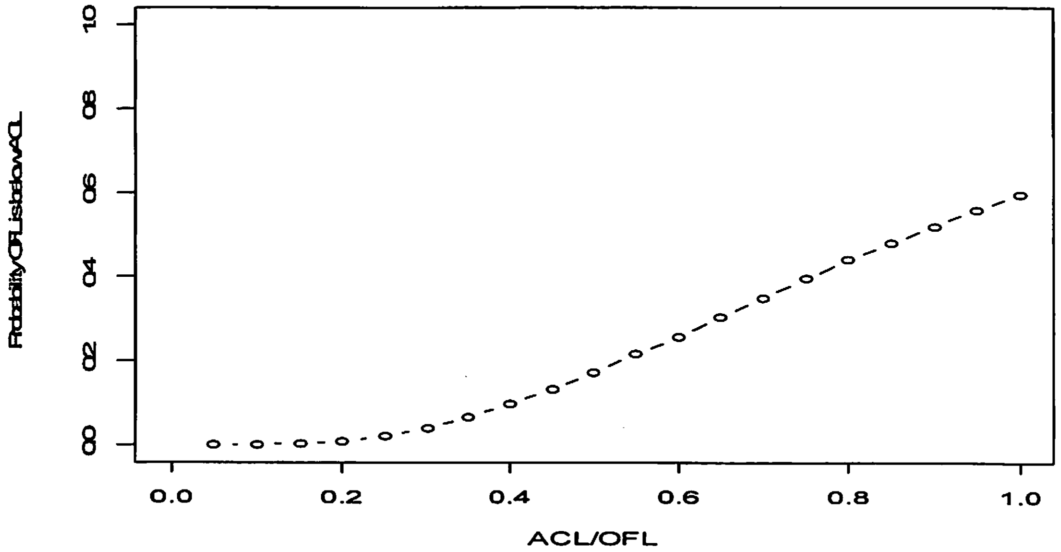

Figure 6. Probability of ACL exceeding OFL for various levels of ACL/OFL for Bering sea Tanner crab with current biomass CV = 0.25. 87% OFL to get 50% probability of exceeding OFL. 50% OFL to get 20% exceeding OFL. 75% OFL gives about 35% prob of exceeding OFL.

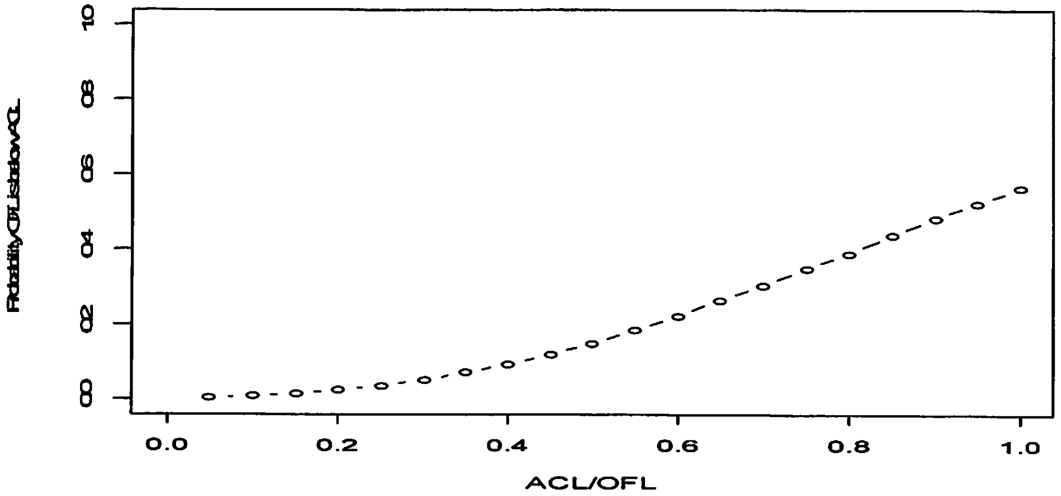

Figure 7. Probability of ACL exceeding OFL for various levels of ACL/OFL for Bering sea Tanner crab. Higher cv=0.40 on M to account for uncertainty in discard mortality of +/- 20 – 30%. Results in a cv on catch OFL of about 0.51 (0.1 higher than with cv on M of 0.2). 92%OFL gives about 50% probability exceeding OFL. 57% OFL gives about 20% probability of exceeding OFL. 75% OFL gives about 35% probabaility of exceeding OFL.

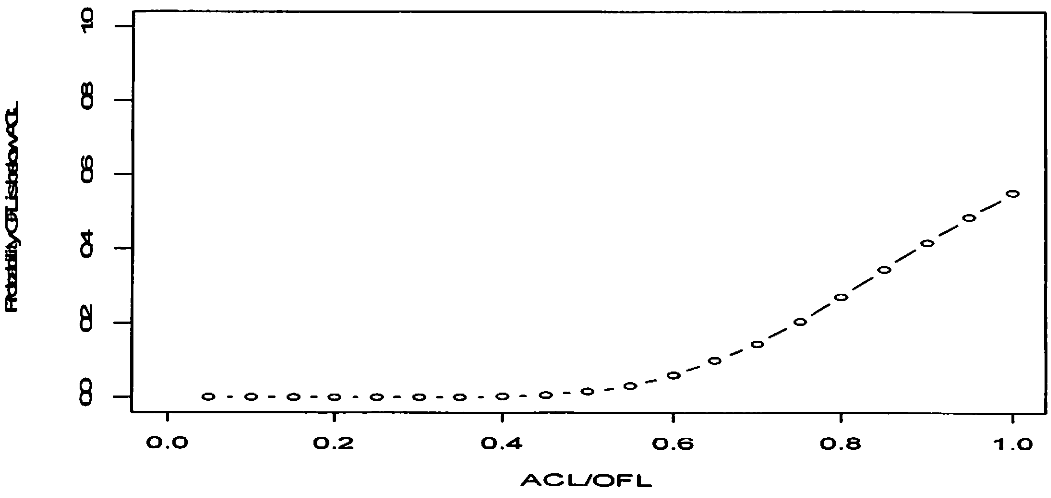

Figure 8. Probability ACL exceeds the OFL for various ratios of ACL to OFL for Bering sea Tanner crab. Only variability on current biomass (cv=0.15), CV =0 on M and Bref for comparison with groundfish analysis.

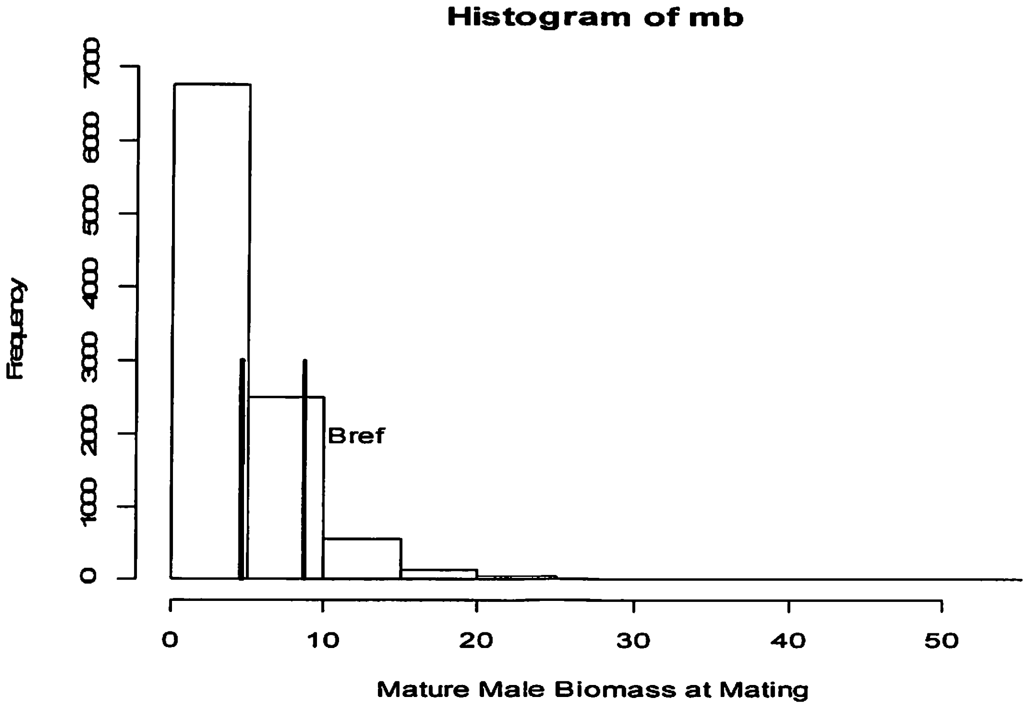

Figure 9. Histogram of mature male biomass at mating for Pribilof blue king crab. Vertical lines are mean MMB (4.6 mill lbs) and Bref (9.28 mill lbs).

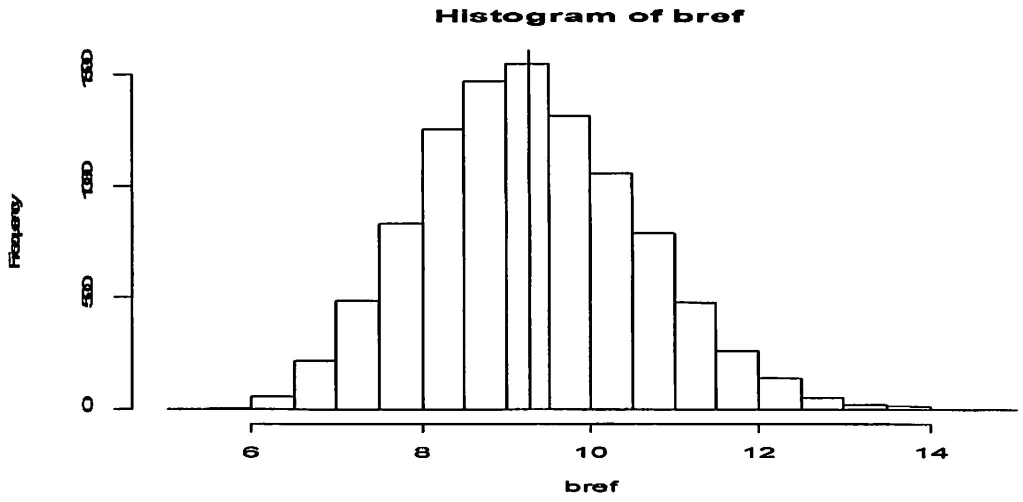

Figure 10. Histogram of distribution of Bref from nonparametric bootstrap for Pribilof blue king crab. Vertical line is mean (9.28 mill lbs).

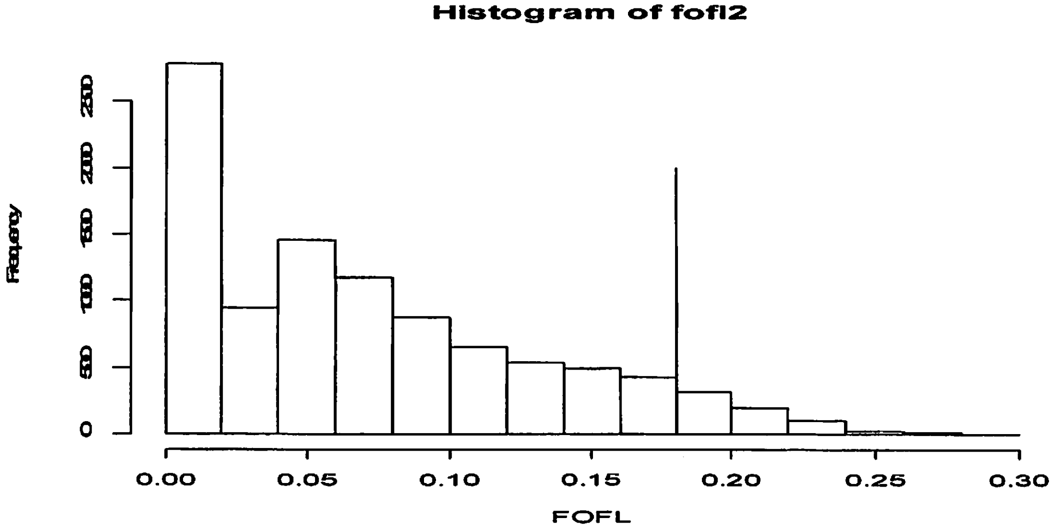

Figure 11. Fofl from control rule for Pribilof blue king crab. Vertical line is maximum F =M=0.18.

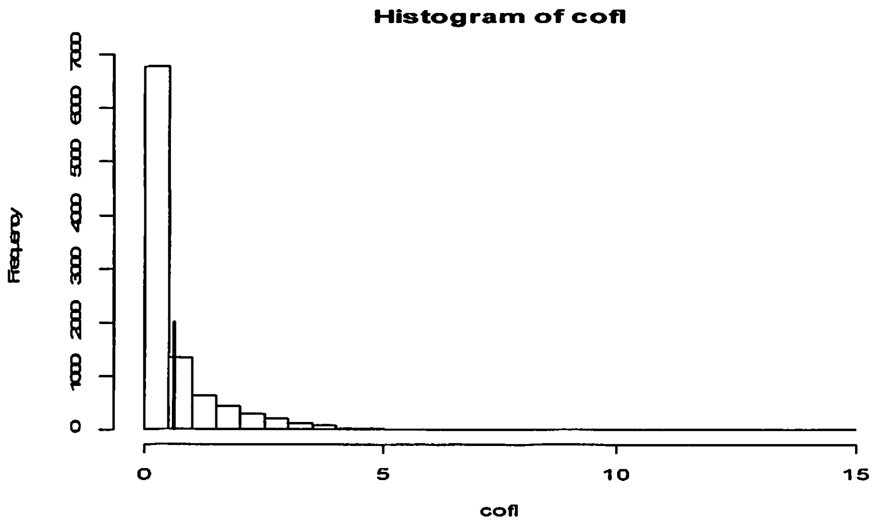

Figure 12. Historgram of catch OFL for Pribilof blue king crab when survey mature male biomass is 5.6 mill lbs.

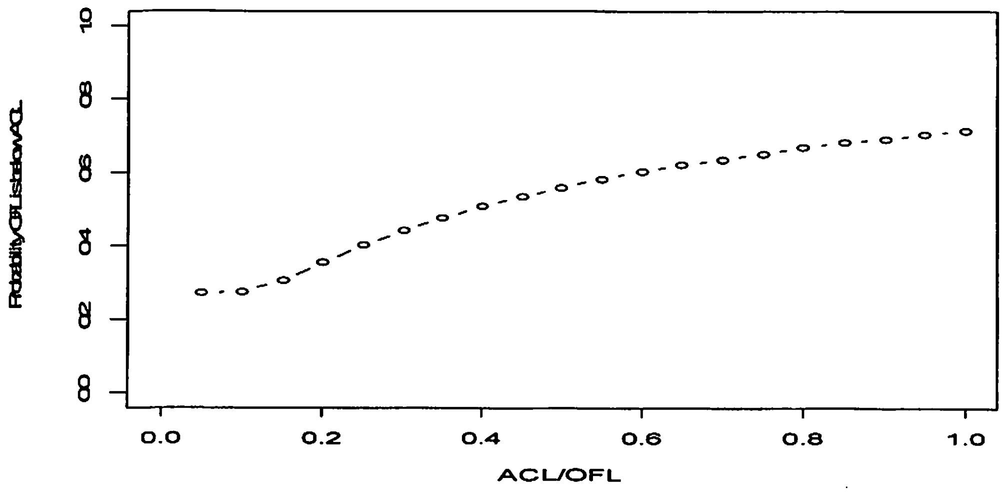

Figure 13. Pribilof blue king crab. Probability that ACL is greater than the OFL as the ratio of ACL to OFL varies, when current MMB at mating is about 50% Bref.

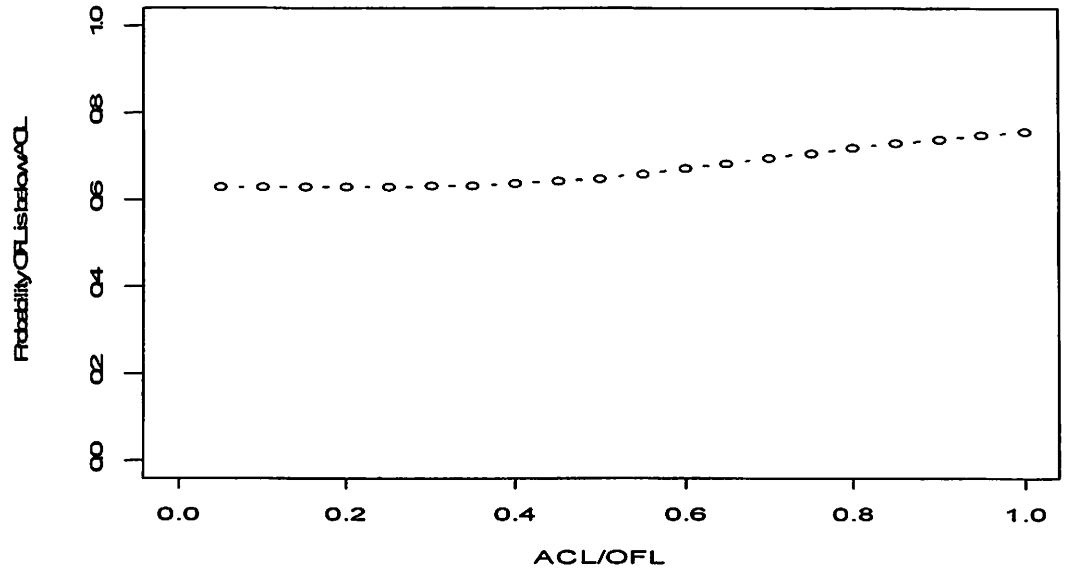

Figure 14. Pribilof blue king crab. Probability of ACL exceeding the OFL with current survey biomass at 2.6 mill lbs which results in MMB at 25% of Bref (2.3 mill lbs) for various levels of ACL/OFL.

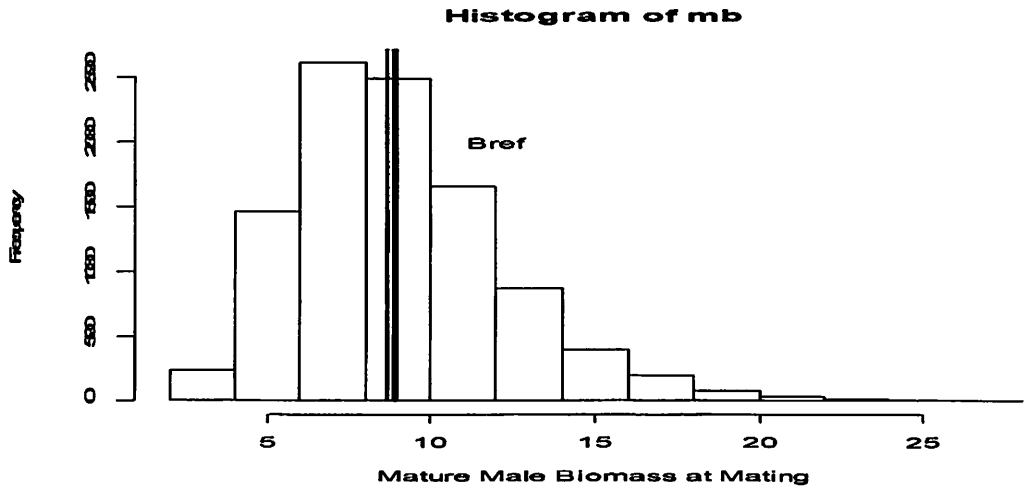

Figure 15. Histogram of mature male biomass at mating for Pribilof red king crab. Vertical lines are mean MMB (8.9 mill lbs) and Bref (8.66 mill lbs).

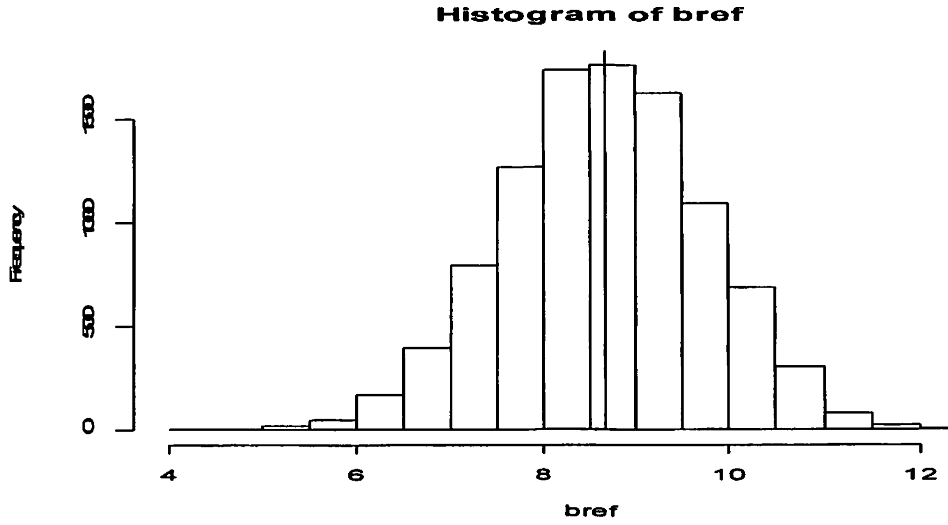

Figure 16. Histogram of distribution of Bref from nonparametric bootstrap for Pribilof red king crab. Vertical line is mean (8.66 mill lbs).

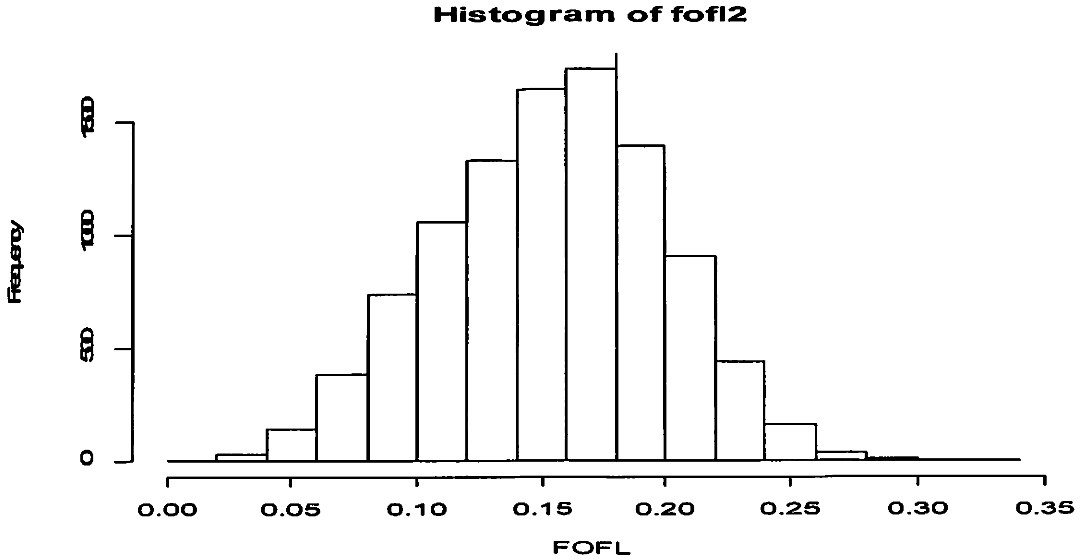

Figure17. Fofl from control rule for Pribilof red king crab. Vertical line is Fref =M=0.18.

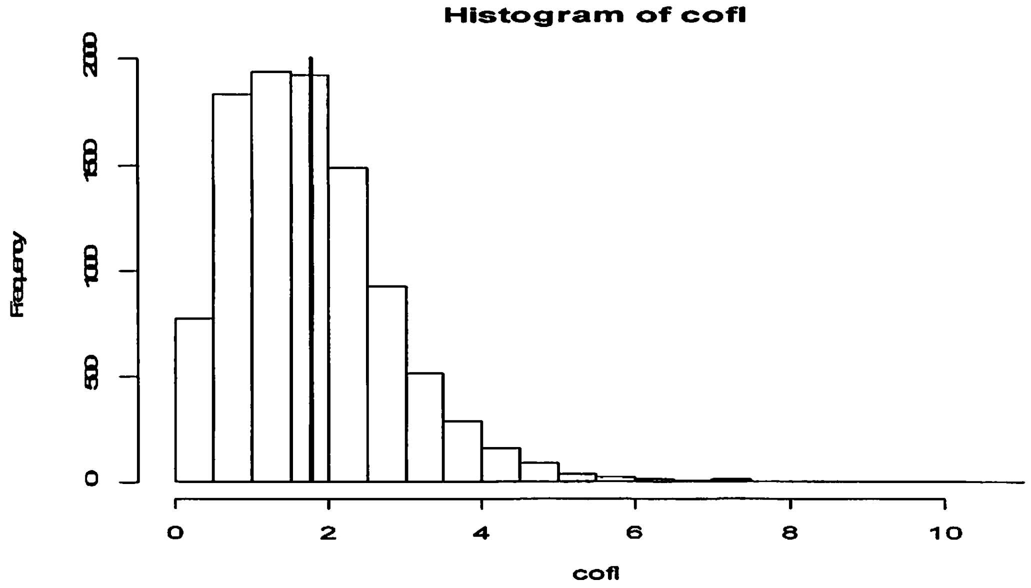

Figure 18. Histogram of catch OFL for Pribilof red king crab with current survey mature male biomass is 12.5 mill lbs. Vertical line is mean OFL.

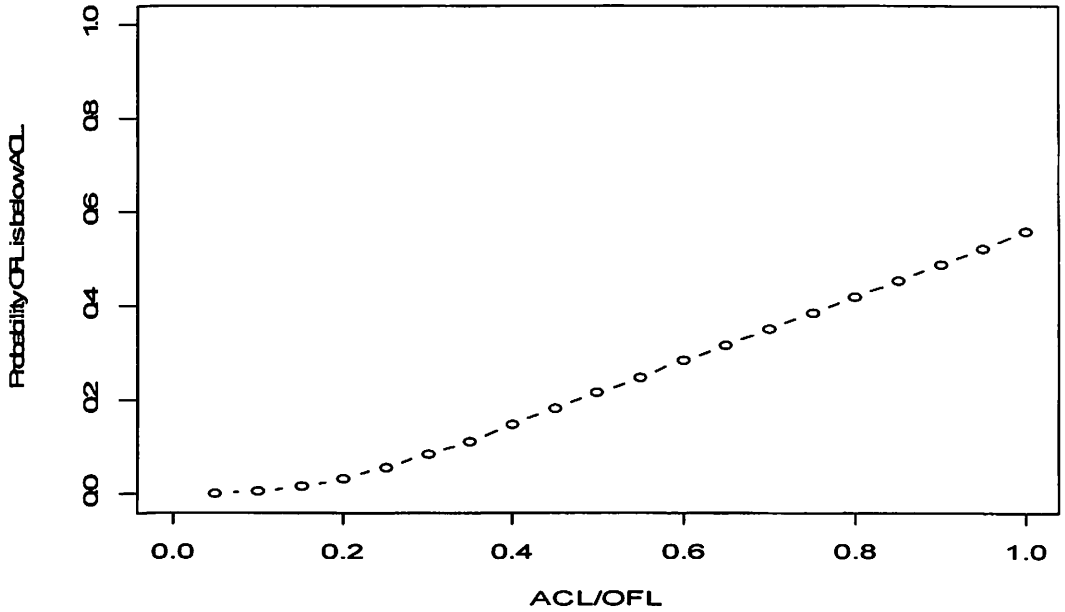

Figure 19. Probability that ACL is greater than the OFL as the ratio of ACL to OFL varies for Pribilof red king crab.

AGENDA D-2(a)(5)
OCTOBER 2009

Setting Annual Catch Limits (ACLs) for BSAI and GOA Groundfish

Staff

NOAA Fisheries, Alaska Fisheries Science Center

Contents

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Executive Summary

The purpose of this document is to present several approaches to incorporating uncertainty into the specification of Annual Catch Limits (ACLs) in the BSAI and GOA Groundfish FMPs as required by the 2006 Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (MSRA). The current system of ABC- and OFL-setting in these FMPs is, to some extent at least, already compliant with the new ACL requirements by virtue of the fact that ABC is always less than OFL. Nevertheless, several analyses were conducted to examine the current framework and some potential ways to better account for uncertainty in setting these harvest specifications.

Section 1.1 introduces a general method to incorporate scientific uncertainty into management advice that utilizes surveys or survey proxies to set the buffer between ABC and OFL (the P^* approach). Several examples are given from different regions and data types. The method described in Section 1.1 is provided as an example that could be adopted at some future date by the NPFMC.

In Section 1.2, the P^* approach method is applied to BSAI and GOA groundfish examples from different tiers. In these examples, the values of P^* required to match the existing buffers are computed, given those stocks' respective levels of uncertainty.

In Section 1.3, a decision-theoretic approach is presented that allows ACLs to vary with uncertainty given a specified level of risk aversion. This method is more computationally intensive, but may have more desirable optimality properties. Section 1.4 is a primer on the definition of risk aversion with some simple examples. In Section 6, we present a summary of the analyses thus far and recommendations for future work.

The results shown in Sections 2 and 5 show that the buffers currently prescribed by the BSAI and GOA Groundfish FMPs can be expressed in terms of responses to scientific uncertainty. The average buffer size was ~17% for Tier 3 stocks and 25% (as prescribed in the tier system) for Tiers 5 and 6. The relationship between CV and P^* is shown in Figure 2.2. The decision-theoretic approach provided in Section 5 shows that the average level of absolute risk aversion implied by the current Tier system is 0.4.

1. A general method to adjust catch limits/targets with survey uncertainty.[1]

1.1 Introduction

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) was reauthorized and amended on January 12, 2007, by the Magnuson Stevens Fishery Conservation and Management Reauthorization Act (MSRA 2007). The MSRA established new requirements to end and prevent overfishing, including Annual Catch Limits (ACLs) and Accountability Measures (AMs). Specifically in MSA section 303 (a)(15), fishery management plans shall

> "establish a mechanism for specifying annual catch limits in the plan (including a multiyear plan), implementing regulations, or annual specifications, at a level such that overfishing does not occur in the fishery, including measures to ensure accountability."

These annual catch limits are to apply to all fisheries with two exceptions: (1) stock that have a life cycles of one year or less, and (2) fisheries that are provided for under an international agreement in which the U.S. participates (e.g. The International Pacific Halibut Commission). A working group was convened to provide guidance on the application of ACLs for U.S. fisheries (Rosenberg et al. 2007) and a final rule on

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[1] Contributed by Dana Hanselman

guidance for the implementation of ACLs was published on Januray 16, 2009 and was enacted on February 17, 2009 (Department of Commerce 2009). Several key guiding principles were:

1. As a default or starting point, preventing overfishing applies to ALL stocks, therefore, so should ACLs.
2. To successfully end and prevent overfishing, OFL (Overfishing Level) > ABC (Acceptable Biological Catch) $\geq$ ACL.
3. Uncertainty is inevitable and should be accounted for in setting ABC and ACL.
4. Consideration of risk must include some evaluation of the vulnerability of a stock to the fishery.

One of the difficulties of meeting the first guideline is that across regions and stock, stock assessment scientists apply a wide variety of analytical techniques on a wide variety of data types and quality to determine limits and targets for fishing mortality. Ideally, risk and uncertainty could be estimated directly from data and managers could choose what level of risk-aversion that is appropriate for particular fisheries. Unfortunately, a small proportion of fisheries have sufficient data to estimate reliable probability distributions of key parameters such as female spawning biomass and MSY fishing mortality (e.g. only two stocks in the Alaska region). Therefore, to meet the first guideline, a procedure is needed that works for fisheries that are both data-poor and data-rich.

However, to satisfy the third and fourth guidelines, uncertainties about both the stock size and the vulnerability of a stock to the fishery need to be accommodated for. As stated previously, quantification of these uncertainties is straightforward for data-rich stocks and can be estimated from maximum likelihood or Bayesian models. The majority of stocks do not have the data to produce model-derived estimates of uncertainty, and must rely on simpler methods.

In this study, a simple generalized procedure is introduced that uses survey biomass uncertainty to adjust quotas to compute an Acceptable Biological Catch (ABC) that incorporates uncertainty. As opposed to techniques that use model derived uncertainty estimates, this technique is available to nearly all stock and regions (assuming the stock is caught in a survey) and potentially captures both process and measurement error. The coefficient of variation (CV) of a time series of biomass estimates or a Kalman filter derived CV potentially accounts for uncertainty due to the life history characteristics of the stock (short-lived stock with rapid fluctuations), and poorly surveyed stock (high variability from sporadic capture). Under current federal budget constraints, important biomass surveys are in jeopardy. Therefore, the uncertainty adjustment is compounded by the length of time since the last survey. Since some regions do not regularly update assessments, this adjustment could also be used to account for the length between assessment updates. To illustrate the technique, the adjustment is applied to a variety of stocks across regions.

1.2 Methods

Table 1. Abbreviations and mathematical symbols

ACL	Annual Catch Limit
ABC	Acceptable Biological Catch
CV	Coefficient of Variation (SD/mean)
OFL	Overfishing Level
Z^{1}	Inverse-normal function

1.2.1 Caddy-McGarvey Extended

Caddy and McGarvey (1996) developed a framework to compute a "target reference point" using simple statistical theory to allow a manager to choose an acceptable probability of exceeding MSY or a "limit reference point". In the Caddy-McGarvey framework (CM), a probability distribution for fishing mortality is assumed and MSY is assumed known exactly. Prager et al. (2003) generalized the CM framework by allowing uncertainty in both estimates of fishing mortality and MSY fishing mortality. While the Prager et al. (2003) method is preferable in situations where an estimate of the precision of

MSY is easily obtainable, an approach that applies to more levels of data availability is preferred. The CM framework can be reversed to determine a buffer size utilizing uncertainty in the limit reference point based on the uncertainty in a survey biomass index.

A straightforward way to implement an ACL would be to base it on the way the NPFMC currently determines biological reference points. In the FMPs for groundfish fisheries in Alaska, a tier system was adopted that prescribes different methods for setting OFL and ABC for different levels available data. The tier system provides a buffer to account for uncertainty within the same perceived level of data-richness, however, uncertainty is not explicitly accounted for between stocks at the same tier level. Uncertainty could be explicitly addressed as follows. First, estimate the OFL as prescribed by the appropriate tier for the stock and data-quality. Then, select what level of risk is acceptable that the ABC/ACL exceeds the true OFL. Presumably, this level should not exceed 50%, which would mean ABC is set equal to or higher than OFL, a level that is prohibited by the MSRA.

The assumption could be made that the buffer proportion could be either normal or lognormal.

$$\Pr(ABC > OFL) = \int_{p_{next}}^{\infty} \frac{1}{\sqrt{2\pi}\sigma_{p_{next}}} e^{\left[-\frac{(p_{next}-p)^2}{2\sigma^2_{p_{next}}}\right]} dp = P^* \qquad (1)$$

Using the normal approximation of this integral to apply a buffer to OFL yields

$$ABC = OFL \cdot p_{next} = OFL(1 + CV_{OFL} Z^{-1}(P^*)) \qquad (2)$$

where $CV_{p_{next}}$ is the approximation of survey CV used, Z^1 is the inverse normal approximation at P^*, which is the level of risk assumed by the manager for the probability that the ABC exceeds the OFL. In Excel™ format this would be "=OFL*NORMSINV(*P**,1,CV)."

The lognormal approximation is

$$ABC = OFL \cdot p_{next} = OFL\left[e^{\sqrt{\log_e(1+CV^2_{OFL})}Z^{-1}(P^*)}\right] \qquad (3)$$

where $\sqrt{\log_e(1+CV^2_{OFL})}$ is a correction to maintain constant CV between probability distributions. This can be calculated in Excel™ using "=OFL*LOGINV(*P**,0, SQRT(LN(1+CV^2)))."

Finally, each year following a survey without a new survey, there would be a compounding of the uncertainty buffer based on multiplicative probabilities.

$$ABC_t = OFL_t \cdot (p_{next})^{\frac{t}{i}} \qquad (4)$$

where ABC_t is the acceptable biological catch in year *t* from the last survey estimate, and *i* is an arbitrary constant if it is to desired to assume that the probabilities are not i.i.d. events. In these examples *i*=2. Illustrations of these three different methods for probabilistically determining the catch limit are contrasted in Figure 1.

1.2.2 Choosing a CV from survey data

Essential to the methods described here is the choice of CV used as a proxy for the uncertainty of OFL. One approach is to assert that a CV that accounts for not only the uncertainty of the most recent survey, but the inter-survey variability contains information about both the quality of the survey (measurement error) and the biological variability (process error) of the stock. A number of methods to choose the appropriate CV are discussed, and show two methods are presented in the examples that could serve as candidate methods.

Several ways to compute a survey biomass CV for use in this method exist:

1) The sampling error CV of the last survey
2) The mean of all survey sampling error CVs
3) The mean of the last several sampling error CVs (e.g. last 3)
4) The CV of the time series of the biomass index
5) The posterior Kalman filter CV of the biomass index time series
6) An assessment model derived CV estimate

Because this is a method to be used across as many possible stocks as possible, methods 1-5 are discussed. Method 6 is only mentioned to point out that model-based estimates of uncertainty for data-rich stocks could be used. There are advantages and disadvantages to each approach. When the sampling error CV of the last survey is used (1), this gives maximum weight to the most recent information and accounts for the distributional aspects of the population and how well it is sampled by the survey, but not temporal changes in the population. When the mean sampling CV of all surveys is used (2), this gives what the "typical" sampling error is for the stock, but does not account for trends in time (e.g. distributional changes). Method 3 is a compromise between (1) and (2) that weights recent information, but protects against the use of one outlier CV. Computing the CV of the time series of the biomass index utilizes the information of large changes between surveys (4), which can be caused by both sampling error and biological/environmental changes. The CV of the underlying state variable could be computed using a random-walk Kalman filter model (5), which also accounts for process and measurement error, but in a more rigorous method than (4) and is briefly explained in Appendix 1.1A.

1.2.3 Choosing a *P** value

The value of P^* chosen should be chosen as a measure of management uncertainty and desired risk aversion. One way to choose this value would be to make an adjustment to P^* based on past performance of the ABC setting system. Since ABC must not be set higher than OFL, the maximum value of P^* is 0.5. An adjustment based on past performance could be based on the proportion of overages in some number of recent years. A simple formula for P^* would be:

$$P^* = 0.5 - 0.5\frac{o}{t+1} - c \qquad (5)$$

Where o is the number of overages during t past assessment years. One is added to the denominator to insure a P^* of zero does not occur and c is a constant for additional management uncertainty.

1.3 Results/Examples

To illustrate the different versions of the method, to the method is applied to stocks that vary in life history, region, and data-richness. Data sets for of eight stocks were compiled from various sources with their associated time series of survey abundance indices and CVs in Table 1. Some of these stock are surveyed annually, have current surveys, and are considered well sampled. Others have been surveyed in the past, but not synoptically and have no current survey.

Three specific examples were chosen to represent different typical situations. In each stock's time-series graph, the Kalman Filter estimates of the time-series with associated uncertainty are shown.

Current, annual, synoptic surveys: George's Bank Atlantic cod

The Northeast Fisheries Science Center has conducted an autumn bottom trawl survey from 1963-2007. The weight/tow and associated CVs from this survey provided the basis for estimation of an uncertainty buffer for Atlantic cod. This is an example of a stock that has an annual long-term survey, with good distributional coverage, and has shown large changes in the population size (Figure 2).

<u>Current, biennial/triennial, synoptic survey: Gulf of Alaska arrowtooth flounder</u>

The Alaska Fisheries Science Center has conducted a triennial/biennial bottom trawl survey from 1984-2007. The absolute biomass estimates (tons) and associated CVs from this survey were used to calculate the uncertainty buffer for GOA arrowtooth flounder. This is an example of a stock that has a current, non-annual, medium-term survey with good distributional coverage and low survey CVs (Figure 3).

<u>Past, annual, non-synoptic survey: Gulf of Mexico red grouper</u>

The Southeast Fisheries Science Center has conducted a longline survey for Gulf of Mexico red grouper from 2000-2005 (Ingram et al. 2005). An abundance index derived from a zero-inflated delta-lognormal model of longline survey data was used to calculate uncertainty buffers for GOM red grouper. This is an example of a model-derived abundance index and CV, formed by a short-term survey data set, with changing distributional coverage, and high CVs (Figure 4).

1.3.1 Effect of survey uncertainty

The different methods of calculating the survey uncertainty described in section 1.2.2 give variable results depending on which of the five methods are calculated (Table 2). Because the time series are different in terms of inter-annual variability (large changes in abundance), and in terms of sampling variability (large annual sampling CVs), different methods behave differently depending on the stock. In the Gulf of Mexico red grouper stock, the CV of the time series was similar to other methods, while in the GOA arrowtooth stock, this method yielded a CV four times higher. Like the GOA arrowtooth stock, George's Bank cod have experienced large changes in biomass so this method is accounting for potential large changes in population, whether environmentally or anthropogenically driven. The Kalman filter estimates generally had the lowest CVs, this is because the filtering process is recursively utilizing information from the rest of the time series to smooth the measurement error component.

When these methods are applied for the three example stocks for an ACL adjustment in the next year (Table 3), the adjustment can be slight (GOA arrowtooth flounder), or substantial (George's Bank cod). For most cases, using the coefficient of variation of the time series of biomass estimates yielded the largest downward adjustment, while the CV of the last Kalman filter estimate yielded the smallest downward adjustment.

1.3.2 Effect of P^* value

The choice of P^* value has a large effect on the size of the downward adjustment. If management is very risk-averse and chose to target exceeding the OFL in only one of twenty years, the adjustment would be severe for all three stocks under method 4 (time series CV) (Figure 5). Under method 5 (Kalman filter), the P^* makes relatively little difference for arrowtooth flounder but has a much larger effect on red grouper and George's Bank cod. If the simple P^* formula (5) presented earlier was used, it could be based on the proportion of recent overages. This would be a way to assign an accountability measure (AM) to this method. Arrowtooth has no catch levels in excess of TAC, and data for the other two examples were unavailable. The following table shows example results of the calculations of P^* given the number catches in excess of ABC in the last five years with c=0:

<u>Overages</u>	<u>0</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
P^*	0.50	0.42	0.33	0.25	0.17	0.08

1.3.3 Effect of loss of survey

Compounding the effects of losing a survey over many years could lead to large adjustments for stocks where the status is already uncertain. The results presented in Figure 6 were estimated assuming an independence value (*i*) of 2 in equation (4) to compensate for autocorrelation in the unobserved time series. In this analysis, a short lapse in survey would lead to comparable reductions in ABC, while long lapses would lead to disparate differences based on stock uncertainty.

1.4 Discussion

This section introduces a relatively simple and general approach for deriving an adjustment to a standard catch limit (OFL) to account for scientific uncertainty. The method could be considered by the NPFMC at some future date. The ideas in this study are not novel, but a variation on prior authors' work (Caddy and McGarvey 1996, and Prager et al. 2003).

The analysis demonstrates how survey uncertainty can be incorporated directly into setting new limits and targets required by the new MSRA guidelines. In its most basic form, the method could be used with variable quantities (*P**, *i,* and *c*) set the same across stocks and regions which would promote transparency and standardization. Additionally, in the interest of simplicity, one of the more straightforward methods at deriving CV might be used such as the average of the last several surveys.

The method provides a flexible framework to allow input from managers on the amount of risk aversion to be applied. The values of *P** and *c* should likely be set to represent management uncertainty, risk-aversion, and socioeconomic concerns by bodies such as the regional management councils. As demonstrated in the examples, this value could be set based on past overages in the fishery. This would be an example of an Accountability Measure where the buffer is automatically reduced when limits are exceeded less often.

Stock assessment biologists could set the value of *i* with some measure of autocorrelation in the survey time-series, fishing pressure, and vulnerability of the stock that reflect how important annual surveys should be in determining future uncertainty buffers. Simulation work based on the known data and biology would be useful in evaluating different values for any of these quantities on a stock-specific basis.

This method can operate within existing management framework. It is not a method that sets a hard biomass target, it sets an uncertainty adjustment to the best available scientific judgment as to what OFL is for that stock. This adjustment would become smaller, both when the stock is better surveyed, and management effectively limits catch.

This method requires some kind of survey or survey proxy to come up with a defensible CV to apply. The CV methods used in the examples are not the most straightforward, but capture more potential information about the stocks in question. The CV of a time-series would yield a high buffer when the species is well surveyed but has a substantial trend. The Kalman filter method is more rigorous, but less transparent to stakeholders.

Most species that are caught in a fishery are also caught in a survey, but there will always be stocks or species that "slip though the mesh". For these species, there still will need to be some data-poor system to apply an uncertainty buffer. These should likely be not be subject to Annual Catch Limits because information is so tenuous that any number would be quite arbitrary. The MSRA guidelines do allow for Ecosystem Component stocks to be exempt from ACLs and for some stocks, this will be the necessary avenue. Future work in this area should be focused on how to deal with rare or low-catchability stocks.

1.5 Literature Cited

Caddy, J. F., and R. McGarvey. 1996. Targets or limits for management of fisheries? N. Am. J. Fish. Manage. 16:479–487.

Department of Commerce. 2009. Magnuson-Stevens Act Provisions; Annual Catch Limits; National Standard Guidelines. Federal Register 74: 11 (Jan. 16, 2009). 50 CFR Part 600. pp. 3178-3213. http://www.nmfs.noaa.gov/msa2007/docs/acl_final_rule.pdf.

Ingram, G. W., M. Grace, L. Lombardi-Carlson, and T. Henwood. 2005. Catch rates, distribution and size/age composition of red grouper, *Epinephelus morio*, collected during NOAA Fisheries Bottom Longline Surveys from the U.S. Gulf of Mexico. SEDAR 12-DW-5. http://www.sefsc.noaa.gov/sedar/download/S12%20DW05%20longline%20survey.pdf?id=DOCUMENT

Ingram, G. W. 2007. Abundance indices of king mackerel, *Scomberomorus cavalla*, collected during SEAMAP shallow water trawl surveys in the South Atlantic Bight (1989-2006). SEDAR 16-DW-09. http://www.sefsc.noaa.gov/sedar/download/S16_DW_09.pdf?id=DOCUMENT

Limpert, E., W.A. Stahel, and M. Abbt. 2001. Lognormal distributions across the sciences: keys and clues. Bioscience 51:5, 341– 352.

Meinhold, J., and N.D. Singpurwalla. 1983. Understanding the Kalman filter. Am. Statistician 37: 123-7.

MSRA (Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2007). 2007. Pub. L. No. 109-479, 120 Stat. 3575. May 2007.

Pella, J.J. 1993. Utility of structural time series models and the Kalman filter for predicting consequences of fishery actions. In Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Edited by G. Kruse, D.M. Eggers, R.J. Marasco, C. Pautzke, and T.J. Quinn, II. Alaska Sea Grant College Program Report No. 93-02. University of Alaska, Fairbanks, Alaska. pp. 571–594.

Prager, M. H., C. E. Porch, K. W. Shertzer, and J. F. Caddy. 2003. Targets and limits for management of fisheries: a simple probability-based approach. N. Am. J. Fish. Manage. 23:349–361.

Quinn II, T. J., and R. B. Deriso. 1999. Quantitative Fish Dynamics, 542 p. Oxford Univ. Press, New York, NY.

Rosenberg, A., D. Agnew, E. Babcock, A. Cooper, C. Mogensen, R. O'Boyle, J. Powers, G. Stefánsson, and J. Swasey. 2007. Annual catch limits report from the Lenfest working group. Lenfest Ocean Program and MRAG Americas. 36 pp.

Schirripa, M.J. 2007. Status of the sablefish resource off the continental U.S. Pacific coast in 2007. http://www.pcouncil.org/groundfish/gfsafe1008/Sable07v3_0.pdf

Schnute, 1994. A general framework for developing sequential fisheries models. Can. J. Fish. Aquat. Sci. 51, pp. 1676–1688.

Stewart, We. J. 2007. Updated U.S. English sole stock assessment: Status of the resource in 2007. http://www.pcouncil.org/groundfish/gfsafe1008/2007_English_sole_update_council.pdf

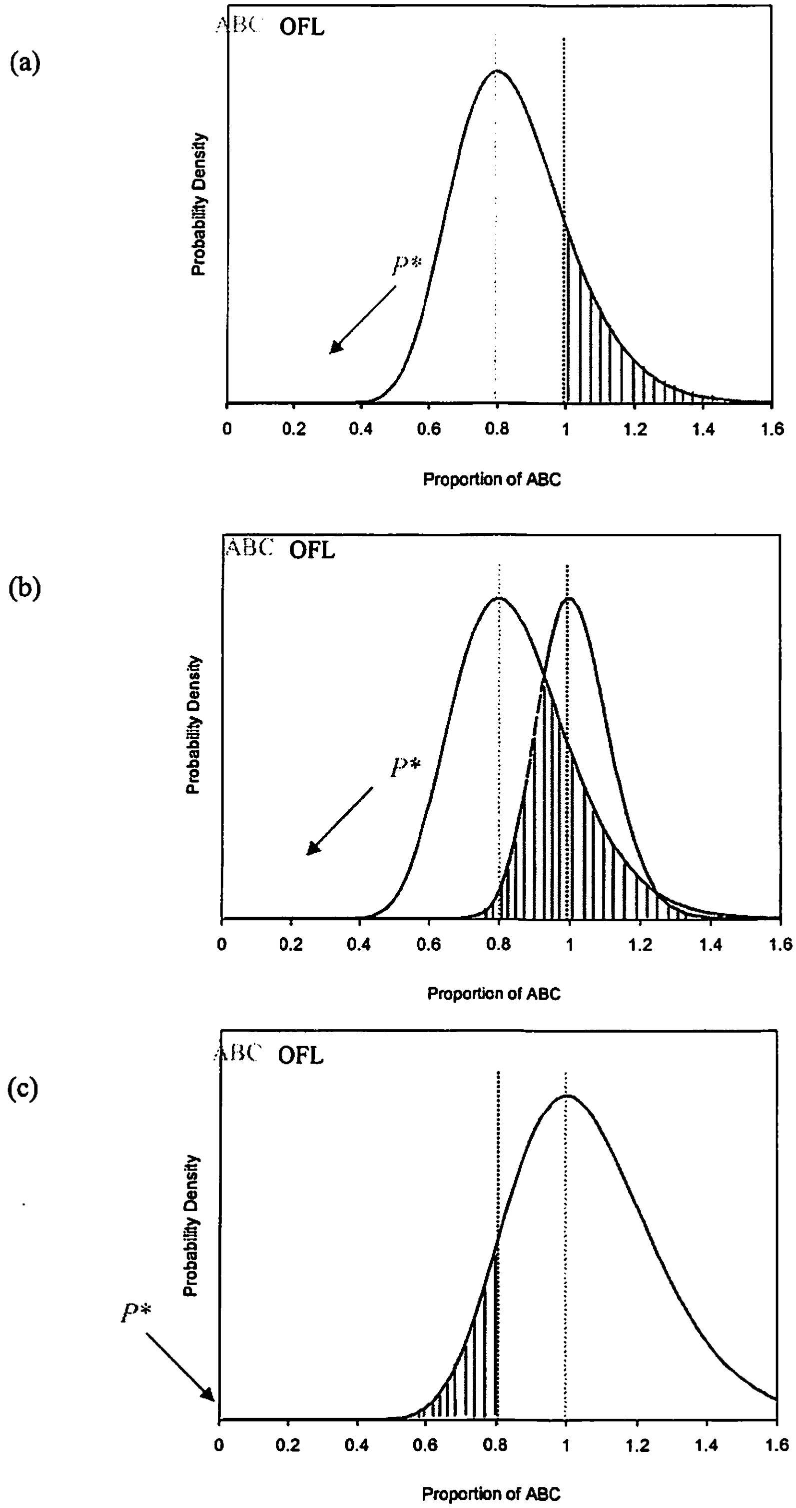

Figure 1. Representations of the interpretation of P^* for each of three methods (a) Caddy-McGarvey (1996), (b) Prager et al. (2003), (c) present study. Shaded areas correspond to P^*.

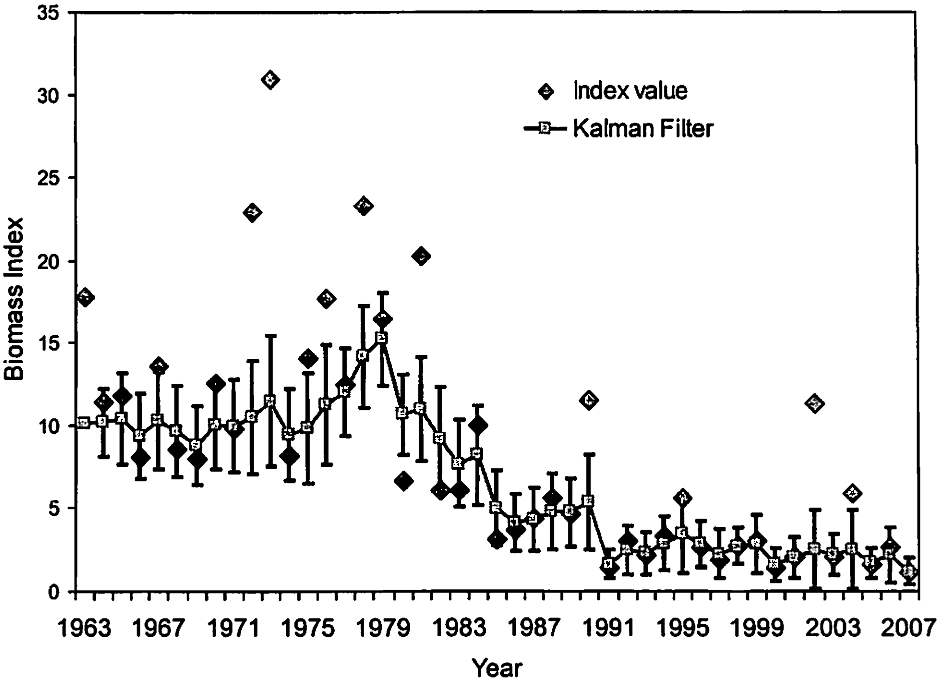

Figure 2. NEFSC autumn trawl survey index of George's Bank Cod (blue diamonds), and Kalman Filter estimates (pink squares with blue line).

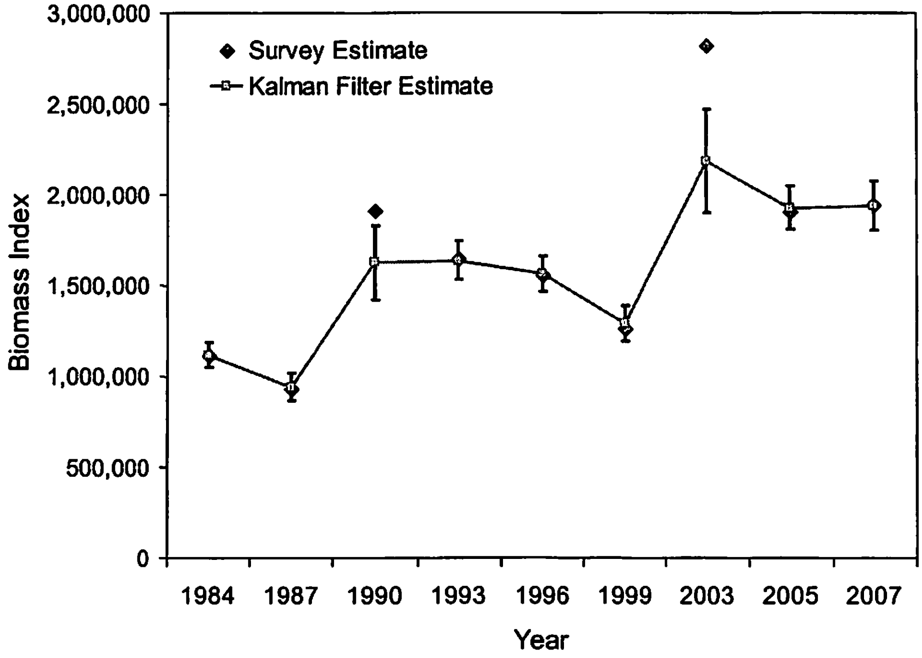

Figure 3. AFSC bottom trawl survey index of Gulf of Alaska arrowtooth flounder (blue diamonds), and Kalman Filter estimates (pink squares with blue line).

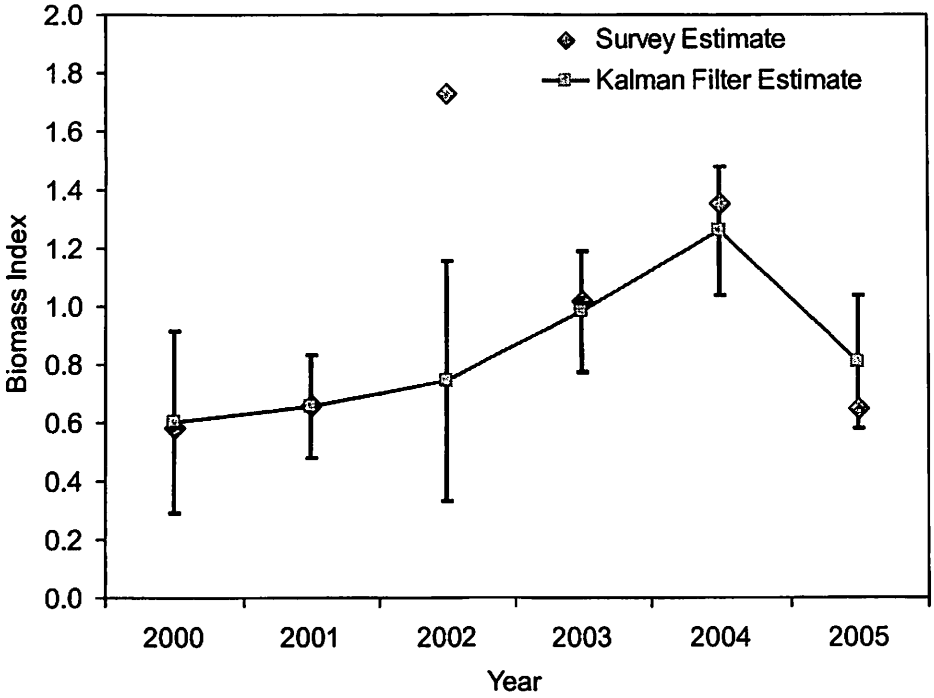

Figure 4. Red snapper (blue diamonds), and Kalman Filter estimates (pink squares with blue line).

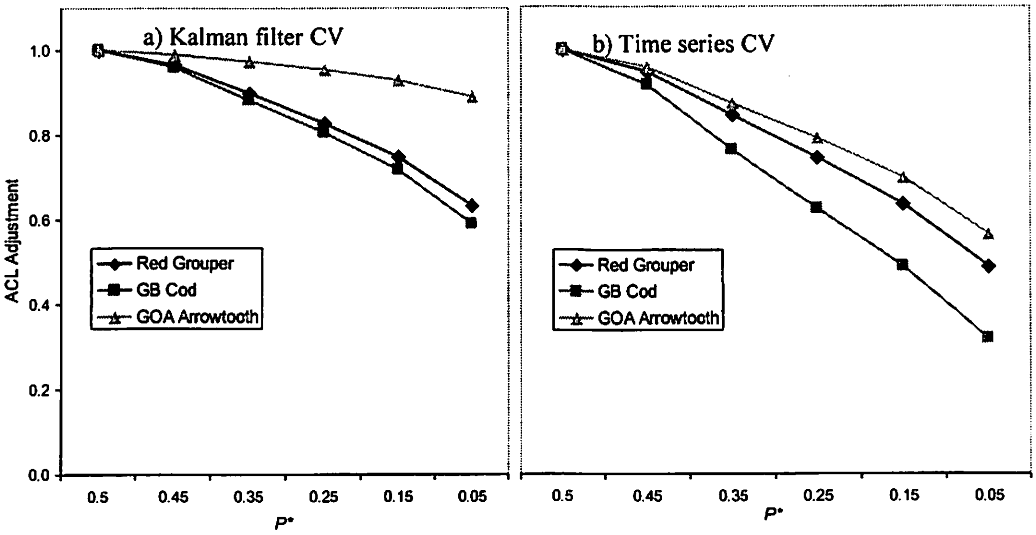

Figure 5. Comparison of different P^* values for two different methods of calculating CVs for use in ACL adjustment.

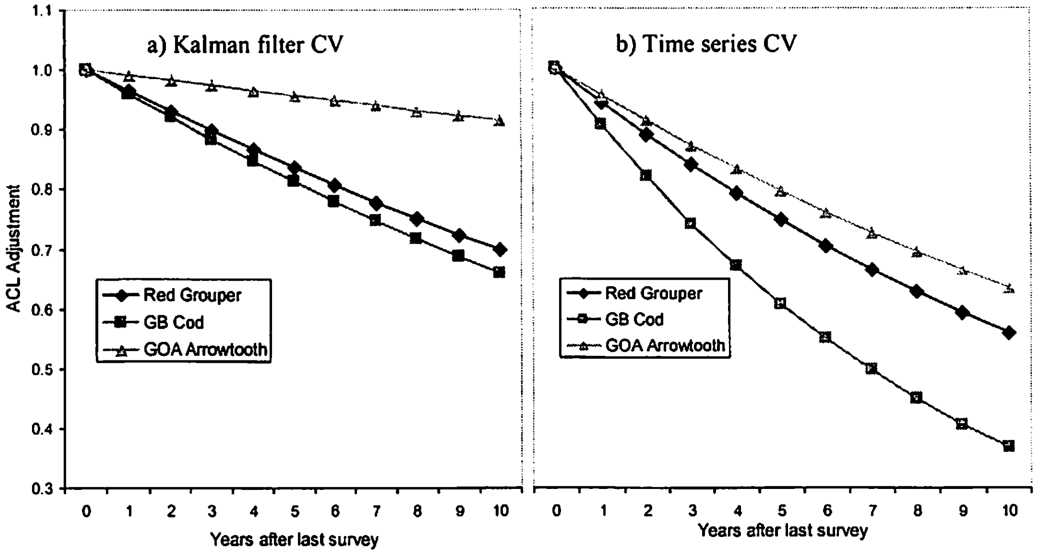

Figure 6. Effect on adjustment to ABC as years without surveys compound. *P**=0.4, i=2.

Table 2. Biomass indices and uncertainty (CV, coefficient of variation) for eight stocks.

	King Mackerel[a]		Red grouper[b]		English sole[c]		WC sablefish[d]		Acadian redfish[e]		George's Bank Cod[e]		GOA Northern rockfish[f]		GOA Arrowtooth Flounder[f]	
	Index	CV	Index	CV	Index	CV	Index	CV	Index	CV	Index	CV	Index	CV	Index	CV
1963											17.80	0.27				
1964									53.6	0.75	11.40	0.30				
1965									13.2	0.37	11.80	0.32				
1966									29.3	0.45	8.10	0.23				
1967									24.4	0.37	13.60	0.23				
1968									40.4	0.43	8.60	0.25				
1969									23.8	0.26	8.00	0.20				
1970									33.0	0.19	12.60	0.19				
1971									23.4	0.22	9.80	0.26				
1972									24.6	0.19	22.90	0.36				
1973									17.0	0.18	30.90	0.29				
1974									24.2	0.30	8.20	0.21				
1975									40.0	0.29	14.10	0.41				
1976									15.3	0.39	17.70	0.24				
1977									17.3	0.15	12.50	0.14				
1978									20.7	0.16	23.30	0.15				
1979									16.0	0.21	16.50	0.13				
1980					3,544	0.17			12.6	0.31	6.70	0.25				
1981									12.2	0.32	20.30	0.44				
1982									3.5	0.27	6.10	0.42				
1983					4,651	0.09			4.1	0.23	6.10	0.30				
1984									3.9	0.38	10.00	0.32	39,334	0.29	1,112,215	0.07
1985									5.7	0.31	3.10	0.46				
1986					6,254	0.09			8.0	0.34	3.70	0.27				
1987									5.5	0.32	4.40	0.30	136,417	0.29	931,598	0.08
1988									6.3	0.57	5.60	0.34				
1989	0.81	0.21			8,395	0.15			6.8	0.30	4.70	0.29				
1990	2.38	0.16							12.2	0.33	11.50	0.42	107,076	0.42	1,907,177	0.13
1991	0.70	0.22							8.4	0.45	1.40	0.30				
1992	0.84	0.24			9,510	0.10			8.1	0.29	3.00	0.32				
1993	0.45	0.25							11.2	0.33	2.20	0.34	104,480	0.35	1,551,657	0.06
1994	0.71	0.23							5.9	0.43	3.30	0.33				
1995	1.23	0.20			5,992	0.11			4.7	0.24	5.60	0.47				
1996	2.26	0.17							30.6	0.33	2.70	0.28	98,965	0.27	1,639,632	0.07
1997	0.52	0.24							18.9	0.39	1.90	0.48				
1998	1.79	0.20			15,312	0.08	69,733,110	0.23	31.7	0.45	2.80	0.21				
1999	1.21	0.18					72,400,243	0.29	22.9	0.24	3.00	0.43	242,187	0.61	1,262,151	0.08
2000	0.82	0.22	0.58	0.68			90,313,581	0.23	26.2	0.29	1.40	0.37				
2001	0.45	0.23	0.66	0.29	12,551	0.09	74,986,689	0.20	28.2	0.25	2.10	0.35				
2002	0.51	0.21	1.73	0.83			66,560,943	0.20	41.9	0.33	11.30	0.45				
2003	0.99	0.20	1.02	0.22			87,161,424	0.27	65.5	0.49	2.10	0.32	66,310	0.48	2,819,095	0.13
2004	0.62	0.36	1.35	0.19	36,113	0.15	123,453,322	0.34			5.90	0.70				
2005	0.73	0.49	0.65	0.41			101,271,759	0.22	47.0	0.23	1.60	0.30	359,026	0.37	1,899,770	0.07
2006	1.01	0.22					95,970,856	0.20	50.2	0.30	2.70	0.45				
2007									50.4	0.25	1.10	0.37	227,069	0.38	1,939,055	0.08

Sources: [a] Age-0 king mackerel from SEAMAP SEFSC shall trawl survey, Ingram (2007) p. 8; [b] SEFSC longline survey from Ingram et al. (2005); [c] NWFSC triennial northern bottom trawl survey, Stewart (2007), p.107; [d] NWFSC slope survey, Schirripa (2007), p. 54; [e] NEFSC autumn bottom trawl survey, Legault 2008 (pers. comm., Woods Hole, MA, NEFSC/NMFS); [f] Gulf of Alaska biennial/triennial bottom trawl survey (RACEBASE AFSC/NMFS).

Table 2. Results of using methods 1-5 for calculating CV for use in ABC adjustment for survey uncertainty for eight stocks.

Method	King Mackerel	**Red grouper**	English sole	WC sablefish	Acadian redfish	**George's Bank Cod**	GOA Northern	**GOA Arrowtooth**
(1) CV_last	0.22	0.41	0.15	0.20	0.25	0.37	0.38	0.08
(2) CV_mean	0.24	0.44	0.12	0.24	0.32	0.32	0.38	0.09
(3) CV_last 3	0.36	0.28	0.11	0.25	0.26	0.37	0.41	0.09
(4) CV_all	0.58	0.46	0.88	0.21	0.71	0.79	0.73	0.36
(5) CV_KF	0.22	0.18	0.16	0.16	0.16	0.33	0.29	0.07

Table 3. ABC adjustment in 1st year using lognormal method, $P^*=0.25$, i=2

Method	King Mackerel	**Red Grouper**	English Sole	WC Sablefish	Acadian redfish	**George's Bank Cod**	GOA Northern	**GOA Arrowtooth**
(1) CV_last	0.864	0.767	0.904	0.875	0.847	0.785	0.781	0.948
(2) CV_mean	0.852	0.753	0.923	0.852	0.810	0.810	0.781	0.941
(3) CV_last 3	0.790	0.831	0.929	0.847	0.842	0.785	0.767	0.941
(4) CV_all	0.695	0.744	0.600	0.869	0.650	0.625	0.644	0.790
(5) CV_KF	0.866	0.829	0.901	0.902	0.897	0.806	0.785	0.954

Appendix 1A: Kalman filter methods

This appendix describes how a posterior CV on the last survey biomass can be estimated using the Kalman filter method. Specific recursive equations for the univariate Kalman filter approach are presented. Useful overviews of the Kalman filter are provided by Meinhold and Singpurwalla (1983) and Pella (1993). Schnute (1994) provides general theory of the Kalman filter approach for estimating fisheries models.

Observation equation

$y_t = b_t + v_t$

where y_t is an estimate of the unobservable state of nature, which is the sum of b_t, the biomass estimate at time *t* and v_t is the observation error.

State equation

$b_t = b_{t-1} + w_t$ where b_t is the sum of the previous biomass estimate and a process error, w_t.

It is assumed that w_t and v_t are independent.

Prediction equations

$\hat{b}_{t|t-1} = \hat{b}_{t-1}$ where the prior biomass $\hat{b}_{t|t-1}$ in year *t* is equal to the posterior biomass in year *t*-1.

$P_{t|t-1} = P_{t-1} + \sigma_w^2$ with the prior variance $P_{t|t-1}$ is equal to the posterior variance P_{t-1} in year *t*-1 summed with the process error σ_w^2.

Update equations

$F_t = P_{t|t-1} + \sigma_v^2$ The mean squared error of $\hat{y}_{t|t-1}, F_t$ is the sum of the prior variance $P_{t|t-1}$ at time *t*-1 and the observation error σ_v^2 at time *t* and $e_t = y_t - \hat{b}_{t|t-1}$ with the error, e_t, is defined as the difference from the survey biomass estimate y_t in year *t* from the prior biomass estimate $\hat{b}_{t|t-1}$.

$\hat{b}_t = \hat{b}_{t|t-1} + P_{t|t-1}F_t^{-1}e_t$ is the posterior or Kalman predicted estimate of biomass $\hat{b}_t$ in year *t* is equal to the prior estimate $\hat{b}_{t|t-1}$ summed with the prior variance $P_{t|t-1}$ divided by the mean squared error of $\hat{y}_{t|t-1}, F_t$ and multiplied by the prediction error e^t.

$P_t = P_{t|t-1} - P_{t|t-1}^2 F_t^{-1}$

The posterior or Kalman variance, P_t, is the prior variance $P_{t|t-1}$ minus the square of the prior variance, $P_{t|t-1}^2$, divided by the mean squared error of $\hat{y}_{t|t-1}, F_t$.

2. Application of the *P** approach to selected Alaska groundfish stocks[2]

The *P** approach is essentially *the probability that ACL is in excess of OFL, given that our assumptions about the uncertainty of OFL are true.* In applying the *P** approach (Table 1), the lognormal distribution was used to represent the uncertainty around OFL. An estimate of the uncertainty of OFL could be obtained for some Tier 3 stocks, but for simplicity, the CV of ending year spawning biomass was compared with the three-year average CV of trawl survey biomass for Tier 3 stocks. For Tiers 5 and 6, the survey biomass CV was the only data available to estimate a proxy for OFL uncertainty. For comparison, the buffers that are currently imposed by the Tier system are included. The current buffers are based on the ratio of $F_{40\%}$ to $F_{35\%}$ (Tier 3), 0.75 times natural mortality (Tier 5), or 0.75 times average catch (Tier 6). *P** that would yield the current buffers were estimated. The buffers for all stocks under the two CV methods given a *P** value of 0.12 (the average over all buffers in the previous column) are then calculated. For the average buffer size in Tier 3 (~0.83) and Tiers 5 and 6 (0.75), the relationship between CV and *P** is shown in Figure 1.

Table 1 mainly shows that using survey CVs is generally more robust than using model CVs. Unless all stocks were modeled using identical assumptions and data types, the CVs among and between tiers are not comparable. For example, it is unlikely that EBS pollock really have a six-fold higher amount of uncertainty than sablefish. For the survey CV method, a *P** of 0.12 gives buffers ranging from 0.57 for the least precisely surveyed fish (harlequin rockfish) to 0.90 for a precisely surveyed fish (arrowtooth flounder). Additionally, the method can be applied to Tier 6 stocks. Trawl survey biomass estimates are not used for Tier 6 stocks. However, using the trawl survey uncertainty to construct a buffer for Tier 6 stocks may not be unreasonable. In Tier 6 stocks the survey biomass estimates are not used because they are highly uncertain. However, if the P* approach was applied, this uncertainty would lead to a large buffer. This would accomplish the objective, which is to explicitly account for uncertainty, where more uncertainty results in a larger buffer.

This method requires some kind of survey or survey proxy to come up with a defensible CV to apply. Most species that are caught in a fishery are also caught in a survey, but there will always be stocks or species that "slip though the mesh". Species not caught in the groundfish surveys should not be subject to Annual Catch Limits because information is so tenuous that any number would be quite arbitrary. The MSRA guidelines do allow Ecosystem Component stocks to be exempt from ACLs and for some stocks, this will be necessary.

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[2] Contributed by Dana Hanselman

Table 1. Current buffer size for a selection of NPFMC species compared to *P** necessary to obtain that buffer for two different CV types. SSB CV is CV for ending year spawning biomass. Survey CV of last 3 is the average CV of the last 3 trawl surveys. *P**=0.12 is the buffer size at the mean *P** from the *P** Survey column.

Stock	Tier	F_{40}	F_{35}	Buffer size	SSB CV	Survey CV of last 3	*P** SSB	*P** Survey	Buffer at P*=0.12 (SSB)	Buffer at P*=0.12 (Survey)
GOA POP	3	0.06	0.07	0.84	29%	17%	0.27	0.15	0.72	0.82
GOA Arrowtooth	3	0.19	0.22	0.84	4%	9%	0.00	0.03	0.95	0.90
GOA Pollock	3	0.13	0.15	0.87	11%	14%	0.10	0.15	0.88	0.85
GOA P. Cod	3	0.44	0.54	0.81	16%	18%	0.10	0.13	0.83	0.81
GOA Rougheye	3	0.04	0.05	0.83	40%	17%	0.31	0.13	0.64	0.82
Sablefish	3	0.09	0.10	0.84	4%	13%	0.00	0.09	0.95	0.86
GOA Harlequin	5			0.75		51%		0.28		0.57
GOA Sleeper shark	6			0.75		29%		0.15		0.72
EBS Pollock	1	0.28	0.33	0.85	24%	10%	0.25	0.06	0.76	0.89
BSAI Flathead	3	0.28	0.34	0.82	6%	11%	0.00	0.03	0.93	0.88
BS N. Rockfish	3	0.04	0.05	0.83	9%	24%	0.02	0.22	0.90	0.75
BSAI Shortraker	5			0.75		26%		0.13		0.74
BSAI G. Grenadier	6			0.75		10%		0.00		0.89

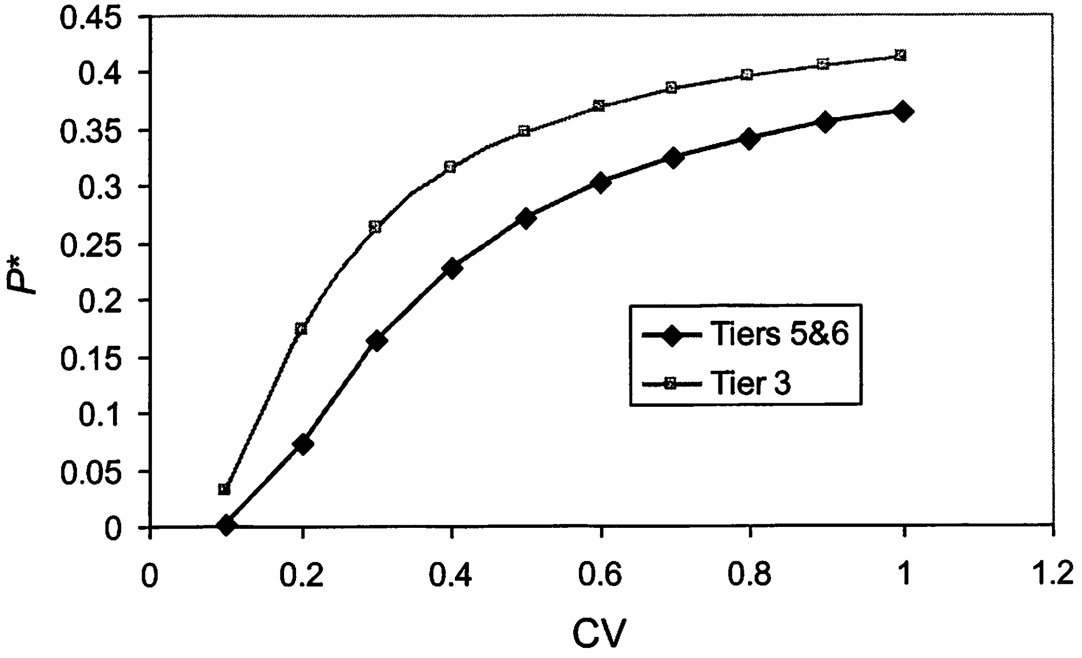

Figure 1. Relationship between assumed CV of OFL and *P** value for Tiers 3 and 5/6 for groundfish.

3. A decision-theoretic approach to setting buffers between fishery management targets and limits[3]

3.1 Introduction

Inclusion of a buffer between fishery management targets and limits has been advocated for many years (e.g., Rosenberg et al. 1994 (reprinted 1996), Restrepo et al. 1998). The 1998 version of the National Standard 1 (NS1) guidelines (50 CFR §600.310) suggested setting a buffer between targets and limits (paragraph (f)(5)(i)), and by the time the current version of the NS1 guidelines was published in 2009, these concepts had gained sufficient acceptance that the National Marine Fisheries Service was able to conclude, "Use of catch targets associated with catch limits is a *well-recognized principle* of fishery management" (response to Comment 8, emphasis added).

Still, use of the terms "limit" and "target" in the NS1 guidelines is somewhat complicated. A catch "limit" can mean either the "overfishing limit" (OFL) or the "annual catch limit" (ACL). The term "target" can also refer to a variety of measures. For example, it can refer to the "annual catch target" (ACT), an optional management measure. The ACT can be as high as the ACL, which in turn can be as high as the "acceptable biological catch" (ABC), which in turn can be as high as the OFL. In addition, the response to Comment 4 makes reference to a plurality of "catch *targets*" (emphasis added) used to meet the requirements of NS1.

To minimize confusion, a particular set of definitions will be used here. These definitions have been chosen so as to be consistent with conventional usage. Dictionaries tend to define "target" as "something aimed at" or "something to be achieved," and they tend to list synonyms such as "goal" and "objective." Dictionary definitions of "limit" tend to list synonyms such as "boundary" and "border." The terms *target* and *limit*, along with *buffer*, will be defined here as follows:

- The target catch is the amount of catch for which managers are aiming, based on a strategy designed to achieve some management objective. It is assumed that the target catch is based on a target fishing mortality rate. If the target catch described here is used in the context of the NS1 guidelines, it could conceivably refer to any of the system of catch reference points with the exception of OFL.
- The limit catch is the amount of catch that managers are trying to avoid, with the understanding that remedial action will be required in the event that the limit is exceeded. It is assumed that the limit catch is based on a limit fishing mortality rate. In the context of the NS1 guidelines, the limit catch described here is best interpreted as the OFL.
- The buffer is equal to 1 minus the ratio of the target fishing mortality rate to the limit fishing mortality rate.

Another principle suggested in the 1998 version of the NS1 guidelines and amplified considerably in the 2009 version is that the size of the buffer should vary directly with some measure of uncertainty. Types of uncertainty to be considered might include process uncertainty (random variability in population dynamics), estimation uncertainty (random variability in estimates of parameters or population numbers at age), and implementation uncertainty (random variability in catch).

The objective of this paper is to show how decision theory can be used to set fishery management targets and limits in a statistically optimal manner, and such that the buffer varies directly with the amount of uncertainty.

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[3] Contributed by Grant Thompson

3.2 Theory

3.2.1 Notational conventions

The following notational conventions are observed:

- Vectors are represented by lower case letters in bold.
- Scalars (including elements of vectors and acronyms used as names of scalar quantities) are represented by lower case letters in italics.
- Names of standard operators (exponent, logarithm, differentiation, etc.) are shown in lower case, non-italicized font to distinguish them from functions and parameters specific to this paper.
- Functions whose form or values might differ depending on the variable to which they apply are denoted by a generic symbol subscripted by the name of the variable to which they apply (e.g, probability density function (pdfs) are represented generically by the letter p, with the pdf of a particular variable x written $p_x(x)$).

A list of symbols is provided in Table 1.

3.2.2 Noncentral moments and order means

Before embarking on decision theory proper, it may prove helpful to provide a brief review of two key statistical concepts. If: 1) q is a real number; 2) z is a positive, continuous random variable; and 3) $p_z(z)$ represents the probability density function (pdf) of z; then the qth noncentral moment, $ncm_z(q)$, is defined as

$$ncm_z(q) = \left(\int_0^\infty z^q \cdot p_z(z) \, \mathrm{d}z \right) \quad ,$$

and the qth order mean, $om_z(q)$, is defined as the qth root of the qth noncentral moment:

$$om_z(q) = ncm_z(q)^{1/q} \quad .$$

(Order means are also referred to as generalized means, Hölder means, or power means.)

In the special case of $q = 0$, the qth order mean reaches the following limit:

$$om_z(0) = \exp\left(\int_0^\infty \ln(z) \cdot p_z(z) \, \mathrm{d}z \right) \quad .$$

Some well-known order means include the arithmetic mean ($q = 1$), the geometric mean (the limit as q approaches 0), and the harmonic mean ($q = -1$). The fundamental theorem of inequalities states that the values of the order means always increase monotonically with order (e.g., Mitrinović et al. 1993). For example, the arithmetic mean is always greater than the geometric mean and the geometric mean is always greater than the harmonic mean.

3.2.3 Risk aversion and utility

The idea of risk aversion may be developed by considering a series of hypothetical wagers. Suppose that a subject is presented with the following wagers (the terms "net worth" and "wealth" will be treated as synonymous):

1) The subject increases his/her net worth by 100% with probability 0.5 and decreases his/her net worth by 100% with probability 0.5.
2) The subject increases his/her net worth by 300% with probability 0.25 and decreases his/her net worth by 100% with probability 0.75.

3) The subject increases his/her net worth by 9900% with probability 0.01 and decreases his/her net worth by 100% with probability 0.99.

Let the subject's net worth be scaled such that the current value is unity. If the subject declines all of the above wagers, his/her net worth does not change. If the subject accepts one of the above wagers, his/her expected net worth would be

$$prob_1 \cdot (1 + prize_1) + prob_2 \cdot (1 + prize_2) = 1 \quad .$$

All of the above wagers are "fair bets" in the sense that the subject's expected net worth is equal to his/her current net worth, but most people would decline them. Are these people behaving irrationally?

In 1738, Daniel Bernoulli published a paper (English translation 1954) in which he proposed a solution to a problem similar to the above. A footnote in Bernoulli's paper cited a work by Gabriel Cramer from 1728 that had proposed a similar solution. In the Cramer-Bernoulli solution, an aversion to fair bets, particularly fair bets with large stakes, is not necessarily irrational if the subjective well-being conferred by wealth—the *utility* of wealth—is nonlinear. That is, wealth may exhibit (in fact, *typically* exhibits) decreasing marginal returns in terms of utility. For example, most individuals would not perceive themselves to be twice as "happy" or "content" if their net wealth were to double suddenly. If utility is a nonlinear function of wealth, then the appropriate objective function is not expected *wealth*, but expected *utility*. The objective of expected utility maximization is the cornerstone of decision theory (e.g., French 1986). This is sometimes identified with minimizing *risk*, where risk is defined as any negative linear transform of expected utility (e.g., DeGroot 1970).

In the hypothetical wagers described above, expected utility would be represented by

$$prob_1 \cdot utility\,(1 + prize_1) + prob_2 \cdot utility\,(1 + prize_2) \quad .$$

Pratt (1964) and Arrow (1965, 1971) showed that aversion to risk is a quantifiable attribute of an individual's utility function, which describes the relationship between utility u and wealth w. Pratt and Arrow showed that "absolute risk aversion," *ara*, can be defined as the negative ratio of the second and first derivatives of the utility function:

$$ara = -\frac{\left(\dfrac{d^2 u}{d w^2}\right)}{\left(\dfrac{d u}{d w}\right)} \quad .$$

Specifying a value of *ara* for the following family of curves results in a utility function exhibiting absolute risk aversion equal to that specified value ("constant absolute risk aversion," CARA):

$$u(w \mid ara) = \frac{1 - \exp(-ara \cdot w)}{\exp(ara) - 1} \quad .$$

Risk neutrality is represented by *ara*=0. Taking the limit of the above equation as *ara* approaches zero gives the special case of linear utility:

$$u(w \mid 0) = w \quad .$$

Some examples of utility curves of the type represented by the above family of curves are shown in Figure 1. The central message of this figure is that the utility curves of risk-averse individuals exhibit *decreasing* marginal returns (second derivative is negative), the utility curve of risk-neutral individuals exhibit *constant* marginal returns (second derivative is zero), and the utility curves of risk-prone individuals exhibit *increasing* marginal returns (second derivative is positive).

As examples, alternative *ara* values of −1, 0, and 1 can be considered in the context of the hypothetical set of wagers described at the beginning of this section. For each combination of wager and *ara* value, expected wealth ("E(wealth)") and expect utility ("E(utility)") are shown below (quantities to the left of the vertical line are independent of *ara*):

Wager	Prize 1	Prob. 1	Prize 2	Prob. 2	E(wealth)	*ara*	Utility 1	Utility 2	E(utility)
1	+100%	0.5	−100%	0.5	1	−1	10.107	0	5.054
1	+100%	0.5	−100%	0.5	1	0	2.000	0	1
1	+100%	0.5	−100%	0.5	1	1	0.503	0	0.252
2	+300%	0.25	−100%	0.75	1	−1	84.791	0	21.198
2	+300%	0.25	−100%	0.75	1	0	4.000	0	1
2	+300%	0.25	−100%	0.75	1	1	0.571	0	0.143
3	+9900%	0.01	−100%	0.99	1	−1	4.3×10^{43}	0	4.3×10^{41}
3	+9900%	0.01	−100%	0.99	1	0	100.000	0	1
3	+9900%	0.01	−100%	0.99	1	1	0.582	0	0.006

The other necessary piece of information is the expected utility resulting from a decision to decline the wagers. Because a decision to decline the wagers will result in current wealth remaining unchanged with certainty, the expected utility of this decision is simply the utility associated with current wealth. This will vary with the level of risk aversion. If *ara* = −1, utility of current wealth is 2.718; if *ara* = 0, utility of current wealth is 1.000; and if *ara* = 1, utility of current wealth is 0.368. It should be emphasized that comparison of expected utilities across *ara* values is not meaningful, because the scale of the utility function is arbitrary; the important thing is how expected utility varies across the set of possible decisions for a *given* value of *ara*.

Note that expected utility is equal to current utility (1.000) for all three wagers if the subject is risk neutral (i.e., if *ara*=0). However, if the subject is risk prone (represented here by an *ara* value of −1), all three wagers have an expected utility in excess of the subject's current utility (2.718). Conversely, if the subject is risk averse (represented here by an *ara* value of 1), all three wagers have an expected utility below the subject's current utility (0.368). Moreover, the attractiveness of the various wagers for the subject with an *ara* value of −1 is directly correlated with the *un*attractiveness of the same wagers for the subject with an *ara* value of 1.

In the above examples, changes in wealth have been scaled relative to current wealth. When using CARA utility, some sort of normalization is often necessary, because the optimal decision can sometimes depend on the units in which wealth is measured. To emphasize the fact that wealth is measured on some sort of relative scale, the remainder of this section will use the notation *rw* (for "relative wealth") instead of *w*.

As indicated previously, order means play a key role in this approach, at least when the utility function is of the CARA form. To see this, begin by defining "antilog relative wealth" arw=exp(rw) and let $p_{rw}(rw)$ and $p_{arw}(arw)$ represent the pdfs of *rw* and *arw*, respectively, where $p_{arw}(arw)$ can be derived straightforwardly from $p_{rw}(rw)$ as $p_{arw}(arw)=p_{rw}(\ln(arw))/arw$.

In general, $p_{rw}(rw)$ will involve one or more parameters. To keep things simple (for now), assume that the values of all parameters in $p_{rw}(rw)$ and $p_{arw}(arw)$ are known (i.e., *rw* and *arw* are the only random variables). It will also typically be the case that the pdf depends on one or more "control parameters" whose values can be set through some sort of decision process. Again to keep things simple, assume that there is only one control parameter, f, so that the pdf can be written $p_{rw}(rw|f)$. Expected utility is then given by

$$\begin{aligned}
&\int_{-\infty}^{\infty} u(rw|ara)\cdot p_{rw}(rw|f)\,\mathrm{d}rw = \\
&\int_{-\infty}^{\infty}\left(\frac{1-\exp(-ara\cdot rw)}{\exp(ara)-1}\right)\cdot p_{rw}(rw|f)\,\mathrm{d}rw = \\
&\int_{0}^{\infty}\left(\frac{1-arw^{-ara}}{\exp(ara)-1}\right)\cdot p_{arw}(arw|f)\,\mathrm{d}arw = \\
&\frac{1-ncm_{arw}(-ara|f)}{\exp(ara)-1} = \frac{1-om_{arw}(-ara|f)^{-ara}}{\exp(ara)-1}\quad.
\end{aligned}\tag{1}$$

Focusing on the last line of Equations (1), the left-hand side appears to be simpler than the right-hand side, as it lacks an exponent contained on the right-hand side. Furthermore, the left-hand side is expressed in terms of noncentral moments, which are probably more familiar to fishery scientists than the order means used on the right-hand side. However, the right-hand side has a very practical feature that the left-hand side lacks: Maximizing expected utility is equivalent to maximizing an order mean regardless of the value of *ara*. On the other hand, maximizing expected utility is equivalent to maximizing a noncentral moment only if *ara* is negative; otherwise, it is equivalent to *minimizing* a noncentral moment. These results are derived in Appendix 3A.

Thus, the problem of maximizing expected utility can be viewed as choosing the value of *f* that maximizes a particular order mean of the random variable *arw*, namely, the mean of order –*ara*. For example: If *ara* = –1, the problem of maximizing expected utility is equivalent to maximizing the *arithmetic* mean of *arw*; if *ara* = 0, the problem of maximizing expected utility is equivalent to maximizing the *geometric* mean of *arw*; and if *ara* = 1, the problem of maximizing expected utility is equivalent to maximizing the *harmonic* mean of *arw* (these are only examples, and are not intended to imply that *ara* can or should take only integer values).

It should be noted that this result is completely independent of the functional form of $p_{rw}(rw)$.

In developing Equations 1 above, it was assumed (temporarily, in the interest of simplicity) that the values of all parameters in $p_{rw}(rw)$ were known (i.e., that *rw* was the only random variable). More generally, however, $p_{rw}(rw)$ will typically involve a parameter vector $\boldsymbol{\alpha}$ of length *n*, where the values of individual parameters are unknown and which can therefore be viewed as additional random variables. To emphasize the dependence of the pdf on the parameters, let the pdf be written $p_{rw}(rw|\boldsymbol{\alpha},f)$. The objective, then, is to find the value of *f* that maximizes

$$\begin{aligned}
&\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\cdots\int_{-\infty}^{\infty} u(rw|ara)\cdot p_{rw}(rw|\boldsymbol{\alpha},f)\cdot p_{\boldsymbol{\alpha}}(\boldsymbol{\alpha})\,\mathrm{d}\alpha_1\ldots\mathrm{d}\alpha_n\,\mathrm{d}rw = \\
&\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\cdots\int_{-\infty}^{\infty}\left(\frac{1-\exp(-ara\cdot rw)}{\exp(ara)-1}\right)\cdot p_{rw}(rw|\boldsymbol{\alpha},f)\cdot p_{\boldsymbol{\alpha}}(\boldsymbol{\alpha})\,\mathrm{d}\alpha_1\ldots\mathrm{d}\alpha_n\,\mathrm{d}rw = \\
&\int_{0}^{\infty}\int_{-\infty}^{\infty}\cdots\int_{-\infty}^{\infty}\left(\frac{1-arw^{-ara}}{\exp(ara)-1}\right)\cdot p_{arw}(arw|\boldsymbol{\alpha},f)\cdot p_{\boldsymbol{\alpha}}(\boldsymbol{\alpha})\,\mathrm{d}\alpha_1\ldots\mathrm{d}\alpha_n\,\mathrm{d}arw = \\
&\frac{1-ncm_{arw}(-ara|f)}{\exp(ara)-1} = \frac{1-om_{arw}(-ara|f)^{-ara}}{\exp(ara)-1}\quad.
\end{aligned}\tag{2}$$

where $p_{\boldsymbol{\alpha}}(\boldsymbol{\alpha})$ is the joint posterior distribution of the elements of $\boldsymbol{\alpha}$. Comparing Equations 1 and 2, it can be seen that the existence of uncertainty in the parameters of $p_{rw}(rw)$ does not change the fundamental nature of the solution at all; the solution is still the value of *f* that maximizes the –*ara*th order mean of *arw*; the only difference is that a multiple integral rather than a single integral is required.

3.2.4 Relating the theory to fishery management

To relate the theory to fishery management, the key step is to identify a suitable measure of the wealth generated by the fishery. Because the Magnuson-Stevens Fishery Conservation and Management Act focuses on maximum sustainable yield (*msy*) as the benchmark from which other management quantities are derived, it could be argued that long-term yield should be the central measure of wealth for fisheries managed under that statute. It will therefore be assumed here that wealth is proportional to yield *y* in the limit as time $t \rightarrow \infty$, which implies that the relevant pdf is the stationary distribution. As indicated in the previous subsection, it is helpful to normalize wealth so that scale does not play a role in the solution. Here, wealth (yield) will be normalized by expressing it relative to *msy*. The ratio of *y* to *msy* will be referred to as "relative yield" (*ry*), and exp(*ry*) will be referred to as "antilog relative yield" (*ary*). Thus, to relate the theory described in the previous subsection to fishery management, *w* is replaced by *y*, *rw* is replaced by *ry*, and *arw* is replaced by *ary*. Equation 2 then becomes:

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\cdots\int_{-\infty}^{\infty} u(ry|ara)\cdot p_{ry}(ry|\boldsymbol{\alpha},f)\cdot p_{\boldsymbol{\alpha}}(\boldsymbol{\alpha})\,\mathrm{d}\alpha_1\ldots\mathrm{d}\alpha_n\,\mathrm{d}ry =$$

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\cdots\int_{-\infty}^{\infty}\left(\frac{1-\exp(-ara\cdot ry)}{\exp(ara)-1}\right)\cdot p_{ry}(ry|\boldsymbol{\alpha},f)\cdot p_{\boldsymbol{\alpha}}(\boldsymbol{\alpha})\,\mathrm{d}\alpha_1\ldots\mathrm{d}\alpha_n\,\mathrm{d}ry =$$

$$\int_{0}^{\infty}\int_{-\infty}^{\infty}\cdots\int_{-\infty}^{\infty}\left(\frac{1-ary^{-ARA}}{\exp(ara)-1}\right)\cdot p_{ary}(ary|\boldsymbol{\alpha},f)\cdot p_{\boldsymbol{\alpha}}(\boldsymbol{\alpha})\,\mathrm{d}\alpha_1\ldots\mathrm{d}\alpha_n\,\mathrm{d}ary =$$

$$\frac{1-ncm_{ary}(-ara|f)}{\exp(ara)-1}=\frac{1-om_{ary}(-ara|f)^{-ara}}{\exp(ara)-1} \quad .$$

The solution is the value of *f* that maximizes the *–ara*th order mean of *ary*. All that remains is to assign a meaning to the control parameter *f*, which in the case of fishery management is straightforwardly interpreted as a fishing mortality rate.

The optimal fishing mortality rate will typically depend on the level of risk aversion assumed. For example, a limit fishing mortality rate could be associated with an *ara* value of zero (risk neutrality), and a target fishing mortality rate could be associated with some positive level of *ara* (risk aversion). In this view, both the limit and the target are optima, with the difference in the two rates arising from a difference in the levels of risk aversion used to compute them.

3.3 Application

3.3.1 A Simple example model

A simple example model is developed in Appendix 3B. This example consists of an age-structured stock in which, were it not for stochastic variability, the numbers-at-age vector in year t+1 would be a linear function of the numbers-at-age vector in year *t* and in which both process error and management error are multivariate normal. Several other simplifying assumptions are made to keep the dimensionality of the example from becoming overwhelming. In particular, it is assumed in this example that all parameter values are known. It should be emphasized that this assumption is *not* inherent to the overall approach described in this paper and that, were it not for the need to keep the example simple, uncertainty in parameter values would be considered in addition to process uncertainty and management uncertainty.

A very helpful feature of this example model is that the stationary distribution of *y* is normal, with mean $\mu ysta(f)$ and variance $\Sigma ysta(f)$. The stationary distribution of *ry* is then normal with mean $\mu ysta(f)/msy$ and variance $\Sigma ysta(f)/msy^2$, and the stationary distribution of *ary* is then lognormal with the same parameters as the distribution of *ry*, that is:

$$p_{ary}\left(ary \middle| \frac{\mu ysta(f)}{msy}, \frac{\Sigma ysta(f)}{msy^2}\right) = \sqrt{\frac{1}{2\cdot\pi\cdot\frac{\Sigma ysta(f)}{msy^2}}}\cdot\left(\frac{1}{ary}\right)\cdot\exp\left(-\frac{\left(\ln(ary)-\frac{\mu ysta(f)}{msy}\right)^2}{2\cdot\frac{\Sigma ysta(f)}{msy^2}}\right) \quad .$$

The $-ara^{th}$ order mean of the stationary distribution of *ary*, given *f*, is described by

$$om_{ary}(-ara|f) = \exp\left(\frac{\mu ysta(f)}{msy} - \frac{ara\cdot\Sigma ysta(f)}{2\cdot msy^2}\right) \quad .$$

As described in the Theory section, the decision-theoretic optimum is the *f* that maximizes $om_{ary}(-ara|f)$. Because maximizing the logarithm of a function is equivalent to maximizing the function itself, it is also possible (in the special case of this simple model) to view the decision-theoretic optimum as the value of *f* that maximizes the quantity

$\mu ysta(f)/msy - ara\cdot\Sigma ysta(f)/(2\cdot msy^2)$.

In the special case of risk neutrality (ara=0), the decision-theoretic optimum is simply to maximize mean stationary yield; that is, to fish at $f=f_{msy}$. Because the stationary distribution of yield is normal, this is equivalent to stating that the risk-neutral optimum is to fish at a rate such that there is a 50% chance that yield at time *t* will exceed *msy* in the limit as $t\rightarrow\infty$. In what follows, the limit fishing mortality rate is defined as f_{msy}, corresponding to a risk-neutral approach.

3.3.2 Experimental design

The main parameters in this simple model consist of three coefficients of variation and three rates. The coefficients of variation describe the amounts of management error (cv_m, which can be partitioned into estimation error and implementation error as described in Appendix 3B), process error at all ages except age 0 (cv_p), and process error at age 0 (cv_r). The rates are the relative spawning per recruit at *msy* ($rspr_{msy}$), the discrete annual natural mortality rate (v), and the discrete annual fishing mortality rate at *msy* (f_{msy}). To get some idea of how each of these parameters affects the buffer between the target fishing mortality rate f_{tar} and f_{msy}, and to get some idea of the range of buffer sizes across likely ranges of parameter values, each of the parameters was assigned a set of three possible values independent of the values of the other parameters, with the following exception: A unique set of f_{msy} values was associated with each combination of $rspr_{msy}$ and v values, because the range of feasible f_{msy} values depends on the values of $rspr_{msy}$ and v (see Appendix 3B).

The values of cv_m, cv_p, cv_r, $rspr_{msy}$, and v are shown below:

cv_m	cv_p	cv_r	$rspr_{msy}$	v
0.1	0.05	0.2	0.35	0.1
0.2	0.10	0.3	0.40	0.2
0.3	0.15	0.4	0.45	0.3

The f_{msy} values correspond to the 25%, 50%, and 75% quartiles of the feasible range associated with a given pair of $rspr_{msy}$ and v values. These f_{msy} values are shown below:

	v=0.1			v=0.2			v=0.3		
$rspr_{msy}$	25%	50%	75%	25%	50%	75%	25%	50%	75%
0.35	0.124	0.135	0.146	0.220	0.237	0.254	0.304	0.322	0.340
0.40	0.103	0.112	0.121	0.187	0.201	0.216	0.262	0.278	0.294
0.45	0.086	0.094	0.101	0.158	0.171	0.184	0.225	0.239	0.254

The above two tables represent a factorial design of 3^6=729 parameter combinations.

Each value of v was mapped into a knife-edged, integer age of maturity (equal to the knife-edged age of recruitment to the fishery) derived from Jensen's (1996) Equation 7 as follows:

$$a_r = \text{round}\left(-\frac{3\cdot\ln(3)}{2\cdot\ln(1-v)}\right) \quad .$$

Each combination of v and f_{msy} values was mapped into a lower bound for the "age-plus" group, specified as the youngest integer age at which no more than 1% of the cohort numbers initially present at the age of recruitment would remain if the cohort where fished at f=f_{msy}:

$$a_{max} = a_r + \text{ceiling}\left(\frac{-\ln(100)}{\ln(1-f_{msy})+\ln(1-v)}\right) \quad ,$$

where the "ceiling" function returns the smallest integer greater than or equal to the argument.

The value of f_{tar} corresponding to each of the 729 sets of parameter values was then computed for each of four alternative ara values: 0.25, 0.50, 0.75, and 1.00.

For each ara-specific set of 729 data points, the coefficients of the following equation were estimated by ordinary least squares regression:

$$\begin{aligned}\text{logit}\left(f_{tar}/f_{msy}\right) = {} & \beta_0 + \beta_1\cdot\ln(cv_m) + \beta_2\cdot\ln(cv_p) + \beta_3\cdot\ln(cv_r) + \\ & \beta_4\cdot\text{logit}(rspr_{msy}) + \beta_5\cdot\text{logit}(f_{msy}) + \beta_6\cdot\text{logit}(v) \quad .\end{aligned} \tag{3}$$

Finally, for the entire set of results (4 alternative ara values x 729 parameter combinations per alternative = 2,916 total points), the coefficients of the following equation were estimated by ordinary least squares regression:

$$\begin{aligned}\text{logit}\left(f_{tar}/f_{msy}\right) = \gamma_0 + {} & \left(\begin{aligned}&\gamma_1\cdot\ln(cv_m) + \gamma_2\cdot\ln(cv_p) + \gamma_3\cdot\ln(cv_r) + \\ &\gamma_4\cdot\text{logit}(rspr_{msy}) + \gamma_5\cdot\text{logit}(f_{msy}) + \gamma_6\cdot\text{logit}(v)\end{aligned}\right) + \\ & \left(\begin{aligned}&\gamma_7\cdot\ln(cv_m) + \gamma_8\cdot\ln(cv_p) + \gamma_9\cdot\ln(cv_r) + \\ &\gamma_{10}\cdot\text{logit}(rspr_{msy}) + \gamma_{11}\cdot\text{logit}(f_{msy}) + \gamma_{12}\cdot\text{logit}(v)\end{aligned}\right)\cdot\ln(ara) \quad .\end{aligned} \tag{4}$$

3.4 Results

The ranges of the f_{tar}/f_{msy} ratio and buffer sizes for the 729 parameter combinations under each of the four alternative values of *ara* (taken one at a time) are shown below:

Statistic	*ara*=0.25	*ara*=0.50	*ara*=0.75	*ara*=1.00
minimum f_{tar}/f_{msy}	0.34	0.26	0.23	0.20
average f_{tar}/f_{msy}	0.65	0.56	0.50	0.47
maximum f_{tar}/f_{msy}	0.94	0.90	0.87	0.84
maximum buffer (buffer=1-f_{tar}/f_{msy})	0.66	0.74	0.77	0.80
average buffer (buffer=1-f_{tar}/f_{msy})	0.35	0.44	0.50	0.53
minimum buffer (buffer=1-f_{tar}/f_{msy})	0.06	0.10	0.13	0.16

The regression estimates of the coefficients in Equation 3 are shown below:

Coefficient	*ara*=0.25	*ara*=0.50	*ara*=0.75	*ara*=1.00
β_0, intercept	-7.728	-7.482	-7.387	-7.343
β_1, slope with respect to $\ln(cv_m)$	-0.241	-0.207	-0.188	-0.176
β_2, slope with respect to $\ln(cv_p)$	-0.480	-0.452	-0.439	-0.431
β_3, slope with respect to $\ln(cv_r)$	-0.518	-0.489	-0.475	-0.467
β_4, slope with respect to $\text{logit}(rspr_{msy})$	-8.924	-8.179	-7.813	-7.585
β_5, slope with respect to $\text{logit}(f_{msy})$	-9.262	-8.459	-8.062	-7.813
β_6, slope with respect to $\text{logit}(v)$	7.441	6.797	6.479	6.280

The coefficient of determination was 0.93 for each of the four alternative values of *ara*, both on the logit scale and when back-transformed into the ratio f_{tar}/f_{msy}.

The regression estimates of the coefficients in Equation 4 are shown below:

Coefficient	Value	Coefficient	Value
γ_0, intercept	-7.485		
γ_1, slope w.r.t. $\ln(cv_m)$	-0.184	γ_7, slope w.r.t. $\ln(cv_m)\cdot\ln(ara)$	0.032
γ_2, slope w.r.t. $\ln(cv_p)$	-0.442	γ_8, slope w.r.t. $\ln(cv_p)\cdot\ln(ara)$	0.014
γ_3, slope w.r.t. $\ln(cv_r)$	-0.482	γ_9, slope w.r.t. $\ln(cv_r)\cdot\ln(ara)$	0.008
γ_4, slope w.r.t. $\text{logit}(rspr_{msy})$	-7.696	γ_{10}, slope w.r.t. $\text{logit}(rspr_{msy})\cdot\ln(ara)$	0.726
γ_5, slope w.r.t. $\text{logit}(f_{msy})$	-7.909	γ_{11}, slope w.r.t. $\text{logit}(f_{msy})\cdot\ln(ara)$	0.828
γ_6, slope w.r.t. $\text{logit}(v)$	6.355	γ_{12}, slope w.r.t. $\text{logit}(v)\cdot\ln(ara)$	-0.666

On the logit scale, the coefficient of determination was 0.94 for the combined results across the four alternative values of *ara*. When back-transformed into the ratio f_{tar}/f_{msy}, the aggregate coefficient of determination was 0.95.

For all four alternative values of *ara*, the *lowest* value of the f_{tar}/f_{msy} ratio across the 729 parameter combinations was obtained when the values of all parameters were at their respective maxima. For all four alternative values of *ara*, the *highest* value of the f_{tar}/f_{msy} ratio across the 729 parameter combinations was obtained when the value of $rspr_{msy}$ was at its maximum and the values of all other parameters were at their respective minima.

3.5 Discussion

3.5.1 Summary

The approach described here relies on decision theory, a theory which has been exhaustively developed over many years. Decision theory is a normative approach to making decisions in the face of uncertainty. For each possible decision (e.g., target catch level), decision theory considers both the probability and the utility (i.e, relative desirability) associated with each possible outcome. The optimal decision is the one that maximizes expected utility. Decision theory is thus ideally suited to fishery management, where the existence of significant uncertainty is an inevitable fact of life, and where a large spectrum of possible consequences resulting from management decisions is typical.

3.5.2 Decision theory and the probability-only approach

Of course, decision theory is not the only possible approach to making fishery management decisions. On the contrary, use of decision theory in this context is rather rare. In discussions about fishery management targets, the approach that arises most often is one that can aptly be described as the "probability-only" approach. The two approaches may be contrasted in terms of their respective definitions and treatments of "risk." As noted in the Theory section, the decision-theoretic approach defines risk as expected loss; in this approach, risk is something to be minimized. The probability-only approach, on the other hand, defines risk as the probability of breaching a limit; in this approach, risk is something to be set equal to a pre-specified critical value. In the decision-theoretic approach, both the probabilities and utilities associated with the various possible outcomes are considered in attempting to achieve a goal; in the probability-only approach, the utilities associated with the various possible outcomes are ignored, and "target" is defined in terms of a specified probability of breaching a limit.

The definition of "target" used in the decision-theoretic approach is consistent with standard dictionary definitions. The definition used in the probability-only approach, however, is difficult to reconcile with standard dictionary definitions. As noted in the Introduction, dictionaries tend to define "target" as "something aimed at," and they frequently use the sport of marksmanship as an illustration thereof. In marksmanship, the shooter is invariably concerned with achieving a high score. It is easy to imagine a real marksman following a decision-theoretic approach, wherein he or she aims so that his or her expected score is maximized (assuming, for simplicity, that utility is linear with respect to score). On the other hand, it is difficult to imagine a real marksman following a probability-only approach, wherein he or she would specify a minimum acceptable score and a critical probability level, then aim so that the chance of falling below the minimum is equal to the critical probability level. This contrast is illustrated in Figure 2, where the solid dots represent shots taken by a marksman following the decision-theoretic approach and the open dots represent shots taken by a marksman following the probability-only approach. In the context of fisheries, the probability-only approach to setting targets exhibits similar difficulties. Except by coincidence, there simply is nothing optimal about fishing so that the probability of exceeding the limit equals some pre-specified critical level. An optimal fishing mortality rate for a given level of risk aversion will always map into some probability of exceeding any given limit, but that probability will typically be different between species and, for that matter, between years for a given species. Conversely, a fishing mortality rate that satisfies a given probability of exceeding a specified limit will always correspond to an optimal fishing mortality for some level of risk aversion, but that level of risk aversion will typically vary between species and years.

3.5.3 Compatibility with the NS1 guidelines

Although the probability-only approach lacks the optimality properties of the decision-theoretic approach, it does have the advantage of mapping much more straightforwardly than the decision-theoretic approach into the system of reference points described in the NS1 Guidelines. For example, paragraph (f)(4) of the NS1 Guidelines states, in part, "The determination of ABC should be based, when possible, on the probability that an actual catch equal to the stock's ABC would result in overfishing.... The ABC control rule must articulate how ABC will be set compared to the OFL based on the scientific knowledge about the stock or stock complex and the scientific uncertainty in the estimate of OFL and any other scientific uncertainty." Thus, in the case of ABC at least, the NS1 Guidelines clearly anticipate that the probability-only approach will be used. The first sentence in the preceding excerpt essentially states that the probability-only approach "should" be used except when it is impossible to do so. The second sentence says that the buffer between ABC and OFL "must" be based at least in part on scientific uncertainty in the estimate of OFL. While not explicitly prohibiting a decision-theoretic approach, this sentence makes it harder to justify a decision-theoretic approach. This is because the target in the decision-theoretic approach is not based directly on the uncertainty in the limit; rather, the target and the limit are derived independently of each other by considering all relevant uncertainty in the context of the two reference points' respective levels of risk aversion.

Therefore, if a decision-theoretic approach is used to set ABC, it will not provide a perfect fit with the NS1 Guidelines. Another option would be to use a decision-theoretic approach to set some other target such as ACT, or some other measure in the system of catch targets to which the response to Comment 4 alludes. If a decision-theoretic approach is used to set ACT, management uncertainty could include both control (implementation) error and estimation error, as described in Appendix 3B. If used to set ABC, better compliance with the NS1 Guidelines would be achieved by restricting management uncertainty to estimation error only. A third option would be to use the probability-only approach as a constraint on the decision-theoretic approach. For example, ABC could be set according to the decision-theoretic approach unless the resulting fishing mortality rate implied a probability of exceeding f_{msy} that was greater than some pre-specified level.

3.5.4 Simple example model: pros and cons

The simple example model described in Appendix 3B and used in the Application section necessarily makes some sacrifices in order to keep the exposition and analysis from becoming so complicated as to be overwhelming. In terms of systematic dynamics, some of the more restrictive assumptions are the timing of intra-annual events (fishing precedes spawning, which precedes natural mortality), the linear weight-at-age relationship, knife-edged recruitment to both the fishery and spawning population at the same age, and the linear stock-recruitment relationship. All but the last of these could be addressed without changing the basic linear nature of the model, but at the cost of added complexity. For example, additional flexibility in the timing of intra-annual events can be achieved by changing the time scale of the model from an annual one to a seasonal or monthly one (although fishing would still have to precede natural mortality in each time step). The weight-at-age, selectivity, and maturity schedules can be made more general by choosing more flexible functional forms, with more parameters. The assumption of a linear stock-recruitment relationship, however, is necessary in order to preserve the basic linear nature of the model. In order for this assumption to be strictly true, the population would have to be open to immigration. Rather than restricting use of the model only to cases where significant immigration occurs, it is better to regard this assumption simply as an approximation. In terms of stochastic dynamics, the assumption that all errors (control, estimation, and process) are normally distributed with constant covariance matrices is a strong one. Obviously, this assumption cannot be exactly accurate, as it implies non-zero probability of negative population size (and yield). As with the linear stock-recruitment relationship, it is best to regard this assumption simply as an approximation. The main reasons for making this assumption are: 1) it is better than assuming no error at all, and 2) it is what makes many of the closed-form solutions derived in Appendix 3B possible.

While the assumptions listed in the preceding paragraph impose costs in terms of foregone generality, they allow some insights that might not otherwise be possible:

1) "Management Strategy Evaluation" becomes possible in a single step. Incorporation of estimation error in an assessment/management/population feedback loop was first explored by de la Mare

(1986). In principle, this type of feedback is characterized by the following steps: A) a target harvest level is computed on the basis of a stock assessment with error, B) the harvest is removed from the actual population, and C) data from the actual population are used to make the estimate of stock size/structure in the next time period. Inclusion of this type of feedback has since been adopted as an essential element of "management strategy evaluation" in the sense of Smith (1994), Sainsbury et al. (2000), and others. Because of the linear/normal nature of the simple example model, the results of this feedback (at any point in time or in the limit as $t \rightarrow \infty$) can be computed in a single, closed-form solution.

2) Risk aversion can be interpreted in terms of a mean-variance tradeoff. As noted in the Application section, the simple example model developed in Appendix 3B has the convenient property that, when the utility function is of the CARA form, the decision-theoretic optimum can be obtained by maximizing the quantity $\mu ysta(f)/msy - ara \cdot \Sigma ysta(f)/(2 \cdot msy^2)$ with respect to f. This emphasizes the fact that, in at least some applications, optimality can be interpreted in terms of a tradeoff between mean and variance. The weight applied to the variance is exactly equal to the level of absolute risk aversion, thus providing (in the context of this model) another interpretation of the Pratt-Arrow measure of absolute risk aversion.

3) Reasonably simple regressions permit rapid first approximation of optimal buffer sizes. Because the simple example model involves so few parameters, it was possible to explore the parameter space in all dimensions simultaneously through a factorial experimental design. The resulting regressions gave excellent fits, and should provide reasonable estimates of optimal buffer sizes in cases where data, time, or other resources are insufficient to conduct a full, case-specific analysis; at least when parameter values fall within the ranges considered in the experiment. Of course, caution should be exercised when extrapolating beyond the range of the data used to estimate the regression coefficients. For example, the logit transform of each coefficient of variation has a negative regression coefficient, implying that, *ceteris paribus*, setting any one of the coefficients of variation sufficiently close to zero would cause the buffer to vanish. In addition to being potentially useful for estimating case-specific buffers, the regressions give a general idea of the range of likely buffer sizes for the four alternative values of absolute risk aversion considered. For example, average buffer sizes extended from a low of 35% to a high of 53%, although the range of buffer sizes for any given value of absolute risk aversion was considerably larger than the range of the averages. As emphasized in the Application section, these regressions did not consider uncertainty in the parameter estimates themselves. Whenever possible, a full analysis should consider parameter uncertainty also.

3.5.5 Past applications and future directions

The approach described here has several precedents in the fishery management literature. Similar approaches were described by Thompson (1992, 1998, 1999), and in Restrepo et al. (1998, Section 3.1). A related approach was used to specify the buffer between OFL and ABC in "Tier 1" of the Bering Sea/Aleutian Islands and Gulf of Alaska Groundfish Fishery Management Plans (BSAI and GOA Groundfish FMPs), which has been in effect since 1996. The approach analyzed in Alternative 3b of the Programmatic Supplemental Environmental Impact Statement for the BSAI and GOA Groundfish FMPs (National Marine Fisheries Service 2004) was almost identical to the one described here.

This paper was intended to describe a decision-theoretic approach to setting fishery management targets, limits, and buffers. Some parts of the presentation have been very general, while others have relied on specific assumptions to illustrate the approach. The simplifying assumptions used in Appendix 3B are examples of the latter. As another example, it has been assumed throughout this presentation that the utility function is of the CARA form. It should be understood that this assumption was made as a matter of convenience rather than necessity, and that many other assumptions regarding the shape of the utility function are possible. Another simple alternative would be to assume constant *relative* (rather than absolute) risk aversion, where the utility function is proportional to w^{1-rra}, with rra representing the level of relative risk aversion. This functional form is particularly useful when there is no possibility of resource extinction in the future, but poses problems in cases where the probability of extinction is non-zero. Other alternatives that could be explored include incorporation of additional variables in the utility function, for example abundances (or abundances and yields) of incidentally caught species.

3.6 References

Arrow, K. J. *Aspects of the theory of risk-bearing.* 1965. Yrjö Jahnssonin Säätiö, Helsinki.

Arrow, K. J. *Essays in the theory of risk-bearing.* 1971. Markham Publishing Company, Chicago. 278 p.

Bernoulli, D. 1954. Exposition of a new theory on the measurement of risk. *Econometrica* 22:23-36.

Caswell, H. 2001. *Matrix population models: construction, analysis, and interpretation* (second edition). Sinauer Associates, Sunderland, MA, USA. 722 p.

de la Mare, W. K. 1986. On the management of exploited whale populations. Ph.D. thesis, University of York.

DeGroot, M. H. 1970. *Optimal Statistical Decisions.* McGraw-Hill, New York. 489 p.

French, S. 1986. *Decision theory: an introduction to the mathematics of rationality.* Halsted Press, John Wiley and Sons, New York. 448 p.

Jensen, A. L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 53:820-822.

Mitrinović, D. S., J. E. Pečarić, and A. M. Fink. 1993. *Classical and new inequalities in analysis.* Kluwer Academic Publishers, Boston.

National Marine Fisheries Service. 2004. *Programmatic Supplemental Environmental Impact Statement for the Alaska Groundfish Fisheries Implemented under the Authority of the Fishery Management Plans for the Groundfish Fishery of the Gulf of Alaska and the Groundfish Fishery for the Bering Sea and Aleutian Islands Area.* DOC, NOAA, NMFS, P.O. Box 21668, Juneau, AK 99802. URL: http://www.fakr.noaa.gov/sustainablefisheries/seis/intro.htm

Pratt, J. W. 1964. Risk aversion in the small and in the large. *Econometrica* 32:122-136.

Restrepo, V. R., G. G. Thompson, P. M. Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. L. Taylor, P. R. Wade, and J. F. Witzig. 1998. *Technical guidance on the use of precautionary approaches to implementing NS1 of the Magnuson-Stevens Fishery Conservation and Management Act.* U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-31. 54 p.

Rosenberg, A., P. Mace, G. Thompson, G. Darcy, W. Clark, J. Collie, W. Gabriel, A. MacCall, R. Methot, J. Powers, V. Restrepo, T. Wainwright, L. Botsford, J. Hoenig, and K. Stokes. 1994 (reprinted in 1996 with minor modifications). *Scientific review of definitions of overfishing in U.S. Fishery Management Plans.* U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-17. 205 p.

Sainsbury, K. J., Punt, A. E., and Smith, A. D. M. 2000. Design of operational management strategies for achieving fishery ecosystem objectives. *ICES Journal of Marine Science*, 57: 731-741.

Smith, A. D. M. 1994. Management strategy evaluation – the light on the hill. In D. A. Hancock (editor), *Population Dynamics for Fisheries Management*, p. 249-253. Australian Society for Fish Biology, Perth.

Thompson, G. G. 1992. A Bayesian approach to management advice when stock-recruitment parameters are uncertain. *Fishery Bulletin, U.S.* 90:561-573.

Thompson, G. G. 1998. Application of the Kalman Filter to a stochastic differential equation model of population dynamics. *Statistics in Ecology and Environmental Modeling 2: Decision Making and Risk Assessment in Biology*, D. J. Fletcher, L. Kavalieris, and B. J. Manly (editors), 181-203. Otago Conference Series No. 6. University of Otago Press, Dunedin, New Zealand.

Thompson, G. G. 1999. Optimizing harvest control rules in the presence of natural variability and parameter uncertainty. *Proceedings of the Fifth National NMFS Stock Assessment Workshop: Providing Scientific Advice to Implement the Precautionary Approach Under the Magnuson-Stevens Fishery Conservation and Management Act*, V. R. Restrepo (editor), p. 124-145. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-40.

Table 1. Definitions of symbols used in the main text.

Symbol	Definition
α	parameter vector used in a probability density function
β	vector of coefficients in linear model described by Equation 3
γ	vector of coefficients in linear model described by Equation 4
$\mu ysta$	mean of the stationary distribution of yield
$\Sigma ysta$	variance of the stationary distribution of yield
a_{max}	lower bound of "age-plus" group
a_r	age of recruitment (equals age of maturity in simple example model)
ara	absolute risk aversion
arw	antilog relative wealth
ary	antilog relative yield
cv_m	coefficient of variation (management error)
cv_p	coefficient of variation (process error for all ages except age 0)
cv_r	coefficient of variation (process error for age 0)
f	control parameter (generally), fishing mortality rate (specifically)
f_{msy}	fishing mortality rate at maximum sustainable yield
f_{tar}	target fishing mortality rate
msy	maximum sustainable yield
n	length of parameter vector used in a probability density function
ncm	noncentral moment
om	order mean
p	probability density
$rspr_{msy}$	equilibrium relative spawning per recruit at maximum sustainable yield
rw	relative wealth
ry	relative yield
t	time
u	utility
v	discrete natural mortality rate
w	wealth
y	yield (in biomass)

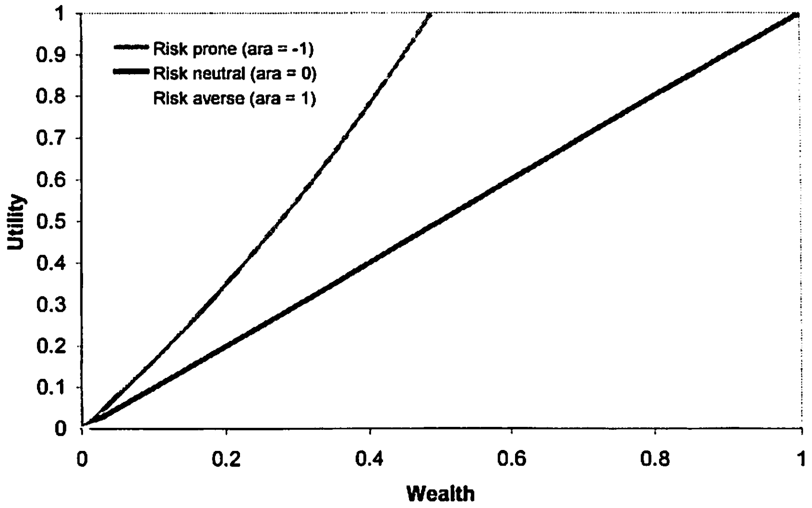


Figure 1. Example utility functions. A risk-prone utility function is characterized by a positive second derivative (represented here by the red curve, with an absolute risk aversion (*ara*) of −1), a risk-neutral utility function is characterized by a zero second derivative (represented here by the red line, with an *ara* of 0), and a risk-averse utility function is characterized by a negative second derivative (represented here by the green line, with an *ara* of 1).

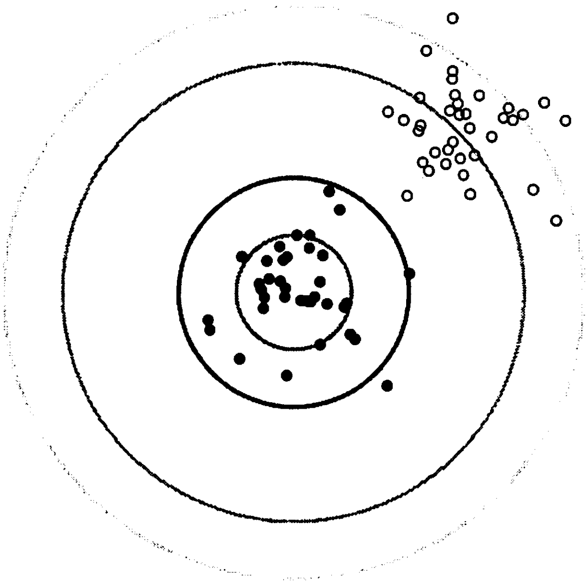


Figure 2. Marksmanship as an illustration of the decision-theoretic and probability-only approaches. Neighboring pairs of concentric circles above are all separated by a distance of 0.2. Two marksmen are equally accurate. Their shots tend to be randomly distributed according to a bivariate normal distribution centered at the point of aim, with a standard deviation of 0.147 in both the horizontal and vertical dimensions and no correlation between horizontal and vertical errors. The two marksmen take 36 shots each. One marksman attempts to maximize his expected score by aiming for the center. His shots are shown by the solid dots. The other marksman aims for a point on the next-to-outermost circle, thereby achieving a 10% probability of hitting outside the outermost circle. His shots are shown by the open dots.

Appendix 3A: Noncentral moments, order means, and expected utility

The last lines in Equations (1) and (2) of the main text indicate that, when the utility function takes the CARA form, expected utility is equal to both of the following expressions:

$$\frac{1-ncm_{arw}(-ara|f)}{\exp(ara)-1} \quad , \tag{A1}$$

and

$$\frac{1-om_{arw}(-ara|f)^{-ara}}{\exp(ara)-1} \quad . \tag{A2}$$

This appendix examines the extent to which maximizing expected utility is equivalent to maximizing a noncentral moment and maximizing an order mean.

<u>Expected utility written in terms of a noncentral moment</u>

When expected utility is written as Expression A1, the first derivative is

$$\frac{\left(\dfrac{\mathrm{d}\,ncm_{arw}(-ara|f)}{\mathrm{d}f}\right)}{1-\exp(ara)} \quad .$$

The only way to set the above expression equal to zero is to set the derivative of the *–ara*th noncentral moment equal to zero. Thus, maximizing expected utility must correspond either to maximizing or minimizing the *–ara*th noncentral moment. To determine which of these is the case, it is necessary to examine the second derivative.

The second derivative of expected utility is

$$\frac{\left(\dfrac{\mathrm{d}^2\,ncm_{arw}(-ara|f)}{\mathrm{d}f^2}\right)}{1-\exp(ara)} \quad .$$

The second derivative of expected utility at the optimum must be negative (because expected utility is being maximized rather than minimized). In order for this condition to obtain, the numerator and denominator in the above expression must be of opposite sign. However, note that the denominator is positive for all *ara*<0 and negative for all *ara*>0, which means that the second derivative of the *–ara*th noncentral moment must be negative for all *ara*<0 and positive for all *ara*>0. Therefore, maximizing expected utility is equivalent to *maximizing* the *–ara*th noncentral moment when *ara* is *negative*, but it is equivalent to *minimizing* the *–ara*th noncentral moment when *ara* is *positive*.

<u>Expected utility written in terms of an order mean</u>

Turning to the alternative of writing expected utility as Expression A2, define a function $\lambda(f)$ as follows:

$$\lambda(f)=\left(\frac{ara}{\exp(ara)-1}\right)\cdot om_{arw}(-ara|f)^{-ara-1} \quad .$$

Note that $\lambda(f)$ is always positive for all values of *ara*.

The first derivative of expected utility with respect to *f* can then be written

$$\lambda(f)\cdot\left(\frac{\mathrm{d}\,om_{arw}(-ara|f)}{\mathrm{d}f}\right) \quad .$$

Because $\lambda(f)$ is always positive, the only way to set the first derivative of expected utility equal to zero is to set the first derivative of the mean of order *–ara* equal to zero, meaning that the optimum occurs at either a maximum or a minimum of the mean of order *–ara*. To determine which of these is the case, it is necessary to examine the second derivative.

The second derivative of expected utility with respect to *f* is

$$\lambda(f)\cdot\left(\frac{\mathrm{d}^2 om_{arw}(-ara|f)}{\mathrm{d}f^2}-\left(\frac{ara+1}{om_{arw}(-ara|f)}\right)\cdot\left(\frac{\mathrm{d}\,om_{arw}(-ara|f)}{\mathrm{d}f}\right)^2\right) \quad .$$

As shown above, the first derivative of the mean of order *–ara* must equal zero at the optimum. Therefore, when evaluated at the optimum (f_{tar}), the second derivative of expected utility simplifies to

$$\lambda(f_{tar})\cdot\left(\frac{\mathrm{d}^2 om_{arw}(-ara|f_{tar})}{\mathrm{d}f_{tar}^{\;2}}\right) \quad .$$

Because the second derivative of expected utility at the optimum must be negative and because $\lambda(f)$ is always positive, the above expression implies that the second derivative of the mean of order *–ara* must be negative, meaning that maximizing expected utility is equivalent to maximizing the mean of order –*ara*.

Appendix 3B: Simple example model

This appendix presents the simple example model used in the Application section of the main text. A list of symbols unique to this appendix is provided in Table B

Notational Conventions

In addition to the notational conventions listed in the main text, the following are observed:

- Matrices are represented by upper case letters in bold.
- A matrix or vector superscripted by "<*t*>" represents the realization at time *t*.

Systematic Dynamics

All fishing is assumed to take place before any natural mortality occurs. Per-capita fishing mortality is assumed to be independent of age for all ages $a \geq a_r$ and will be represented in the form of a discrete annual exploitation rate f, while per-capita natural mortality is assumed to be independent of age for all ages $a \geq 0$ and will be represented in the form of a discrete annual natural mortality rate v. The first age in the population is defined as age 0, and an "age-plus" category is defined for ages $a \geq a_{max}$. The $(a_{max}+1)\times 1$ vector of equilibrium population numbers at age will be written as a function of the exploitation rate, $\mathbf{xequ}(f)$. For a given equilibrium number of recruits to the population at age 0, $xequ(f)_0$, the remaining elements of the equilibrium numbers-at-age vector are given by

$$
\begin{aligned}
xequ(f)_a &= (1-v)\cdot xequ(f)_{a-1} \quad \forall \quad 1 < a \leq a_r \\
xequ(f)_a &= (1-f)\cdot(1-v)\cdot xequ(f)_{a-1} \quad \forall \quad a_r < a < a_{max} \\
xequ(f)_a &= \left(\frac{1}{f+v-f\cdot v}-1\right)\cdot xequ(f)_{a-1} \quad \forall \quad a = a_{max} \quad .
\end{aligned}
$$

Equilibrium exploitable numbers per recruit (i.e., per recruit to the population at age 0) is given by

$$
xpr(u) = (1-v)^{a_r}\cdot\sum_{a=a_r}^{\infty}\big((1-f)\cdot(1-v)\big)^{a-a_r} = \frac{(1-v)^{a_r}}{f+v-f\cdot v} \quad .
$$

Weight is assumed to be a linear function of age, $c\cdot(1+d\cdot a)$, where c and d are positive constants. Equilibrium average weight at or above any age $a \geq a_r$ conditional upon exploitation rate u is given by

$$
w_{ave}(a|f) = \frac{xequ(f)_a\cdot\sum_{i=a}^{\infty}\big((1-f)\cdot(1-v)\big)^{i-a}\cdot c\cdot(1+d\cdot i)}{xequ(f)_a\cdot\sum_{i=a}^{\infty}\big((1-f)\cdot(1-v)\big)^{i-a}} = c\cdot\left(1+d\cdot\left(a-1+\frac{1}{f+v-f\cdot v}\right)\right) \quad .
$$

For example, equilibrium average weight in the "age-plus" group is given by $w_{ave}(a_{max}|f)$. The elements of the $(a_{max}+1)\times 1$ weight-at-age vector $\mathbf{w}(f)$ are thus given by

$$
\begin{aligned}
w(f)_a &= c\cdot(1+d\cdot a) \quad \forall \quad 0 \leq a < a_{max} \\
w(f)_a &= w_{ave}(a|f) \quad \forall \quad a = a_{max} \quad .
\end{aligned}
$$

(Note that the elements of $\mathbf{w}(f)$ are actually independent of f except for the element corresponding to the "age-plus" group.)

Equilibrium exploitable biomass per recruit (i.e., per recruit to the population at age 0) is given by

$$bpr(f) = (1-v)^{a_r} \cdot \sum_{a=a_r}^{\infty} \left(\left((1-f) \cdot (1-v) \right)^{a-a_r} \cdot c \cdot (1 + d \cdot a) \right) = xpr(f) \cdot w_{ave}(a_r | f) \quad .$$

The derivative of *bpr* with respect to exploitation rate is

$$\frac{\mathrm{d}\, bpr}{\mathrm{d} f} = -xpr(f) \cdot \left(\frac{1-v}{f+v-f \cdot v} \right) \cdot \; w_{ave}(1 \,|\, f) + w_{ave}(a_r \,|\, f) - c \qquad .e$$

Spawning is assumed to take place after all fishing takes place and before any natural mortality takes place. Fecundity is assumed to be zero for all ages $a<a_r$ and proportional to weight for all ages $a \geq a_r$. Without loss of generality, the latter can be simplified to an assumption that fecundity is *equal* to weight for all ages $a \geq a_r$. Equilibrium spawning per recruit (i.e., per recruit to the population at age 0) is therefore given by $spr(f)=(1-f) \cdot bpr(f)$.

Equilibrium recruitment at age 0, $xequ_0(f)$, is assumed to be a linear function of spawning, which implies that the following equation must hold:

$$xequ_0(f) = g + h \cdot spr(f) \cdot xequ_0(f) \quad ,$$

where g and h are positive constants. Solving the above gives

$$xequ_0(f) = \frac{g}{1 - h \cdot spr(f)} = \frac{g}{1 - h \cdot (1-f) \cdot bpr(f)} \quad .$$

Equilibrium yield (in biomass) is given by

$$yequ(f) = f \cdot bpr(f) \cdot xequ_0(f) \quad .$$

The derivative of equilibrium yield with respect to exploitation rate is given by

$$\frac{\mathrm{d}\, yequ}{\mathrm{d} f} = g \cdot \left(\frac{\left(1 - h \cdot bpr(f)\right) \cdot bpr(f) + f \cdot \left(\frac{\mathrm{d}\, bpr}{\mathrm{d} f} \right)}{\left(1 - (1-f) \cdot h \cdot bpr(f)\right)^2} \right) \quad .$$

Let the exploitation rate at *msy* and the equilibrium recruited biomass at *msy* be designated f_{msy} and b_{msy}, respectively. The following pair of equations must then hold by definition:

$$\frac{\mathrm{d}\, yequ}{\mathrm{d} f} \bigg|_{f=f_{msy}} = 0 \quad ,$$

$$xequ_0(f_{msy}) \cdot bpr(f_{msy}) = b_{msy} \quad .$$

For given values of f_{msy} and b_{msy}, the above pair of equations can be solved for g and h as follows:

$$h = \frac{bpr(f_{msy}) + f_{msy} \cdot \left(\frac{\mathrm{d}\, bpr}{\mathrm{d} f} \bigg|_{f=f_{msy}} \right)}{bpr(f_{msy})^2} \quad ,$$

$$g = b_{msy} \cdot \left(\frac{1}{bpr(f_{msy})} - h \cdot (1 - f_{msy}) \right) \quad .$$

Because few stock assessment models assume a linear weight-at-age relationship, the values of the weight-at-age parameters c and d (the intercept and slope/intercept ratio of the relationship, respectively) may be difficult for some practitioners to interpret readily. Fortunately, it is possible to reparameterize the model in terms of more familiar quantities. Let equilibrium relative spawning per recruit be defined as $rspr(f)=spr(f)/spr(0)$, and let $rspr_{msy}$ represent equilibrium relative spawning per recruit at msy. The parameter d can be computed as a function of $a_r, f_{msy}, rspr_{msy}$, and v as follows:

$$d=\frac{1-rspr_{msy}\cdot\left(\dfrac{f_{msy}}{(1-f_{msy})\cdot v}+1\right)}{rspr_{msy}\cdot\left(\dfrac{f_{msy}}{(1-f_{msy})\cdot v}+1\right)\cdot\left(a_r-1+\dfrac{1}{v}\right)-a_r+1-\dfrac{1}{f_{msy}+(1-f_{msy})\cdot v}}\quad .$$

For admissible values of the parameters, d is a monotone decreasing function of $rspr_{msy}$.

Because d is constrained to be positive, any set of values for the parameters a_r, $rspr_{msy}$, and v implies a range of admissible values for f_{msy}. The *minimum* admissible value for f_{msy} is given by setting the *denominator* of the above equation equal to zero (thereby setting d=∞), while the *maximum* admissible for f_{msy} is given by setting the *numerator* of the above equation equal to zero (thereby setting d=0). The maximum admissible for f_{msy} is the simpler of these to compute, and is given by

$$f_{msymax}=\frac{(1-rspr_{msy})\cdot v}{(1-rspr_{msy})\cdot v+rspr_{msy}}\quad .$$

The minimum admissible for f_{msy} can be obtained by solving a quadratic equation. Let the coefficients κ_0, κ_1, and κ_2 be defined as follows:

$$\kappa_0=-\big((a_r-1)\cdot(1-rspr_{msy})\cdot v+(1-rspr_{msy})\big)\cdot v^2\quad ,$$

$$\kappa_1=\big(2\cdot(a_r-1)\cdot(1-rspr_{msy})\cdot v^2-(a_r-2)\cdot(1-2\cdot rspr_{msy})\cdot v+2\cdot rspr_{msy}\big)\cdot v\quad ,$$

$$\kappa_2=\big((a_r-1)\cdot(1-rspr_{msy})\cdot v^2+(a_r-2)\cdot rspr_{msy}\cdot v+rspr_{msy}\big)\cdot(1-v)\quad .$$

The minimum admissible for f_{msy} can then be obtained as follows:

$$f_{msymin}=\frac{-\kappa_1+\sqrt{\kappa_1^2-4\cdot\kappa_0\cdot\kappa_2}}{2\cdot\kappa_2}\quad .$$

The transition of the numbers-at-age vector from one time period to the next is linear, with the non-zero elements of the $(a_{max}+1)\times(a_{max}+1)$ slope matrix $\Theta(f)$ defined as

$$\theta(f)_{0,a}=(1-f)\cdot h\cdot w(f)_a\quad\forall\quad a_r\le a\le a_{max}$$

$$\theta(f)_{a+1,a}=1-v\quad\forall\quad 0\le a<a_r$$

$$\theta(f)_{a+1,a}=(1-f)\cdot(1-v)\quad\forall\quad a_r\le a<a_{max}$$

$$\theta(f)_{a,a}=(1-f)\cdot(1-v)\quad\forall\quad a=a_{max}\quad ,$$

and the only non-zero element of the $(a_{max}+1)\times 1$ intercept vector $\boldsymbol{\rho}$ defined as $\rho_0=g$.

The population's transition from one time period to the next is then given by

$$\mathbf{x}^{<t+1>}=\Theta(f)\cdot\mathbf{x}^{<t>}+\boldsymbol{\rho}\quad .\qquad\text{(B1)}$$

The equilibrium vector of population numbers at age is then given in closed form by

$$\mathbf{xequ}(f) = \left(\mathbf{I} - \Theta(f)\right)^{-1} \cdot \boldsymbol{\rho} \quad , \tag{B2}$$

where **I** is the identity matrix of order $a_{max}+1$.

Because it is assumed that the fishing precedes spawning and that spawning precedes natural mortality, the slope matrix may be partitioned into an expression of the form $\boldsymbol{\Delta}(f)\cdot(\mathbf{I}-\boldsymbol{\Phi}\cdot f)$. The reason for this partitioning is developed over the next few paragraphs. In the meantime, let the non-zero elements of the $(a_{max}+1)\times(a_{max}+1)$ matrices $\boldsymbol{\Delta}(f)$ and $\boldsymbol{\Phi}$ be defined as

$$\begin{aligned}
&\delta(f)_{0,a} = h \cdot w(f)_a \quad \forall \quad a_r \le a \le a_{max} \\
&\delta(f)_{a+1,a} = 1 - v \quad \forall \quad 0 \le a < a_{max} \\
&\delta(f)_{a,a} = 1 - v \quad \forall \quad a = a_{max} \quad ,
\end{aligned}$$

and

$$\phi_{a,a} = 1 \quad \forall \quad a_r \le a \le a_{max} \quad .$$

Using the substitution $\Theta(f)=\boldsymbol{\Delta}(f)\cdot(\mathbf{I}-\boldsymbol{\Phi}\cdot f)$, the transition equation can be rewritten and expanded as follows:

$$\begin{aligned}
&\mathbf{x}^{<t+1>} = \boldsymbol{\Delta}(f)\cdot\left(\mathbf{I}-\boldsymbol{\Phi}\cdot f\right)\cdot\mathbf{x}^{<t>} + \boldsymbol{\rho} \\
&\mathbf{x}^{<t+1>} = \boldsymbol{\Delta}(f)\cdot\mathbf{x}^{<t>} - \boldsymbol{\Delta}(f)\cdot\boldsymbol{\Phi}\cdot f\cdot\mathbf{x}^{<t>} + \boldsymbol{\rho} \quad .
\end{aligned}$$

Note that the term $\boldsymbol{\Phi}\cdot f\cdot\mathbf{x}^{<t>}$ in the second line of the above represents the catch vector (in numbers at age), while the term $\boldsymbol{\Delta}(f)\cdot\boldsymbol{\Phi}\cdot f\cdot\mathbf{x}^{<t>}$ represents the *effects* of the catch vector (in numbers at age) on next year's numbers at age.

Pre-multiplying the catch vector at time t by the transpose of the weight-at-age vector gives yield (in biomass) at time t:

$$y(f)_t = \mathbf{w}(f)' \cdot \boldsymbol{\Phi} \cdot f \cdot \mathbf{x}^{<t>} \quad . \tag{B3}$$

An alternative equation for equilibrium yield can be obtained by substituting $\mathbf{xequ}(f)$ for $\mathbf{x}^{<t>}$ in the above, giving

$$yequ(f) = \mathbf{w}(f)' \cdot \boldsymbol{\Phi} \cdot f \cdot \mathbf{xequ}(f) \quad . \tag{B4}$$

Stochastic Dynamics

Let $\boldsymbol{\varepsilon}\mathbf{p}^{<t>}$ represent the $(a_{max}+1)\times1$ vector of process error terms realized at time t. The transition equation is the same as in the purely systematic case, except that $\boldsymbol{\varepsilon}\mathbf{p}^{<t>}$ is added to the right-hand side, as shown below:

$$\begin{aligned}
&\mathbf{x}^{<t+1>} = \Theta(f)\cdot\mathbf{x}^{<t>} + \boldsymbol{\rho} + \boldsymbol{\varepsilon}\mathbf{p}^{<t>} \\
&\mathbf{x}^{<t+1>} = \boldsymbol{\Delta}(f)\cdot\left(\mathbf{I}-\boldsymbol{\Phi}\cdot f\right)\cdot\mathbf{x}^{<t>} + \boldsymbol{\rho} + \boldsymbol{\varepsilon}\mathbf{p}^{<t>} \\
&\mathbf{x}^{<t+1>} = \boldsymbol{\Delta}(f)\cdot\mathbf{x}^{<t>} - \boldsymbol{\Delta}(f)\cdot\boldsymbol{\Phi}\cdot f\cdot\mathbf{x}^{<t>} + \boldsymbol{\rho} + \boldsymbol{\varepsilon}\mathbf{p}^{<t>} \quad .
\end{aligned}$$

As in the case of purely systematic dynamics, the term $\boldsymbol{\Phi}\cdot f\cdot\mathbf{x}^{<t>}$ in the third line of the above represents the catch vector (in numbers at age), which, when pre-multiplied by the transpose of the weight-at-age vector gives yield (in biomass), just as in Equation B3. Many modern fishery management systems operate by setting a target level of yield for each season (year) and closing the fishery once the target yield is reached. If the target yield is computed as $\mathbf{w}(f)' \cdot \mathbf{\Phi} \cdot f \cdot \mathbf{x}^{<t>}$ (or a close analogue), then the target yield necessarily corresponds to an underlying target catch vector $\mathbf{\Phi} \cdot f \cdot \mathbf{x}^{<t>}$. If the target yield is based on an *estimate* of $\mathbf{x}^{<t>}$ (rather than $\mathbf{x}^{<t>}$ itself) and this estimate is in error by an additive amount $\boldsymbol{\varepsilon}\mathbf{e}^{<t>}$, then the target catch vector will be computed as $\mathbf{\Phi} \cdot f \cdot (\mathbf{x}^{<t>} + \boldsymbol{\varepsilon}\mathbf{e}^{<t>})$. Another complicating factor is that the actual catch vector seldom matches the target catch vector exactly. It will be assumed here that the difference between the actual catch vector and the target catch vector is equal to $\mathbf{\Phi} \cdot f \cdot \boldsymbol{\varepsilon}\mathbf{c}^{<t>}$, where $\boldsymbol{\varepsilon}\mathbf{c}^{<t>}$ is an error term. The actual catch vector is thus equal to $\mathbf{\Phi} \cdot f \cdot (\mathbf{x}^{<t>} + \boldsymbol{\varepsilon}\mathbf{e}^{<t>}) + \mathbf{\Phi} \cdot f \cdot \boldsymbol{\varepsilon}\mathbf{c}^{<t>} = \mathbf{\Phi} \cdot f \cdot (\mathbf{x}^{<t>} + \boldsymbol{\varepsilon}\mathbf{e}^{<t>} + \boldsymbol{\varepsilon}\mathbf{c}^{<t>})$, and the transition equation may be rewritten and simplified as

$$
\begin{aligned}
\mathbf{x}^{<t+1>} &= \mathbf{\Delta}(f) \cdot \mathbf{x}^{<t>} - \mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f \cdot \left(\mathbf{x}^{<t>} + \boldsymbol{\varepsilon}\mathbf{e}^{<t>} + \boldsymbol{\varepsilon}\mathbf{c}^{<t>}\right) + \boldsymbol{\rho} + \boldsymbol{\varepsilon}\mathbf{p}^{<t>} \\
\mathbf{x}^{<t+1>} &= \mathbf{\Delta}(f) \cdot \left(\mathbf{I} - \mathbf{\Phi} \cdot f\right) \cdot \mathbf{x}^{<t>} - \mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f \cdot \left(\boldsymbol{\varepsilon}\mathbf{e}^{<t>} + \boldsymbol{\varepsilon}\mathbf{c}^{<t>}\right) + \boldsymbol{\rho} + \boldsymbol{\varepsilon}\mathbf{p}^{<t>} \qquad \text{(B5)} \\
\mathbf{x}^{<t+1>} &= \mathbf{\Theta}(f) \cdot \mathbf{x}^{<t>} - \mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f \cdot \left(\boldsymbol{\varepsilon}\mathbf{e}^{<t>} + \boldsymbol{\varepsilon}\mathbf{c}^{<t>}\right) + \boldsymbol{\rho} + \boldsymbol{\varepsilon}\mathbf{p}^{<t>} \quad .
\end{aligned}
$$

So far, the distributions of the three error terms have not been identified. It will be assumed here that all three are multivariate normal with mean zero. When combined with the linear form of the transition equation, this assumption implies that the expected value of the numbers-at-age vector at time t+1, $\boldsymbol{\mu}\mathbf{x}^{<t+1>}$, can be obtained from Equation B1 simply by replacing each occurrence of x with $\boldsymbol{\mu}\mathbf{x}$ as follows:

$$\boldsymbol{\mu}\mathbf{x}^{<t+1>} = \mathbf{\Theta}(f) \cdot \boldsymbol{\mu}\mathbf{x}^{<t>} + \boldsymbol{\rho} \quad .$$

Likewise, the expected value of the stationary distribution of numbers at age, $\boldsymbol{\mu}\mathbf{xsta}$, can be obtained from Equation B2 simply by replacing **xequ** with $\boldsymbol{\mu}\mathbf{xsta}$ as follows:

$$\boldsymbol{\mu}\mathbf{xsta}(f) = \left(\mathbf{I} - \mathbf{\Theta}(f)\right)^{-1} \cdot \boldsymbol{\rho} \quad .$$

Returning to the specification of the error term distributions, it will furthermore be assumed that the off-diagonal elements of the covariance matrices are all zero and that the diagonal elements are proportional to equilibrium numbers at age evaluated at f=f_{msy}. In the cases of $\boldsymbol{\varepsilon}\mathbf{c}^{<t>}$ and $\boldsymbol{\varepsilon}\mathbf{e}^{<t>}$, the non-zero elements of the covariance matrices $\mathbf{\Sigma c}$ and $\mathbf{\Sigma e}$ are thus computed as

$$
\begin{aligned}
\sigma c_{a,a} &= cv_c^{\,2} \cdot \mu xsta(f_{msy})_a^{\,2} \quad \forall \quad 0 \le a \le a_{max} \\
\sigma e_{a,a} &= cv_e^{\,2} \cdot \mu xsta(f_{msy})_a^{\,2} \quad \forall \quad 0 \le a \le a_{max} \quad ,
\end{aligned}
$$

where cv_c and cv_e are coefficients of variation. Because $\boldsymbol{\varepsilon}\mathbf{c}^{<t>}$ and $\boldsymbol{\varepsilon}\mathbf{e}^{<t>}$ appear additively in the transition equation, they can be replaced by a multivariate normal "management error" term $\boldsymbol{\varepsilon}\mathbf{m}^{<t>}$ with mean zero and covariance matrix $\mathbf{\Sigma m} = \mathbf{\Sigma e} + \mathbf{\Sigma c}$. Alternatively, the non-zero elements of $\mathbf{\Sigma m}$ may be computed as

$$\sigma m_{a,a} = cv_m^{\,2} \cdot \mu xsta(f_{msy})_a^{\,2} \quad \forall \quad 0 \le a \le a_{max} \quad ,$$

where cv_m is given by

$$cv_m = \sqrt{cv_c^{\,2} + cv_e^{\,2}} \quad .$$

The covariance matrix for the process error term ($\mathbf{\Sigma p}$) will be assumed to take a slightly different form. Given that most age-structured stock assessment models allow for process error only at a single age (either the age of recruitment to the population or the first age of recruitment to the fishery), it may be overly constraining to assume a constant coefficient of variation across all ages for the process error term. Instead, one coefficient of variation will be specified for age 0 (cv_r) and another will be specified for all other ages (cv_p). The non-zero elements of $\mathbf{\Sigma p}$ are thus computed as

$$\sigma p_{a,a} = cv_r^{\,2} \cdot \mu xsta(f_{msy})_a^{\,2} \quad \forall \quad a = 0$$

$$\sigma p_{a,a} = cv_p^{\,2} \cdot \mu xsta(f_{msy})_a^{\,2} \quad \forall \quad 0 < a \le a_{max} \quad .$$

From the third line of Equation B5, and using the substitution $\mathbf{\Sigma m}=\mathbf{\Sigma e}+\mathbf{\Sigma c}$, the covariance of the transition distribution of numbers at age, $\mathbf{\Sigma x}$, is given recursively by

$$\mathbf{\Sigma x}(f)^{<t+1>} = \mathbf{\Theta}(f) \cdot \mathbf{\Sigma x}(f)^{<t>} \cdot \mathbf{\Theta}(f)' + (\mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f) \cdot (\mathbf{\Sigma e} + \mathbf{\Sigma c}) \cdot (\mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f)' + \mathbf{\Sigma p}$$

$$\mathbf{\Sigma x}(f)^{<t+1>} = \mathbf{\Theta}(f) \cdot \mathbf{\Sigma x}(f)^{<t>} \cdot \mathbf{\Theta}(f)' + (\mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f) \cdot \mathbf{\Sigma m} \cdot (\mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f)' + \mathbf{\Sigma p} \quad .$$

Taking the limit of the above as $t \to \infty$, the covariance of the stationary distribution of numbers at age, $\mathbf{\Sigma xsta}$, is given implicitly by

$$\mathbf{\Sigma xsta}(f) = \mathbf{\Theta}(f) \cdot \mathbf{\Sigma xsta}(f) \cdot \mathbf{\Theta}(f)' + (\mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f) \cdot \mathbf{\Sigma m} \cdot (\mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f)' + \mathbf{\Sigma p} \quad .$$

The above implicit equation can be solved in closed form as follows:

$$\mathbf{\Sigma xsta}(f) = \text{vect}^{-1}\left((\mathbf{I2} - \mathbf{\Theta}(f) \otimes \mathbf{\Theta}(f))^{-1} \cdot \text{vect}\left((\mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f) \cdot \mathbf{\Sigma m} \cdot (\mathbf{\Delta}(f) \cdot \mathbf{\Phi} \cdot f)' + \mathbf{\Sigma p} \right) \right) \quad ,$$

where **I2** is the identity matrix of order $(a_{max}+1)^2$, "vect" is the vectorization operator (stacking the columns of a matrix so as to form a vector), "vect^{-1}" is the inverse vectorization operator (parsing the elements of a vector into individual columns so as to form a matrix), and "⊗" denotes the Kronecker product (e.g., Caswell (2001), p. 658).

Because yield is a linear transform of numbers at age, the transition distribution of yield is normal with mean $\mu y(f)_t$ and variance $\Sigma y(f)_t$, and the stationary distribution of yield is normal with mean $\mu ysta(f)$ and variance $\Sigma ysta(f)$. These parameters are derived below.

The expected value of the transition distribution of yield can be obtained from Equation B3 simply by replacing **x** with **μx** and y with μy as follows:

$$\mu y(f)_t = \mathbf{w}(f)' \cdot \mathbf{\Phi} \cdot f \cdot \mathbf{\mu x}^{<t>} \quad .$$

Likewise, the expected value of the stationary distribution of yield can be obtained from Equation B4 simply by replacing **xequ** with **μxsta** and *yequ* with *μysta* as follows:

$$\mu ysta(f) = \mathbf{w}(f)' \cdot \mathbf{\Phi} \cdot f \cdot \mathbf{\mu xsta}(f) \quad .$$

The variance of the transition distribution of yield is given by

$$\Sigma y(f)_t = (\mathbf{w}(f)' \cdot \mathbf{\Phi} \cdot f) \cdot (\mathbf{\Sigma x}(f)_t + \mathbf{\Sigma m}) \cdot (\mathbf{w}(f)' \cdot \mathbf{\Phi} \cdot f)' \quad .$$

Taking the limit of the above as $t \to \infty$, the variance of the stationary distribution of yield is given by

$$\Sigma ysta(f) = (\mathbf{w}(f)' \cdot \mathbf{\Phi} \cdot f) \cdot (\mathbf{\Sigma xsta}(f) + \mathbf{\Sigma m}) \cdot (\mathbf{w}(f)' \cdot \mathbf{\Phi} \cdot f)' \quad .$$

Table B1. Definitions of symbols used only in Appendix 1.3B. See Table 1 in main text for definitions of other symbols.

Symbol	Definition
Δ	portion of transition slope not contributing directly to harvest
$\boldsymbol{\varepsilon c}$	control error term
$\boldsymbol{\varepsilon e}$	estimation error term
$\boldsymbol{\varepsilon m}$	management error term
$\boldsymbol{\varepsilon p}$	process error term
$\boldsymbol{\Theta}$	slope of transition equation
$\boldsymbol{\kappa}$	coefficients of quadratic equation used to compute f_{msymin}
$\boldsymbol{\mu x}$	mean of population numbers-at-age transition distribution
$\boldsymbol{\mu xsta}$	mean of population numbers-at-age stationary distribution
μy	mean of yield transition distribution
$\boldsymbol{\rho}$	intercept of transition equation
$\boldsymbol{\Sigma c}$	covariance of control error term
$\boldsymbol{\Sigma e}$	covariance of estimation error term
$\boldsymbol{\Sigma m}$	covariance of management error term
$\boldsymbol{\Sigma p}$	covariance of process error term
$\boldsymbol{\Sigma x}$	covariance of population numbers-at-age transition distribution
$\boldsymbol{\Sigma xsta}$	covariance of population numbers-at-age stationary distribution
Σy	variance of yield transition distribution
$\boldsymbol{\Phi}$	portion of transition slope contributing directly to harvest
a	age (in years)
bpr	equilibrium exploitable biomass per recruit to the population at age 0
c	intercept of linear weight-at-age relationship
d	ratio of slope to intercept in linear weight-at-age relationship
f_{msymax}	maximum feasible value of f_{msy} for given values of a_r, $rspr_{msy}$, and v
f_{msymin}	maximum feasible value of f_{msy} for given values of a_r, $rspr_{msy}$, and v
g	intercept of linear stock-recruitment relationship
h	slope of linear stock-recruitment relationship
$\mathbf{I}$	identity matrix of order a_{max}+1
$rspr$	equilibrium relative spawning per recruit to the population at age 0
spr	equilibrium spawning per recruit to the population at age 0
$\mathbf{w}$	equilibrium weight at age
w_{ave}	equilibrium average weight (at or above a specified age)
$\mathbf{x}$	population numbers at age
$\mathbf{xequ}$	equilibrium population numbers at age
xpr	equilibrium population size per recruit at age 0
$yequ$	equilibrium yield

4. What does risk aversion mean?[4]

As the individual words in the term imply, "risk aversion" is the characteristic of being averse to risk. However, not all risk-averse individuals are equally risk averse. Thus, it is useful to have a quantitative definition of risk aversion, so that risk attitudes can be compared across individuals.

For example, suppose that Jim and John have the same net worth. To keep things simple, let net worth (= "wealth") be normalized so that Jim and John's current net worth has a value of unity. Suppose that each man is offered a gamble that provides a 55% chance of doubling his entire net worth and a 45% chance of losing everything. Note that a decision to accept the gamble has an expected monetary value of 1.1, while a decision to decline the gamble has an expected monetary value of 1.0. Suppose further that Jim and John both decline the gamble. Because the expected monetary value of accepting the gamble is greater than the expected monetary value of declining the gamble, it is clear that both Jim and John are risk averse.

Now suppose that the probability associated with winning is increased to 60%, and suppose that Jim still declines the gamble but John now accepts it. It has already been established that both Jim and John are risk averse, but apparently Jim is more risk averse than John.

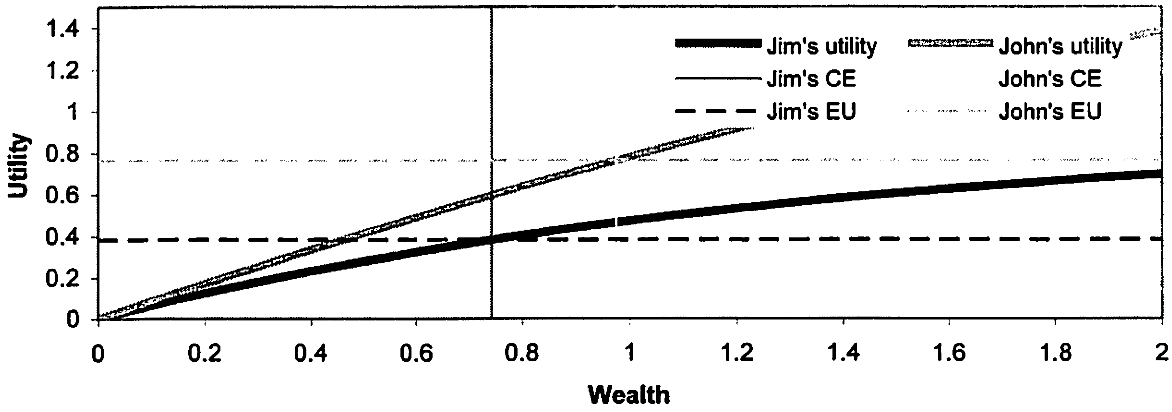
Finally, suppose that many other gambles are offered to Jim and John. By plotting the results of their responses, it becomes clear that Jim and John are both attempting to maximize their respective expected utilities in every instance; and, in fact, the differences in their respective preferences are due entirely to the fact that they have different utility functions, viz.,

$$u(w) = \frac{1-\exp(-0.75\cdot w)}{\exp(0.75)-1} \text{ for Jim, and } \quad u(w) = \frac{1-\exp(-0.25\cdot w)}{\exp(0.25)-1} \text{ for John,}$$

where u is utility and w is wealth.

Expected utility (EU) is computed by multiplying the probability of each outcome by the utility associated with that outcome, then summing across outcomes. For a given EU, a

"certainty equivalent" (CE) can be computed by inverting the utility function (i.e., by replacing $u(w)$ with EU on the left-hand side of the utility function, then solving for w). The utility functions are plotted with the EUs and CEs for the original 55/45 gamble below:



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[4] Contributed by Grant Thompson

Note that Jim and John's respective behaviors are both completely rational, given their respective utility functions. In the original 55/45 gamble, the expected utilities and certainty equivalents for Jim and John are as follow:

	Expected utility		Certainty equivalent	
Name	Accept	Decline	Accept	Decline
Jim	0.383	0.472	0.743	1.000
John	0.762	0.779	0.975	1.000

Because the expected utility of declining the original gamble is greater than the expected utility of accepting for both Jim and John, it makes sense for both Jim and John to decline. An alternative way to look at this is to see that the certainty equivalent of declining the original gamble is greater than the certainty equivalent of accepting for both Jim and John.

Turning to the second set of choices (where the probability of winning was increased to 60%), the expected utilities and certainty equivalents for Jim and John are as follow:

	Expected utility		Certainty equivalent	
Name	Accept	Decline	Accept	Decline
Jim	0.417	0.472	0.837	1.000
John	0.831	0.779	1.077	1.000

Here, the expected utility of declining the gamble is still greater than the expected utility of accepting for Jim, but not for John. Likewise, the certainty equivalent of declining the gamble is still greater than the certainty equivalent of accepting for Jim, but not for John.

Summarizing so far, Jim and John are both risk averse, but Jim is more risk averse than John, and the differences between Jim's and John's preferences are due entirely to the differences between their utility functions. It follows, then, that risk aversion must be an attribute of the utility function. However, determining *which* attribute of the utility function appropriately captures the individual's attitude toward risk turns out to involve a fairly complicated derivation. Fortunately, the derivation yields a pair of fairly simple results. The "absolute risk aversion" *ara* is given by

$$ara = -\frac{\left(\frac{\mathrm{d}^2 u}{\mathrm{d} w^2}\right)}{\left(\frac{\mathrm{d} u}{\mathrm{d} w}\right)} ,$$

and the "relative risk aversion" *rra* is given by $w \times ara$. It turns out that the form of the utility functions exhibited by Jim and John are of a very special type, in that they exhibit constant *ara* (i.e., the value of *ara* is independent of w). In Jim's case ara=0.75, and in John's case ara=0.25. This form is called the CARA (for "constant absolute risk aversion") utility function.

Because the technical definition of risk aversion involves first and second derivatives, this definition is not likely to be grasped readily by those unfamiliar with calculus. In the interest of making these definitions accessible to a wider audience, some alternative interpretations will be provided here, with the understanding that these inevitably involve imposition of additional assumptions.

Alternative Interpretation #1: Suppose that the utility function is of the CARA form and wealth is normalized such that current net worth has a value of unity. For a two-outcome gamble in which one outcome consists of doubling current net worth with probability P and the other consists of losing everything with probability $1-P$, the breakeven probability of winning, P^*, can be written entirely as a function of *ara*:

$$P^* = \frac{\exp(-ara)-1}{\exp(-2\cdot ara)-1} \quad .$$

Limiting cases of the above include $P^*=0$ as *ara* approaches $-\infty$ (complete risk proclivity), $P^*=0.5$ as *ara* approaches 0 (complete risk neutrality), and $P^*=1$ as *ara* approaches ∞ (complete risk aversion).

Alternative Interpretation #2: As in Alternative Interpretation #1, suppose that the utility function is of the CARA form and wealth is normalized such that current net worth has a value of unity. However, consider a gamble somewhat different from that entertained in Alternative Interpretation #1, where a guaranteed incentive payment of (normalized) amount X is added to both outcomes. The breakeven incentive payment, X^*, can be written entirely as a function of P and *ara*:

$$X^* = \frac{\ln\ (1-P)\cdot\exp(ara)+P\cdot\exp(-ara)}{ara} \quad .$$

Limiting cases of the above include $X^*=-1$ as *ara* approaches $-\infty$ (complete risk proclivity), $X^*=1-2\cdot P$ as *ara* approaches 0 (complete risk neutrality), and $X^*=1$ as *ara* approaches ∞ (complete risk aversion).

Alternative Interpretation #3: As in Alternative Interpretations #1 and #2, suppose that the utility function is of the CARA form. Here, however, suppose that wealth is measured in terms of long-term yield from a fishery, and suppose that long-term yield is normally distributed with parameters that are functions of the fishing mortality rate. The optimal fishing mortality rate is that which maximizes a mean-variance tradeoff where the mean has a weight of unity and the variance has a weight of $-ara/2$.

5. Decision-theoretic estimates of risk aversion implied by current NPFMC buffers for selected groundfish stocks[5]

In this section, the regression approach described in section 3 was used to back calculate the amount of risk aversion currently captured by the NPFMC tier system for groundfish. The analysis was performed on all Tiers 1 and 3 stocks.

5.1 Data

Assessment authors provided the inupt files used to run projections for the annual TAC specification process. These files contained the most recent estimates of natural mortality, weight, selectivity, etc. In addition, authors provided the following information:

1) The minimum age corresponding to the vectors in the projection model data file.
2) For Tier 1 assessments, the values of FOFL and maxFABC; for Tier 3 assessments, the values of F35% and F40%.
3) The CV of current abundance, and the definition of "current abundance" (e.g., it could be spawning biomass, age 3+ biomass, total numbers, etc.).
4) The frequency with which fishery selectivity is assumed to change in the model (e.g., every 3 years, every 5-10 years, just once, never, etc.).

5.2 Approach

The data described above were used to obtain the inputs needed to run the regression (Equation 4 in Section 3 above). There are seven such inputs:

1) the CV of numbers at age in the terminal year (assumed constant across age)
2) the CV of numbers at the first age in the model (i.e., the recruitment CV)
3) the CV of process error for ages beyond the first age in the model (assumed constant across age)
4) the relative spawning per recruit at MSY (estimated for Tier 1 stocks, assumed equal to 35% in Tier 3 stocks)
5) the fishing mortality rate at MSY (assumed constant across age beyond a knife-edge age of recruitment to the fishery)
6) the natural mortality rate (assumed constant across age)
7) the level of absolute risk aversion (or the ratio of FABC/FOFL, if the regression is inverted)

The data from the projection model that were used in the analysis included the following:

A) the natural mortality rate
B) the maturity at age schedule
C) the weight at age schedule
D) the numbers at age schedule for the terminal year
E) the recruitment time series
F) the selectivity schedule (which was used to convert the "actual" F35% value into an "equivalent" knife-edged F35% value)

The information from the assessment authors was translated into the necessary inputs as follows:

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[5] Contributed by Grant Thompson

1) The level of relative spawning per recruit was set equal to 0.35 for all Tier 3 stocks, and was set equal the value corresponding to the arithmetic mean of Fmsy for all Tier 1 stocks.
2) The discrete annual mortality rate was set equal to 1-exp(-M).
3) The process error CV for the first age in the model was set equal to the standard deviation of the estimated first age abundances divided by the mean of the estimated first age abundances.
4) The process error CV for ages beyond the first age in the model was set equal to 0.05 for assessments in which commercial selectivity was allowed to change at least once per decade, and was set equal to 0.10 for assessments in which commercial selectivity was not allowed to change at least once per decade. The figure of 0.05 was based on an analysis of the impact of the annually varying selectivities in the GOA pollock assessment, and the figure of 0.10 was included for contrast.
5) The management error CV (restricted here to error in estimated numbers at age) was obtained by finding the value which, when applied across all ages in the assessment's definition of "abundance" (sometimes an age+ biomass, other times spawning biomass), gave an overall CV for current abundance that matched the value provided by the author.
6) The discrete annual fishing mortality rate at MSY was estimated initially by using M, full selection F35% (for Tier 3 stocks) or full selection Fmsy (for Tier 1 stocks), and estimated selectivity to generate an equilibrium catch curve beginning at the age of 50% maturity, the slope of which was then assumed to equal M + "age-averaged" Fmsy, after which the age-averaged Fmsy was converted to a discrete time scale as 1-exp(-Fmsy). However, most of the resulting Fmsy values fell outside the admissible range dictated by the linear model (described in Section 3 above). When this occurred the percentile of the admissible range for each Fmsy estimate was calculated as (Fmsy-Fmsymin)/(Fmsymax-Fmsymin). Here are some hypothetical examples: (a) if the estimate was 0.1 and the admissible range was 0.2 to 0.4, the percentile was (0.1-0.2)/(0.4-0.2)=-0.5; (b) if the estimate was 0.3 and the admissible range was 0.2 to 0.4, the percentile was (0.3-0.2)/(0.4-0.2)=0.5; and (c) if the estimate was 0.5 and the admissible range was 0.2 to 0.4, the percentile was (0.5-0.2)/(0.4-0.2)=1.5. This was followed by computing the mean of the percentiles, which was 0.1 (i.e., 10%). Finally, the Fmsy value for each stock was assumed to be equal to the 0.1 percentile for the admissible range defined by the other parameters for that stock.

5.3 Results

The spreadsheet showing the inputs and results are shown in Tables 5.1 – 5.4. Table 5.1 shows the results when the initial Fmsy estimates were used, but truncated at the bounds of the admissible range. Table 5.2 shows the results when Fmsy was set at the 0.1 percentile with ARA=0.5. Table 5.3 shows the results when Fmsy was set at the 0.1 percentile with ARA=0.4. Table 5.4 provides a summary across groundfish stocks by Tier.

The analysis was completed for the 3 Tier 1 stocks and the 21 Tier 3 stocks, and the rows of the table are grouped accordingly: rows 2-7 summarize the results for the Tier 1 stocks, rows 8-13 summarize the results for the Tier 3 stocks, and rows 14-19 summarize the results for the combined Tier 1-3 stocks.

Columns C-D of Table 5.4 show the level of risk aversion implied by the current harvest control rules (this involves inverting the regression). Column C shows the ratio of maxFABC/FOFL under the current harvest control rules. Column D shows the level of absolute risk aversion implied by this ratio. Note that Tier 1 tends to imply less risk aversion than Tier 3, due largely to the fact that the maxFABC/FOFL ratios for yellowfin sole and northern rock sole (particularly northern rock sole) are so large. The range of implied absolute risk aversions is large, particularly for Tier 3 (0.16-1.56). In general, the results in this portion of the table were very sensitive to the level of relative spawning per recruit corresponding to FMSY (estimated individually for Tier 1 stocks, assumed equal to 35% for Tier 3 stocks), the value of FMSY, the natural mortality rate, and the maxFABC/FOFL ratio. The results were not very sensitive to the levels of uncertainty associated with estimation error, recruitment process error, and post-recruitment process error. The large sensitivities with respect to some inputs may be due in part to the fact that the results were obtained by inverting the regression.

Columns E-F of Table 5.4 show the ratio of maxFABC/FOFL that would be implied by an assumed level of absolute risk aversion (this is the way the regression was originally intended to be used). Column E shows the assumed level, which was set equal to the median of the Tier 3 values in column D (0.40). Column F shows the maxFABC/FOFL ratios implied by the assumed level of absolute risk aversion. Note that the assumed absolute risk aversion of 0.40 results in the same average maxFABC/FOFL ratio under Tier 3 as do the current harvest control rules (0.82), but the range is slightly larger (0.72-0.87 in column C versus 0.70-0.94 in column F). In general, the results in columns E-F are much less sensitive to the inputs than are the results in columns E-F.

5.4 Discussion

This assessment indicates that the current buffers between ABC and OFL in the BSAI and GOA Groundfish FMPs can be viewed in terms of a response to scientific uncertainty given a specified level of risk aversion.

There are some caveats that should be considered with this analysis. Equation 4 (Section 3) is provided only for use in cases where there is insufficient time or resources to use Equation 2 (Section 3). This is an example of such a case. See also the Discussion in Section 1.

Table 1.5.1

			Input parameters						Relative fmsy		Implied fratio		Implied ara	
FMP	Stock	Tier	cv(m)	cv(p)	cv(r)	rspr	fmsy	v	Initial	Final	ara1	fratio1	fratio2	ara2
BSAI	BS walleye pollock	1	0.63	0.05	0.64	0.28	0.31	0.26	-0.25	0.00	0.50	0.82	0.83	0.43
BSAI	BSAI yellowfin sole	1	0.18	0.10	0.56	0.34	0.13	0.11	-0.15	0.00	0.50	0.85	0.92	0.19
BSAI	BSAI northern rock sole	1	0.10	0.10	0.62	0.30	0.18	0.14	-0.36	0.00	0.50	0.82	0.99	0.01
Both	BSAI/GOA sablefish	3	0.14	0.10	0.89	0.35	0.11	0.10	-0.29	0.00	0.50	0.83	0.84	0.44
BSAI	AI walleye pollock	3	0.36	0.10	0.59	0.35	0.24	0.19	0.67	0.67	0.50	0.27	0.81	0.00
BSAI	BSAI Pacific cod	3	0.32	0.05	0.75	0.35	0.28	0.29	-0.58	0.00	0.50	0.79	0.82	0.40
BSAI	BSAI Greenland turbot	3	0.73	0.10	1.19	0.35	0.17	0.11	1.43	1.00	0.50	0.10	0.81	0.00
BSAI	BSAI arrowtooth flounder	3	0.14	0.10	0.48	0.35	0.24	0.24	-0.11	0.00	0.50	0.81	0.80	0.52
BSAI	BSAI flathead sole	3	0.24	0.10	0.47	0.35	0.19	0.18	-0.26	0.00	0.50	0.81	0.82	0.45
BSAI	BSAI Alaska plaice	3	0.15	0.10	0.63	0.35	0.29	0.22	4.78	1.00	0.50	0.14	0.72	0.00
BSAI	BSAI Pacific ocean perch	3	0.84	0.05	0.57	0.35	0.07	0.06	-0.16	0.00	0.50	0.91	0.84	1.16
BSAI	BSAI northern rockfish	3	0.84	0.10	0.65	0.35	0.05	0.04	0.10	0.10	0.50	0.90	0.84	0.96
BSAI	AI blackspotted and rougheye rockfish	3	0.75	0.10	0.90	0.35	0.04	0.03	0.32	0.32	0.50	0.83	0.83	0.51
BSAI	BSAI Atka mackerel	3	0.40	0.05	0.67	0.35	0.33	0.26	1.19	1.00	0.50	0.16	0.81	0.00
BSAI	BSAI Alaska skate	3	0.10	0.10	0.19	0.35	0.13	0.12	-1.10	0.00	0.50	0.90	0.87	0.76
GOA	GOA walleye pollock	3	0.20	0.05	1.17	0.35	0.25	0.26	-0.25	0.00	0.50	0.81	0.86	0.30
GOA	GOA Pacific cod	3	0.38	0.05	0.92	0.35	0.37	0.32	1.34	1.00	0.50	0.18	0.81	0.00
GOA	GOA Dover sole	3	0.36	0.10	0.47	0.35	0.13	0.08	1.83	1.00	0.50	0.22	0.78	0.00
GOA	GOA arrowtooth flounder	3	0.31	0.10	0.38	0.35	0.19	0.18	-0.26	0.00	0.50	0.82	0.84	0.40
GOA	GOA flathead sole	3	0.27	0.10	0.33	0.35	0.25	0.18	2.72	1.00	0.50	0.17	0.78	0.00
GOA	GOA Pacific ocean perch	3	0.88	0.10	0.77	0.35	0.07	0.06	-0.13	0.00	0.50	0.87	0.84	0.65
GOA	GOA northern rockfish	3	0.84	0.10	0.63	0.35	0.07	0.06	0.05	0.05	0.50	0.86	0.84	0.63
GOA	GOA rougheye and blackspotted rockfish	3	0.89	0.10	0.52	0.35	0.05	0.03	0.34	0.34	0.50	0.84	0.83	0.56
GOA	GOA dusky rockfish	3	0.54	0.10	0.86	0.35	0.10	0.07	0.69	0.69	0.50	0.36	0.81	0.01
	Minimum:	1	0.10	0.05	0.56	0.28	0.13	0.11	-0.36	0.00	0.50	0.82	0.83	0.01
	Average:	1	0.30	0.08	0.61	0.31	0.21	0.17	-0.26	0.00	0.50	0.83	0.91	0.21
	Median:	1	0.18	0.10	0.62	0.30	0.18	0.14	-0.25	0.00	0.50	0.82	0.92	0.19
	Maximum:	1	0.63	0.10	0.64	0.34	0.31	0.26	-0.15	0.00	0.50	0.85	0.99	0.43
	Standard Deviation:	1	0.29	0.03	0.04	0.03	0.09	0.08	0.10	0.00	0.00	0.02	0.08	0.21
	CV:	1	0.94	0.35	0.07	0.10	0.46	0.47	-0.41	n/a	0.00	0.02	0.09	1.01
	Minimum:	3	0.10	0.05	0.19	0.35	0.04	0.03	-1.10	0.00	0.50	0.10	0.72	0.00
	Average:	3	0.46	0.09	0.67	0.35	0.17	0.15	0.59	0.39	0.50	0.60	0.82	0.37
	Median:	3	0.36	0.10	0.63	0.35	0.17	0.12	0.10	0.10	0.50	0.81	0.82	0.40
	Maximum:	3	0.89	0.10	1.19	0.35	0.37	0.32	4.78	1.00	0.50	0.91	0.87	1.16
	Standard Deviation:	3	0.28	0.02	0.26	0.00	0.10	0.09	1.32	0.45	0.00	0.33	0.03	0.35
	CV:	3	0.62	0.25	0.39	0.00	0.58	0.63	2.25	1.15	0.00	0.54	0.04	0.95
	Minimum:	1-3	0.10	0.05	0.19	0.28	0.04	0.03	-1.10	0.00	0.50	0.10	0.72	0.00
	Average:	1-3	0.44	0.09	0.66	0.34	0.18	0.15	0.48	0.34	0.50	0.63	0.83	0.35
	Median:	1-3	0.36	0.10	0.63	0.35	0.18	0.13	-0.03	0.02	0.50	0.81	0.83	0.40
	Maximum:	1-3	0.89	0.10	1.19	0.35	0.37	0.32	4.78	1.00	0.50	0.91	0.99	1.16
	Standard Deviation:	1-3	0.28	0.02	0.24	0.02	0.10	0.09	1.26	0.44	0.00	0.31	0.05	0.34
	CV:	1-3	0.64	0.25	0.37	0.05	0.56	0.60	2.62	1.28	0.00	0.50	0.06	0.96

Table 1.5.1 (continued)

			Elasticities of implied fratio							Elasticities of implied ara						
FMP	Stock	Tier	cv(m)	cv(p)	cv(r)	rspr	fmsy	v	fratio	cv(m)	cv(p)	cv(r)	rspr	fmsy	v	fratio
BSAI	BS walleye pollock	1	-0.04	-0.08	-0.08	-1.94	-2.10	1.57	-0.12	-0.26	-0.56	-0.60	-14.27	-15.47	11.55	-7.28
BSAI	BSAI yellowfin sole	1	-0.02	-0.04	-0.04	-0.99	-0.78	0.61	-0.06	-0.12	-0.23	-0.25	-6.70	-5.28	4.16	-6.21
BSAI	BSAI northern rock sole	1	0.00	0.00	0.00	-0.12	-0.10	0.08	-0.01	-0.01	-0.01	-0.01	-0.37	-0.33	0.25	-2.30
Both	BSAI/GOA sablefish	3	-0.03	-0.07	-0.08	-2.02	-1.53	1.21	-0.13	-0.24	-0.51	-0.55	-14.27	-10.84	8.58	-6.99
BSAI	AI walleye pollock	3	-0.04	-0.09	-0.09	-2.40	-2.12	1.60	-0.10	-0.01	-0.01	-0.01	-0.28	-0.26	0.19	-0.08
BSAI	BSAI Pacific cod	3	-0.04	-0.08	-0.09	-2.27	-2.11	1.73	-0.13	-0.23	-0.49	-0.53	-14.00	-13.06	10.68	-6.04
BSAI	BSAI Greenland turbot	3	-0.04	-0.09	-0.09	-2.40	-1.94	1.46	-0.08	0.00	0.00	0.00	-0.01	-0.01	0.01	0.00
BSAI	BSAI arrowtooth flounder	3	-0.04	-0.09	-0.10	-2.52	-2.23	1.79	-0.15	-0.29	-0.63	-0.68	-17.60	-15.52	12.51	-7.01
BSAI	BSAI flathead sole	3	-0.04	-0.08	-0.09	-2.27	-1.88	1.50	-0.13	-0.25	-0.55	-0.59	-15.41	-12.75	10.16	-6.72
BSAI	BSAI Alaska plaice	3	-0.06	-0.13	-0.14	-3.53	-3.35	2.45	-0.12	0.00	0.00	0.00	-0.09	-0.09	0.07	-0.02
BSAI	BSAI Pacific ocean perch	3	-0.03	-0.07	-0.08	-2.02	-1.46	1.16	-0.13	-0.52	-1.28	-1.40	-33.96	-24.37	19.36	-18.19
BSAI	BSAI northern rockfish	3	-0.03	-0.07	-0.08	-2.02	-1.43	1.14	-0.13	-0.44	-1.05	-1.14	-28.18	-19.82	15.76	-14.82
BSAI	AI blackspotted and rougheye rockfish	3	-0.04	-0.08	-0.08	-2.14	-1.51	1.20	-0.13	-0.27	-0.60	-0.64	-16.62	-11.68	9.27	-7.76
BSAI	BSAI Atka mackerel	3	-0.04	-0.09	-0.09	-2.40	-2.39	1.75	-0.08	0.00	0.00	0.00	-0.04	-0.04	0.03	-0.01
BSAI	BSAI Alaska skate	3	-0.03	-0.06	-0.06	-1.64	-1.27	1.01	-0.10	-0.37	-0.85	-0.93	-23.26	-17.97	14.22	-14.73
GOA	GOA walleye pollock	3	-0.03	-0.06	-0.07	-1.77	-1.58	1.29	-0.11	-0.18	-0.36	-0.39	-10.43	-9.39	7.65	-5.65
GOA	GOA Pacific cod	3	-0.04	-0.09	-0.09	-2.40	-2.57	1.91	-0.09	0.00	0.00	0.00	-0.06	-0.07	0.05	-0.02
GOA	GOA Dover sole	3	-0.05	-0.10	-0.11	-2.78	-2.14	1.63	-0.10	0.00	-0.01	-0.01	-0.19	-0.15	0.11	-0.05
GOA	GOA arrowtooth flounder	3	-0.03	-0.07	-0.08	-2.02	-1.67	1.33	-0.12	-0.23	-0.49	-0.53	-13.87	-11.49	9.16	-6.73
GOA	GOA flathead sole	3	-0.05	-0.10	-0.11	-2.78	-2.49	1.83	-0.09	0.00	0.00	0.00	-0.06	-0.06	0.04	-0.01
GOA	GOA Pacific ocean perch	3	-0.03	-0.07	-0.08	-2.02	-1.46	1.16	-0.13	-0.33	-0.74	-0.80	-20.38	-14.71	11.69	-10.34
GOA	GOA northern rockfish	3	-0.03	-0.07	-0.08	-2.02	-1.46	1.16	-0.12	-0.32	-0.72	-0.78	-19.95	-14.39	11.42	-10.08
GOA	GOA rougheye and blackspotted rockfish	3	-0.04	-0.08	-0.08	-2.14	-1.51	1.20	-0.13	-0.30	-0.67	-0.72	-18.58	-13.08	10.37	-8.75
GOA	GOA dusky rockfish	3	-0.04	-0.09	-0.09	-2.40	-1.80	1.39	-0.11	-0.02	-0.02	-0.03	-0.82	-0.63	0.49	-0.26
	Minimum:	1	-0.04	-0.08	-0.08	-1.94	-2.10	0.08	-0.12	-0.26	-0.56	-0.60	-14.27	-15.47	0.25	-7.28
	Average:	1	-0.02	-0.04	-0.04	-1.02	-0.99	0.75	-0.06	-0.13	-0.27	-0.29	-7.11	-7.03	5.32	-5.26
	Median:	1	-0.02	-0.04	-0.04	-0.99	-0.78	0.61	-0.06	-0.12	-0.23	-0.25	-6.70	-5.28	4.16	-6.21
	Maximum:	1	0.00	0.00	0.00	-0.12	-0.10	1.57	-0.01	-0.01	-0.01	-0.01	-0.37	-0.33	11.55	-2.30
	Standard Deviation:	1	0.02	0.04	0.04	0.91	1.01	0.75	0.06	0.13	0.28	0.30	6.96	7.72	5.74	2.62
	CV:	1	-0.93	-0.93	-0.93	-0.90	-1.02	1.00	-0.89	-0.99	-1.03	-1.04	-0.98	-1.10	1.08	-0.50
	Minimum:	3	-0.06	-0.13	-0.14	-3.53	-3.35	1.01	-0.15	-0.52	-1.28	-1.40	-33.96	-24.37	0.01	-18.19
	Average:	3	-0.04	-0.08	-0.09	-2.28	-1.90	1.47	-0.11	-0.19	-0.43	-0.46	-11.81	-9.06	7.23	-5.92
	Median:	3	-0.04	-0.08	-0.09	-2.27	-1.80	1.39	-0.12	-0.23	-0.49	-0.53	-14.00	-11.49	9.16	-6.72
	Maximum:	3	-0.03	-0.06	-0.06	-1.64	-1.27	2.45	-0.08	0.00	0.00	0.00	-0.01	-0.01	19.36	0.00
	Standard Deviation:	3	0.01	0.01	0.02	0.41	0.51	0.35	0.02	0.17	0.39	0.43	10.59	7.83	6.24	5.63
	CV:	3	-0.18	-0.18	-0.18	-0.18	-0.27	0.24	-0.17	-0.88	-0.91	-0.92	-0.90	-0.86	0.86	-0.95
	Minimum:	1-3	-0.06	-0.13	-0.14	-3.53	-3.35	0.08	-0.15	-0.52	-1.28	-1.40	-33.96	-24.37	0.01	-18.19
	Average:	1-3	-0.03	-0.08	-0.08	-2.12	-1.79	1.38	-0.11	-0.18	-0.41	-0.44	-11.22	-8.81	6.99	-5.84
	Median:	1-3	-0.04	-0.08	-0.08	-2.14	-1.73	1.36	-0.12	-0.23	-0.49	-0.53	-13.94	-11.17	8.87	-6.47
	Maximum:	1-3	0.00	0.00	0.00	-0.12	-0.10	2.45	-0.01	0.00	0.00	0.00	-0.01	-0.01	19.36	0.00
	Standard Deviation:	1-3	0.01	0.02	0.02	0.63	0.64	0.46	0.03	0.16	0.38	0.41	10.21	7.68	6.09	5.31
	CV:	1-3	-0.29	-0.29	-0.29	-0.30	-0.36	0.34	-0.28	-0.88	-0.93	-0.93	-0.91	-0.87	0.87	-0.91

Table 1.5.2 (continued)

			Input parameters						Relative fmsy		Implied fratio		Implied ara	
FMP	Stock	Tier	cv(m)	cv(p)	cv(r)	rspr	fmsy	v	Initial	Final	ara1	fratio1	fratio2	ara2
BSAI	BS walleye pollock	1	0.63	0.05	0.64	0.28	0.32	0.26	-0.25	0.10	0.50	0.76	0.83	0.26
BSAI	BSAI yellowfin sole	1	0.18	0.10	0.56	0.34	0.13	0.11	-0.15	0.10	0.50	0.79	0.92	0.11
BSAI	BSAI northern rock sole	1	0.10	0.10	0.62	0.30	0.19	0.14	-0.36	0.10	0.50	0.77	0.99	0.00
Both	BSAI/GOA sablefish	3	0.14	0.10	0.89	0.35	0.12	0.10	-0.29	0.10	0.50	0.77	0.84	0.27
BSAI	AI walleye pollock	3	0.36	0.10	0.59	0.35	0.20	0.19	0.67	0.10	0.50	0.68	0.81	0.18
BSAI	BSAI Pacific cod	3	0.32	0.05	0.75	0.35	0.28	0.29	-0.58	0.10	0.50	0.74	0.82	0.25
BSAI	BSAI Greenland turbot	3	0.73	0.10	1.19	0.35	0.13	0.11	1.43	0.10	0.50	0.66	0.81	0.16
BSAI	BSAI arrowtooth flounder	3	0.14	0.10	0.48	0.35	0.24	0.24	-0.11	0.10	0.50	0.75	0.80	0.33
BSAI	BSAI flathead sole	3	0.24	0.10	0.47	0.35	0.19	0.18	-0.26	0.10	0.50	0.75	0.82	0.27
BSAI	BSAI Alaska plaice	3	0.15	0.10	0.63	0.35	0.23	0.22	4.78	0.10	0.50	0.70	0.72	0.43
BSAI	BSAI Pacific ocean perch	3	0.84	0.05	0.57	0.35	0.07	0.06	-0.16	0.10	0.50	0.88	0.84	0.74
BSAI	BSAI northern rockfish	3	0.84	0.10	0.65	0.35	0.05	0.04	0.10	0.10	0.50	0.90	0.84	0.94
BSAI	AI blackspotted and rougheye rockfish	3	0.75	0.10	0.90	0.35	0.04	0.03	0.32	0.10	0.50	0.92	0.83	1.31
BSAI	BSAI Atka mackerel	3	0.40	0.05	0.67	0.35	0.26	0.26	1.19	0.10	0.50	0.77	0.81	0.36
BSAI	BSAI Alaska skate	3	0.10	0.10	0.19	0.35	0.14	0.12	-1.10	0.10	0.50	0.87	0.87	0.48
GOA	GOA walleye pollock	3	0.20	0.05	1.17	0.35	0.26	0.26	-0.25	0.10	0.50	0.75	0.86	0.18
GOA	GOA Pacific cod	3	0.38	0.05	0.92	0.35	0.30	0.32	1.34	0.10	0.50	0.77	0.81	0.34
GOA	GOA Dover sole	3	0.36	0.10	0.47	0.35	0.10	0.08	1.83	0.10	0.50	0.83	0.78	0.75
GOA	GOA arrowtooth flounder	3	0.31	0.10	0.38	0.35	0.19	0.18	-0.26	0.10	0.50	0.76	0.84	0.24
GOA	GOA flathead sole	3	0.27	0.10	0.33	0.35	0.19	0.18	2.72	0.10	0.50	0.77	0.78	0.48
GOA	GOA Pacific ocean perch	3	0.88	0.10	0.77	0.35	0.07	0.06	-0.13	0.10	0.50	0.82	0.84	0.40
GOA	GOA northern rockfish	3	0.84	0.10	0.63	0.35	0.07	0.06	0.05	0.10	0.50	0.84	0.84	0.49
GOA	GOA rougheye and blackspotted rockfish	3	0.89	0.10	0.52	0.35	0.04	0.03	0.34	0.10	0.50	0.93	0.83	1.56
GOA	GOA dusky rockfish	3	0.54	0.10	0.86	0.35	0.08	0.07	0.69	0.10	0.50	0.81	0.81	0.49
	Minimum:	1	0.10	0.05	0.56	0.28	0.13	0.11	-0.36	0.10	0.50	0.76	0.83	0.00
	Average:	1	0.30	0.08	0.61	0.31	0.21	0.17	-0.26	0.10	0.50	0.77	0.91	0.12
	Median:	1	0.18	0.10	0.62	0.30	0.19	0.14	-0.25	0.10	0.50	0.77	0.92	0.11
	Maximum:	1	0.63	0.10	0.64	0.34	0.32	0.26	-0.15	0.10	0.50	0.79	0.99	0.26
	Standard Deviation:	1	0.29	0.03	0.04	0.03	0.10	0.08	0.10	0.00	0.00	0.02	0.08	0.13
	CV:	1	0.94	0.35	0.07	0.10	0.45	0.47	-0.41	0.00	0.00	0.02	0.09	1.02
	Minimum:	3	0.10	0.05	0.19	0.35	0.04	0.03	-1.10	0.10	0.50	0.66	0.72	0.16
	Average:	3	0.46	0.09	0.67	0.35	0.16	0.15	0.59	0.10	0.50	0.79	0.82	0.51
	Median:	3	0.36	0.10	0.63	0.35	0.14	0.12	0.10	0.10	0.50	0.77	0.82	0.40
	Maximum:	3	0.89	0.10	1.19	0.35	0.30	0.32	4.78	0.10	0.50	0.93	0.87	1.56
	Standard Deviation:	3	0.28	0.02	0.26	0.00	0.09	0.09	1.32	0.00	0.00	0.07	0.03	0.37
	CV:	3	0.62	0.25	0.39	0.00	0.55	0.63	2.25	0.00	0.00	0.09	0.04	0.73
	Minimum:	1-3	0.10	0.05	0.19	0.28	0.04	0.03	-1.10	0.10	0.50	0.66	0.72	0.00
	Average:	1-3	0.44	0.09	0.66	0.34	0.16	0.15	0.48	0.10	0.50	0.79	0.83	0.46
	Median:	1-3	0.36	0.10	0.63	0.35	0.16	0.13	-0.03	0.10	0.50	0.77	0.83	0.35
	Maximum:	1-3	0.89	0.10	1.19	0.35	0.32	0.32	4.78	0.10	0.50	0.93	0.99	1.56
	Standard Deviation:	1-3	0.28	0.02	0.24	0.02	0.09	0.09	1.26	0.00	0.00	0.07	0.05	0.37
	CV:	1-3	0.64	0.25	0.37	0.05	0.54	0.60	2.62	0.00	0.00	0.09	0.06	0.80

Table 1.5.2 (continued)

			Elasticities of implied fratio							Elasticities of implied ara						
FMP	Stock	Tier	cv(m)	cv(p)	cv(r)	rspr	fmsy	v	fratio	cv(m)	cv(p)	cv(r)	rspr	fmsy	v	fratio
BSAI	BS walleye pollock	1	-0.04	-0.08	-0.08	-1.94	-2.13	1.57	-0.11	-0.18	-0.35	-0.38	-9.28	-10.24	7.55	-4.53
BSAI	BSAI yellowfin sole	1	-0.02	-0.04	-0.04	-0.99	-0.78	0.61	-0.06	-0.08	-0.14	-0.15	-4.27	-3.40	2.66	-3.79
BSAI	BSAI northern rock sole	1	0.00	0.00	0.00	-0.12	-0.10	0.08	-0.01	0.00	-0.01	-0.01	-0.20	-0.19	0.14	-1.22
Both	BSAI/GOA sablefish	3	-0.03	-0.07	-0.08	-2.02	-1.54	1.21	-0.12	-0.16	-0.33	-0.36	-9.59	-7.35	5.79	-4.51
BSAI	AI walleye pollock	3	-0.04	-0.09	-0.09	-2.40	-2.03	1.60	-0.13	-0.13	-0.25	-0.27	-7.39	-6.29	4.97	-2.83
BSAI	BSAI Pacific cod	3	-0.04	-0.08	-0.09	-2.27	-2.13	1.73	-0.13	-0.17	-0.33	-0.36	-9.69	-9.16	7.42	-4.02
BSAI	BSAI Greenland turbot	3	-0.04	-0.09	-0.09	-2.40	-1.85	1.46	-0.13	-0.12	-0.22	-0.24	-6.60	-5.13	4.05	-2.51
BSAI	BSAI arrowtooth flounder	3	-0.04	-0.09	-0.10	-2.52	-2.25	1.79	-0.14	-0.20	-0.42	-0.46	-12.14	-10.85	8.66	-4.64
BSAI	BSAI flathead sole	3	-0.04	-0.08	-0.09	-2.27	-1.89	1.50	-0.13	-0.17	-0.35	-0.38	-10.21	-8.55	6.76	-4.27
BSAI	BSAI Alaska plaice	3	-0.06	-0.13	-0.14	-3.53	-3.09	2.45	-0.20	-0.26	-0.56	-0.60	-15.73	-13.77	10.91	-4.40
BSAI	BSAI Pacific ocean perch	3	-0.03	-0.07	-0.08	-2.02	-1.47	1.16	-0.12	-0.38	-0.87	-0.94	-23.72	-17.15	13.58	-12.18
BSAI	BSAI northern rockfish	3	-0.03	-0.07	-0.08	-2.02	-1.43	1.14	-0.13	-0.43	-1.03	-1.13	-27.75	-19.53	15.52	-14.57
BSAI	AI blackspotted and rougheye rockfish	3	-0.04	-0.08	-0.08	-2.14	-1.50	1.20	-0.14	-0.54	-1.36	-1.49	-35.71	-24.76	19.72	-18.21
BSAI	BSAI Atka mackerel	3	-0.04	-0.09	-0.09	-2.40	-2.17	1.75	-0.13	-0.22	-0.46	-0.50	-13.15	-11.93	9.63	-5.33
BSAI	BSAI Alaska skate	3	-0.03	-0.06	-0.06	-1.64	-1.28	1.01	-0.10	-0.26	-0.58	-0.62	-16.14	-12.60	9.92	-9.82
GOA	GOA walleye pollock	3	-0.03	-0.06	-0.07	-1.77	-1.60	1.29	-0.10	-0.12	-0.23	-0.25	-6.92	-6.31	5.10	-3.60
GOA	GOA Pacific cod	3	-0.04	-0.09	-0.09	-2.40	-2.31	1.91	-0.14	-0.21	-0.44	-0.47	-12.48	-12.05	9.95	-5.04
GOA	GOA Dover sole	3	-0.05	-0.10	-0.11	-2.78	-2.07	1.63	-0.16	-0.39	-0.90	-0.97	-24.42	-18.10	14.29	-9.13
GOA	GOA arrowtooth flounder	3	-0.03	-0.07	-0.08	-2.02	-1.68	1.33	-0.11	-0.16	-0.31	-0.33	-9.10	-7.63	6.03	-4.23
GOA	GOA flathead sole	3	-0.05	-0.10	-0.11	-2.78	-2.31	1.83	-0.16	-0.28	-0.61	-0.66	-17.11	-14.27	11.28	-6.14
GOA	GOA Pacific ocean perch	3	-0.03	-0.07	-0.08	-2.02	-1.47	1.16	-0.12	-0.23	-0.49	-0.52	-13.75	-10.00	7.92	-6.68
GOA	GOA northern rockfish	3	-0.03	-0.07	-0.08	-2.02	-1.46	1.16	-0.12	-0.27	-0.58	-0.63	-16.32	-11.82	9.37	-8.07
GOA	GOA rougheye and blackspotted rockfish	3	-0.04	-0.08	-0.08	-2.14	-1.51	1.20	-0.14	-0.63	-1.62	-1.78	-42.23	-29.30	23.33	-21.89
GOA	GOA dusky rockfish	3	-0.04	-0.09	-0.09	-2.40	-1.76	1.39	-0.14	-0.27	-0.59	-0.64	-16.47	-12.07	9.55	-6.86
	Minimum:	1	-0.04	-0.08	-0.08	-1.94	-2.13	0.08	-0.11	-0.18	-0.35	-0.38	-9.28	-10.24	0.14	-4.53
	Average:	1	-0.02	-0.04	-0.04	-1.02	-1.00	0.75	-0.06	-0.09	-0.17	-0.18	-4.58	-4.61	3.45	-3.18
	Median:	1	-0.02	-0.04	-0.04	-0.99	-0.78	0.61	-0.06	-0.08	-0.14	-0.15	-4.27	-3.40	2.66	-3.79
	Maximum:	1	0.00	0.00	0.00	-0.12	-0.10	1.57	-0.01	0.00	-0.01	-0.01	-0.20	-0.19	7.55	-1.22
	Standard Deviation:	1	0.02	0.04	0.04	0.91	1.03	0.75	0.05	0.09	0.18	0.19	4.55	5.13	3.77	1.74
	CV:	1	-0.93	-0.93	-0.93	-0.90	-1.02	1.00	-0.89	-1.00	-1.04	-1.05	-0.99	-1.11	1.09	-0.55
	Minimum:	3	-0.06	-0.13	-0.14	-3.53	-3.09	1.01	-0.20	-0.63	-1.62	-1.78	-42.23	-29.30	4.05	-21.89
	Average:	3	-0.04	-0.08	-0.09	-2.28	-1.85	1.47	-0.13	-0.27	-0.60	-0.65	-16.51	-12.79	10.18	-7.57
	Median:	3	-0.04	-0.08	-0.09	-2.27	-1.76	1.39	-0.13	-0.23	-0.49	-0.52	-13.75	-11.93	9.55	-5.33
	Maximum:	3	-0.03	-0.06	-0.06	-1.64	-1.28	2.45	-0.10	-0.12	-0.22	-0.24	-6.60	-5.13	23.33	-2.51
	Standard Deviation:	3	0.01	0.01	0.02	0.41	0.43	0.35	0.02	0.14	0.37	0.41	9.46	6.15	4.89	5.18
	CV:	3	-0.18	-0.18	-0.18	-0.18	-0.23	0.24	-0.16	-0.52	-0.62	-0.63	-0.57	-0.48	0.48	-0.69
	Minimum:	1-3	-0.06	-0.13	-0.14	-3.53	-3.09	0.08	-0.20	-0.63	-1.62	-1.78	-42.23	-29.30	0.14	-21.89
	Average:	1-3	-0.03	-0.08	-0.08	-2.12	-1.74	1.38	-0.12	-0.24	-0.54	-0.59	-15.02	-11.77	9.34	-7.02
	Median:	1-3	-0.04	-0.08	-0.08	-2.14	-1.72	1.36	-0.13	-0.21	-0.45	-0.48	-12.82	-11.34	9.01	-4.84
	Maximum:	1-3	0.00	0.00	0.00	-0.12	-0.10	2.45	-0.01	0.00	-0.01	-0.01	-0.20	-0.19	23.33	-1.22
	Standard Deviation:	1-3	0.01	0.02	0.02	0.63	0.58	0.46	0.04	0.14	0.38	0.42	9.79	6.54	5.21	5.08
	CV:	1-3	-0.29	-0.29	-0.29	-0.30	-0.33	0.34	-0.29	-0.59	-0.69	-0.71	-0.65	-0.56	0.56	-0.72

Table 1.5.3

			Input parameters						Relative fmsy		Implied fratio		Implied ara	
FMP	Stock	Tier	cv(m)	cv(p)	cv(r)	rspr	fmsy	v	Initial	Final	ara1	fratio1	fratio2	ara2
BSAI	BS walleye pollock	1	0.63	0.05	0.64	0.28	0.32	0.26	-0.25	0.10	0.40	0.78	0.83	0.26
BSAI	BSAI yellowfin sole	1	0.18	0.10	0.56	0.34	0.13	0.11	-0.15	0.10	0.40	0.82	0.92	0.11
BSAI	BSAI northern rock sole	1	0.10	0.10	0.62	0.30	0.19	0.14	-0.36	0.10	0.40	0.79	0.99	0.00
Both	BSAI/GOA sablefish	3	0.14	0.10	0.89	0.35	0.12	0.10	-0.29	0.10	0.40	0.80	0.84	0.27
BSAI	AI walleye pollock	3	0.36	0.10	0.59	0.35	0.20	0.19	0.67	0.10	0.40	0.71	0.81	0.18
BSAI	BSAI Pacific cod	3	0.32	0.05	0.75	0.35	0.28	0.29	-0.58	0.10	0.40	0.77	0.82	0.25
BSAI	BSAI Greenland turbot	3	0.73	0.10	1.19	0.35	0.13	0.11	1.43	0.10	0.40	0.70	0.81	0.16
BSAI	BSAI arrowtooth flounder	3	0.14	0.10	0.48	0.35	0.24	0.24	-0.11	0.10	0.40	0.78	0.80	0.33
BSAI	BSAI flathead sole	3	0.24	0.10	0.47	0.35	0.19	0.18	-0.26	0.10	0.40	0.78	0.82	0.27
BSAI	BSAI Alaska plaice	3	0.15	0.10	0.63	0.35	0.23	0.22	4.78	0.10	0.40	0.73	0.72	0.43
BSAI	BSAI Pacific ocean perch	3	0.84	0.05	0.57	0.35	0.07	0.06	-0.16	0.10	0.40	0.89	0.84	0.74
BSAI	BSAI northern rockfish	3	0.84	0.10	0.65	0.35	0.05	0.04	0.10	0.10	0.40	0.91	0.84	0.94
BSAI	AI blackspotted and rougheye rockfish	3	0.75	0.10	0.90	0.35	0.04	0.03	0.32	0.10	0.40	0.93	0.83	1.31
BSAI	BSAI Atka mackerel	3	0.40	0.05	0.67	0.35	0.26	0.26	1.19	0.10	0.40	0.80	0.81	0.36
BSAI	BSAI Alaska skate	3	0.10	0.10	0.19	0.35	0.14	0.12	-1.10	0.10	0.40	0.89	0.87	0.48
GOA	GOA walleye pollock	3	0.20	0.05	1.17	0.35	0.26	0.26	-0.25	0.10	0.40	0.78	0.86	0.18
GOA	GOA Pacific cod	3	0.38	0.05	0.92	0.35	0.30	0.32	1.34	0.10	0.40	0.79	0.81	0.34
GOA	GOA Dover sole	3	0.36	0.10	0.47	0.35	0.10	0.08	1.83	0.10	0.40	0.85	0.78	0.75
GOA	GOA arrowtooth flounder	3	0.31	0.10	0.38	0.35	0.19	0.18	-0.26	0.10	0.40	0.78	0.84	0.24
GOA	GOA flathead sole	3	0.27	0.10	0.33	0.35	0.19	0.18	2.72	0.10	0.40	0.80	0.78	0.48
GOA	GOA Pacific ocean perch	3	0.88	0.10	0.77	0.35	0.07	0.06	-0.13	0.10	0.40	0.84	0.84	0.40
GOA	GOA northern rockfish	3	0.84	0.10	0.63	0.35	0.07	0.06	0.05	0.10	0.40	0.86	0.84	0.49
GOA	GOA rougheye and blackspotted rockfish	3	0.89	0.10	0.52	0.35	0.04	0.03	0.34	0.10	0.40	0.94	0.83	1.56
GOA	GOA dusky rockfish	3	0.54	0.10	0.86	0.35	0.08	0.07	0.69	0.10	0.40	0.83	0.81	0.49
	Minimum:	1	0.10	0.05	0.56	0.28	0.13	0.11	-0.36	0.10	0.40	0.78	0.83	0.00
	Average:	1	0.30	0.08	0.61	0.31	0.21	0.17	-0.26	0.10	0.40	0.80	0.91	0.12
	Median:	1	0.18	0.10	0.62	0.30	0.19	0.14	-0.25	0.10	0.40	0.79	0.92	0.11
	Maximum:	1	0.63	0.10	0.64	0.34	0.32	0.26	-0.15	0.10	0.40	0.82	0.99	0.26
	Standard Deviation:	1	0.29	0.03	0.04	0.03	0.10	0.08	0.10	0.00	0.00	0.02	0.08	0.13
	CV:	1	0.94	0.35	0.07	0.10	0.45	0.47	-0.41	0.00	0.00	0.02	0.09	1.02
	Minimum:	3	0.10	0.05	0.19	0.35	0.04	0.03	-1.10	0.10	0.40	0.70	0.72	0.16
	Average:	3	0.46	0.09	0.67	0.35	0.16	0.15	0.59	0.10	0.40	0.82	0.82	0.51
	Median:	3	0.36	0.10	0.63	0.35	0.14	0.12	0.10	0.10	0.40	0.80	0.82	0.40
	Maximum:	3	0.89	0.10	1.19	0.35	0.30	0.32	4.78	0.10	0.40	0.94	0.87	1.56
	Standard Deviation:	3	0.28	0.02	0.26	0.00	0.09	0.09	1.32	0.00	0.00	0.07	0.03	0.37
	CV:	3	0.62	0.25	0.39	0.00	0.55	0.63	2.25	0.00	0.00	0.08	0.04	0.73
	Minimum:	1-3	0.10	0.05	0.19	0.28	0.04	0.03	-1.10	0.10	0.40	0.70	0.72	0.00
	Average:	1-3	0.44	0.09	0.66	0.34	0.16	0.15	0.48	0.10	0.40	0.81	0.83	0.46
	Median:	1-3	0.36	0.10	0.63	0.35	0.16	0.13	-0.03	0.10	0.40	0.80	0.83	0.35
	Maximum:	1-3	0.89	0.10	1.19	0.35	0.32	0.32	4.78	0.10	0.40	0.94	0.99	1.56
	Standard Deviation:	1-3	0.28	0.02	0.24	0.02	0.09	0.09	1.26	0.00	0.00	0.06	0.05	0.37
	CV:	1-3	0.64	0.25	0.37	0.05	0.54	0.60	2.62	0.00	0.00	0.08	0.06	0.80

Table 5.3 (continued)

Table 1.5.3 (continued)

			Elasticities of implied fratio							Elasticities of implied ara						
FMP	Stock	Tier	cv(m)	cv(p)	cv(r)	rspr	fmsy	v	fratio	cv(m)	cv(p)	cv(r)	rspr	fmsy	v	fratio
BSAI	BS walleye pollock	1	-0.04	-0.08	-0.08	-1.97	-2.17	1.60	-0.11	-0.22	-0.44	-0.47	-11.60	-12.80	9.43	-5.66
BSAI	BSAI yellowfin sole	1	-0.02	-0.04	-0.04	-1.01	-0.80	0.63	-0.06	-0.10	-0.18	-0.19	-5.34	-4.25	3.33	-4.74
BSAI	BSAI northern rock sole	1	0.00	0.00	0.00	-0.12	-0.11	0.08	-0.01	-0.01	-0.01	-0.01	-0.25	-0.23	0.18	-1.52
Both	BSAI/GOA sablefish	3	-0.03	-0.07	-0.08	-2.06	-1.57	1.24	-0.12	-0.20	-0.42	-0.44	-11.99	-9.19	7.24	-5.64
BSAI	AI walleye pollock	3	-0.04	-0.09	-0.09	-2.44	-2.07	1.63	-0.13	-0.16	-0.31	-0.33	-9.24	-7.87	6.21	-3.54
BSAI	BSAI Pacific cod	3	-0.04	-0.08	-0.09	-2.32	-2.18	1.77	-0.13	-0.21	-0.42	-0.45	-12.11	-11.45	9.27	-5.03
BSAI	BSAI Greenland turbot	3	-0.04	-0.09	-0.09	-2.44	-1.89	1.49	-0.13	-0.14	-0.28	-0.30	-8.25	-6.42	5.06	-3.13
BSAI	BSAI arrowtooth flounder	3	-0.04	-0.09	-0.10	-2.57	-2.30	1.83	-0.14	-0.25	-0.53	-0.57	-15.17	-13.56	10.83	-5.81
BSAI	BSAI flathead sole	3	-0.04	-0.08	-0.09	-2.32	-1.93	1.53	-0.13	-0.22	-0.44	-0.47	-12.76	-10.69	8.45	-5.33
BSAI	BSAI Alaska plaice	3	-0.06	-0.13	-0.14	-3.60	-3.15	2.50	-0.20	-0.32	-0.70	-0.75	-19.66	-17.21	13.64	-5.50
BSAI	BSAI Pacific ocean perch	3	-0.03	-0.07	-0.08	-2.06	-1.50	1.19	-0.12	-0.47	-1.09	-1.18	-29.65	-21.44	16.98	-15.23
BSAI	BSAI northern rockfish	3	-0.03	-0.07	-0.08	-2.06	-1.46	1.16	-0.13	-0.54	-1.29	-1.41	-34.69	-24.41	19.41	-18.21
BSAI	AI blackspotted and rougheye rockfish	3	-0.04	-0.08	-0.08	-2.19	-1.53	1.22	-0.14	-0.68	-1.70	-1.86	-44.64	-30.95	24.65	-22.76
BSAI	BSAI Atka mackerel	3	-0.04	-0.09	-0.09	-2.44	-2.22	1.79	-0.13	-0.27	-0.58	-0.62	-16.43	-14.91	12.04	-6.66
BSAI	BSAI Alaska skate	3	-0.03	-0.06	-0.06	-1.67	-1.31	1.03	-0.10	-0.33	-0.72	-0.78	-20.18	-15.75	12.40	-12.27
GOA	GOA walleye pollock	3	-0.03	-0.06	-0.07	-1.80	-1.63	1.32	-0.10	-0.15	-0.29	-0.31	-8.65	-7.89	6.37	-4.50
GOA	GOA Pacific cod	3	-0.04	-0.09	-0.09	-2.44	-2.36	1.95	-0.14	-0.26	-0.55	-0.59	-15.60	-15.07	12.44	-6.30
GOA	GOA Dover sole	3	-0.05	-0.10	-0.11	-2.83	-2.11	1.67	-0.16	-0.48	-1.12	-1.22	-30.52	-22.62	17.86	-11.41
GOA	GOA arrowtooth flounder	3	-0.03	-0.07	-0.08	-2.06	-1.72	1.36	-0.11	-0.19	-0.39	-0.42	-11.37	-9.54	7.54	-5.29
GOA	GOA flathead sole	3	-0.05	-0.10	-0.11	-2.83	-2.36	1.87	-0.16	-0.35	-0.76	-0.82	-21.39	-17.84	14.10	-7.68
GOA	GOA Pacific ocean perch	3	-0.03	-0.07	-0.08	-2.06	-1.50	1.19	-0.12	-0.29	-0.61	-0.65	-17.19	-12.50	9.90	-8.35
GOA	GOA northern rockfish	3	-0.03	-0.07	-0.08	-2.06	-1.49	1.18	-0.12	-0.33	-0.73	-0.79	-20.40	-14.78	11.71	-10.09
GOA	GOA rougheye and blackspotted rockfish	3	-0.04	-0.08	-0.08	-2.19	-1.54	1.23	-0.14	-0.79	-2.03	-2.23	-52.79	-36.62	29.16	-27.37
GOA	GOA dusky rockfish	3	-0.04	-0.09	-0.09											
	Minimum:	1	-0.04	-0.08	-0.08	-1.97	-2.17	0.08	-0.11	-0.22	-0.44	-0.47	-11.60	-12.80	0.18	-5.66
	Average:	1	-0.02	-0.04	-0.04	-1.04	-1.03	0.77	-0.06	-0.11	-0.21	-0.22	-5.73	-5.76	4.31	-3.97
	Median:	1	-0.02	-0.04	-0.04	-1.01	-0.80	0.63	-0.06	-0.10	-0.18	-0.19	-5.34	-4.25	3.33	-4.74
	Maximum:	1	0.00	0.00	0.00	-0.12	-0.11	1.60	-0.01	-0.01	-0.01	-0.01	-0.25	-0.23	9.43	-1.52
	Standard Deviation:	1	0.02	0.04	0.04	0.93	1.05	0.77	0.05	0.11	0.22	0.23	5.68	6.42	4.71	2.17
	CV:	1	-0.93	-0.93	-0.93	-0.90	-1.02	1.00	-0.89	-1.00	-1.04	-1.05	-0.99	-1.11	1.09	-0.55
	Minimum:	3	-0.06	-0.13	-0.14	-3.60	-3.15	1.03	-0.20	-0.79	-2.03	-2.23	-52.79	-36.62	5.06	-27.37
	Average:	3	-0.04	-0.08	-0.09	-2.32	-1.89	1.51	-0.13	-0.33	-0.75	-0.81	-20.63	-16.04	12.76	-9.50
	Median:	3	-0.04	-0.08	-0.09	-2.25	-1.80	1.42	-0.13	-0.28	-0.59	-0.64	-16.81	-14.85	11.88	-6.48
	Maximum:	3	-0.03	-0.06	-0.06	-1.67	-1.31	2.50	-0.10	-0.14	-0.28	-0.30	-8.25	-6.42	29.16	-3.13
	Standard Deviation:	3	0.01	0.01	0.02	0.42	0.45	0.37	0.02	0.18	0.47	0.52	12.13	7.88	6.27	6.65
	CV:	3	-0.18	-0.18	-0.18	-0.18	-0.24	0.24	-0.17	-0.53	-0.64	-0.65	-0.59	-0.49	0.49	-0.70
	Minimum:	1-3	-0.06	-0.13	-0.14	-3.60	-3.15	0.08	-0.20	-0.79	-2.03	-2.23	-52.79	-36.62	0.18	-27.37
	Average:	1-3	-0.04	-0.08	-0.08	-2.15	-1.78	1.41	-0.12	-0.30	-0.68	-0.73	-18.69	-14.70	11.66	-8.78
	Median:	1-3	-0.04	-0.08	-0.08	-2.19	-1.72	1.36	-0.13	-0.26	-0.55	-0.59	-15.60	-13.56	10.83	-5.81
	Maximum:	1-3	0.00	0.00	0.00	-0.12	-0.11	2.50	-0.01	-0.01	-0.01	-0.01	-0.25	-0.23	29.16	-1.52
	Standard Deviation:	1-3	0.01	0.02	0.02	0.66	0.61	0.48	0.04	0.18	0.48	0.53	12.50	8.36	6.66	6.50
	CV:	1-3	-0.29	-0.29	-0.29	-0.30	-0.34	0.34	-0.29	-0.61	-0.71	-0.73	-0.67	-0.57	0.57	-0.74

Table 5.4

Tier	Statistic	Actual fratio	Implied ara	Assumed ara	Implied fratio
1	Minimum:	0.83	0.00	0.40	0.78
1	Average:	0.91	0.12	0.40	0.80
1	Median:	0.92	0.11	0.40	0.79
1	Maximum:	0.99	0.26	0.40	0.82
1	Standard Dev:	0.08	0.13	0.00	0.02
1	CV:	0.09	1.02	0.00	0.02
3	Minimum:	0.72	0.16	0.40	0.70
3	Average:	0.82	0.51	0.40	0.82
3	Median:	0.82	0.40	0.40	0.80
3	Maximum:	0.87	1.56	0.40	0.94
3	Standard Dev:	0.03	0.37	0.00	0.07
3	CV:	0.04	0.73	0.00	0.08
1-3	Minimum:	0.72	0.00	0.40	0.70
1-3	Average:	0.83	0.46	0.40	0.81
1-3	Median:	0.83	0.35	0.40	0.80
1-3	Maximum:	0.99	1.56	0.40	0.94
1-3	Standard Dev:	0.05	0.37	0.00	0.06
1-3	CV:	0.06	0.80	0.00	0.08

6. Conclusions and recommendations

The management of groundfish in the North Pacific Fishery Management Council framework already has catch limits in place. These catch limits, depending on tier, incorporate uncertainty in different ways and are not necessarily based on the uncertainty of the data. The tier system is often based more on the quantity of the data available rather than the precision of the data. In general this system may already be largely compliant with the new regulations, since the amount of data is usually related to the level of uncertainty about stock status. Nevertheless, the current surely can be improved. This document presents several examples of potential ways to account more explicitly for uncertainty in the buffer between ACL (ABC) and OFL. The $P*$ approach is relatively simple, but does not account for all potential sources of uncertainty. The decision-theoretic approach has the capability of incorporating more sources of uncertainty and clearly defines risk, but also is more difficult to implement. These analyses are just several potential options among a myriad of choices to improve the formulation of a buffer. Perhaps the greatest challenge in implementing a procedure that is both consistent and quantitative, is formulating a method that can be used from the most data-rich stocks to the most data-poor stocks. None of these methods does this flawlessly, but could be adapted to include data-poor stocks within their frameworks. We recommend that further analyses be conducted to explore the properties of potential future changes to catch limits and targets through simulation. We also believe managers should consider what is an acceptable probability of overfishing or appropriate level of risk aversion?

AGENDA D-2(a)(6)
OCTOBER 2009

DRAFT ACTION PLAN FOR ANNUAL CATCH LIMIT AMENDMENTS TO THE GROUNDFISH FMPS OF THE BERING SEA/ALEUTIAN ISLANDS AND GULF OF ALASKA

June 17, 2009

PROPOSED ACTION Amend the Groundfish FMPs of Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) to comply with the Magnuson-Stevens Reauthorization Act (MSRA).

PROBLEM STATEMENT/OBJECTIVE On January 16, 2009, NMFS issued final guidelines for National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act (MSA). They provide guidance on how to comply with new annual catch limit (ACL) and accountability measure (AM) requirements for ending overfishing of fisheries managed by federal fishery management plans (FMPs). Annual catch limits are amounts of fish allowed to be caught in a year. A legal review of the groundfish FMPs found there were inadequacies in the FMP texts that need to be addressed. Several work groups (e.g., ABC/ACT Control Rules, Vulnerability Evaluations) have been created to produce reports on how to carry out the more technical components of the guidelines. Statutory deadlines require compliance with the MSA by the start of the 2011 fisheries although these reports have not been finalized.

This action is necessary to facilitate compliance with requirements of the MSA to end and prevent overfishing, rebuild overfished stocks, and achieve optimum yield.

ANALYSIS An EA for one amendment to the BSAI and GOA Groundfish FMPs is required; categorical exclusions are planned for six housekeeping amendments.[1]

RANGE OF ALTERNATIVES[2]

Alternative 1: Status Quo. The Groundfish FMPs remain unchanged.

Alternative 2: Action Alternative. Revise the BSAI and GOA Groundfish FMPs to meet the National Standard 1 guideline requirements for annual catch limits.

Action 1: Identify Stocks in the Fishery

Option 1: Status quo. Target species, other species, prohibited species, forage fish, and nonspecified species are in the fishery. [*Annual catch limits required for all stocks*].

Option 2: Target species and other species are in the fishery; forage fish and prohibited species are under an Ecosystem Component category; nonspecified species are removed from the FMPs. [*Annual catch limits and accountability measures required for target and other species. Other management measures apply to target, forage fish, and prohibited species. No management of nonspecified species.*]

Rejected options:

Option 3: Target species and other species are in the fishery. [*Forage fish, prohibited species, and nonspecified species would be removed from the FMPs. Annual catch limits and accountability measures required for target and other species.*]

Option 4: Target species and other species are in the fishery; forage fish, prohibited species, and nonspecified species are under an Ecosystem Component category. [*Annual catch limits and accountability measures required for target and other species. Other management measures apply to target, forage fish, and prohibited species and may apply to nonspecified species.*]

Prepared by Jane DiCosimo

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[1] Federal regulations are not required to be revised therefore an RIR/IRFA is not required.

[2] The Council may revise these alternatives during its review of the draft analysis.

Action 2: Housekeeping: Amend the FMP text to explain current practices.

These include adding text to the FMPs to describe:

- Specification of Minimum Stock Size Thresholds (MSSTS). This description is currently incorporated into the annual Stock Assessment and Fishery Evaluation (SAFE) reports.
- Measures that are taken if and when a stock drops below MSST. This is an ongoing evaluation and a management response will occur when needed.
- Accountability measures that are triggered if an ACL (ABC) is exceeded; reference the current in-season management system which has a more timely response than what would occur in the following year.
- Ecological factors that are considered by the Council in reducing Optimum Yield from Maximum Sustainable Yield.
- How the tier levels for Acceptable Biological Catch and Overfishing Level (OFL) are based on the scientific knowledge about the stock/complex and the scientific uncertainty in the estimate of OFL and any other scientific uncertainty.
- How the stock assessments account for all catch

APPLICABLE LAWS NEPA, MSA

STAFF RESOURCES

NPFMC	Jane DiCosimo
NOAA AKR	Sue Salveson, Melanie Brown
NOAA AFSC	Dr. Grant Thompson, Dr. Anne Hollowed, Dr. Paul Spencer, Dr. Olav Ormseth
NOAA Habitat	No habitat implications
NOAA PR	Kaja Brix
NOAA GCAK	Clayton Jernigan
HQ	Galen Tromble, Rick Methot, Mark Milliken, Mark Nelson

MAJOR ISSUES

- The Council and NMFS have placed this amendment (along with Crab FMP amendment) among its highest priorities for action. Statutory deadline of January 1, 2011 for implementation of ACL/AM requirements for groundfish requires final action no later than April 2010.

- NMFS identified that no changes to federal regulations will result from the proposed action, therefore, a Regulatory Impact Review (RIR) and Regulatory Flexibility Analyses (IRFA/FRFA) is not required

- Improvements to uncertainty calculations and management of vulnerable species beyond meeting legal requirements (i.e., non-specified species) will require separate trailing plan amendments.

- The Council (Non-Target Species Committee) will reevaluate its previous tasking priorities for revising management of (1) BSAI skates (scheduled for October 2009 final action), (2) BSAI/GOA squids (scheduled for December 2009 final action, (3) BSAI/GOA sharks and sculpins (scheduled for February 2010 final action), (4) BSAI/GOA octopods (not scheduled), and (5) BSAI/GOA grenadiers (not scheduled). The committee will meet on September 15, 2009.

- The Groundfish Plan Teams will review/comment on technical analyses and proposed actions at their 2009 meetings.

TIMELINE TO IMPLEMENTATION[3]

January 2009	*NMFS HQ issues final guidelines for National Standard 1.*
April 2009	*NMFS HQ issues draft working group reports (e.g., ABC/ACT Control Rules, Vulnerability Evaluations) on how to carry out the technical components of the guidelines.*
April/May	*Interagency staffs meet numerous times to coordinate NPFMC response.*
May 2009	*Annual Catch Limit Work Shop at AFSC coordinates SSC and Groundfish Plan Teams response(s).*
June 2009	*Council approves draft action and tasks staff with preparation of analysis*
August 2009	AFSC releases technical analyses on 1) incorporating uncertainty into stock assessments and 2) groundfish vulnerable to overfishing
September 2009	Groundfish Plan Teams reviews draft alternatives and technical analyses on uncertainty and vulnerability
October 2009	AFSC staff presents progress report on technical analyses to SSC
November 2009	Release of initial review draft of EA
November 2009	Groundfish Plan Team review of EA
February 2010	Council conducts final action and selects a preferred alternative; staff submits final EA for NMFS review
March 2010	NMFS publishes 2010/2011 harvest specifications
April 2010	Council staff submits EA to NMFS for Secretarial review; NMFS publishes NOA (and proposed rule if necessary) to implement ACL amendments
September 2010	PTs recommends proposed 2011 and 2012 harvest specifications based on new ACL amendments; SOC approves ACL amendments (any regulations to follow)
October 2010	Council recommends proposed 2011 and 2012 harvest specifications based on new ACL amendments; NMFS publishes final rule implementing ACL amendments, if necessary
November 2010	PTs recommends final 2011 and 2012 harvest specifications
December 2010	Council recommends final 2011 and 2012 harvest specifications
Late 2010	NMFS publishes inseason adjustment to correct mis-specified 2011 harvest specifications that were published March 2010, if needed
January 1, 2011	Revised harvest specifications are in effect

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[3] Timelines for action in 2009 could be delayed by one or more meetings if AFSC vulnerability analysis is not completed by August 1, 2009.

AGENDA D-2(a)(7)
OCTOBER 2009

Alaska groundfish vulnerability analysis

September 3, 2009
Olav A. Ormseth, NOAA/NMFS/AFSC

1) Overview of need and methodology
2) Results and discussion of the vulnerability analysis
3) Implications for stock classification and non-target stocks

Overview

The implementation of new National Standard guidelines published by NOAA Fisheries in 2009 requires the classification of fish stocks in a fishery management plan (FMP). Target stocks, as well as non-target stocks that are caught incidentally in large numbers, are considered to be “in the fishery”. Annual catch limits (ACLs) are required for these stocks. Fishery management councils have the option of designating a second category of less-impacted stocks, “Ecosystem Components” (EC), for which ACLs are not required. However, these stocks are monitored and councils may adopt management measures designed to limit incidental catches of EC stocks.

To aid in the classification of stocks, as well as to provide advice on the formation of stock complexes and other management actions, NOAA Fisheries convened a Vulnerability Evaluation Working Group (VEWG) in 2008. This group was tasked with developing an analytical tool for assessing the vulnerability of stocks in an FMP (the word “vulnerability” appears frequently in the National Standard guidelines). The work of the VEWG is complete and will be published soon as a NOAA Technical Memorandum and in a peer-reviewed journal. A preliminary report and other supporting materials that explain the group’s work in detail can be found at www.nmfs.noaa.gov/msa2007/vulnerability.htm. Here, a brief review of the analysis is provided to aid interpretation of the results for Alaska groundfish.

The analysis developed by the VEWG is based on previous work in Australia and elsewhere. It compares two main features of a fish stock that together influence its vulnerability to fishing: productivity, which determines a population’s natural capacity for growth and its resilience to fishery impacts; and susceptibility, which indicates how severe those fishery impacts are likely to be for the population. Productivity and susceptibility are evaluated by scoring a number of related attributes. For productivity, these are mainly life-history traits such as natural mortality rate and age at maturity; susceptibility attributes include spatial overlap between the stock and the fishery, stock status, etc. The table below lists all attributes evaluated in the productivity-susceptibility analysis (PSA):

productivity attributes	susceptibility attributes
r	management strategy
maximum age	areal overlap
maximum size	geographic concentration
growth rate (*k*)	vertical overlap
natural mortality	fishing rate relative to M
measured fecundity	biomass of spawners (SSB) or other proxies
breeding strategy	seasonal migrations
recruitment pattern	schooling/aggregation and other behaviors
age at maturity	gear selectivity
mean trophic level	survival after capture and release
	desirability/value of the fishery
	fishery impact to habitat

Each attribute is scored with a 1, 2, or 3, indicating low, medium, and high values, respectively. Each attribute score is then weighted according to the analyst's interpretation of the relevance of each attribute. In the Alaska groundfish PSA, all attributes were weighted equally with the exception of recruitment pattern, which was deemed to have an inconsistent relationship to productivity and received a weight half that of the other attributes. The weighted attribute scores are used to calculate mean scores for productivity and susceptibility that are used in two separate ways:

1) The scores are depicted graphically in a scatter plot, with productivity on the x-axis and susceptibility on the y-axis. This provides a strong visual appreciation of differences among stocks. In addition, the x-axis is reversed (i.e. it starts at 3 and ends at 1), so that the area of the plot close to the origin (which is at 3,1) corresponds to high-productivity, low-susceptibility stocks. Such stocks are considered to have low vulnerability. The further a stock is from the origin, the more vulnerable to fishing it is likely to be.
2) Following on (1), the Euclidean, or straight-line, distance from the origin to the stock's datapoint is calculated and used as a measure of the stock's overall vulnerability. The distance is calculated as:

$$\sqrt{(P-3)^2+(S-1)^2}$$

where P = productivity and S = susceptibility.

Each attribute score is also evaluated for the quality of the data used to determine the score. Data quality scores range from 1 to 5 as follows:

1: (Best data) Information is based on established and substantial data
2: (Adequate Data) Information with limited coverage and corroboration
3: (Limited Data) Limited confidence; may be based on similar taxa
4: (Very Limited Data) Expert opinion or based on general literature review
5: (No Data) No information to base score on

The data quality scores are reported in tables and the average data quality scores are depicted graphically (green = data quality <2; yellow = data quality >2 but <3; red = data quality >3).

A separate PSA was conducted for each region, Gulf of Alaska (GOA) and Bering Sea/ Aleutian Islands (BSAI). Stock assessment authors were asked to provide attribute scores for the stocks they are responsible for, and the analyst (Ormseth) used those scores to produce the PSA. One of the difficulties of producing a PSA is that the susceptibility of a stock depends on the gear type under consideration (e.g. a skate is more susceptible to a bottom trawl than a midwater trawl). In this analysis, the attributes were scored according to the fishery and gear type that would have the most impact on the stock- e.g. squids were evaluated relative to midwater trawl gear, where most of the incidental catch occurs.

Results and Discussion

The results of the GOA analysis are presented in Table 1 and Figure 1; the results of the BSAI analysis are presented in Table 2 and Figure 2. The results indicate the following:

1) Productivity varies widely among stocks in both regions, but susceptibility is constrained to moderate values. This is especially true for the BSAI. This is probably due in large part to the fact that all stocks evaluated in each PSA are included in that region's FMP (with the exception of giant grenadier; see below). Thus, a common level of susceptibility among the stocks makes sense.
2) The main target stocks (e.g. pollock and Pacific cod) in each region have the highest susceptibility scores.

3) Data quality is highest for target stocks and lowest for non-target stocks. There is no relationship between data quality and vulnerability.
4) Vulnerability does not appear to depend on whether a stock is targeted or not. In Tables 1 & 2, stocks are listed in order of increasing vulnerability. The target stocks are distributed among the intermediate vulnerability scores in each region, with non-target stocks displaying the lowest and highest scores. This is likely because, although target stocks tend to have higher susceptibility they also have higher productivity.
5) There are no clear divisions among stocks in the PSA, i.e. there appears to be a continuum of vulnerability rather than distinct levels of vulnerability.
6) High vulnerability scores can be a result of low productivity, high susceptibility, or both. For example, in the GOA, pollock and Dover sole have similar vulnerability scores (1.44 and 1.34, respectively) despite the lower productivity of Dover sole.

Implications for stock classification and nontarget management

Ecosystem components

There are no clear divisions among the stocks in their vulnerability scores, and the working group that developed the methodology did not provide any guidance regarding how the vulnerability score of a stock corresponds to the appropriate management measures for that stock (this was done on purpose due to the difficulty of making divisions that would be broadly applicable in different regions). However, considering the vulnerability scores relative to each other and particularly to the scores of target stocks provides some insight into how stocks should be classified.

In the **BSAI** (Figure 2), squid have the lowest vulnerability (0.84) and they have the most distinct vulnerability score. In addition, vulnerability scores for target stocks begin at 1.39 (yellowfin sole). The analyses conducted by the VE WG also suggested that target stocks and nontarget stocks commonly believed to be conservation concerns (e.g. BSAI skates) tended to have vulnerability scores greater than 1. Thus, the PSA for this region suggests that squid may be a candidate for EC classification.

This conclusion is supported by the results for the **GOA**, where squid, capelin, and eulachon form a somewhat distinct, high-productivity group. Eulachon have the highest susceptibility score of this group, as they are the only member of the forage fish category that is regularly caught in the groundfish fisheries. The PSA results suggest that the current management measures used for capelin and eulachon as part of the forage fish classification (i.e. no ACLs) may also be appropriate for squid. Octopus have a vulnerability score almost equivalent to eulachon and so may be considered for EC classification. However, their lower productivity separates them from the squid/forage fish group. This separation is even more pronounced in the BSAI.

In summary, the PSA results demonstrate that squid and forage fishes have relatively low vulnerability to commercial fishing and may be candidates for an EC classification. Octopus also have low vulnerability scores. While some sculpin species have relatively low scores (though still greater than 1), other members of that group have high scores. As a result, sculpins should remain "in the fishery". Skates and sharks have high vulnerability scores and require ACLs.

Giant grenadier

Grenadiers are not listed in the current FMPs but were included in the analysis due to potential conservation concerns. The PSA results suggest that grenadiers should be included as stocks "in the fishery" in the FMPs for both regions. In the GOA, the vulnerability score for giant grenadier is between Pacific cod and Pacific ocean perch (Table 1). In the BSAI, giant grenadier is between Pacific cod and pollock. Thus, management measures (ACLs) appropriate for these target species should also be applied to grenadiers.

A suggestion for management of EC stocks

The National Standard guidelines do not specify what management measures should be applied to EC stocks. While protections are not mandated for EC stocks, neither are they prohibited. In addition, councils are encouraged to apply measures that are consistent with National Standard 9, which deals with the reduction of bycatch. Thus the NPFMC has wide latitude to apply conservation measures to EC stocks that it feels are appropriate, and I suggest the following measures for consideration for EC stocks:

1) Similar to the current practice for forage fishes, directed fishing would be prohibited.
2) Maximum retention allowances (MRAs) would be applied to all EC stocks, but the MRA level could vary among individual stocks.
3) Because they have no ACLs, the potential exists for incidental catches of EC stocks to become excessively high, even if current conditions indicate low vulnerability. For example, catches of squid might increase if the pollock population grows and pollock harvests increase. To prevent this from happening, the council could implement a strict catch monitoring system with consequences if catches exceed a threshold. This threshold (the "allowable incidental catch", AIC) would be based on current methods used to determine overfishing level (OFL) for either Tier 5 or Tier 6 species- i.e. it would be based on either survey biomass or historical catch. If the AIC for a stock were to be exceeded more than once every three years there would be a mandatory review of the stock's status by the Plan Teams and SSC, with the possibility of reclassification of that stock as "in the fishery" if warranted. This approach would ensure that the EC classification does not result in uncontrolled incidental catches of EC stocks.

Implications for stock complexes

While it is not the focus of this report, the PSAs presented here are also useful for considering how and whether stocks are formed into stock complexes. The National Standard guidelines suggest, among other requirements, that stocks in a complex should have similar vulnerability scores. The results for Alaska groundfish demonstrate that the Other Species complex is an inappropriate grouping (members of the complex are on opposite ends of the vulnerability spectrum) and support the NPFMC's move towards breaking the Other Species complex into individual species groups. In addition, there is considerable variability in vulnerability among the sculpins. The NPFMC might consider breaking sculpins into two groups or basing the management of sculpins on the most vulnerable species.

Table 1. Results of the productivity/ susceptibility analysis for the Gulf of Alaska region. Fish stocks are organized in order of increasing vulnerability score. Bold italics indicate target species.

ID #	**stock name**	**productivity**	**susceptibility**	**vulnerability**	**data quality**		
					P	**S**	**average**
1	capelin	2.75	1.50	0.56	2.58	3.27	2.93
2	squid	2.63	1.71	0.81	2.79	3.55	3.17
3	eulachon	2.69	2.00	1.05	2.68	2.36	2.52
4	octopus	2.14	1.63	1.06	2.89	3.82	3.36
5	great sculpin	1.88	1.71	1.33	3.11	3.18	3.14
6	plain sculpin	1.88	1.71	1.33	3.11	3.18	3.14
7	***Dover sole***	***1.71***	***1.36***	***1.34***	***1.63***	***1.64***	***1.63***
8	***rex sole***	***1.87***	***1.73***	***1.35***	***1.32***	***1.64***	***1.48***
9	***pollock***	***2.29***	***2.25***	***1.44***	***1.63***	***2.36***	***2.00***
10	yellow Irish lord	1.75	1.86	1.52	3.11	3.18	3.14
11	***sablefish***	***1.76***	***2.08***	***1.64***	***1.11***	***1.27***	***1.19***
12	bigmouth sculpin	1.50	1.71	1.66	3.11	3.18	3.14
13	***Pacific cod***	***2.00***	***2.42***	***1.73***	***1.53***	***1.45***	***1.49***
14	giant grenadier	1.44	1.79	1.75	2.05	2.00	2.03
15	***Pacific ocean perch***	***1.74***	***2.29***	***1.81***	***1.47***	***1.41***	***1.44***
16	***rougheye rockfish***	***1.30***	***1.68***	***1.83***	***1.95***	***1.68***	***1.81***
17	big skate	1.33	1.90	1.89	1.63	3.00	2.32
18	salmon shark	1.19	1.75	1.96	1.95	3.73	2.84
19	longnose skate	1.22	1.90	1.99	1.53	3.27	2.40
20	spiny dogfish	1.11	1.91	2.10	1.84	3.00	2.42
21	sleeper shark	1.00	2.00	2.24	3.63	3.73	3.68

Table 2. Results of the productivity/ susceptibility analysis for the Bering Sea and Aleutian Islands region. Fish stocks are organized in order of increasing vulnerability score. Bold italics indicate target species.

ID #	stock name	productivity	susceptibility	vulnerability	data quality		
					prod	susc	average
1	squid	2.63	1.75	0.84	2.37	3.55	2.96
2	octopus	2.14	1.63	1.06	2.89	3.82	3.36
3	red Irish lord	2.13	1.71	1.13	2.47	2.91	2.69
4	Alaska plaice	2.12	1.73	1.14	1.74	1.73	1.73
5	threaded sculpin	2.14	1.83	1.20	2.37	3.36	2.87
7	longfin Irish lord	2.00	1.83	1.30	2.37	3.55	2.96
8	great sculpin	1.88	1.71	1.33	1.95	2.91	2.43
9	plain sculpin	1.88	1.71	1.33	1.95	2.91	2.43
10	great sculpin	1.88	1.71	1.33	1.95	2.91	2.43
11	warty sculpin	1.88	1.71	1.33	2.26	2.82	2.54
12	***yellowfin sole***	***1.88***	***1.82***	***1.39***	***1.74***	***1.73***	***1.73***
13	spinyhead sculpin	1.86	1.83	1.41	2.79	3.55	3.17
14	thorny sculpin	1.86	1.83	1.41	3.00	3.55	3.27
15	northern rock sole	1.88	1.91	1.44	1.74	1.73	1.73
16	arrowtooth flounder	1.73	1.73	1.46	2.05	1.73	1.89
17	yellow Irish lord	1.75	1.86	1.52	1.63	2.82	2.22
18	armorhead sculpin	1.71	1.83	1.53	2.68	3.55	3.11
19	***greenland turbot***	***1.65***	***1.75***	***1.55***	***2.42***	***2.55***	***2.48***
20	***Atka mackerel***	***2.12***	***2.33***	***1.60***	***1.95***	***2.00***	***1.97***
21	***sablefish***	***1.76***	***2.08***	***1.64***	***1.63***	***1.27***	***1.45***
22	bigmouth sculpin	1.50	1.71	1.66	1.95	2.91	2.43
23	***pollock (EBS)***	***2.00***	***2.33***	***1.67***	***1.53***	***1.27***	***1.40***
24	giant grenadier	1.47	1.79	1.72	2.00	2.00	2.00
6	***Pacific cod***	***2.00***	***2.42***	***1.73***	***1.53***	***1.45***	***1.49***
25	whitebrow skate	1.39	1.78	1.79	2.89	3.36	3.13
26	butterfly skate	1.39	1.78	1.79	2.89	3.64	3.27
27	roughshoulder skate	1.39	1.88	1.83	3.00	3.64	3.32
28	roughtail skate	1.39	1.89	1.84	2.68	3.36	3.02
29	whiteblotched skate	1.39	1.89	1.84	2.79	3.36	3.08
30	mud skate	1.39	1.89	1.84	2.79	3.36	3.08
31	commander skate	1.39	1.89	1.84	2.89	3.36	3.13
32	Bering skate	1.44	2.00	1.85	1.63	3.00	2.32
33	Alaska skate	1.42	2.00	1.87	1.26	2.18	1.72
34	big skate	1.33	1.89	1.89	1.63	3.55	2.59
35	deepsea skate	1.33	1.89	1.89	2.89	3.55	3.22
36	Aleutian skate	1.33	1.90	1.89	1.53	3.09	2.31
37	salmon shark	1.19	1.75	1.96	3.21	3.73	3.47
38	longnose skate	1.22	1.88	1.98	1.53	3.82	2.67
39	spiny dogfish	1.11	1.91	2.10	1.84	3.00	2.42
40	***rougheye rockfish (AI)***	***1.20***	***2.21***	***2.17***	***2.68***	***2.09***	***2.39***
41	sleeper shark	1.00	2.00	2.24	3.63	3.73	3.68

Figure 1
Results of the PSA analysis for the Gulf of Alaska region. Colors and symbol shapes indicate data quality scores. Numbers indicate stocks listed in Table 1. For clarity, not all stocks are labeled.

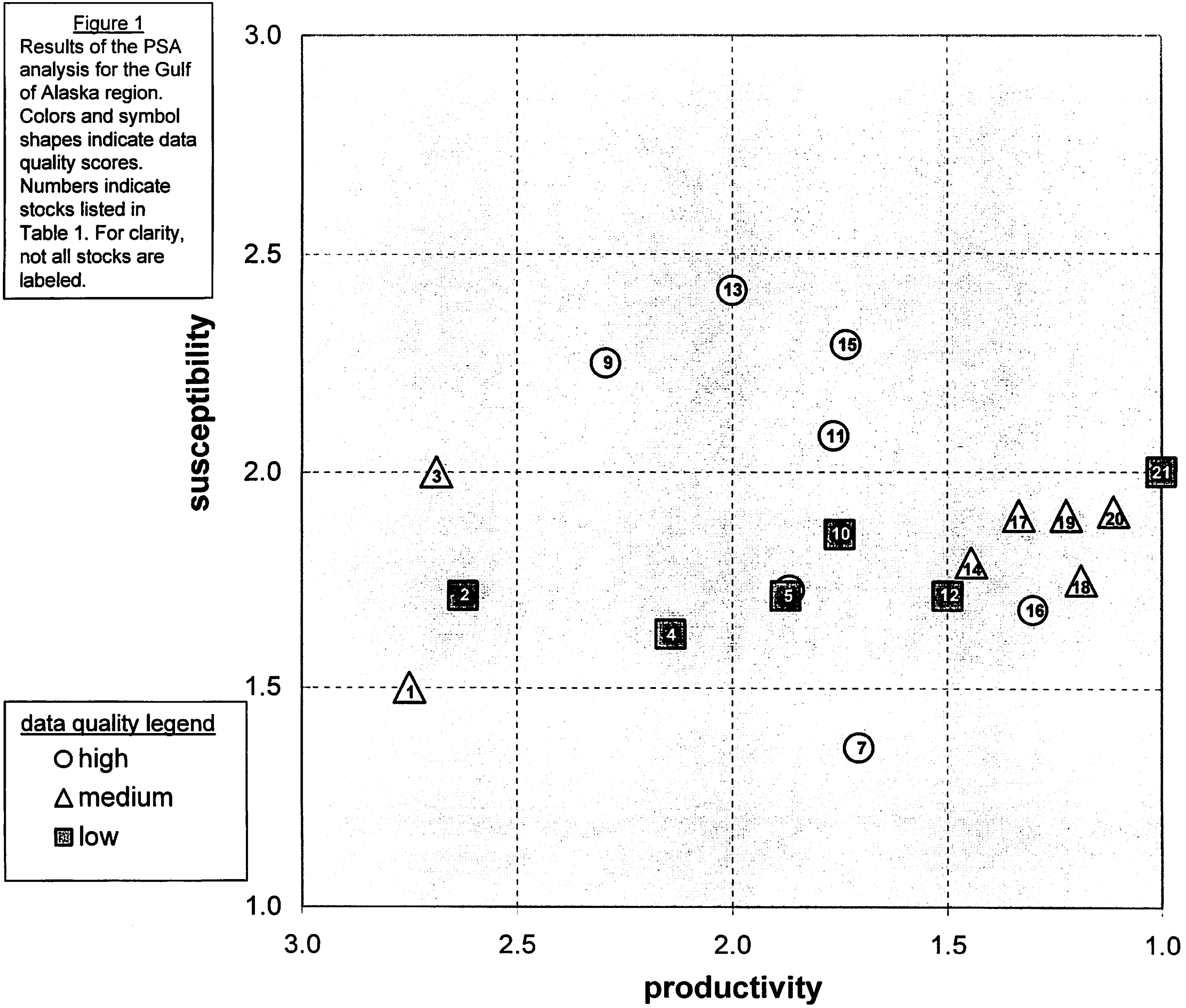
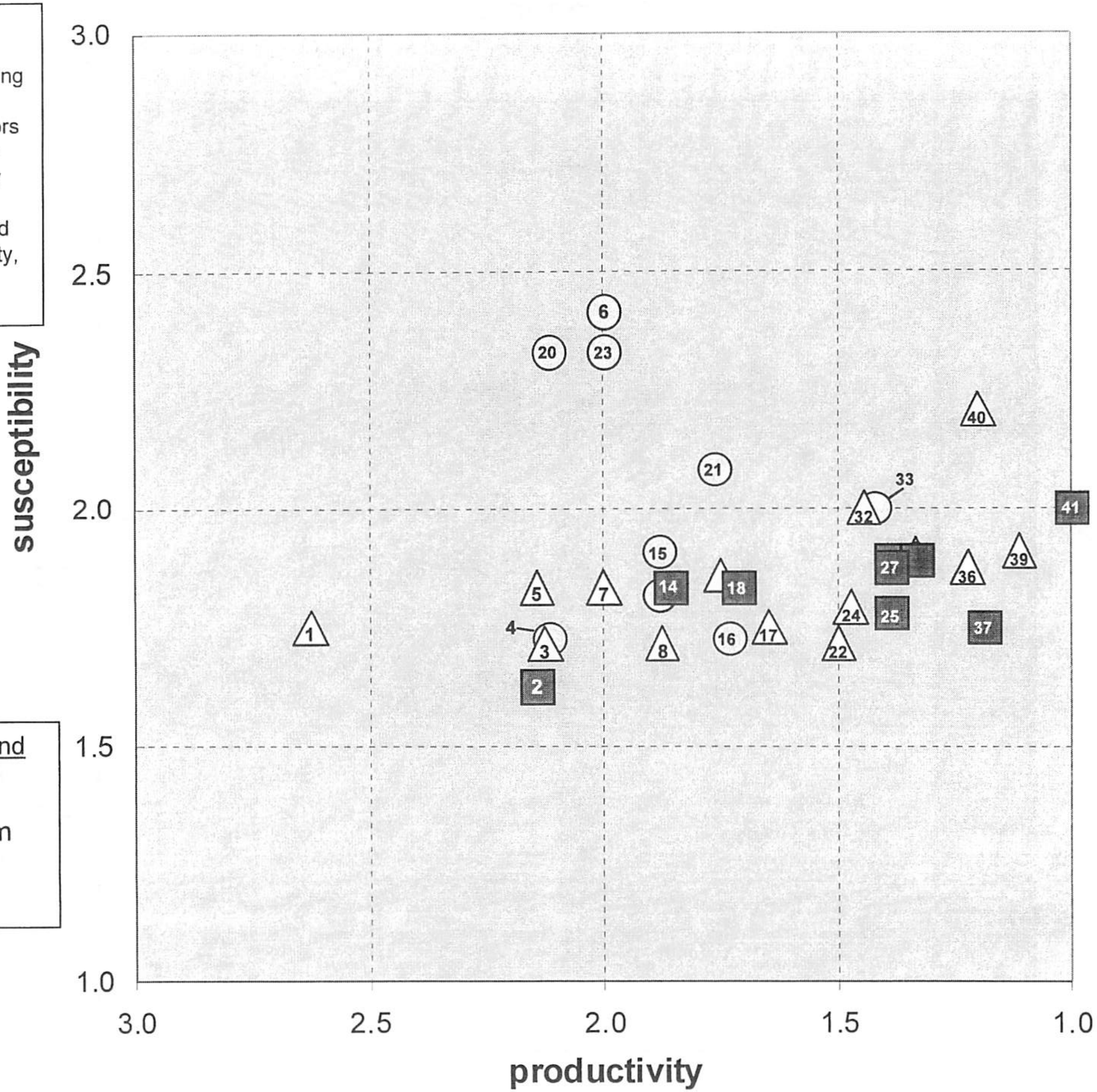


Figure 2
Results of the PSA analysis for the Bering Sea and Aleutian Islands region. Colors and symbol shapes indicate data quality scores. Numbers indicate stocks listed in Table 1. For clarity, not all stocks are labeled.



DRAFT

Non-Target Species Committee

September 15, 2009

Members in attendance: Dave Benson, Dr Paul Spencer, John Gauvin, Julie Bonney, Janet Smoker, Lori Swanson, Karl Haflinger

Members by phone: Ken Goldman, Jon Warrenchuk

Members absent: Michelle Ridgway, Simon Kineen

Committee staff: Jane DiCosimo, Dr Olav Ormseth.

Scientific and Statistics Committee: Anne Hollowed

Plan Team: Dr Loh-lee Low, Dr Grant Thompson, Dr Jon Heifetz, Cleo Brylinsky, Mary Furuness, Tom Pearson

Agency staff: Sue Salveson, Melanie Brown, John Olson, Liz Conners, Phil Rigby, Chris Lunsford, Cindy Tribuzio, Cara Rodgveller, Dave Clausen, Jennifer Mondragon, Craig Faunce, Clayton Jernigan

Public: Ed Richardson.

Agenda The Non-Target Species Committee convened at 8:30 am (PST) on September 15, 2009. The committee adopted the draft agenda, which included reviewing 1) two AFSC reports on managements issues related to conforming to new annual catch limit (ACLs) requirements, 2) BSAI Skate ACL analysis, and 3) Council actions plans for BSAI and GOA Groundfish FMP amendments to a) set ACLs to conform to revised National Standard 1 guidelines and b) set ACLs for i) squid, ii) octopus, iii) sharks, iv) sculpins, and v) grenadier.

Review ACL action plan. This agenda item was scheduled so that the committee could revise the draft ACL action plan, which broadly defined the alternatives for analysis as of June 2009, based on new information provided in the "vulnerability analysis." At the request of the committee, Jane DiCosimo reviewed the status of the draft ACL action plan that was redrafted based on direction by the Council in June 2009. The June 2009 action plan proposed that the Council would consider identifying which groundfish stocks 1) are "in the fishery" (e.g., some or all of the groups now listed under "other species") 2) could be moved into the ecosystem component (EC) category (e.g., forage fish category and prohibited species category), and/or 3) should be moved outside of the FMPs (e.g., non-specified species category). The proposed approach would eliminate the "other species" complex from the FMPs and set separate ACLs for those stocks "in the fishery." Such an approach would mitigate the need for separate FMP amendments to set separate ACLs for squid, octopus, sharks, and sculpins.

The current action plan does not address grenadiers in order to streamline the proposed action. A separate FMP amendment to move grenadiers from the non-specified category into the fishery or into the ecosystem component category likely would require a complementary regulatory impact review/initial regulatory flexibility analysis to implement management measures (e.g., maximum retainable allowances) for grenadiers would still be scheduled for final action; the Council could prioritize the grenadier action to follow the ACL action. The AFSC prepared a report to advise the Council on which non-target stocks could be considered for management under the EC category, which is the subject of a later agenda item (vulnerability analysis).

Julie Bonney asked a number of questions about the process for amending the groundfish FMPs to conform to revised NS1 guidelines and why it is necessary to move away from the currently approved approach of moving one group (e.g., octopus) at a time from the other species complex. Jane responded that the Congressional deadline required action for defining which stocks are "in the fishery" and setting appropriate ACLs for them by January 1, 2011; this timeline necessitates the Council to streamline the analysis so that the Council takes final action no later than April 2010 so that NMFS can approve and implement the amendment by the deadline. Additional discussion on timing and content of the proposed groundfish ACL amendments is also addressed under committee discussion of the vulnerability analysis.

Uncertainty in groundfish stock assessments. This agenda item was information purposes only; no action was required. The purpose of AFSC report was to determine whether the groundfish SAFE Reports adequately incorporate uncertainty to meet new ACL requirements. The FMPs require a "housekeeping" amendment to revise the FMP texts to document the current buffers between OFL and ABC in the Tier system. Incorporation of uncertainty was investigated for Tier 1 and Tier 3 for groundfish target stocks because the buffer is proscribed as 25 percent under Tier 5 and Tier 6 (most non-target stocks)[1]; therefore there are no impacts on non-target species. The paper was presented to the committee under the context of reviewing potential ACL amendments. Dr Grant Thompson summarized the uncertainty paper for groundfish and responded to questions. Pending concurrence from the Groundfish Plan Teams and SSC, the paper suggests that the current ACL process adequately incorporates uncertainty. Methods are proposed to enhance incorporation of uncertainty. The committee accepted this as an informational report and had no recommendations.

Groundfish vulnerability analysis The AFSC initiated an analysis of productivity/susceptibility (PSA) of component species in the "other species" complex and selected example target stocks to assist in the identification of alternatives for moving species and/or species groups into the EC category. Dr Olav Ormseth summarized the results of the PSA. John Gauvin asked about the methodology used to estimate susceptibility. Olav confirmed that the PSA used the fishery and gear type that would have the most impact on the stock to determine a conservative susceptibility ranking. He reported that a separate PSA could be estimated for each fishery and gear type and be weighted appropriately. The PSA suggests that capelin, squid, eulachon, and octopus in the GOA and squid and octopus in the BSAI have low susceptibility and high productivity and could be considered for management under the EC category. The PSA included grenadiers because a June 2008 Council action identified grenadiers as a candidate to be moved under ACL management, after action on the other species groups was final. The PSA suggested that grenadiers should be managed "in the fishery" using ACLs, but the Council may consider additional information for its decision.

Olav stressed that the PSA should not be the only measure for moving stocks into the EC category. In addition to vulnerability rankings, the committee noted that four criteria also must be met to move stocks into the EC category. To be considered for possible EC classification, species should, among other considerations conform to the following criteria; these criteria, otherwise could eliminate some groups from further consideration as EC stocks.

- Be a non-target species or non-target stock;
- Not be determined to be subject to overfishing, approaching overfished, or overfished;
- Not be likely to become subject to overfishing or overfished, according to the best available information, in the absence of conservation and management measures; and
- Not generally be retained for sale or personal use.

John Warrenchuk commented that some species, particularly prey species, may be susceptible to surpassing a management threshold of concern that occurs well before a stock exceeds its overfishing level. He suggested that the committee could recommend an additional vulnerability analysis that ranks the susceptibility of non-target species to management thresholds other than overfishing. One example is prey requirements for endangered species. In this way, a new analysis would rank the susceptibility of species whose removals beyond a certain threshold could cause cross wise issues of marine mammal prey requirements.

The committee recommended that future revisions to the PSA include the following: 1) include separate selectivities for each fishery and gear group; 2) expand the analysis to include all target stocks; 3) graph all stocks; and 4) label the graphs appropriately.

The PSA also included suggestions for management options that are outside of the Council's current suite of alternative for analysis. Staffs from the Council, NOAA, and NMFS noted that NS1 guidance appears unclear on whether 1) prohibited species could be managed under the EC category and 2) the other species complex (in its entirety) could be managed "in the fishery" under a single ACL. Jane suggested

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[1] There are no Tier 2 or Tier 4 groundfish stocks.

that the other species complex did not conform to the definition of a stock complex in the guidelines ("sufficiently similar in geographic distribution, life history, and vulnerabilities to the fishery"). Breaking the other species complex into its component groups was identified as an interim approach in 2008, while the Council awaited publication of the NS1 guidelines. She interpreted the term "other species" in the ACL action plan to include the component other species groups until the PSA would provide a scientific basis for the Council to decide whether to manage the squid, octopus, sharks, and sculpins in the fishery or under the EC category. Some committee members interpreted the action plan to fix the analysis at the other species complex level. Jane reiterated that setting one ACL for the other species complex is the status quo and would not conform to the definition of a management stock in the revised guidelines.

Karl Haflinger expressed concern in accepting the susceptibility scores as presented. He supported the Council's current approach for separating each group sequentially from the other species assemblage. Julie Bonney also spoke in favor of that approach.

Jane DiCosimo described that the Council's intent to streamline the analysis implied proceeding with an FMP amendment (EA only) and to not proceed with an analysis of potential complementary management measures that may be needed for EC species in the same amendment package because of the need to meet the timeline, unless otherwise directed by the Council. She proposed that the Council could initiate a complementary regulatory amendment, if needed, as a separate analysis, which would follow immediately in 2010, so that the FMP amendment and complementary regulatory measures could be implemented at the same time in 2011. She suggested that it may be possible to manage the groups under a collective MRA, as under the status quo.

Committee members expressed concern with proceeding with analyses for the FMP amendments and complementary regulatory amendments on separate timelines. Some members preferred to consider the potential regulatory impacts of the proposed FMP amendments in a joint analysis. Jane suggested the default regulatory regime for separate group ACLs could be continued under the other species complex MRA (status quo). The need for NMFS and NOAA GC to clarify interpretations of the guidance for managing prohibited species and the other species complex resulted in the committee recommendation for another meeting before revising the suite of alternatives for analysis.

BSAI Skates analysis Jane reviewed the status of the ACL action plan for the BSAI skate analysis; it is scheduled for final action in October 2009, with implementation scheduled for the 2011 fishing year. Julie Bonney commented that the proposed MRA for BSAI skates in the arrowtooth target fishery is 0 percent. *The committee recommended that Council set the MRA for BSAI skates at 20 percent in the arrowtooth target category.* Jane noted that such a recommendation was consistent with the range of alternatives included in the analysis, but that other changes to MRAs for the arrowtooth flounder target fishery was outside the bounds of this analysis.

Other Species Group action plans The committee in effect tabled the action plans for squid, octopus, shark, sculpin, and grenadier groups to devote its remaining time to consideration of the draft ACL action plan.

Next meeting *The committee recommended that the Council allow the committee to convene again to revise the alternatives for analysis once several management issues are clarified by staff.* A possible committee meeting date in conjunction with the Groundfish Plan Team meeting November 16-19, 2009 was discussed, but the chair did not select a meeting date until the November Plan Team agenda is released.

The committee identified the following issues that required clarification:

1) guidance on whether the "other species" complex could continue to be managed as a complex "in the fishery" under one ACL or must be replaced with separate ACLs for squid, octopus, sharks, and sculpins to conform with NS1 guidelines for the definition of a stock complex.
2) if group ACLs are listed "in the fishery", can skates, squid, octopus, sharks, and sculpins continue to be managed under a collective "other species" maximum retainable allowance (MRA) in the regulations; is a regulatory amendment required to do so?

3) if some groups are listed “in the fishery” with ACLs and other groups are managed under the EC category, can they continue to be managed under a collective “other species” MRA in the regulations; is a regulatory amendment required to do so?

4) may prohibited species be managed under the EC category (assumed in the draft action plan)?

5) are status determination criteria required for stocks listed under the EC category?

6) if the “other species” category is broken into their respective complexes, might other management measures besides MRAs be considered or required? For example, can squid be processed into something beside fish meal if they are placed into the EC category? If poor quality data (e.g., sharks or octopus) result in a low ACL that might close directed fisheries, could this or other groups be managed under a discard mortality similar to management for halibut?

7) which prohibited species catch (PSC) species must be placed within the FMP as an ACL or EC managed species, and which are exempt from management under the FMPs? Are status determination criteria required for stocks listed under the EC category?

8) how are ACL requirements addressed for prohibited species (e.g., herring) that are managed by the State of Alaska?

9) what is the standard (i.e., good enough) to meet the MSA requirements for setting ACLs in terms of stock complexes? Even if some groups (e.g., sculpins and octopus) are managed at the group level, would they meet the standard for managing at appropriate stock complexes, given the wide mix of species that would be managed under a sculpin assemblage or octopus assemblage, for examples?

10) should grenadiers be included in the ACL FMP amendments or scheduled for a trailing FMP amendment to streamline the analysis to meet the statutory ACL requirements?

11) if option(s) to consider setting ACLs for grenadiers or managing them under the EC category are added to the ACL analysis, is a complementary regulatory amendment required to include them in the “other species” MRA or to set separate MRAs for them?

Adjourn The committee adjourned at 12:15 pm.

APPENDIX TO SEPTEMBER 15, 2009 NON-TARGET SPECIES COMMITTEE MINUTES

RESPONSE TO 11 COMMITTEE QUESTIONS

1) **guidance on whether the "other species" complex could continue to be managed as a complex "in the fishery" under one ACL or must be replaced with separate ACLs for squid, octopus, sharks, and sculpins to conform with NS1 guidelines for the definition of a stock complex.**

NS1 Guidelines state that a "stock complex" means a group of stocks that are sufficiently similar in geographic distribution, life history, and vulnerabilities to the fishery such that the impact of management actions on the stocks is similar. At the time a stock complex is established, the FMP should provide a full and explicit description of the proportional composition of each stock in the stock complex, to the extent possible. Stocks may be grouped into complexes for various reasons, including where stocks in a multispecies fishery cannot be targeted independent of one another and MSY can not be defined on a stock-by-stock basis; where there is insufficient data to measure their status relative to SDC; or when it is not feasible for fishermen to distinguish individual stocks among their catch. The vulnerability of stocks to the fishery should be evaluated when determining if a particular stock complex should be established or reorganized, or if a particular stock should be included in a complex. Stock complexes may be comprised of: one or more indicator stocks, each of which has SDC and ACLs, and several other stocks; several stocks without an indicator stock, with SDC and an ACL for the complex as a whole; or one of more indicator stocks, each of which has SDC and management objectives, with an ACL for the complex as a whole (this situation might be applicable to some salmon species).

Because the "other species" complex does not conform to the NS1 definition of a stock complex, Staff recommends that the Council consider eliminating the "other species" complex AND move sharks, sculpins, octopus, and GOA squids either a) in the fishery or b) under the EC category in the ACL amendments. GOA skates and BSAI squids are managed under separate ACLs; setting separate ACLs for BSAI skates is scheduled for final action in October 2009 and implementation in 2011.

2) **if group ACLs are listed "in the fishery", can skates, squid, octopus, sharks, and sculpins continue to be managed under a collective "other species" maximum retainable allowance (MRA) in the regulations; is a regulatory amendment required to do so?**

NS1 Guidelines are silent on this issue. As long as the management approach conforms to the statutory requirement to develop ACLs and accountability measures that prevent overfishing, it is a policy decision for the Council.

Staff responds affirmatively, that the harvests of squid, skates, octopus, sharks, and sculpins may be managed under a collective "other species" maximum retainable allowance (MRA) in the regulations if those groups are listed in the fishery. In general, a collective MRA would not require a regulatory amendment since a collective other species MRA is the status quo; however GOA skates has its own MRA category and a regulatory amendment would be required to revise their management to return them under the collective MRA. The Council's preliminary preferred alternative for BSAI skates includes no action for setting a unique MRA category for BSAI skates under BSAI Amendment 95.

Staff recommends that the Council consider the status quo approach for managing MRAs. If these species are in the fishery, they need ACLs and annual management measures (AMs), which will prevent overfishing. The ACL analysis can address whether a collective MRA is sufficient to ensure that none of the species complexes (i.e., sharks) will be subject to overfishing. That is, would a collective MRA prevent a complex from being overfished if it comprised, for example, 80 percent of the collective MRA in a given year? If not, the Council would need to provide rationale for why the collective MRA will be effective at prospectively preventing overfishing from occurring.

3) **if some groups are listed "in the fishery" with ACLs and other groups are managed under the EC category, can they continue to be managed under a collective "other species" MRA in the regulations; is a regulatory amendment required to do so?**

NS1 Guidelines are silent on this issue. As long as the management approach conforms to the statutory requirement to develop ACLs and accountability measures that prevent overfishing, it is a policy decision for the Council.

Staff responds affirmatively, that the harvest of squid, skates, octopus, sharks, and sculpins may be managed under a collective "other species" MRA in the regulations even if some groups are managed "in the fishery" under ACLs and other groups are listed under the EC category. In general, this would not require a regulatory amendment since setting a collective MRA is the status quo (except for GOA skates).

The staff response is the same as under #2 (above).

4) **may prohibited species be managed under the EC category (assumed in the draft action plan)?**

NS1 Guidelines state that one criteria to be an EC species is it "not generally be retained for sale or personal use." This requirement could be interpreted to mean that the EC species is not generally retained for sale or use under the particular FMP at issue. If Maximum Sustainable Yield (MSY) and Status Determination Criteria (SDC) (for overfishing) are required, they should be identified under its primary management plan, for example the crab FMP or the salmon FMP. For State/International managed stocks where there is not a federal FMP, MSY and SDC are not required because the stocks are in the groundfish FMP only for purposes of limiting their catch. It is appropriate to have a target stock in its primary FMP, and have it listed as an ecosystem component species in another FMP.

Staff recommends that the Council consider moving prohibited species under the EC category, with written justification. Prohibited species have no economic value for fishermen fishing under the groundfish FMPs due to strict restrictions on their sale and use

5) **are status determination criteria required for stocks listed under the EC category?**

NS1 Guidelines requires SDC for all stocks "in the fishery." Prohibited species are not in the groundfish FMPs for purposes of managing them per se; they are listed as prohibited species so as to limit the impact of the groundfish fishery on their biomass. For stocks that are managed by the State of Alaska and international treaty and for which there is not a federal FMP, federal MSY and SDC criteria are not applicable.

Staff recommends that the Council consider moving prohibited species under the EC category and provide a rationale for why those management actions that apply to stocks in the fishery may not be necessary or appropriate for prohibited species.

6) **if the "other species" category is broken into their respective complexes, might other management measures besides MRAs be considered or required? For example, can squid be processed into something beside fish meal if they are placed into the EC category? If poor quality data (e.g., sharks or octopus) result in a low ACL that might close directed fisheries, could this or other groups be managed under a discard mortality similar to management for halibut?**

Yes, other management measures besides MRAs could be considered and selected by the Council, however, the timeline for complying with ACL requirements may not allow for sufficient time to explore these alternative management approaches. Because of the statutory deadline, staff is recommending that the Council proceed with no changes to the other species (collective) MRA.

The Council would need to provide rationale for why the other species collective MRA would be effective at prospectively preventing overfishing from occurring, whether on a permanent or interim basis. A trailing amendment to consider other regulatory regimes may be appropriate, pending Council direction. The ACL analysis will explore this issue more completely than this brief response.

7) **which prohibited species catch (PSC) species must be placed within the FMP as an ACL or EC managed species, and which are exempt from management under the FMPs? Are status determination criteria required for stocks listed under the EC category?**

Staff preliminarily recommends that all prohibited species be listed under the EC category, *with no other changes to their management*. ACLs or status determination criteria are not required for stocks listed under the EC category. In effect, this action would reorganize the stocks and stock complexes in the FMP to explicitly separate ACL species from those not managed under ACLs. The Council would need to provide rationale for why these species would meet the criteria in NS1 guidelines for EC category species. These criteria and the specific species considered for the EC category will be further analyzed in the analysis for this action.

8) **How are ACL requirements addressed for prohibited species (e.g., herring) that are managed by the State of Alaska?**

The same answer to #2 applies to this specific query regarding herring. Principal management by the State of Alaska does not affect its status as a prohibited species. The Council would need to provide rationale for why prohibited species managed by the State meets the EC category criteria in the NS1 guidelines.

9) **what is the standard (i.e., good enough) to meet the MSA requirements for setting ACLs in terms of stock complexes? Even if some groups (e.g., sculpins and octopus) are managed at the group level, would they meet the standard for managing at appropriate stock complexes, given the wide mix of species that would be managed under a sculpin assemblage or octopus assemblage, for examples?**

There is no one standard for meeting MSA requirements for setting ACLs. The Councils have the authority to recommend management actions that comply with the MSA. The ACL environmental assessment would provide the Council's rationale for listing stock complexes "in the fishery," under the EC category, or outside the FMPs. The basis for listing stocks or stock complexes in particular categories will be based on the SAFE Reports, the AFSC vulnerability (PSA) analysis, and the NS1 guidelines.

10) **should grenadiers be included in the ACL FMP amendments or scheduled for a trailing FMP amendment to streamline the analysis to meet the statutory ACL requirements?**

NS1 Guidelines are silent on this issue, so it is a policy decision for the Council.

Staff recommends streamlining the ACL amendments to the minimum actions necessary to comply with the January 1, 2011 statutory deadline for revised NS1 guidelines. The proposed grenadier FMP amendment, which would move grenadiers either into the fishery as recommended by the Plan Teams or under the EC category would appear to require complementary management measures (e.g., they could be managed under the "other species" complex for the purposes of MRAs via a regulatory amendment). The Plan Teams placed a high priority on a grenadier FMP/regulatory amendment as soon as possible after the ACL FMP amendments.

11) **if option(s) to consider setting ACLs for grenadiers or managing them under the EC category are added to the ACL analysis, is a complementary regulatory amendment required to include them in the "other species" MRA or to set separate MRAs for them?**

NS1 Guidelines are silent on this issue, so it is a policy decision for the Council.

If the Council adopts a FMP amendment to move grenadiers into the fishery, they would be subject to ACLs so their overall harvest would need to be limited. If the Council moves them into the EC category, no limits on their harvest would necessarily be imposed, provided this is consistent with MSA conservation and management requirements (the same as under the status quo where they are not included in the FMP). Staff advises that a regulatory amendment would be required if the Council deems that additional management restrictions are needed to limit the harvest of grenadiers.

PUBLIC TESTIMONY SIGN-UP SHEET

Agenda Item: D-2 (a) ACLs

	NAME *(PLEASE PRINT)*	TESTIFYING ON BEHALF OF:
1	Jon Warrenchuk	Oceana
2	Bubba Cook	WWF
3	Julie Bonney	AGDB
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NOTE to persons providing oral or written testimony to the Council: Section 307(1)(I) of the Magnuson-Stevens Fishery Conservation and Management Act prohibits any person " to knowingly and willfully submit to a Council, the Secretary, or the Governor of a State false information (including, but not limited to, false information regarding the capacity and extent to which a United State fish processor, on an annual basis, will process a portion of the optimum yield of a fishery that will be harvested by fishing vessels of the United States) regarding any matter that the Council, Secretary, or Governor is considering in the course of carrying out this Act.