AGENDA C-3(c, d)
FEBRUARY 2010

MEMORANDUM

TO: Council, SSC and AP Members

FROM: Chris Oliver
Executive Director

DATE: February 2, 2010

SUBJECT: Bering Sea Crab issues

ESTIMATED TIME
4 HOURS
(All C-3 items)

ACTION REQUIRED

(c) NOAA/Bering Sea Fisheries Research Foundation survey report Steve Hughes

(d) Review methodology for ACL analysis and performance measures for rebuilding; review of Crab Stock Assessment and Data Weighting report (SSC only)

BACKGROUND

(c) NOAA/Bering Sea Fisheries Research Foundation survey report

NOAA Fisheries and the Bering Sea Fisheries Research Foundation (BSFRF), an industry organization, conducted a cooperative survey using side-by-side tows with two different types of nets to understand the selectivity of the NMFS annual Bering Sea trawl survey net for snow crab. A report from AFSC staff, attached as Item C-3(c)(1) reviews the research to estimate snow crab selectivity and efforts to understand the sensitivity of the snow crab model to the selectivity parameters. This report discusses the extent to which the cooperative survey data can be compared with the NMFS trawl survey data and the selectivity differences between the two types of nets. A report from BSFRF (initially presented to the Crab Plan Team in September 2009) is attached as Item C-3(c)(2). Representatives from the BSFRF and AFSC will be on hand to report on these surveys.

For the SSC only, the AFSC stock assessment author will present a sensitivity analysis of the NMFS snow crab model regarding the selectivity parameters. Two documents related to treatment of these data in the snow crab model are provided. Item C-3(c)(3) provides results of various runs of the Bering Sea snow crab assessment model under different assumptions regarding survey selectivity and natural mortality and projections evaluating rebuilding under these assumptions. Item C-3(c)(4) evaluates treatment of the 2009 industry survey data as an additional survey in the snow crab assessment model.

(d) Review methodology for ACL analysis and performance measures for rebuilding; review of Crab Stock Assessment and Data Weighting report (SSC only)

ACL analysis and performance measures
A workgroup of Crab Plan Team members, SSC members and other state and federal staff continues to make progress on methodologies for proposed ACLs for BSAI crab stocks to meet statutory requirements. SSC review of draft documents at this time is intended to assist analysts in refining methods for formulating ABC

control rules for BSAI crab stocks which explicitly account for uncertainty. A draft description of the ACL alternatives and the rebuilding options for Snow and Tanner crab stocks is included as Item C-3(d)(1). This includes changes to the snow crab rebuilding alternatives as recommended by the SSC in December. However, further clarification is sought from staff on the request by the SSC in December regarding inclusion of a performance measure in the rebuilding alternatives (rebuilding alternatives are included under Item C-3(d)(1). This request was the following (from December 2009 SSC minutes):

> *We recommend that all of the alternatives include a performance measure to evaluate the probability that the stock does not rebuild by a certain year (for example after 10 years), similar to the $B_{20\%}$ threshold for some groundfish. This would provide a stronger incentive to avoid a potential stock collapse.*

Analysts seek further discussion and clarification from the SSC on the specifics for addressing this request in the alternatives.

A draft impact analysis of ACLs for the Bristol Bay red king crab stock is provided as Item C-3(d)(2). A descriptions and preliminary impact analysis of Tier 5 crab stocks is included as Item C-3(d)(3). Staff will provide overviews of these documents and progress towards the full ACL analysis of BSAI crab stocks. Preliminary review of that analysis is scheduled for April with initial review in June.

Crab stock assessment and data weighting workshop report

In May, 2009, a crab stock assessment workshop was convened at the Alaska Fishery Science Center in Seattle. Workshop participation involved primarily by members of the Crab Plan Team, crab assessment authors, and other scientists involved in groundfish stock assessment and fishery management in Alaska. The workshop provided draft guidelines for structuring stock assessment documents, and guidance on addressing data weighting and diagnostic issues related to stock assessment. The report from the workshop was appended to the 2009 Crab SAFE report and also mailed to you in January. Dr. André Punt of the University of Washington and a member of the Crab Plan Team will provide an overview of the workshop findings.

AGENDA C-1(c)(1)
FEBRUARY 2010

Review of the research to estimate snow crab selectivity by the NMFS trawl survey

David Somerton, Ken Weinberg (RACE Division, Alaska Fisheries Science Center),

and

Scott Goodman (Natural Resource Consultants)

The length-based fishery management model for snow crab contains parameters describing the processes of growth, natural mortality and survey selectivity that may be estimated during the model fitting process but which could be statistically confounded and, compared to those of many Bering Sea age-based fish models, estimated with considerable uncertainty. In the September 2009 snow crab assessment model, growth and natural mortality were fixed in the model and survey selectivity estimated. If survey selectivity could instead be estimated external to the model fitting process, for example, using experimental data, then the outputs of the management model are likely to have less bias and greater precision (Somerton et al. 1999). Here we examine the research, leading to and culminating in the 2009 NMFS-BSFRF cooperative study, which focused on the problem of estimating snow crab survey selectivity from experimental data.

To better understand the research approaches that have been taken, it is important to clearly understand the goal. Survey selectivity is considered in the management model as a size-dependent proportionality between the true population abundance and that estimated by the trawl survey using swept area methodology. It is typically described mathematically using a logistic function, with the asymptote or maximum value of this function referred to as "q". In contrast to this, trawl selectivity is the proportion by size of the animals in the path of the trawl that are actually caught, and, equivalent to survey selectivity, the asymptote of this function can be referred to as "Q" (again: q is global over the population; Q is local to a specific time and location). In all of the approaches described here, survey selectivity is estimated from estimates of trawl selectivity, which, in turn, are estimated from data collected using trawl selectivity experiments.

Several experimental approaches have been used to provide the data needed to estimate snow crab trawl selectivity of the standard 83-112 bottom trawl used by the AFSC to survey the eastern Bering sea; all include some method for obtaining an estimate of the true density of crabs in the trawl path. The first, conducted in 1995, used a Leslie depletion experiment and estimated Q by modeling the change in catch per swept area (cpue) with increasing number of tows in a small area (Somerton unpublished data). Unfortunately, the results of this study were put in question when a Canadian study reported that snow crab are attracted to and quickly repopulate trawl tow paths.

The second study, conducted in 1998, attempted to obtain an estimate of the true density by attaching a heavily weighted auxiliary bag under the trawl to capture crab escaping beneath the footrope (Somerton and Otto, 1999). The estimated trawl selectivity function, based on the ratio of the trawl catch to the combined catch of the trawl and the auxiliary bag (Fig. 1), rises to a maximum of about 0.85 (the asymptote was larger [0.99], but outside of the snow crab size range).

There were two compelling reasons to question the validity of this Q estimate and its use as a proxy for q. First, the auxiliary bag captured so much debris that the increased drag caused a decrease in trawl net spread which, in turn, potentially changed footrope contact and selectivity. To compensate for this, tow length was shortened from the standard 30 min to 15 min, trawl bridles were shortened by 50% (this increases the spreading force and helps to counteract the increased drag) and the experimental area was moved into shallower, sandier areas where net performance was better. Thus the experimental tows were not conducted exactly like the standard survey tows and the experimental area was not representative of the snow crab survey area but instead was restricted to the shallowest and most southerly part (Fig. 2). Second, the catch in the experimental trawl included considerably more small crabs than are observed in survey catches, indicating that some aspect of the experiment was creating an artifact. Although a modified selection model was fit to these data (Fig. 1), the presence of the small crabs again indicated non-standard trawl performance.

To address these problems, in 2009 NMFS and BSFRF jointly conducted a side-by-side trawl selectivity experiment where the true density in the trawl path was to be estimated using both a modified version of the standard NMFS survey trawl and the BSFRF nephrops survey trawl that has been previously used to survey red king crab. The modifications to the NMFS trawl included a layer of small mesh lining the trawl belly to retain small crabs and the addition of a tickler chain in front of the footrope to lift crabs off of the bottom just before footrope passage. Side-by-side trawling is a commonly used technique to determine the selectivity of one trawl relative to another, and produces estimates of selectivity with somewhat higher variances than the auxiliary bag technique because absolute abundance cannot be estimated directly in the path of the standard trawl. However, trawl performance with large debris catches are better controlled with separate trawls than with an auxiliary bag. Unfortunately, during testing prior to the start of the experiment, the modified NMFS trawl filled with debris so rapidly that the net was completely torn away from the remainder of the trawl before it could be retrieved. Since only one additional experimental trawl remained for the side-by-side study, the experimental protocols were changed so that the tickler chain was removed, 37 kg of chain were attached to the footrope and tow lengths of both the experimental and standard trawl were reduced to the same duration (5 min) as the BSFRF tows.

The side-by-side experiment occurred in July, 2009, in an area south of St. Matthew Is. (Fig.2). Twenty-four successful side-by-side tows were conducted simultaneously by two NMFS charter vessels towing the standard and modified NMFS trawls and a BSFRF charter vessel towing the nephrops trawl. The initial intent of the experiment was to use the catch of the original modified trawl to obtain estimates of absolute density; however the ad-hoc modifications to this trawl put this in question. Consequently, the cpue of the modified trawl was tested against that of the nephrops trawl which was assumed to capture all crabs. For all size categories (large males [width>102mm]; medium males [78<width<102]; small males [width<78 mm]; large females [width>50 mm] and small females [width<50 mm]), cpue estimates from the modified trawl were significantly less (max $p<0.02$) than those obtained with the nephrops trawl. Therefore, the BSFRF cpue values were used as estimates of true crab density. The resulting estimates of trawl selectivity (mean ratio of NMFS to BSFRF cpue) were as follows: large males (0.35), medium males (0.27), small males (0.13), large females (0.25) and small females (0.03). Thus an approximate Q value for large males was estimated to be 0.35 (a mean over a width interval rather than a maximum value).

As with the auxiliary bag experiment, there are compelling reasons why this estimate of Q may not be a suitable proxy for q. First, the tow length of the standard trawl was reduced from 30 min to 5 min, and previous research (Somerton et. al 2002) indicated that snow crab cpue increases when tow length is reduced. In addition, the short tow length required inclusion of the "end-effect" catch or the small amount of catch taken outside of the standard tow bounds that is normally ignored for 30 min tows. Second, the experimental area was again locally focused and not representative of the entire snow crab distribution (Fig. 2). Third, the dimensions of the nephrops trawl are smaller than those of the NMFS trawl and towing speed is slower, which could lead to a greater contribution to cpue from the herding of large snow crab into the trawl path (Craig Rose, AFSC, per. comm.).

To address the first two of these issues, a different method was used to estimate trawl selectivity using the normal survey trawl hauls conducted by both NMFS and BSFRF in the 27 NMFS sampling blocks comprising the 3 BSFRF survey areas (Fig. 2). For the respective surveys, NMFS conducted a standard 30 min tow at the center of each of these blocks, while BSFRF conducted 4, randomly located 5 min tows. Although the BSFRF tows differed in both time and location from the NMFS tow in each block, the 4 tows were averaged and used as a proxy for a side-by-side tow to estimate crab abundance within the NMFS tow path. In addition, because the BSFRF survey covered a much larger area than either the side-by-side experiment or the auxiliary bag experiment, spatial covariates, including depth, sediment size and net spread, which have all been correlated with footrope contact (Weinberg and Kotwicki 2008; von Szalay and Somerton, 2005), were included in the selectivity estimation model.

The trawl selectivity model was developed considering the functional form of the model, the spatial covariates that should be included and the consequences of the strong skew in the cpue ratio (i.e., NMFS cpue / BSFRF cpue). Spatial covariates were added in a way that influenced either the value of the asymptote (i.e., in the numerator of the logistic function) or the rate at which the asymptote was reached (i.e., in the denominator). Regardless of the form of the model, net width always improved the model fit (lower AIC) more than either of the other covariates, and the overall best fit was obtained with net width in the denominator (Because the separation distance between the footrope and the bottom increases with increasing net spread [von Szalay and Somerton 2005], a variable asymptote model is conceptually the best model, but it did not fit the data best). The importance of the net width effect indicates that trawl selectivity varies spatially over the survey area. This is evident in Fig. 3 where the best fitting selection model is shown evaluated at the mean and extremes of net spread over the 27 NMFS blocks. When the net spread is low, as it is in the southeastern portion of the 27 blocks, the selectivity is relatively high and similar to that observed with the auxiliary bag experiment that was conducted near this area (Fig. 2). Conversely, when the net spread is high, as it is in the northern, deeper, blocks, the selectivity is relatively low and similar to that observed with the side-by-side experiment that was conducted near this area (Fig. 2).

Because of its strong spatial variation, trawl selectivity experiments need to be conducted over a random or at least representative sample of the survey stations (unlike either the 2009 side-by-side experiment or the 1998 auxiliary bag experiment) and the estimate of survey selectivity needs to be based on some spatially averaged value of trawl selectivity. An example of such a spatially averaged value (Fig. 4) was calculated from the 2009 NMFS survey data by evaluating the trawl selectivity model at 5 mm carapace width intervals at each station, using the measured net spread, then, for each interval, determining the weighted average trawl selectivity where the weighting factors were the cpue by width interval and station. This approach then produces a survey selection function, whose maximum can be correctly interpreted as an estimate of q.

That said, we believe that the survey selection function shown in Fig. 4 is too uncertain and possibly quite biased and should not be used to directly constrain the snow crab management model. The primary reason is that the cpue ratios are highly skewed with some approaching a value of 6 (if the NMFS Q were actually 1.0, and the two tows sampled the same density of crabs, then maximum values of the cpue ratios should be near 1.0). Such high variability in the cpue ratio is the result of the large differences in the time and location of the NMFS and BSFRF sampling. For example, when a catch ratio is calculated from auxiliary bag data, it is constrained to be no greater than 1.0 and when it is calculated from side-by-side data, the catches are highly correlated and the catch ratio rarely exceeds 1.0. However, when the catches from two trawls differ greatly in location or time, then the catches have much lower correlation and, as in our case, cpue ratios can become extreme and these extreme values have a large influence on the fitted selection model. From a purely statistical perspective, the fit could be improved by transforming the values of the cpue (for example, using a fourth root transformation), but this would simply be an attempt to statistically fix a problem in the data that originated from poor experimental design.

An alternative approach was taken to deal with the skew, that is, to fit a model to the mean (over all 27 stations) catch ratio for width intervals including at least 3 individuals (this ignores the spatial variation in trawl selectivity and rests on the assumption that the 27 NMFS stations are representative of the entire snow crab distribution). Two variations were considered: 1) weighted by an estimate of population abundance within each area (NMFS cpue), similar in concept to the spatially averaged selection function shown in Fig.4, and 2) unweighted. Unlike the spatially averaged estimator, where predicted values of selectivity were weighted, in this case the observed values of the cpue ratio were weighted. Such weighting enhanced rather that reduced the effects of large cpue ratios, because the NMFS cpue data was used to both calculate the cpue ratio and to provide the weight, consequently large NMFS catches, which occurred by chance, led to a high cpue ratios coupled to high weights. The best fitting selection curve to the unweighted mean data is shown in Fig. 5

The error associated with the mean selection curve, was estimated using bootstrapping (re-sampling the station data with replacement). The 95% confidence intervals, based on 100 replicates, are also shown in the Fig.5. The confidence intervals produced using this approach are somewhat too narrow because during the bootstrapping process any non-convergent solutions to the model fit were discarded, thus the extreme values of selectivity were likely not generated. Error estimation using Markov Chain Monte Carlo methodology would alleviate this shortcoming.

Assuming that Q can be used as a proxy for q, the above results could be utilized in the snow crab management model two distinct ways. First, the mean and confidence intervals of q at, say, 140 mm (q = 0.76, 95% CI= 0.56-0.95; the true maxima occur beyond the maximum width of snow crab and 140 mm is the largest width interval in this data with sufficient sample size) could be used to construct a Bayesian prior for q in the snow crab model. Second, sensitivity of model outputs to the value of q could be examined by running the model with fixed values of q ranging, for example, between the above 95% CI. In addition, we also recommend that the snow crab model also be run with a fixed value of q set at 0.32, which is the value determined from the NMFS-BSFRF side-by-side experiment that was provided at the September 2009 meeting of the Crab Plan Team (oral presentation by Ken Weinberg and Scott Goodman).

Because of the inherent errors in all of the methods describe above, we believe that a more appropriate strategy would be to conduct another selectivity experiment which has the properties: 1) NMFS towing procedures are the same as used on the survey, 2) trawling is done over a sufficiently broad area to capture the spatial variation in net width or other covariates, 3) trawling is done simultaneously and in close proximity to reduce the likelihood of large cpue ratios. A selectivity study having these attributes has been submitted by BSFRF in a research proposal to the North Pacific Research Board with the objective of having it conducted in cooperation with the AFSC EBS bottom trawl survey during summer 2010. Analysis would then be conducted and completed in the Fall of 2010.

Literature cited

Somerton, DA, Otto, RS. 1999. Net efficiency of a survey trawl for snow crab, *Chionoecetes snow crab*, and Tanner crab, *C. bairdi*. Fishery Bulletin. 617-625.

Somerton, D, Ianelli, J, Walsh, S, Smith, S, Godo, OR, Ramm, D. 1999. Incorporating experimentally derived estimates of survey trawl efficiency into the stock assessment process: a discussion. ICES Journal of Marine Science. 56:299-302.

Somerton, DA, Otto, RS, Syrjala, SE. 2002. Can changes in tow duration on bottom trawl surveys lead to changes in CPUE and mean size? Fisheries Research. 55: 63-70.

von Szalay, PG, Somerton, DA.2005. The effect of net spread on the capture efficiency of a demersal survey trawl used in the eastern Bering Sea shelf. Fish. Res. 74:86-95.

Weinberg, KL, Kotwicki, S. 2008. Factors influencing net width and sea floor contact of a survey bottom trawl. Fisheries Research 93: 265-279.

Figure 1 Snow crab trawl selectivity curve based on the 1998 auxiliary bag study. The trawl selectivity was described with a model combining the processes of escapement under the footrope (the ascending curve) and passage of small crab through the belly mesh due to the auxiliary bag (descending curve). The maximum of the ascending curve, within the size range of male snow crab, could be used as an estimate of Q.

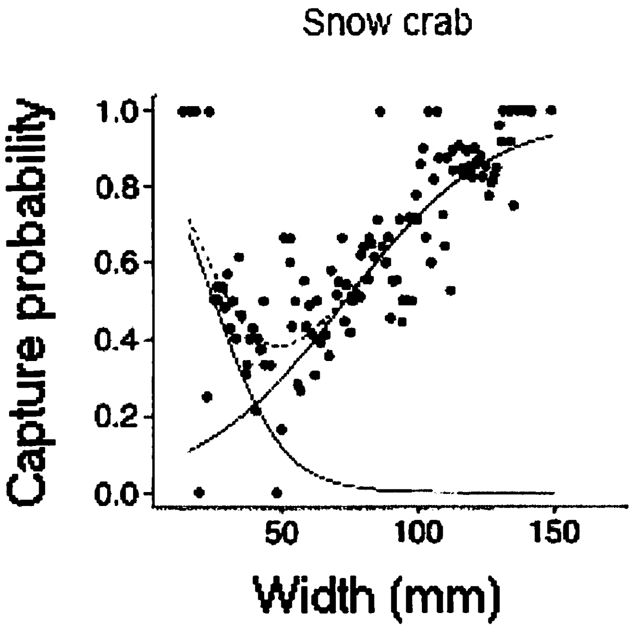


Figure 2. Location of the side-by-side trawling areas (shown with pink shading) and the 3 BSFRF survey areas encompassing the 27 NMFS survey blocks (shown with a red line). Location of the 1998 auxiliary bag experiment sampling areas (blue circles).

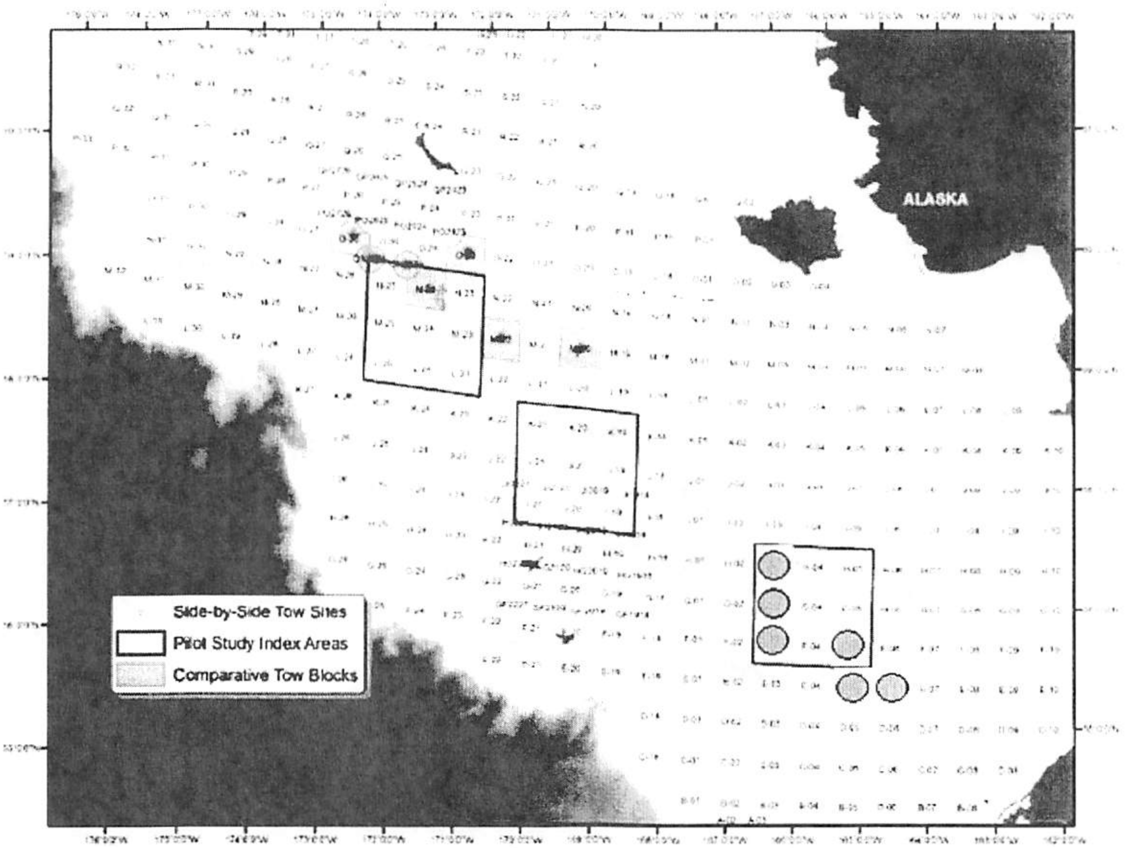


Figure 3. The cpue ratio (NMFS cpue / BSFRF cpue) by 5 mm width interval is shown with the fitted model evaluated at the mean (over the 27 NMFS stations in the 3 BSFRF blocks), maximum and minimum net widths. Also shown is the fitted model ignoring net width. Note, for clarity, ratios > 1.2 were omitted from this figure, however, ratios used in the modeling were quite skewed and as large as 6.0.

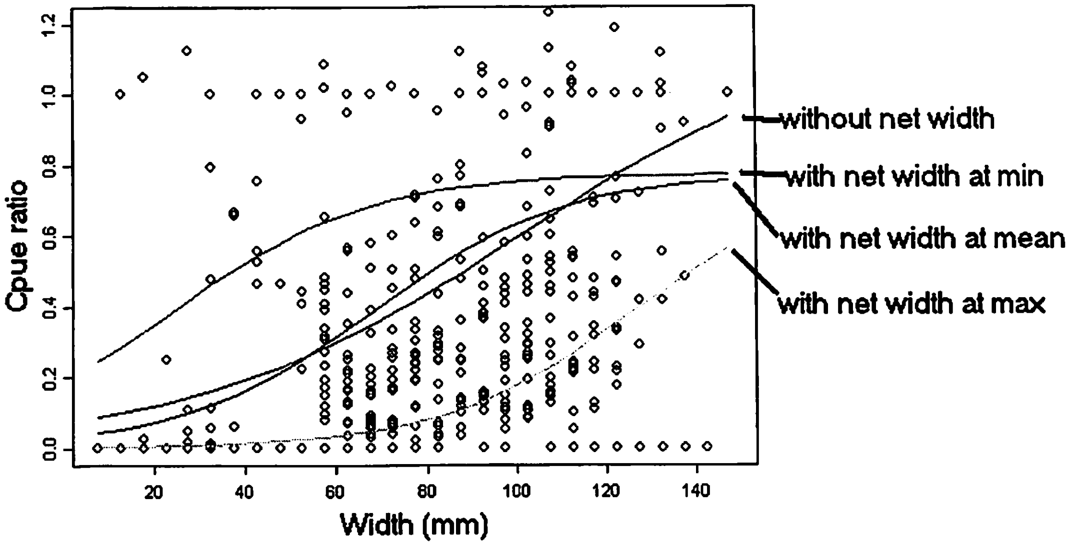


Figure 4. A possible estimator of survey selectivity from trawl selectivity that is spatially varying. This estimate was produced by evaluating the trawl selectivity function, by 5 mm width increments, at each NMFS station using the measured value of net width, then for each increment computing the weighted average where the weighting factors were equal to the station cpue at each width increment.

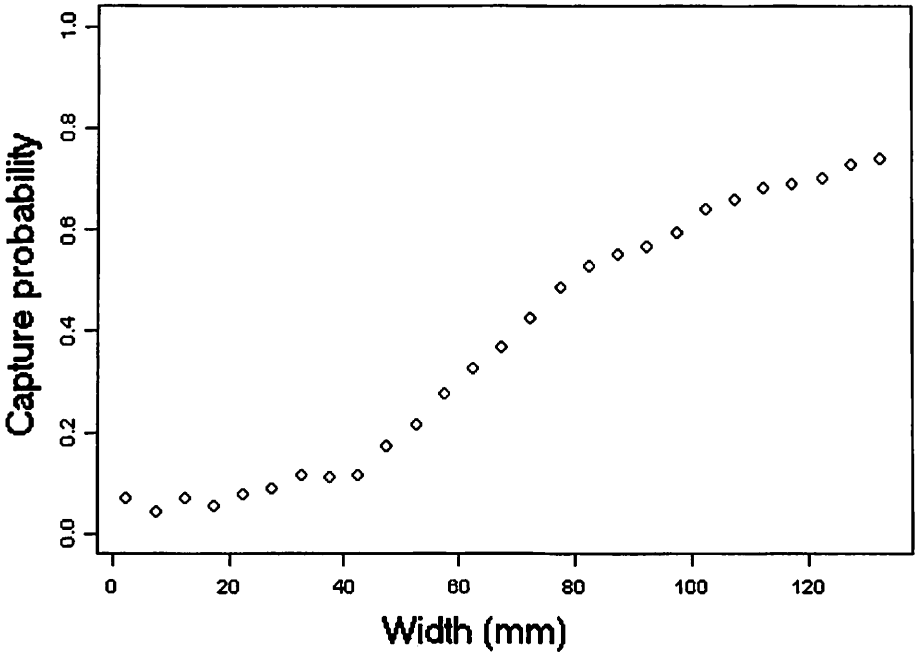
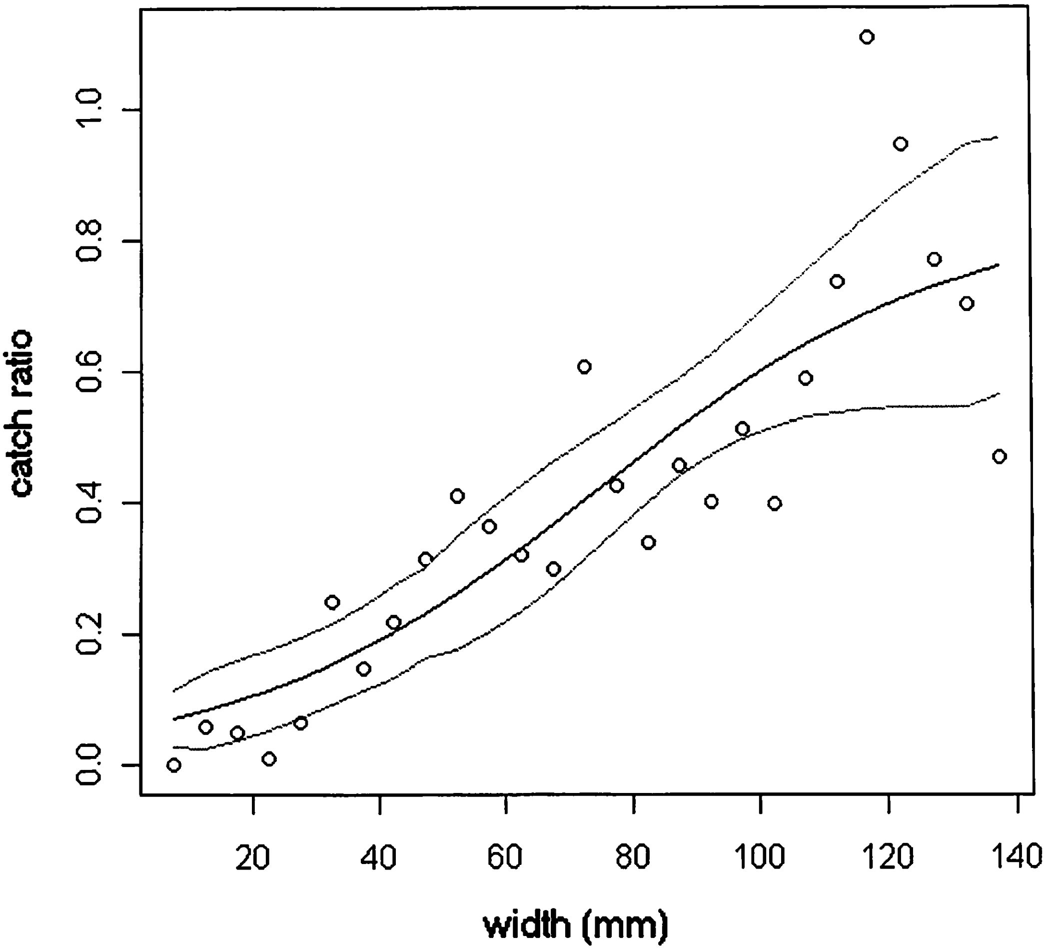


Figure 5. Plot of the mean catch ratio (NMFS/BSFRF) in the 27 NMFS survey areas by 5 mm width intervals and the fit of a logistic function. Also shown are the 95% confidence intervals on the mean selection determined using a process known as bootstrapping.



Preliminary Results of the 2009 NMFS – BSFRF Snow Crab Net Efficiency Study (Jointly Released by NMFS Alaska Fisheries Science Center and Bering Sea Fisheries Research Foundation)

September 4, 2009

The NMFS Alaska Fisheries Science Center Resource Assessment and Conservation Engineering Division's Groundfish Assessment Program, in partnership with the Bering Sea Fisheries Research Foundation, conducted a field experiment to estimate the net efficiency (i.e. proportion of the animals in the trawl swept area that are captured) of the NMFS standard Bering Sea 83/112 survey trawl for snow crab *Chionoecetes opilio*. Similar field work by NMFS to address *opilio* catchability was done previously (Somerton and Otto, 1999. Net efficiency of a survey trawl for snow crab and Tanner crab. Fish. Bull. 97:617-625), however, the underbag methodology used in that previous study did not work well in the muddy areas inhabited by snow crab, so sampling could not be done randomly over the entire species distribution. Because of concerns about the potential bias of the net efficiency estimates produced by using an underbag, a new approach was tried at the end of the 2009 annual eastern Bering Sea bottom trawl survey, using a modified version of the survey trawl that initially included a tickler chain in front of the footrope, 37 kg of additional chain (7.9 m) strung along the center of the footrope, and a fine-mesh liner to capture all of the crabs in the trawl path. The modified trawl was not intended to be a replacement for the standard 83/112 trawl but to provide absolute density estimates of snow crab that could be used as the basis to compute the net efficiency of the standard trawl. Before beginning the experiment, the modified NMFS trawl was tested in the experimental area using a 15 minute tow, but the catch rate was so high that the weight tore the netting away from the head and foot ropes. Since the vessel carried only one additional modified trawl, the decision was made to remove the tickler chain, and shorten the length of the tow from 15 to 5 minutes.

The 2009 field experiment was designed and conducted as a three vessel trawl comparison consisting of: the NMFS chartered *F/V Arcturus* towing the standard 83/112 survey trawl, the NMFS chartered *F/V Aldebaran* towing the NMFS modified survey trawl and the BSFRF chartered *F/V American Eagle* towing a trawl designed for the European *nephrops* fishery. The NMFS modified trawl, with the ad hoc changes in design and fishing protocols, was used in the 24 triplicate side-by-side tows of the experiment involving the three gear types to determine snow crab net efficiency. Exhibit 1 shows the location of the comparative tow work on Bering Sea snow crab grounds.

The first question considered was whether the modified survey trawl and the *nephrops* trawl estimated the same density of snow crab in each category. This question is important because the most unbiased estimate of density is needed to calculate the net efficiency of the standard 83/112 survey trawl. Thus, if the *nephrops* trawl produced a higher density, then its CPUE should be used as the basis for this calculation. For each of the categories, we therefore tested the hypotheses of equality in the CPUE (thousands of crabs per unit swept area) between the modified survey trawl and the *nephrops* trawl (Exhibit 2). Positive values of the test statistic (BSFRF CPUE – NMFS CPUE) and probability levels <0.05 indicate that the BSFRF net efficiency was higher. Crab catch data were divided into five size-sex categories, matching those used in the NMFS Annual Crab Report to Industry, in the following analysis of the experimental data. For all categories, the *nephrops* trawl caught significantly more crabs than the modified survey trawl. Exhibits 3-4 demonstrate the size frequencies of the captured crab by sex taken by each vessel.

The net efficiency of the standard 83/112 survey trawl was then estimated for each category assuming that the *nephrops* trawl caught everything in the tow path (i.e. CPUE of the standard 83/112 trawl divided by the CPUE of the BSFRF trawl averaged over all 24 tows). These values are substantially lower than those found in the previous snow crab net efficiency study. For the large males, for example, the previous estimate is approximately 0.80 while the new estimate is 0.35. This indicates that the standard 83/112 survey trawl has substantial escapement under the footrope of even the largest sizes of snow crab. Exhibits 5-9 provide tabular catch results in numbers of crab caught per square nautical mile by vessel/gear type and net efficiency estimates for each of the five size/sex categories. Exhibits 10-14 provide a graphic presentation of snow crab densities from each of the 24 triplicate tows by the same five size/sex categories and Exhibit 15 provides a summary of snow crab densities derived across the 24 triplicate tows by the same five size/sex categories. Exhibit 16 provides a summary of the NMFS standard 83/112 trawl net efficiency by size and sex category compared to the BSFRF *nephrops* trawl.

The results of this study as described above will be released to the public and to the North Pacific Fishery Management Council's Crab Plan Team meeting on September 14, 2009. Results will also be provided to the snow crab assessment authors for evaluation of the results on the snow crab assessment model during the next crab assessment cycle.

Exhibit 1. Chart showing locations of comparative tows for net efficiency experiment.

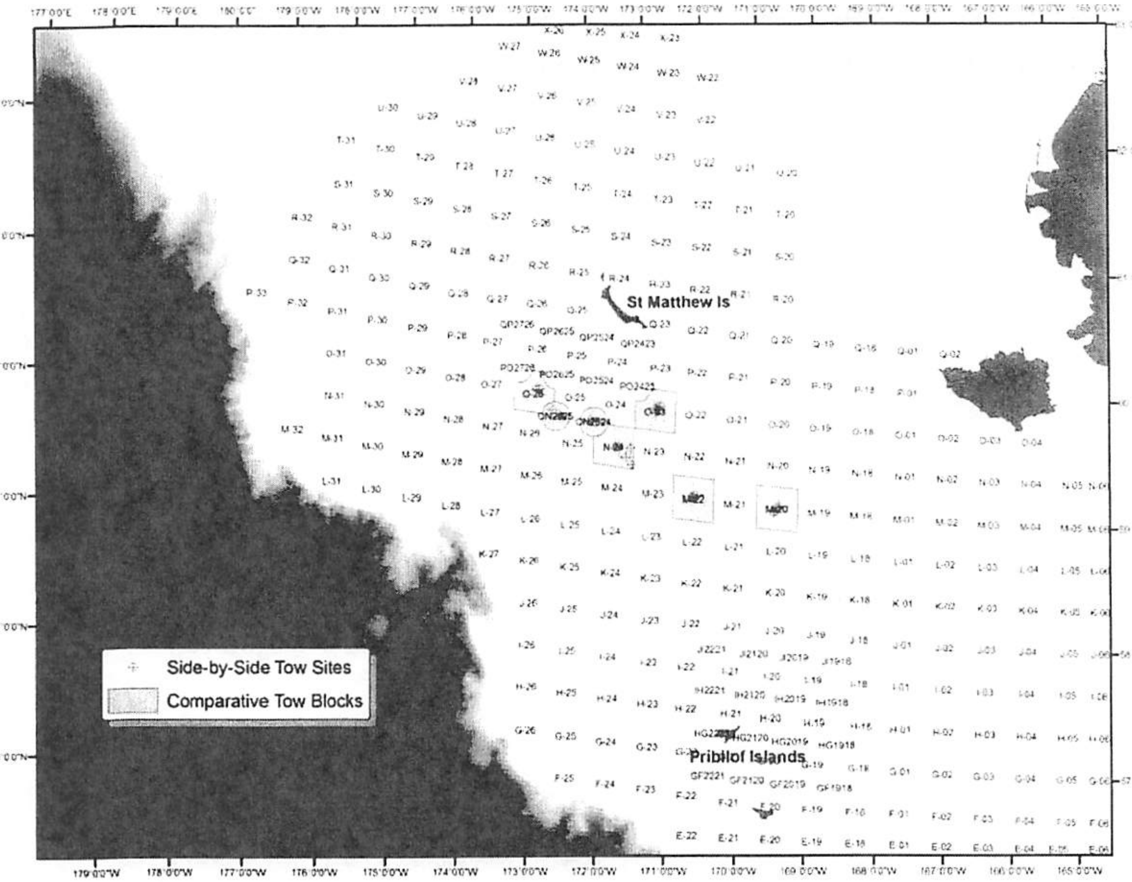


Exhibit 2. One-sample t-Test statistics for comparison of the snow crab CPUEs obtained by the NMFS modified trawl and the BSFRF trawl (BSFRF CPUE - NMFS CPUE). A positive *t*-value and a *p*-value less than 0.05, indicates that the BSFRF trawl was more efficient.

Snow crab length class (chelae width)	t	df	*p*-value
Large male (≥102 mm)	3.2323	23	0.0037
Medium male (78-101 mm)	5.1537	23	0.0000
Small male (<78 mm)	4.3412	23	0.0002
Large female (≥50mm)	2.4048	23	0.0246
Small female (<50mm)	3.5874	23	0.0016

Exhibit 3. Length frequencies of male *opilio* crab binned into 5 mm groups.

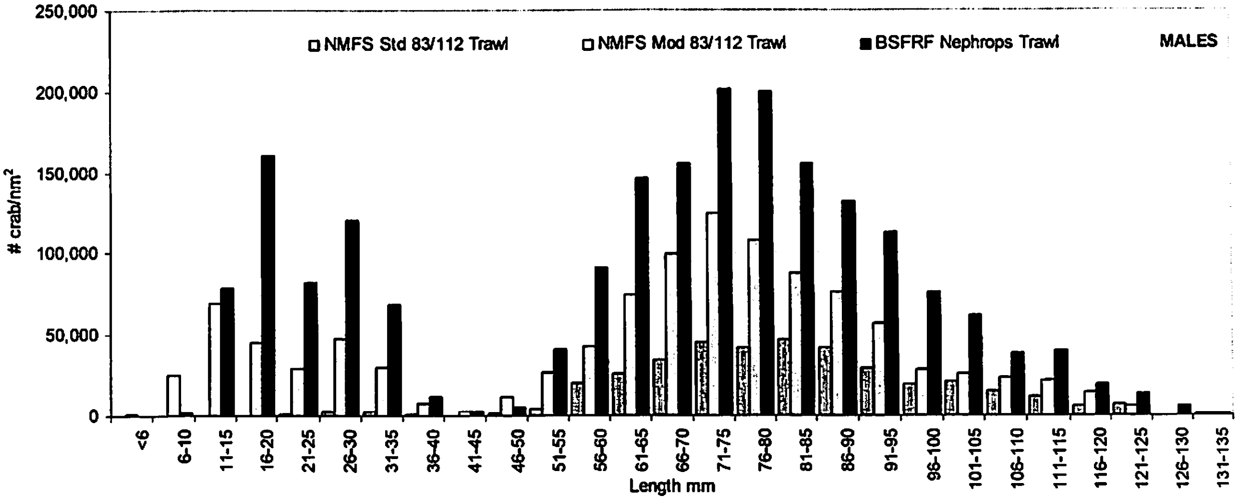


Exhibit 4. Length frequencies of female *opilio* crab binned into 5 mm groups.

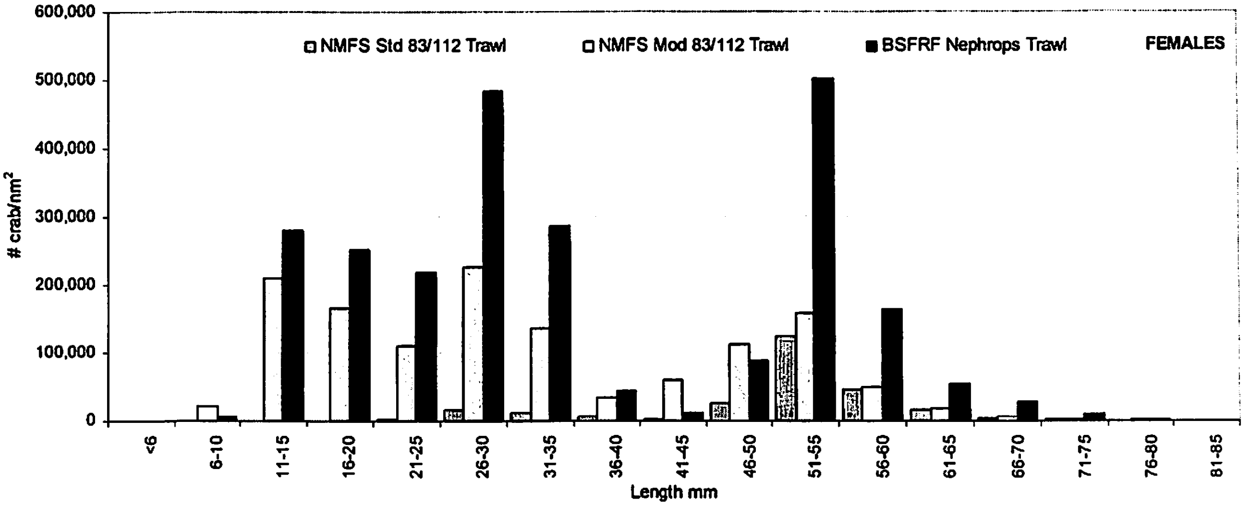


Exhibit 5. Comparison of densities for large male *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment. Net efficiency is defined as the proportion captured within the path of the trawl, which for the NMFS survey trawl for large *opilio* males was 0.35.

LGM	ARC	ALD	AME	Comp Magnitude			Net Efficiency
Tow	A	B	C	B÷A	C÷B	C÷A	A÷C
1	1,684	4,622	9,638	2.7	2.1	5.7	0.17
2	3,959	2,792	3,724	0.7	1.3	0.9	1.06
3	1,962	3,769	2,205	1.9	0.6	1.1	0.89
4	1,831	4,291	5,352	2.3	1.2	2.9	0.34
5	2,917	2,831	4,363	1.0	1.5	1.5	0.67
6	2,977	3,985	18,707	1.3	4.7	6.3	0.16
7	10,867	18,596	33,245	1.7	1.8	3.1	0.33
8	904	1,709	0	1.9	NA	NA	NA
9	284	277	662	1.0	2.4	2.3	0.43
10	0	278	0	NA	NA	NA	NA
11	648	0	1,254	NA	NA	1.9	0.52
12	0	271	589	NA	2.2	NA	0.00
13	2,825	3,946	5,731	1.4	1.5	2.0	0.49
14	8,506	8,786	19,213	1.0	2.2	2.3	0.44
15	4,796	8,302	20,233	1.7	2.4	4.2	0.24
16	7,622	11,915	19,878	1.6	1.7	2.6	0.38
17	1,749	5,969	9,839	3.4	1.6	5.6	0.18
18	1,219	1,070	3,159	0.9	3.0	2.6	0.39
19	1,614	831	1,869	0.5	2.3	1.2	0.86
20	298	1,377	1,370	4.6	1.0	4.6	0.22
21	0	0	0	NA	NA	NA	NA
22	0	663	0	NA	NA	NA	NA
23	0	0	1,659	NA	NA	NA	0.00
24	1,403	676	2,282	0.5	3.4	1.6	0.62
TTL	58,065	86,954	164,973	1.5	1.9	2.8	0.35
AVG	2,419	3,623	6,874				

LGM = large opilio males (≥ 102 mm CW)
ARC = F/V *Arcturus* using NMFS 83/112 std survey trawl
ALD = F/V *Aldebaran* using modified NMFS 83/112 std survey trawl
AME = F/V *American Eagle* using BSFRF *nephrops* survey trawl

Exhibit 6. Comparison of densities for medium male *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment. Net efficiency is defined as the proportion captured within the path of the trawl, which for the NMFS survey trawl for medium *opilio* males was 0.27.

MDM	ARC	ALD	AME	Comp Magnitude			Net Efficiency
Tow	A	B	C	B÷A	C÷B	C÷A	A÷C
1	3,367	7,541	16,233	2.2	2.2	4.8	0.21
2	3,959	5,816	14,897	1.5	2.6	3.8	0.27
3	6,130	20,731	20,950	3.4	1.0	3.4	0.29
4	5,798	18,235	34,253	3.1	1.9	5.9	0.17
5	8,166	21,802	43,626	2.7	2.0	5.3	0.19
6	1,786	1,860	11,107	1.0	6.0	6.2	0.16
7	10,867	18,870	66,491	1.7	3.5	6.1	0.16
8	1,808	2,849	6,000	1.6	2.1	3.3	0.30
9	1,419	2,489	7,948	1.8	3.2	5.6	0.18
10	625	1,668	8,634	2.7	5.2	13.8	0.07
11	1,619	2,149	10,657	1.3	5.0	6.6	0.15
12	2,156	2,439	8,243	1.1	3.4	3.8	0.26
13	5,337	5,637	14,327	1.1	2.5	2.7	0.37
14	2,734	7,936	15,058	2.9	1.9	5.5	0.18
15	3,083	5,634	12,718	1.8	2.3	4.1	0.24
16	6,533	7,830	7,178	1.2	0.9	1.1	0.91
17	4,198	9,129	11,684	2.2	1.3	2.8	0.36
18	11,278	11,497	23,375	1.0	2.0	2.1	0.48
19	10,005	12,181	31,152	1.2	2.6	3.1	0.32
20	10,134	12,117	21,242	1.2	1.8	2.1	0.48
21	20,877	20,969	42,508	1.0	2.0	2.0	0.49
22	11,720	17,889	25,086	1.5	1.4	2.1	0.47
23	20,773	32,309	74,104	1.6	2.3	3.6	0.28
24	12,281	66,201	82,912	5.4	1.3	6.8	0.15
TTL	166,654	315,777	610,382	1.9	1.9	3.7	0.27
AVG	6,944	13,157	25,433				

MDM = medium opilio males (78-101 mm CW)
ARC = F/V *Arcturus* using NMFS 83/112 std survey trawl
ALD = F/V *Aldebaran* using modified NMFS 83/112 std survey trawl
AME = F/V *American Eagle* using BSFRF *nephrops* survey trawl

Exhibit 7. Comparison of densities for small male *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment. Net efficiency is defined as the proportion captured within the path of the trawl, which for the NMFS survey trawl for small *opilio* males was 0.13.

SMM	ARC	ALD	AME	Comp Magnitude			Net Efficiency
Tow	A	B	C	B÷A	C÷B	C÷A	A÷C
1	962	8,270	31,958	8.6	3.9	33.2	0.03
2	2,969	19,077	36,178	6.4	1.9	12.2	0.08
3	1,226	20,312	20,399	16.6	1.0	16.6	0.06
4	1,221	7,509	20,337	6.2	2.7	16.7	0.06
5	2,042	2,831	22,436	1.4	7.9	11.0	0.09
6	0	3,985	10,523	NA	2.6	NA	NA
7	1,863	18,596	36,570	10.0	2.0	19.6	0.05
8	9,946	27,919	70,365	2.8	2.5	7.1	0.14
9	15,889	40,107	84,116	2.5	2.1	5.3	0.19
10	9,370	48,939	88,802	5.2	1.8	9.5	0.11
11	10,365	39,292	99,675	3.8	2.5	9.6	0.10
12	15,707	37,131	88,321	2.4	2.4	5.6	0.18
13	5,337	57,211	31,996	10.7	0.6	6.0	0.17
14	3,038	5,385	14,020	1.8	2.6	4.6	0.22
15	1,370	9,192	8,671	6.7	0.9	6.3	0.16
16	1,089	14,298	11,596	13.1	0.8	10.6	0.09
17	2,099	19,310	41,202	9.2	2.1	19.6	0.05
18	5,182	19,786	41,064	3.8	2.1	7.9	0.13
19	3,873	18,549	39,252	4.8	2.1	10.1	0.10
20	5,067	12,944	24,668	2.6	1.9	4.9	0.21
21	18,680	57,822	87,897	3.1	1.5	4.7	0.21
22	9,376	50,685	112,506	5.4	2.2	12.0	0.08
23	21,747	63,996	166,457	2.9	2.6	7.7	0.13
24	8,421	67,552	59,331	8.0	0.9	7.0	0.14
TTL	156,837	670,699	1,248,341	4.3	1.9	8.0	0.13
AVG	6,535	27,946	52,014				

SMM = small opilio males (<78 mm CW)
ARC = F/V *Arcturus* using NMFS 83/112 std survey trawl
ALD = F/V *Aldebaran* using modified NMFS 83/112 std survey trawl
AME = F/V *American Eagle* using BSFRF *nephrops* survey trawl

Exhibit 8. Comparison of densities for large female *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment. Net efficiency is defined as the proportion captured within the path of the trawl, which for the NMFS survey trawl for large *opilio* females was 0.25.

LGF	ARC	ALD	AME	Comp Magnitude			Net Efficiency
Tow	A	B	C	B÷A	C÷B	C÷A	A÷C
1	2,886	7,784	2,536	2.7	0.3	0.9	1.14
2	742	1,396	4,788	1.9	3.4	6.5	0.16
3	736	4,188	3,308	5.7	0.8	4.5	0.22
4	610	1,073	8,028	1.8	7.5	13.2	0.08
5	875	21,802	3,116	24.9	0.1	3.6	0.28
6	595	1,860	585	3.1	0.3	1.0	1.02
7	1,863	18,870	4,433	10.1	0.2	2.4	0.42
8	39,481	45,335	152,184	1.1	3.4	3.9	0.26
9	34,332	44,064	162,934	1.3	3.7	4.7	0.21
10	46,226	35,109	138,754	0.8	4.0	3.0	0.33
11	36,276	68,084	178,035	1.9	2.6	4.9	0.20
12	23,714	30,084	93,031	1.3	3.1	3.9	0.25
13	1,256	845	1,433	0.7	1.7	1.1	0.88
14	911	283	1,039	0.3	3.7	1.1	0.88
15	0	297	1,734	NA	5.8	NA	NA
16	726	681	1,104	0.9	1.6	1.5	0.66
17	350	702	1,845	2.0	2.6	5.3	0.19
18	3,048	802	4,422	0.3	5.5	1.5	0.69
19	645	1,938	10,592	3.0	5.5	16.4	0.06
20	2,086	6,059	9,593	2.9	1.6	4.6	0.22
21	366	953	3,602	2.6	3.8	9.8	0.10
22	670	2,650	6,842	4.0	2.6	10.2	0.10
23	1,298	1,864	3,871	1.4	2.1	3.0	0.34
24	0	1,689	6,846	NA	4.1	NA	0.00
TTL	199,695	298,412	804,654	1.5	2.7	4.0	0.25
AVG	8,321	12,434	33,527				

LGF = large opilio females (≥ 50 mm CW)
ARC = F/V *Arcturus* using NMFS 83/112 std survey trawl
ALD = F/V *Aldebaran* using modified NMFS 83/112 std survey trawl
AME = F/V *American Eagle* using BSFRF *nephrops* survey trawl

Exhibit 9. Comparison of densities for small female *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment. Net efficiency is defined as the proportion captured within the path of the trawl, which for the NMFS survey trawl for small *opilio* females was 0.03.

SMF	ARC	ALD	AME	Comp Magnitude			Net Efficiency
Tow	A	B	C	B÷A	C÷B	C÷A	A÷C
1	4,810	13,622	56,307	2.8	4.1	11.7	0.09
2	2,227	55,490	76,080	24.9	1.4	34.2	0.03
3	1,716	34,800	29,220	20.3	0.8	17.0	0.06
4	916	19,844	25,154	21.7	1.3	27.5	0.04
5	1,167	10,193	75,411	8.7	7.4	64.6	0.02
6	893	3,985	9,354	4.5	2.3	10.5	0.10
7	3,105	22,425	29,921	7.2	1.3	9.6	0.10
8	6,329	64,327	102,547	10.2	1.6	16.2	0.06
9	4,540	59,268	96,038	13.1	1.6	21.2	0.05
10	7,184	121,098	138,754	16.9	1.1	19.3	0.05
11	8,097	97,003	160,482	12.0	1.7	19.8	0.05
12	3,080	58,814	87,732	19.1	1.5	28.5	0.04
13	1,884	139,405	94,079	74.0	0.7	49.9	0.02
14	1,823	14,171	20,251	7.8	1.4	11.1	0.09
15	685	19,866	17,343	29.0	0.9	25.3	0.04
16	726	24,510	11,596	33.8	0.5	16.0	0.06
17	1,749	62,847	105,158	35.9	1.7	60.1	0.02
18	305	16,043	30,956	52.6	1.9	101.6	0.01
19	323	20,487	29,283	63.5	1.4	90.7	0.01
20	298	14,871	9,593	49.9	0.6	32.2	0.03
21	366	18,109	116,716	49.4	6.4	318.7	0.00
22	335	69,529	145,194	207.6	2.1	433.6	0.00
23	0	2,175	103,967	NA	47.8	NA	0.00
24	0	38,008	52,485	NA	1.4	NA	0.00
TTL	52,557	1,000,889	1,623,619	19.0	1.6	30.9	0.03
AVG	2,190	41,704	67,651				

SMF = small opilio females (< 50 mm CW)
ARC = F/V *Arcturus* using NMFS 83/112 std survey trawl
ALD = F/V *Aldebaran* using modified NMFS 83/112 std survey trawl
AME = F/V *American Eagle* using BSFRF *nephrops* survey trawl

Exhibit 10. Chart of densities by tow for large male *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment.

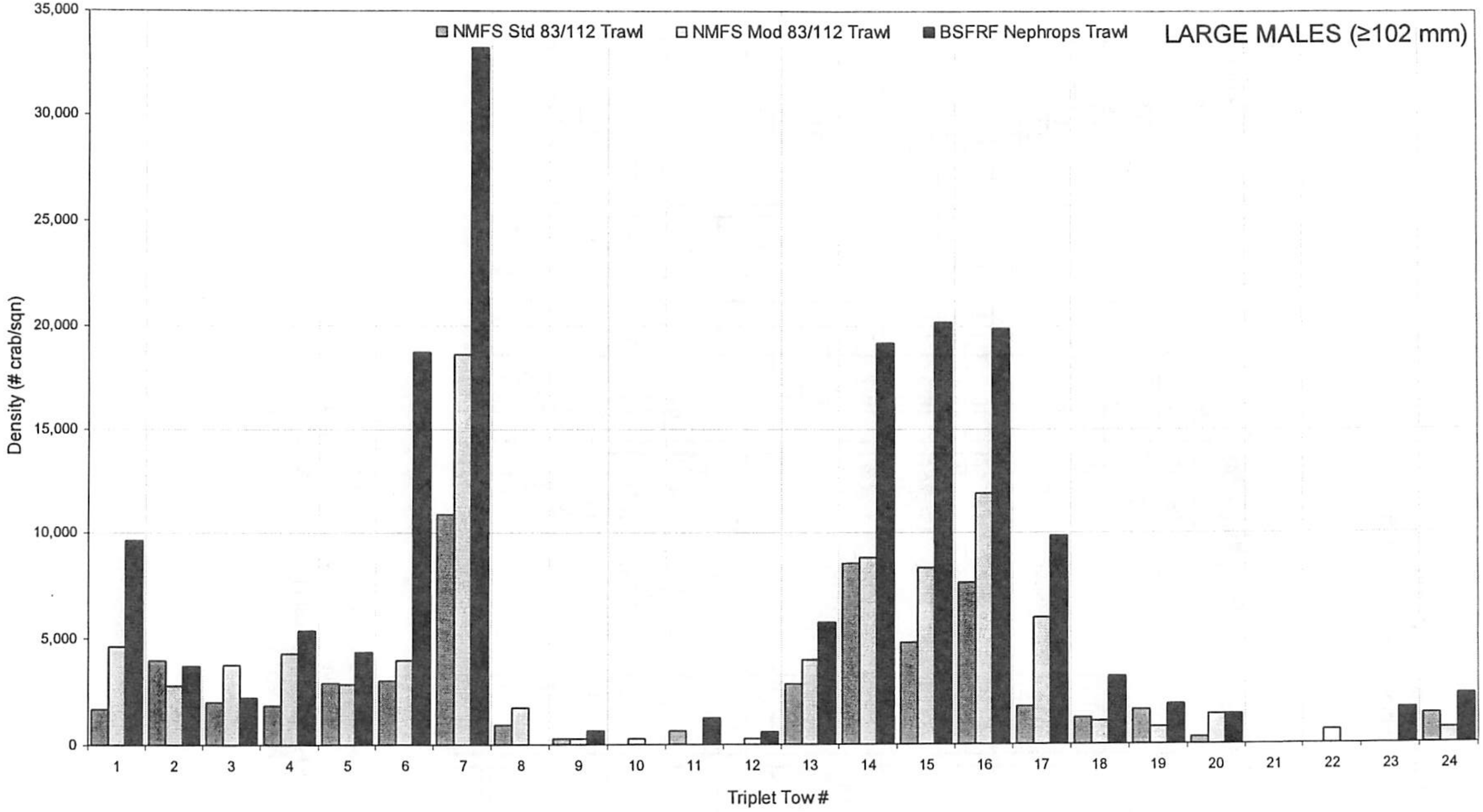


Exhibit 11. Chart of densities by tow for medium male *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment.

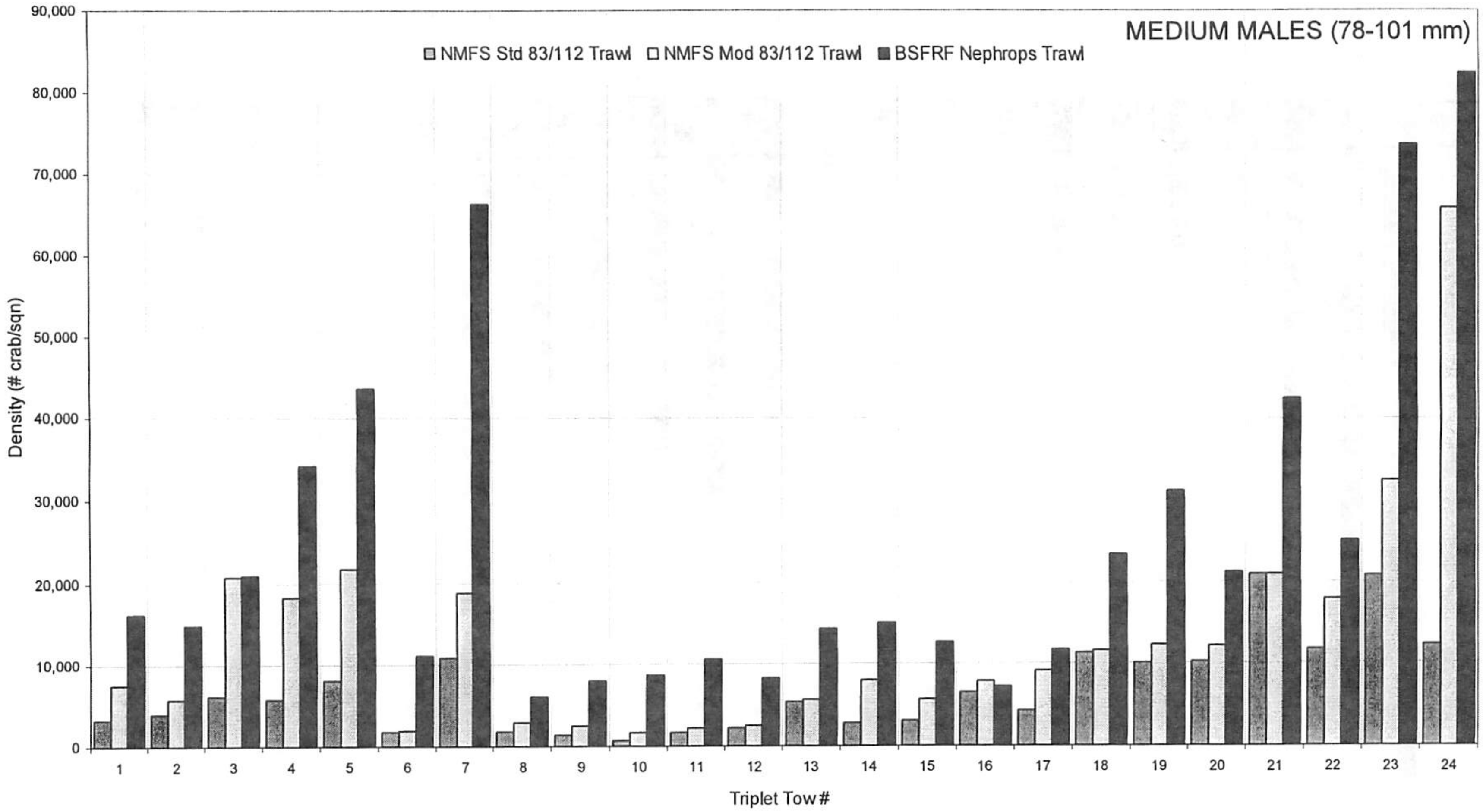


Exhibit 12. Chart of densities by tow for small male *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment.

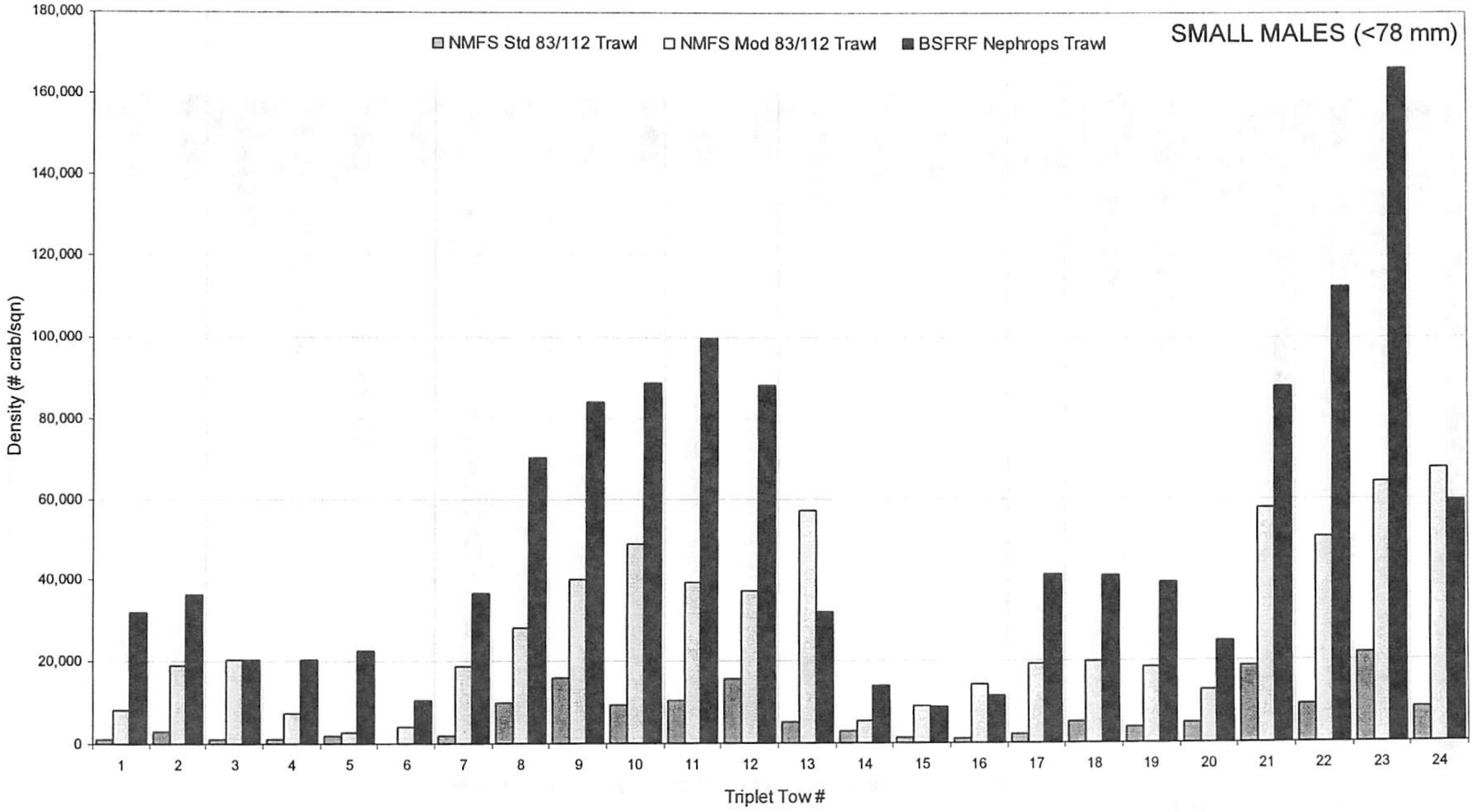


Exhibit 13. Chart of densities by tow for large female *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment.

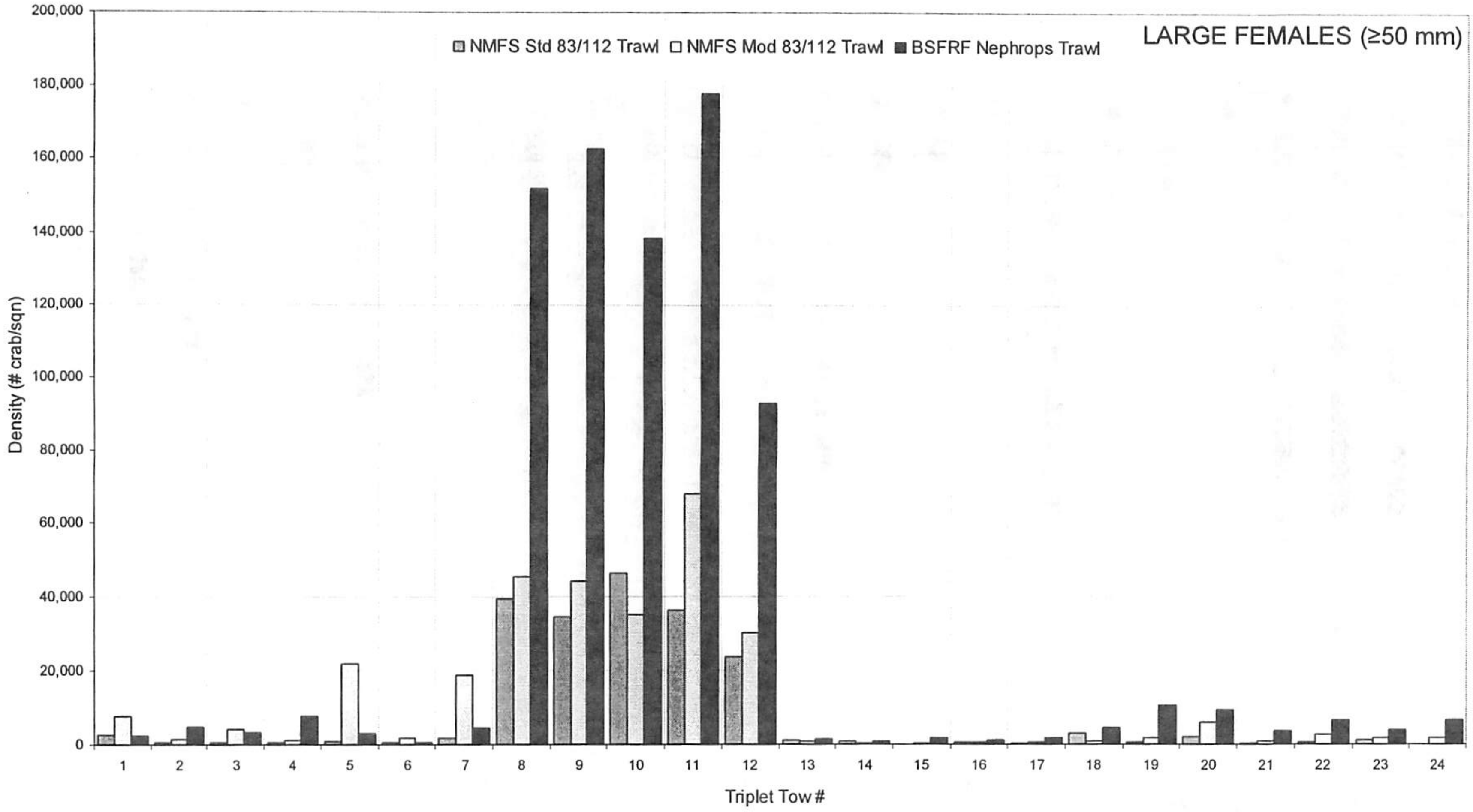


Exhibit 14. Chart of densities by tow for small female *opilio* (#crab/nm2) during 2009 *opilio* net efficiency experiment.

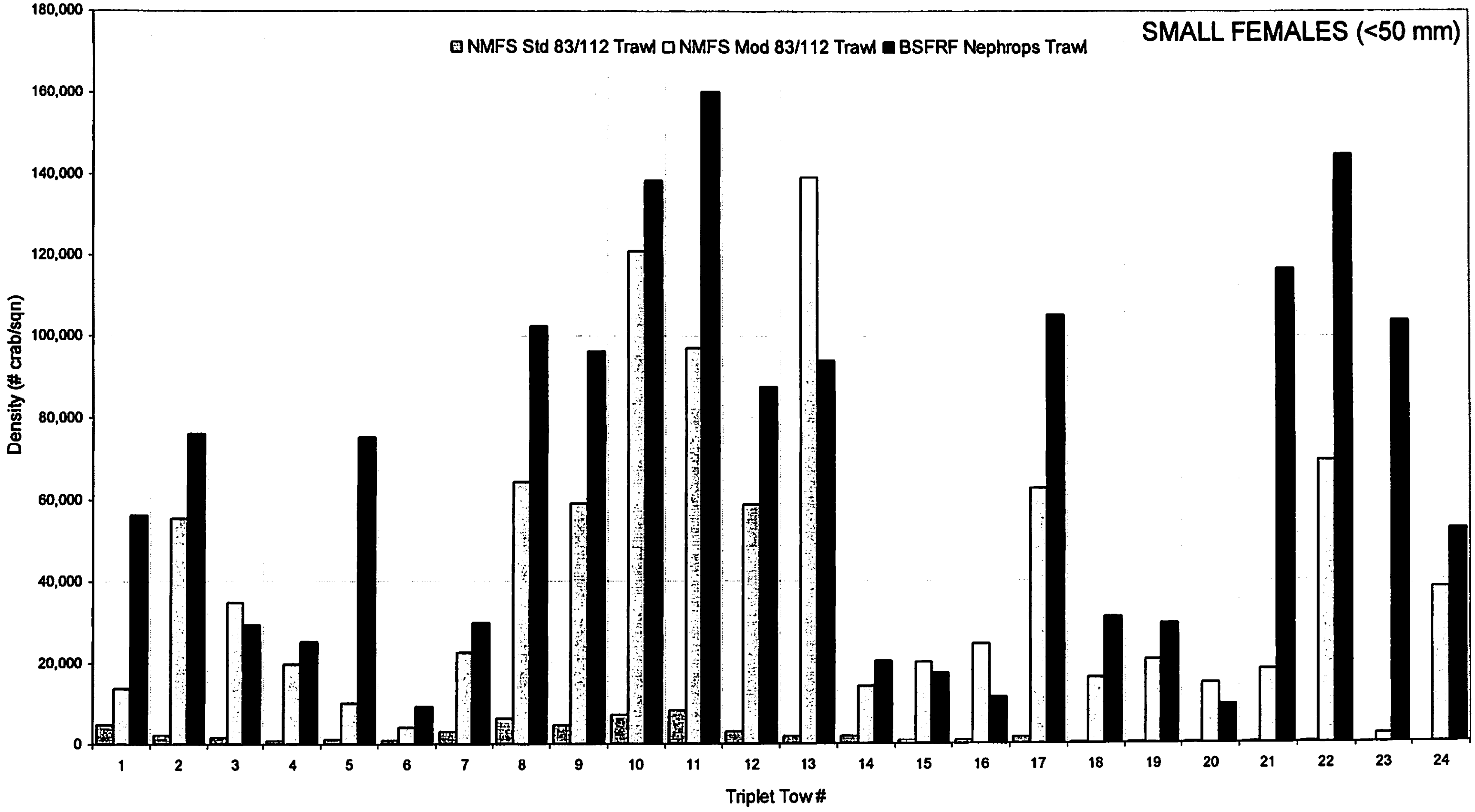
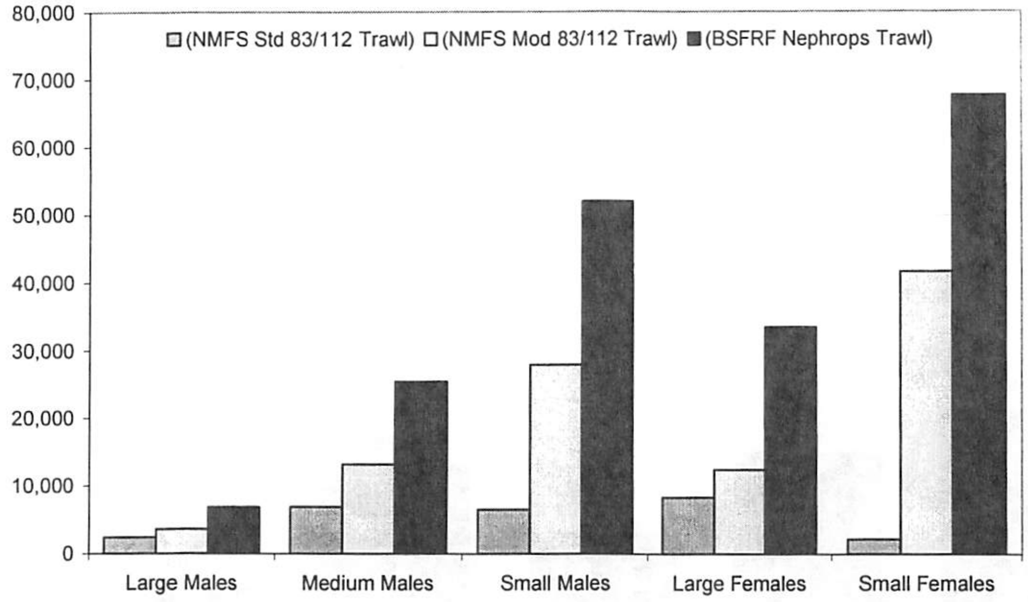
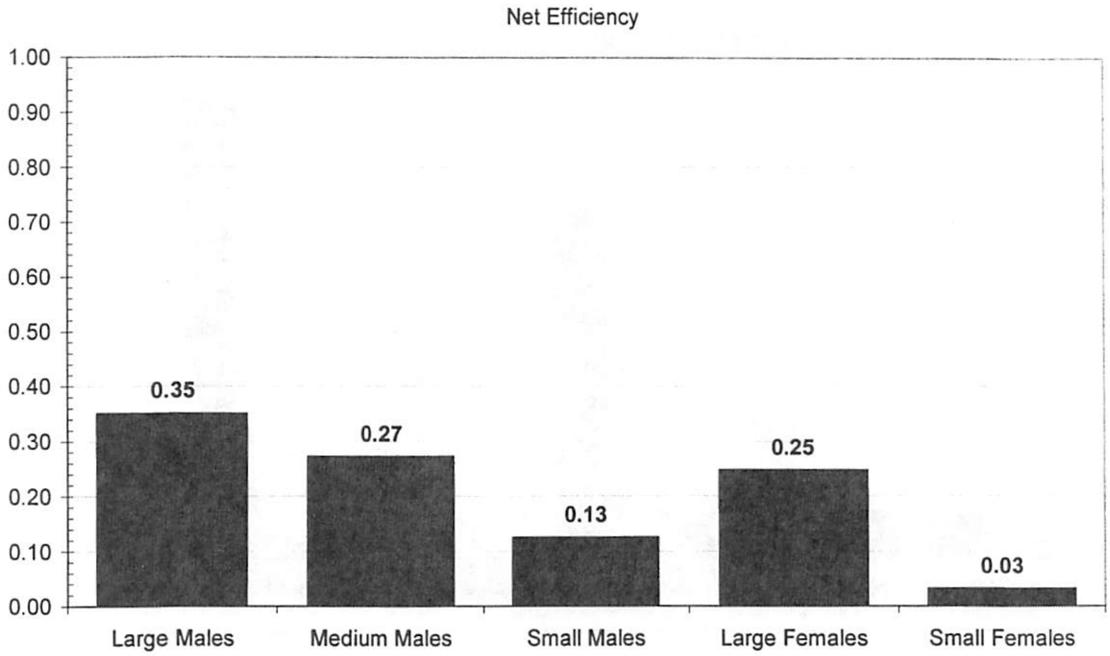


Exhibit 15. Chart and table of average densities for all tows (#crab/nm2) by size and sex category during 2009 *opilio* net efficiency experiment.



	Density Averages from 24 Side by Side Tows (crab/nm^2)		
Opilio Size Sex Category	*F/V Arcturus* (NMFS Std 83/112 Trawl)	*F/V Aldebaran* (NMFS Mod 83/112 Trawl)	*F/V American Eagle* (BSFRF *Nephrops* Trawl)
Large Males (≥ 102 mm)	2,419	3,623	6,874
Medium Males (78-101 mm)	6,944	13,157	25,433
Small Males (< 78 mm)	6,535	27,946	52,014
Large Females (≥ 50 mm)	8,321	12,434	33,527
Small Females (< 50 mm)	2,190	41,704	67,651
Total Opilio (All Sizes)	26,409	98,864	185,499

Exhibit 16. Net efficiency by size and sex category for NMFS standard trawl based on results of 2009 *opilio* net efficiency experiment.



Opilio Size Sex Category	Density Averages from 24 Side by Side Tows (crab/nm^2) *F/V Arcturus* (NMFS Std 83/112 Trawl)	*F/V American Eagle* (BSFRF *Nephrops* Trawl)	Net Efficiency *F/V Arcturus : F/V American Eagle*
Large Males (≥ 102 mm)	2,419	6,874	0.35
Medium Males (78-101 mm)	6,944	25,433	0.27
Small Males (< 78 mm)	6,535	52,014	0.13
Large Females (≥ 50 mm)	8,321	33,527	0.25
Small Females (< 50 mm)	2,190	67,651	0.03

Bering Sea Snow Crab Assessment Model Sensitivity to Survey Selectivity

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January 22, 2010

This document presents results of various runs of the Bering Sea snow crab assessment model under different assumptions regarding survey selectivity and natural mortality. Projections evaluating rebuilding are also presented for some model scenarios. Model runs presented here use different data and model weighting than the September 2009 snow crab assessment. Model runs use the "new" survey data, and likelihood weighting of the observed coefficients of variation on survey biomass with no added weight as recommended by the Crab Plan Team (September 2009 assessment used higher weighting on survey biomass likelihood). The new survey data biomass estimates are on average about 87% of the old survey data due to the actual measured net width used (which are larger) instead of a fixed 50 ft net width.

Somerton et al. 2010 (NPFMC document) estimated a survey selectivity curve for male snow crab using the 108 tows conducted by BSFRF in 2009 compared to the standard NMFS survey tows in the same areas (Figure 1). The curve estimated by Somerton was a three parameter model,

$$Selectivity = \frac{a}{1 + e^{(-(b + c * \text{carapace width}))}}$$

Parameter estimates were: a = 0.8418, b= -2.6466 and c = 0.0354. This curve has a selectivity of 0.76 at 140mm and +/- 95% Confidence Interval of 0.56 to 0.95. Somerton et al. 2010, did not present analyses for female snow crab survey selectivity, although preliminary analyses indicate selectivity would be estimated higher than for males of the same size.

The maximum length bin in the snow crab model is 130-135mm cumulative length bin. Survey selectivity by length (same as carapace width) is estimated in the snow crab model as a 3 parameter equation, Q, size at 50% selected and size at 95% selected,

$$\text{Selectivity}_l = \frac{Q}{1 + e^{\left\{\frac{-\ln(19)(l - l_{50\%})}{(l_{95\%} - l_{50\%})}\right\}}}$$

In model runs presented, Q was fixed at a range of values from 0.55 to 0.95 to evaluate model fit. These values correspond to the 95% confidence interval around the best estimate of maximum selectivity from Somerton et al. 2010 of 0.76 (95% C.I., 0.56, 0.95) (Figure 1). While the Q was fixed, the size at 50% and size at 95% parameters were estimated in the model for the three time periods 1978-1981, 1982-1988, and 1989 to 2009. Survey selectivity was fixed to be the same for males and females. Values lower and higher than the 95% C.I. were run to compare the likelihood values of Q=0.32 estimated from the side by side experiment(BSFRF report) and to determine where the best fitting model occurred (Table 1 and Figure 2). The best fit (lowest likelihood) occurs at about Q=1.2. As Q declines the model fit degrades substantially. The difference in likelihood at Q = 0.76 is 130 more than at the best fitting Q=1.2. Q = 0.85 is would be approximately equivalent to the September 2009 assessment using the old survey data and Q=1.0 based on the average difference in net widths alone.

Another approach to fitting survey selectivity is to use a prior distribution on Q with mean equal to the Somerton et al. 2010 estimate of 0.76 and the estimated standard deviation of 0.1 assuming a normal distribution (95% C.I. 0.56 to 0.95). The model estimated Q = 1.09 with this prior, slightly less than where the best fit is using fixed Q.

When the complete survey selectivity curve was fixed at the Somerton et al. 2010 curve for both males and females, the fit was considerably worse (5108 total likelihood) than at any of the runs with fixed Q only (Table 1). The assessment model estimate of survey selectivity for the 1989 to 2009 period that gives the best fit to the data is flat down to about 40 mm compared to the Somerton et al. 2010 curve which declines as size decreases (Figure 1).

The fit to the male and female survey biomass improves as fixed Q increases to 1.2 (Figures 3 and 4). The new survey data and changes to weighting factors used in the model runs presented here result in a fit to female biomass that is lower than the observed biomass relative to the September 2009 assessment. The fit to the female survey biomass time series improves as Q increases. The fit to female survey biomass is very poor when the Somerton et al. 2010 selectivity is used in the model (Figure 4). Applying the Somerton et al. 2010 selectivity curve results in a lower capture probability for mature female crab than mature male crab due to their smaller size. Mature female snow crab are generally in the size range of 45-65mm. If selectivity is lower for animals in this size range, we would expect to see lower overall numbers of females in the survey data than males if recruitment and natural mortality are similar. The average abundance over the 1978 to 2009 time period shows the ratio of female to male crab is approximately 1.27 to 1 (Figure 5). The average abundance by length for male snow crab is highest in the 40 to 65 mm range. This size range is also the highest abundance by length for of female snow crab due to their terminal molt at maturity. While a lower abundance of males would be expected due to added fishing mortality, this difference is an average of about 600 million crab (female mean abundance = 2,807 million, mean male abundance=2,219 million), more than can be accounted for by the directed male fishery. If male and female abundance were equal in the survey data, this would imply a similar selectivity for mature females (45-65mm) as for males (45-135mm). The declining survey selectivity curve estimated by Somerton et al. 2010 results in much lower selectivity for female crab than male crab due to size differences that if true, implies that the expected female:male sex ratio in the population would need to be much higher than observed in the survey data.

Somerton et al. 2010 also discusses issues that may result in spatial differences in catchability of the standard survey net, due to bottom type and depth. In many years in the survey data, a few large catches of female snow crab account for a large percentage of the survey abundance estimate. For illustration, in the 2004 survey the highest 3 tows in the survey accounted for about 40% of the abundance of females > 50mm. If females tend to aggregate more than males, and the probability of capture is higher when females are aggregated, then this may account for the flat survey selectivity estimated in the model that gives the best fit to the data. This could be explored further by examining the distribution of tows with high abundance using the 1978 to 2009 time series.

Estimating Natural Mortality

The snow crab assessment current has immature male and female M = 0.23, mature female M = 0.29 and mature male M=0.23. The higher M for mature females is a recommendation by the workshop on OFL revisions (2006) and the crab plan team. Survey selectivity was fixed at the Somerton et al. 2010 curve for both males and females and natural mortality estimated. One model scenario estimated one M for males and one M for females. Estimating M improved the total likelihood from 5108 to 4218 (Table 2). The natural mortality estimated for females was 0.28 and for males 0.45 (Table 2). The value of M=0.45 is not plausible for males given the current information on longevity from tagging data of Canadian snow crab. If male natural mortality is fixed at 0.23, female M is estimated lower at 0.16 (total likelihood = 4661).

Estimating Survey Selectivity Separately for Males and Females

Difference in survey selectivity may result from different behavior of male and female snow crab, or differences in spatial distribution of males and females and selectivity of the survey net due to bottom type or depth. Separate survey selectivity curves were fit for females and males for all three time periods in the model. This adds 9 additional parameters to the model. Natural mortality was fixed at mature female M =0.29, mature male = 0.23 and immature crab M=0.23. The results vary by time period (Figures 6 and 7). The earliest time period has the maximum selectivity bounded by 1.2, as selectivity was not estimated well and went to much higher values. Female selectivity was estimated lower than males at sizes less than 60 mm. The 1981 to 1988 period female selectivity was estimated to be slightly less than males with a maximum of about 1.05 for males and 0.95 for females. The later period from 1989 to 2009 female selectivity was estimated higher than males (Figure 7 has the 1989 to 2009 selectivities only for ease of viewing) (maximum about 1.27 compared to male maximum of 1.0). The selectivity remains near the maximum for both males and females until about 50 mm where it begins to decline. Increasing the survey selectivity of females relative to males improves the female fit to the survey biomass. The higher survey selectivity for females in the 1989-2009 period results in an improved fit to the male and female survey biomass (Figures 8 and 9). Model runs with female Q higher than male Q and natural mortality = 0.23 for all crab result in better fits to the female survey biomass than with survey selectivity equal for males and females. Figures 8 and 9 include runs were female Q was fixed to be 1.0 and 1.1 with male Q fixed at 0.85 and natural mortality fixed to be the same for all crab at 0.23..

Rebuilding Projections

Projections for fixed Q values of 0.85, 0.75 and 0.65 were run to evaluate the sensitivity of reference points and rebuilding times to Q (Tables 3, 4 and 5, and Figures 10 and 11). The survey Q was fixed the same for all three time periods in the model and both sexes with the size at 50% and at 95% estimated by the model. B35% increases from 298 million lbs at Q=0.85, to 310 million lbs at Q=0.75 and to 327 million lbs at Q=0.65. F35% declines as Q declines, from 0.8 at Q=0.85, to 0.78 at Q=0.75, and to 0.75 at Q=0.65. In all three scenarios, the stock would not have rebuilt to B35% within the 10 year time frame. The mean biomass using the new survey data declines from 2009/10 to 2012/13 and then increases thereafter. The time to rebuild (two consecutive years above B35% with > 50% probability) is 2017/18 for Q=0.85, 2016/17 for Q=0.75 and 2015/16 at Q=0.65. While MMB was projected to be above B35% in 2009/10 with Q=0.65, MMB declined over the next few years.

Literature Cited

Somerton, D., K. Wenberg and S. Goodman. 2010. Review of the research to estimate snow crab selectivity by the NMFS trawl survey. Report to NPFMC January 2010.

Table 1. Total likelihood, survey length frequency likelihood and survey biomass likelihood for a range of fixed maximum survey selectivity (Q). Male and female survey selectivity set equal and selectivity at 50% and selectivity at 95% parameters estimated by the model. Some likelihood components not shown may be negative, so that the sum of survey length likelihood and survey biomass likelihood may be greater than the total likelihood. Somerton et al. 2010 run is with survey selectivity fixed for both males and females at the logistic curve estimated in the Somerton et al. 2010 using the 108 additional tows conducted by BSFRF.

Q fixed	Total Likelihood	Survey Length	Survey biomass
0.32	4679.18	4217.81	520.075
0.55	4245.50	4083.99	336.708
0.65	4130.45	4051.91	280.521
0.75	4046.38	4026.95	236.346
0.85	3987.72	4007.53	204.147
0.95	3949.25	3992.78	182.557
1.1	3920.70	3977.46	166.719
1.2	3916.78	3970.70	165.273
1.3	3922.39	3966.05	169.887
1.4	3935.85	3963.09	179.711
Q=1.09 estimated in model with prior mean = 0.76, s.d. =0.1	3917.32	3973.63	163.096
Somerton Selectivity fixed	5108.15	4556.89	710.472

Table 2. Model runs with survey selectivity fixed at the Somerton et al. 2010 estimated curve and with natural mortality fixed and estimated.

	Total Likelihood	Male M	Female M	
Somerton selectivity fixed	5108.15	Fixed 0.23	Fixed 0.29	
Somerton selectivity fixed	4218.87	Estimated 0.45	Estimated 0.28	
Somerton selectivity fixed	4661.85	Fixed 0.23	Estimated 0.16	

Table 3. Rebuilding projections at 75% F35% for Q=0.85. B35% = 298.3, F35% = 0.80. Prob. 2 yr. > B35% is the probability of rebuilding to two years in a row above B35%.

	Total catch	Lower 95% C.I. total catch	Upper 95% C.I. total catch	Retained catch	Maximum F (full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Total survey mature biomass	prob B35%	prob 2yr >B35%
2009	53.7	53.4	54.1	48.0	0.45	240.5	163.4	398.2	0.083	0
2010	53.0	21.3	96.7	47.7	0.45	226.0	155.4	384.0	0.083	0.017
2011	42.4	19.5	75.2	38.0	0.41	208.2	135.4	374.1	0.083	0.017
2012	37.3	18.1	65.8	32.4	0.39	205.0	118.8	387.1	0.083	0.017
2013	51.5	25.4	89.1	44.3	0.46	237.0	142.5	447.8	0.117	0.017
2014	74.8	32.5	142.1	65.4	0.52	283.7	189.5	527.1	0.351	0.058
2015	89.9	31.3	193.4	79.6	0.54	317.3	222.5	586.3	0.504	0.311
2016	96.1	28.3	222.6	85.3	0.54	335.4	235.3	621.5	0.58	0.452
2017	98.7	25.0	236.8	87.4	0.53	349.4	241.6	646.3	0.651	0.53
2018	103.5	23.4	241.4	91.6	0.54	363.4	250.6	669.2	0.712	0.603

Table 4. Rebuilding projections at 75% F35% for Q=0.75. B35% = 310.4 million lbs, F35% = 0.78. Prob. 2 yr. > B35% is the probability of rebuilding to two years in a row above B35%.

	Total catch	Lower 95% C.I. total catch	Upper 95% C.I. total catch	Retained catch	Maximum F (full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Total survey mature biomass	prob B35%	prob 2yr >B35%
2009	53.8	53.5	54.2	48.0	0.37	285.4	193.6	399.8	0.289	0
2010	67.0	28.3	112.7	60.4	0.48	257.7	185.6	387.2	0.289	0.088
2011	50.8	23.7	89.1	45.5	0.43	232.0	154.6	369.2	0.289	0.088
2012	43.4	21.5	75.8	37.5	0.41	225.7	132.5	378.2	0.289	0.088
2013	58.7	29.3	98.2	50.1	0.47	259.7	157.0	435.8	0.324	0.09
2014	83.5	37.3	155.5	72.6	0.52	311.3	208.2	512.2	0.53	0.158
2015	99.5	35.1	212.9	87.7	0.54	348.7	245.0	569.2	0.653	0.428
2016	106.0	31.8	243.9	93.6	0.54	368.3	259.0	601.7	0.709	0.555
2017	108.3	27.7	258.5	95.5	0.53	382.6	265.3	623.0	0.768	0.619
2018	112.8	26.0	260.7	99.5	0.54	396.0	274.0	641.4	0.805	0.689

Table 5. Rebuilding projections at 75% F35% for Q=0.65. B35% = 327.3 million lbs, F35% = 0.75. Prob. 2 yr. > B35% is the probability of rebuilding to two years in a row above B35%. MMB is above B35% in 2009/10, however, declines until 2012, so the probability of being above B35% two years in a row is still below 0.5 until 2015/16.

	Total catch	Lower 95% C.I. total catch	Upper 95% C.I. total catch	Retained catch	Maximum F (full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Total survey mature biomass	prob B35%	prob 2yr >B35%
2009	54.0	53.6	54.4	48.0	0.29	347.4	235.6	404.2	0.614	0
2010	86.0	38.4	134.8	77.6	0.51	301.3	227.4	393.1	0.614	0.256
2011	62.6	29.4	106.4	56.0	0.45	264.5	181.4	366.3	0.614	0.256
2012	51.8	25.7	89.2	44.6	0.42	253.9	151.4	370.8	0.614	0.256
2013	68.3	34.6	110.7	57.9	0.48	290.4	176.8	424.8	0.64	0.257
2014	94.8	43.9	173.9	81.9	0.52	348.2	233.5	497.6	0.762	0.337
2015	111.7	40.1	237.2	97.9	0.53	390.2	274.7	551.4	0.834	0.587
2016	118.4	36.3	270.7	104.1	0.53	411.0	290.0	580.4	0.87	0.684
2017	120.1	31.2	286.9	105.5	0.52	424.9	295.8	597.2	0.886	0.742
2018	124.0	29.1	285.6	108.8	0.52	436.7	303.4	610.3	0.905	0.781

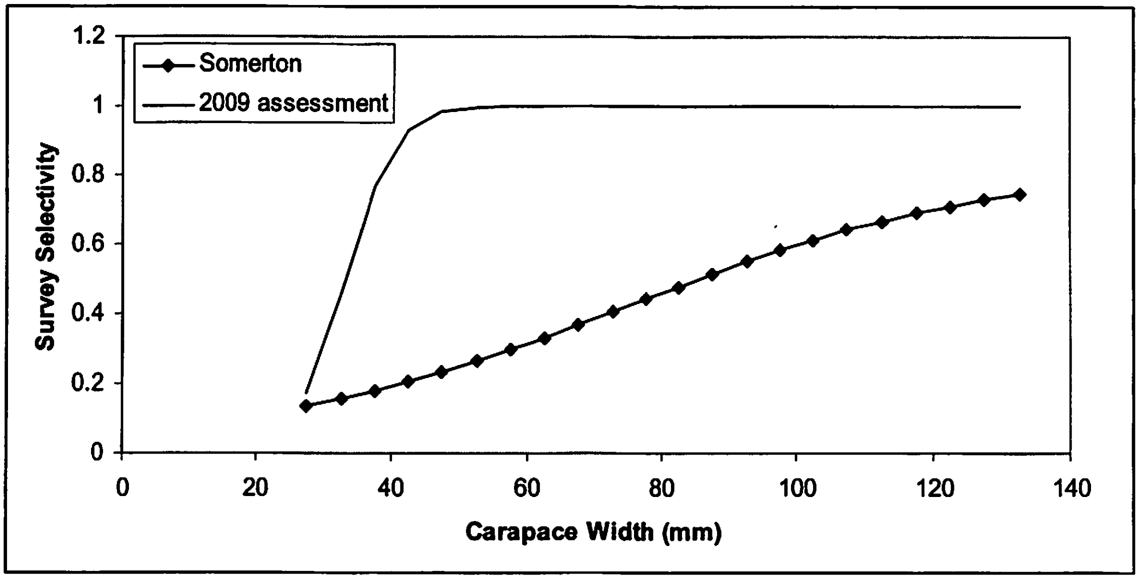

Figure 1. Survey selectivity estimated for the period 1989 to 2009 in the 2009 assessment and the survey selectivity curve estimated by Somerton et al. 2010 from the 108 tows by BSFRF and NMFS standard survey tows.

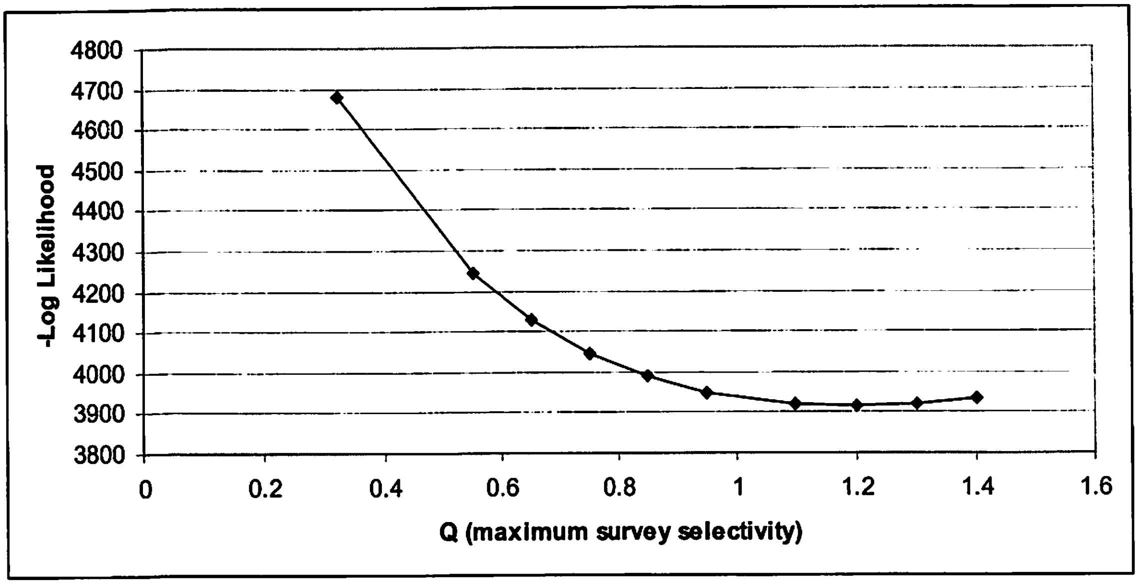

Figure 2. Total likelihood values at fixed maximum survey selectivity (Q) from 0.32 to 1.4. Best fit occurs at the lowest values at about Q=1.2.

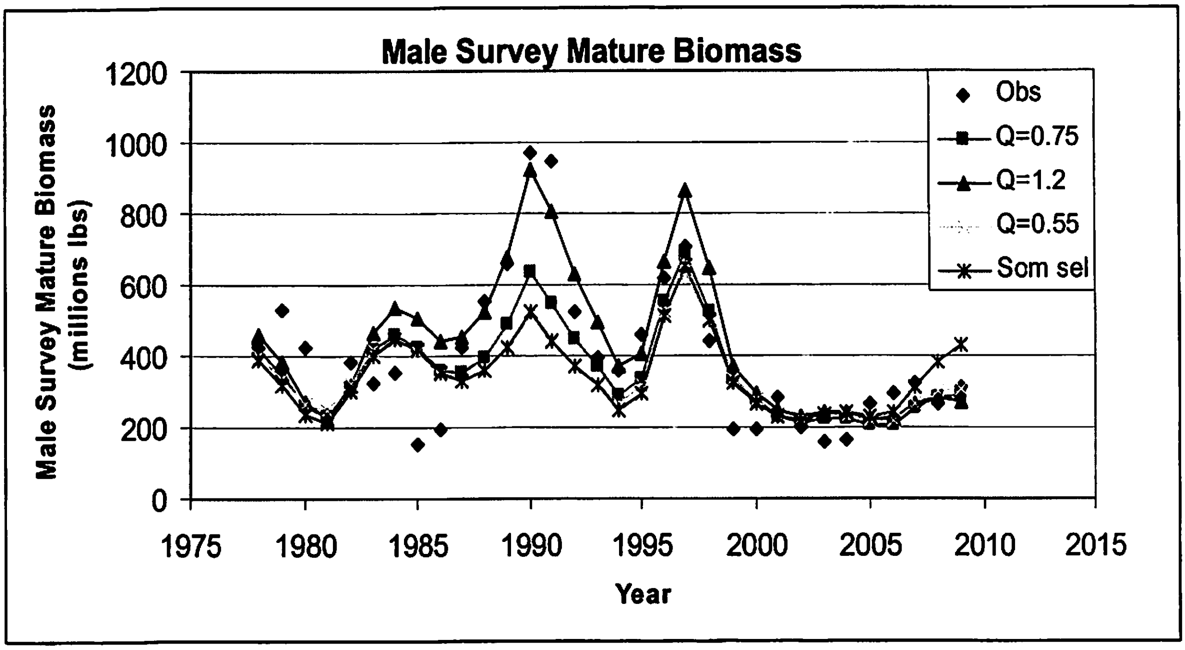

Figure 3. Fit to male mature survey biomass for various levels of fixed Q and for Somerton et al. 2010 selectivity curve.

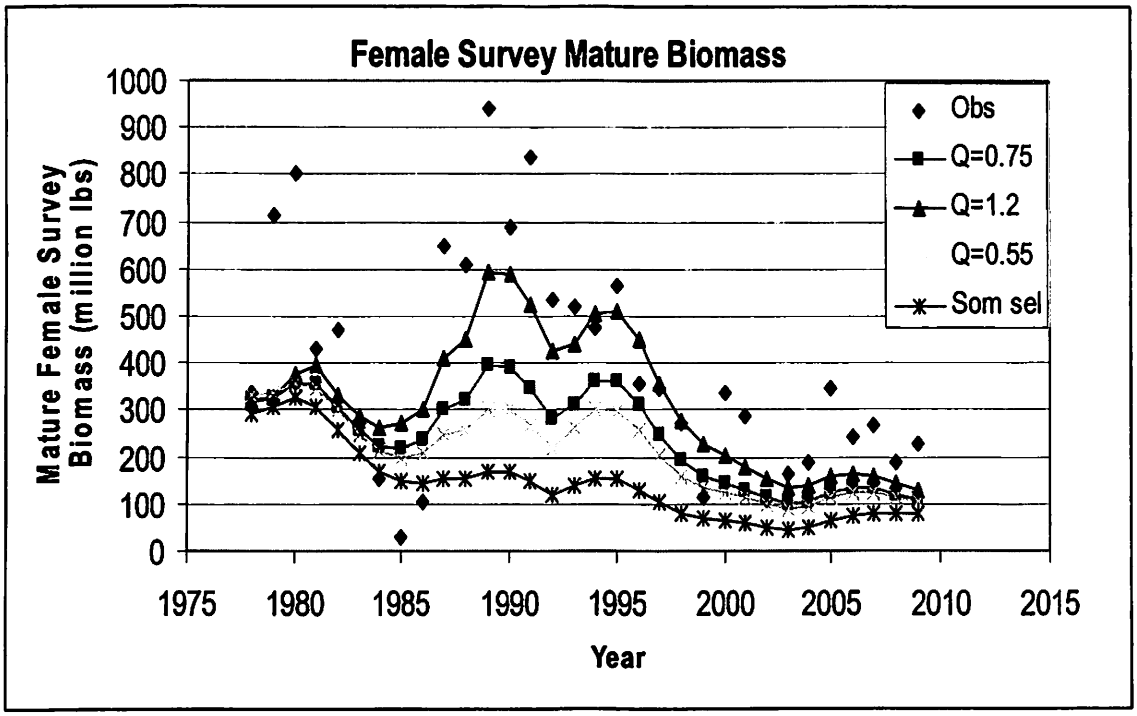

Figure 4. Fit to female mature survey biomass for various levels of fixed Q and for Somerton et al. 2010 selectivity curve.

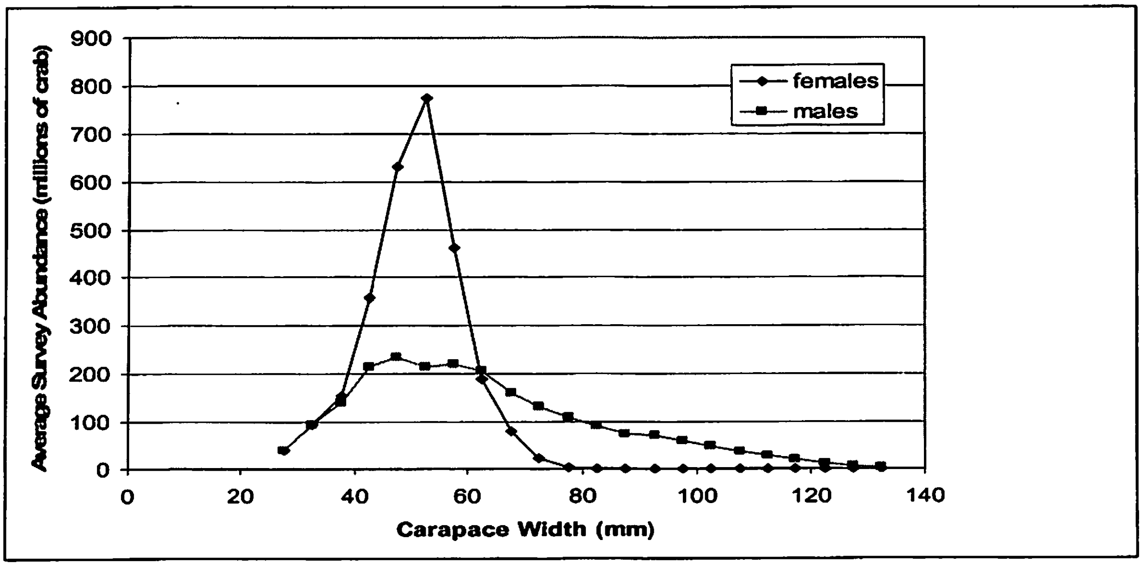

Figure 5. Average observed survey abundance by length from 1978 to 2009 for male and female snow crab.

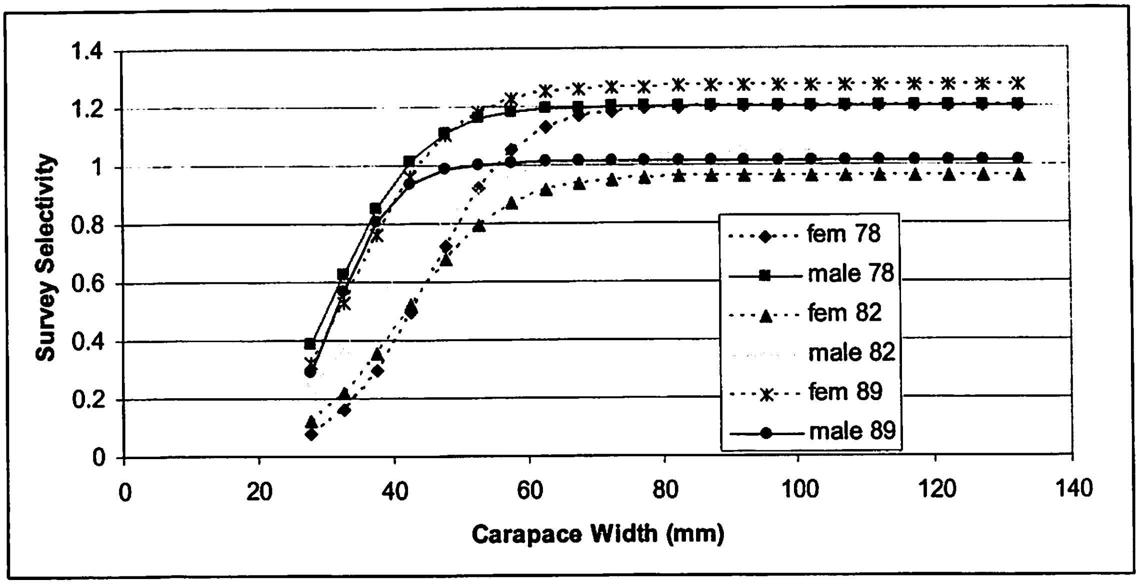

Figure 6. Survey selectivity curves estimated separately for males and females and three time periods. Three parameters were estimated for each curve: 1) Q, 2) size at 50% selected, 3) size at 95% selected. Except the early period 1978-1981 where Q was bounded by 1.2.

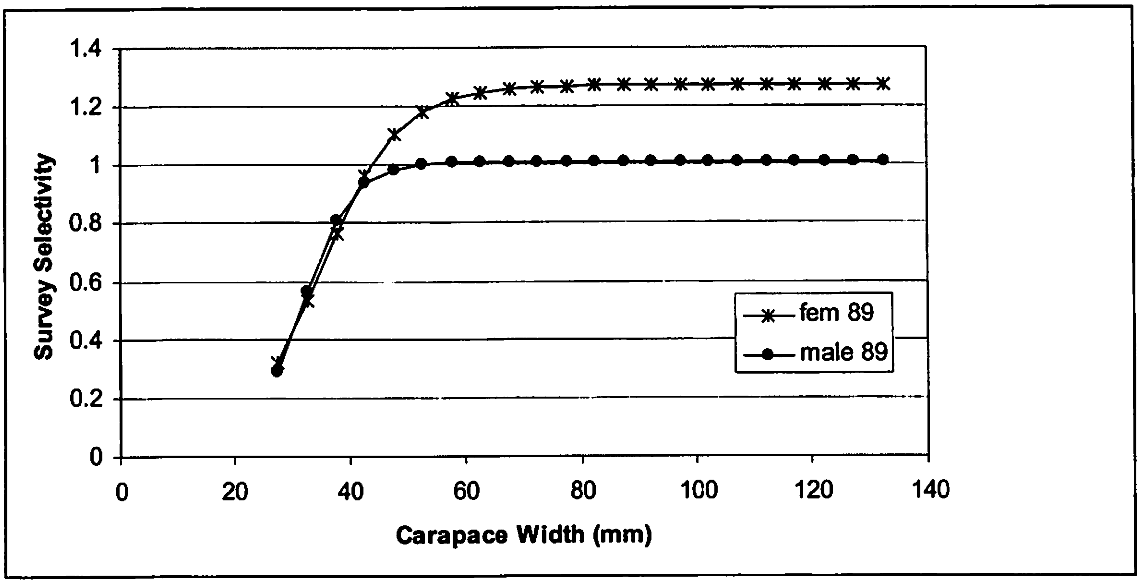

Figure 7. Survey selectivity estimated for males and females separately for 1989-2009.

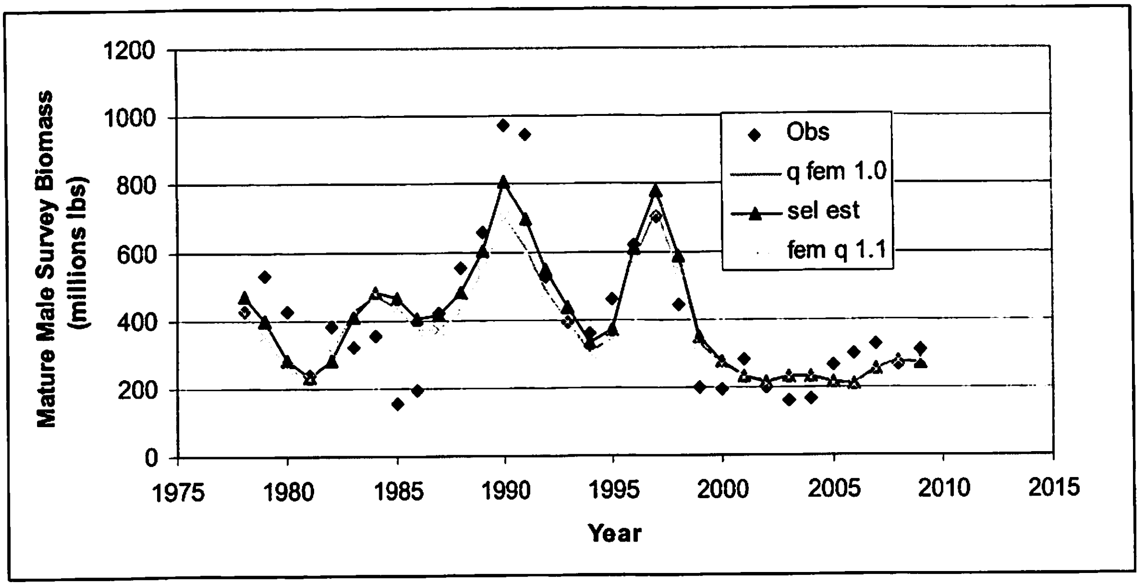

Figure 8. Fit to Mature male survey biomass with survey selectivity estimated separately for male and females (sel est). The curves marked q fem 1.0 and q fem 1.1 have all natural mortality = 0.23 and male Q fixed at 0.85.

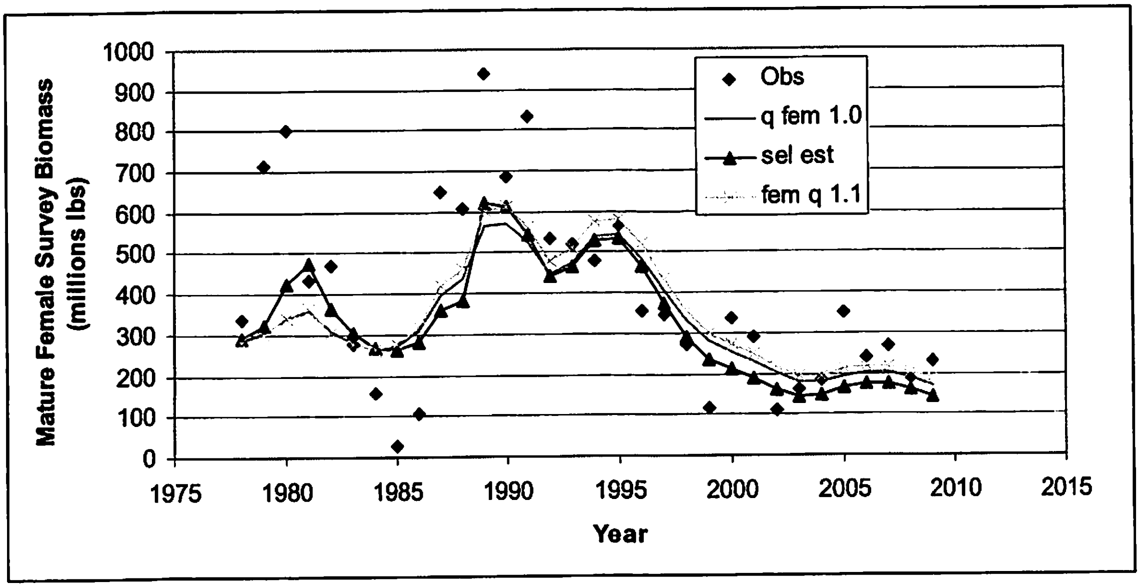

Figure 9. Fit to Mature female survey biomass with survey selectivity estimated separately for male and females (sel est). The curves marked q fem 1.0 (female Q fixed at 1.0) and q fem 1.1(female Q fixed at 1.1) have all natural mortality = 0.23 and male Q fixed at 0.85.

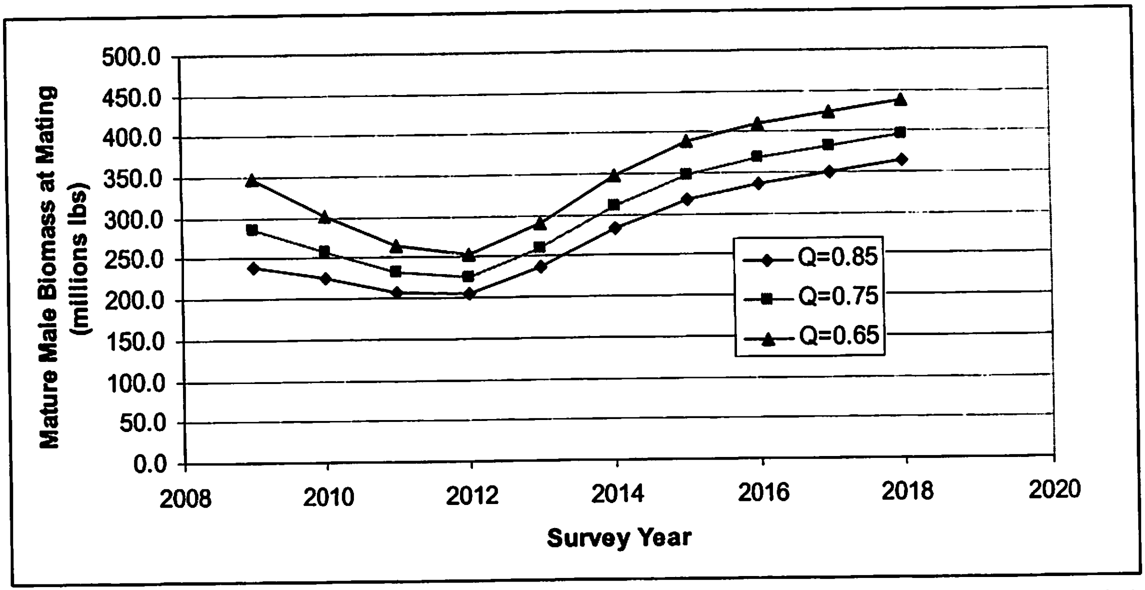

Figure 10. Mature male biomass at mating fishing at 75% F35% projected from 2009/10 to 2018/19 for three values of fixed Q: 0.85, 0.75 and 0.65.

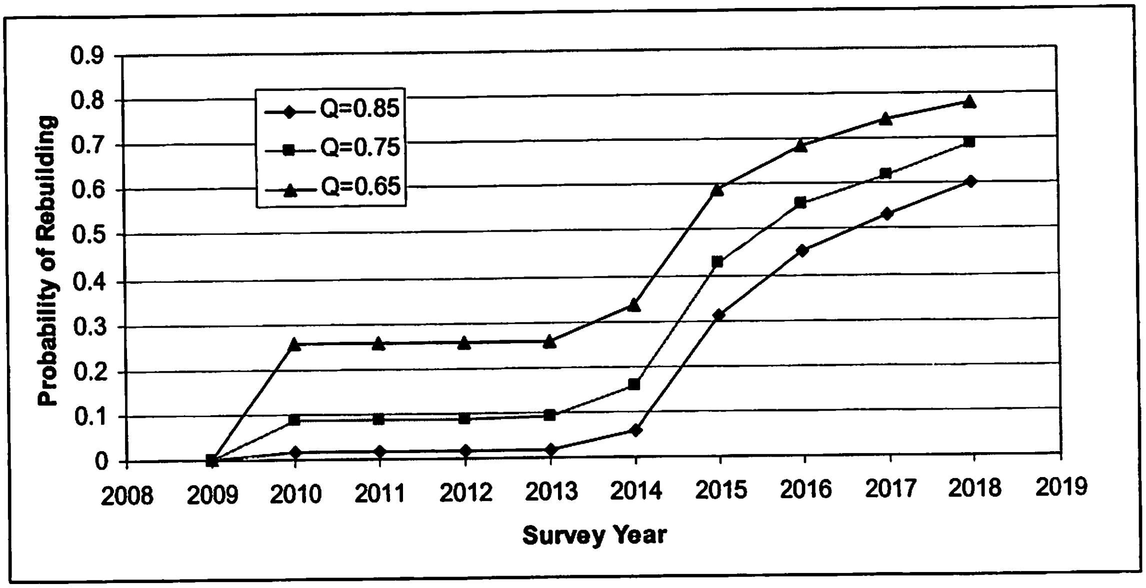

Figure 11. Probability of rebuilding fishing at 75% F35% projected from 2009/10 to 2018/19 for three values of fixed Q: 0.85, 0.75 and 0.65.

Progress Report on Snow crab assessment model estimation of survey Q with added 2009 Industry survey

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February 2, 2010

An industry survey of 108 tows in 27 survey stations (10,827 sq nm) in the Bering Sea was conducted in summer 2009(see Somerton et al 2010). Abundance estimates by length as well as survey biomass for the study area for the industry tows as well as the NMFS tows were added to the stock assessment model as an additional survey. Survey selectivities were estimated using logistic curves for males and females for the NMFS standard survey in the entire Bering Sea area, the industry tows in the study area and the NMFS tows in the study area. Likelihood equations were added to the model for fits to the length frequency by sex for the industry tows in the study area and the NMFS tows in the study area. A likelihood equation was also added for fit to the mature biomass by sex in the study area for the industry tows and NMFS tows separately.
The maximum selectivity for the NMFS study area was estimated by the product of the Q for the NMFS Bering Sea area and the Q for the Industry survey in the study area. The Q for the industry survey in the study area was assumed to represent the fraction of crab available in the study area relative to the entire Bering Sea. The maximum catchability of the industry net in the study area was assumed to be 1.0. A separate Q for females was estimated from the male Q for the NMFS survey in the entire Bering Sea and for the NMFS survey in the study area. The maximum survey selectivity (Q) estimated for the entire Bering Sea area in Somerton et al. 2010 was estimated at 0.76 at 140 mm.

For male survey selectivity,

Industry survey sel = Q (availability) * logistic selectivity
NMFS survey sel in study area = Q(availability)* Q (entire Bering Sea) * logistic sel
NMFS survey entire Bering sea = Q (entire Bering Sea) * logistic sel

Each logistic selectivity was estimated with two parameters.

The abundance estimated by the industry survey in the study area was 66.9 million male crab >=100 mm compared to 36.7 million for the NMFS net (Table 1). The NMFS abundance of females >=50mm (121.5 million) was greater than the industry abundance estimate in the study area (113.6 million). The abundance of male crab in the entire Bering sea survey for 2009 was greatest in the 30 – 60mm size range (Figure 1). The abundance of crab in the 35 to 60mm size range for the industry net in the study area was very low compared to the abundance of the same size range for the NMFS entire Bering Sea survey. The differences in abundance by size for the NMFS entire Bering Sea survey and the Industry study area are due to availability of crab in the study area as well as capture probability. While the abundance of larger male crab for the NMFS net in the study area is less than for the Industry, the abundance of females >45 mm is greater for the NMFS net than the Industry. This difference may be due to towing in different places for the two nets within the study area, or to higher catchability of females due to aggregation behavior. The ratio of abundance of the NMFS net and Industry net in the study area are quite different for males and females (Figure 3). The ratio of abundance indicates a catchability for mature females (mainly 45 – 65 mm) that is greater than 1.0.

The largest tows for small crab in the entire Bering Sea area were north of the study area near St. Matthew Island (Figures 4, 5 and 6). Some higher tows for large males (>=100mm) and for mature females occurred in the study area as well as outside the study areas. These distributions indicate the availability of crab throughout the Bering Sea.

Survey selectivities were estimated for two models, one with no added weight (weight = 1) on the survey biomass fit in the study area, and another with a relatively high weight (50) (Figures 7 and 10). The higher weight on survey biomass fit in the study area results mainly in a better fit to the industry male mature biomass, however, poorer fit to the entire Bering Sea survey length and biomass (Table 3, Figures 8 and 11). The estimate of survey Q for male crab was 0.81 (compare to 0.76 estimated by Somerton et al 2010 using a logistic function) using the higher weight to fit the study area survey biomass (Table 2). The Q was higher (1.05) for a weight of 1.0 on the study area survey biomass fit. Female Q was estimated higher than male Q at 1.24 for the weight 1.0 model and 1.11 with the higher weight model.

Figures 9 and 12 show the fits to the length frequency of male and female crab in the study area for the industry and NMFS tows. Fits to the entire Bering Sea survey biomass for the weight 1.0 model are shown in Figures 13 and 14.

Table 1. Abundance estimates of females and males by size groups for the industry net in the study area, the NMFS net in the study area, and the NMFS survey of the entire Bering Sea. Mature abundance uses a maturity curve.

		Females			Males	
	>25mm	>50mm	mature	>25mm	mature	>100
Industry Study	585.3	113.6	129.4	422.9	200.9	66.9
NMFS Study	150.2	121.5	120.5	119.2	76.9	36.7
NMFS Bering Sea	1773.5	828.7	1,143.9	1,225.0	463.8	147.2

Table 2. Q estimates (maximum survey selectivity) using logistic selectivity curves for the entire Bering Sea (BS) by sex for the NMFS survey and for the Study area with the Industry net and the NMFS net. An added weight 50 on the likelihood equation to fit the biomass in the study area decreased the Q from 1.05 to 0.81 for the NMFS Bering Sea survey.

	Weight 50 Study area biomass	Weight 1.0 Study area biomass
Male Q NMFS BS	0.81	1.05
Q Indust study area	0.36	0.37
Q NMFS Study area	0.29	0.39
Fem Q NMFS BS	1.11	1.24

Table 3. Likelihood values for model run with weight 1 on study area biomass fit and weight 50.

Likelihood	wgt 1	wgt 50
survey length	3978.33	4013.13
survey biomass	146.51	158.819
total	3867.58	4028.72

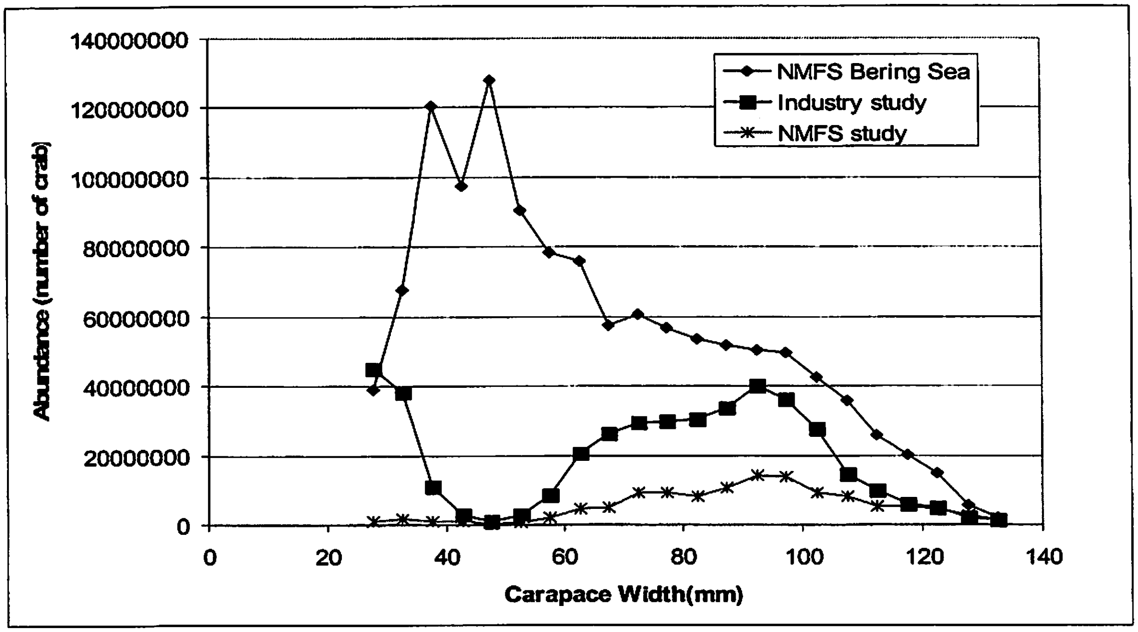

Figure 1. Abundance estimates of male snow crab by 5 mm carapace width(>=25mm) for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the industry net in the study area (108 tows) and the NMFS survey in the study area.

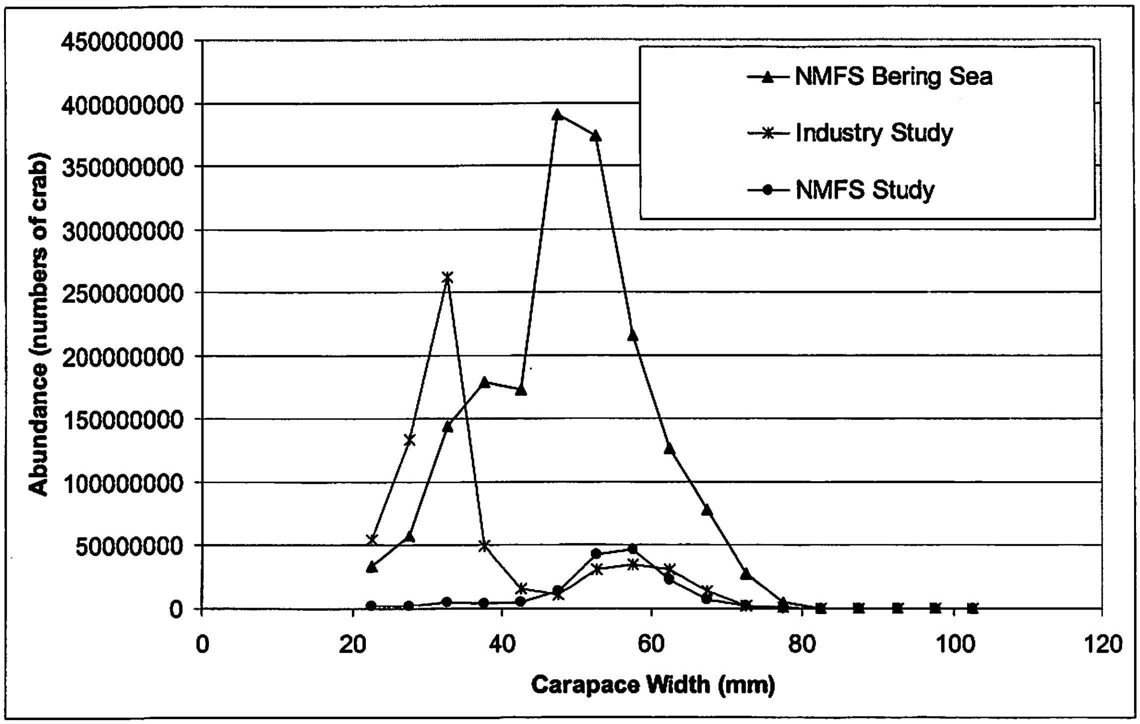

Figure 2. Abundance estimates of female snow crab by 5 mm carapace width for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the industry net in the study area (108 tows) and the NMFS survey in the study area.

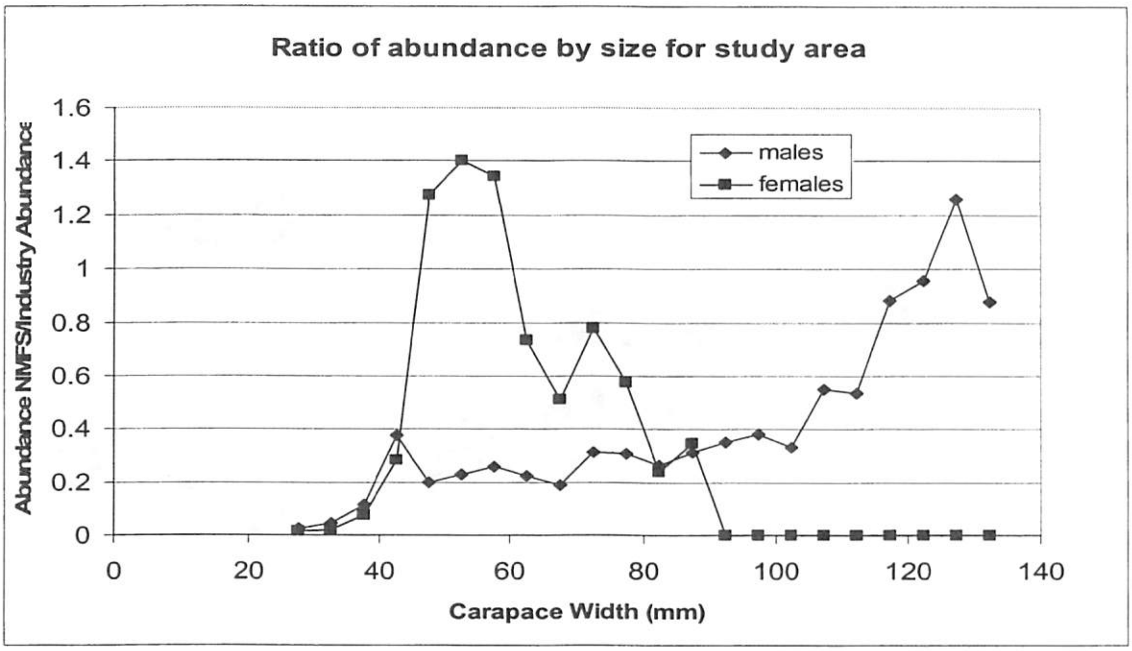

Figure 3. Ratio of abundance in the study area from the NMFS net to the Industry net for male and female crab.

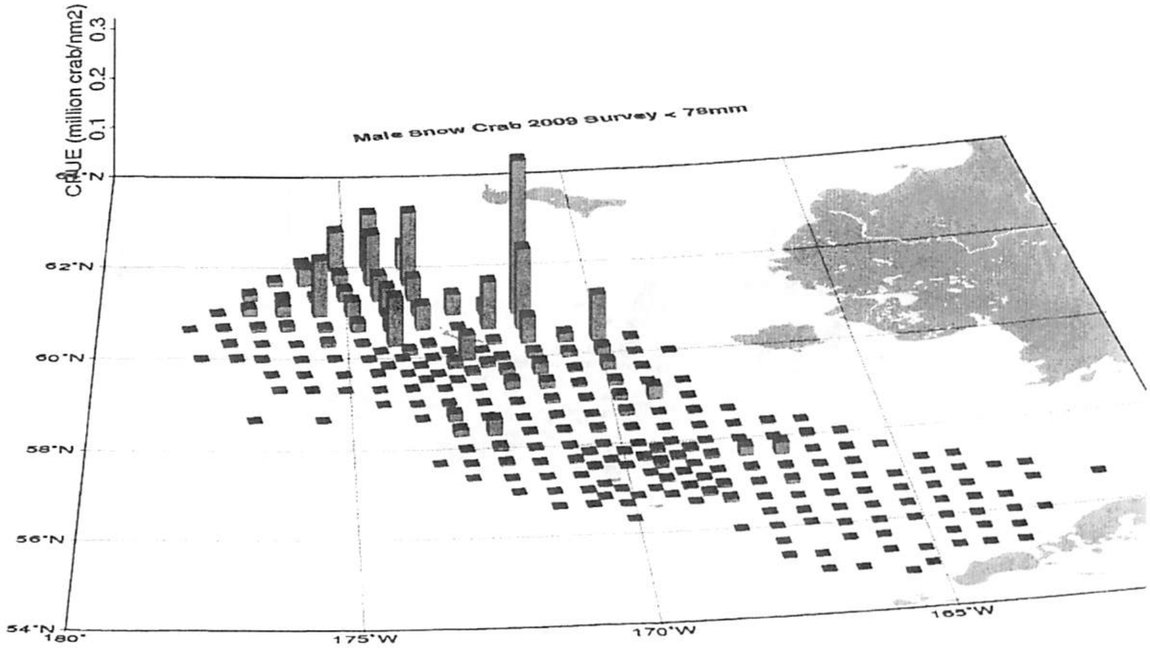

Figure 4. 2009 Survey CPUE (million crab per nm2) of males < 78 mm by tow.

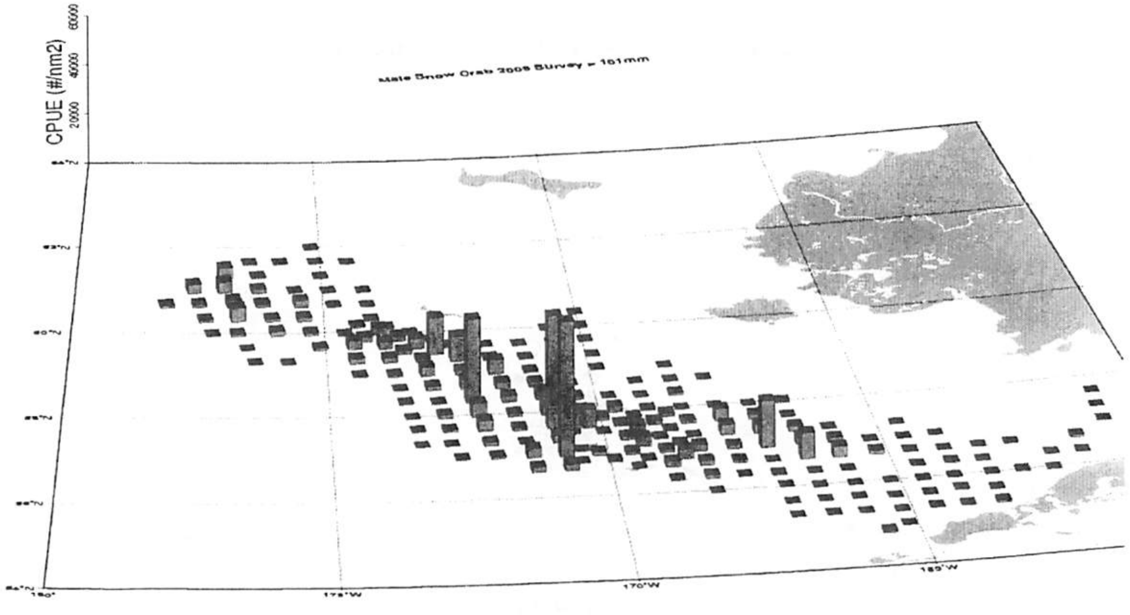

Figure 5. 2009 Survey CPUE (number per nm2) of males > 101 mm by tow.

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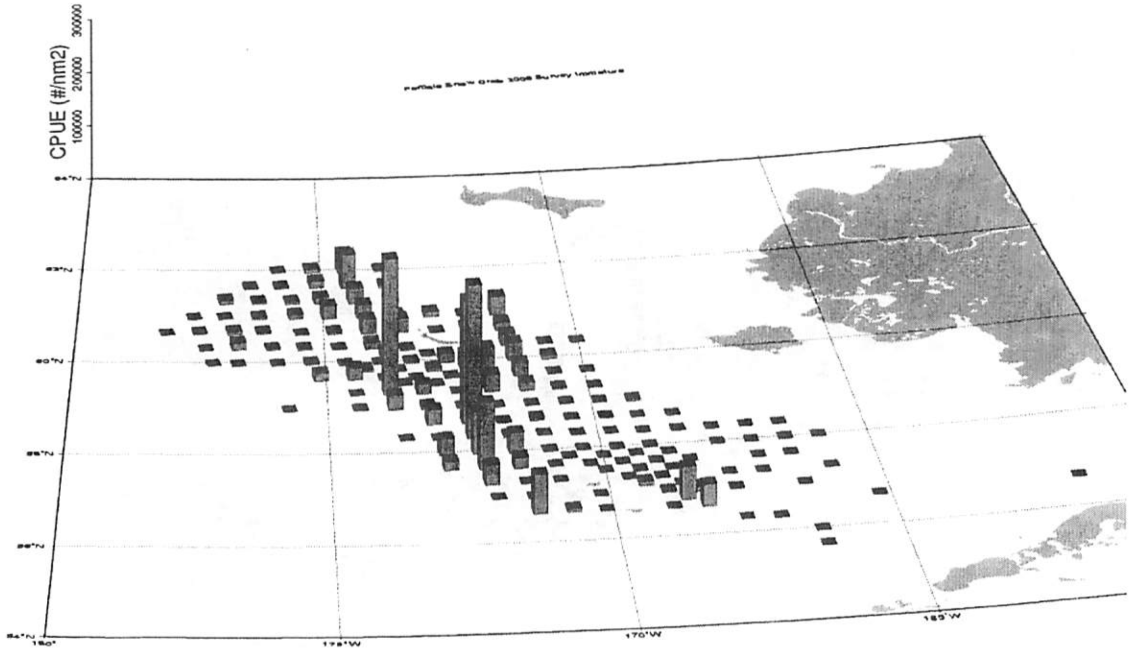

Figure 6. Female survey cpue by haul for mature females with eggs. Scale not same as other plots.

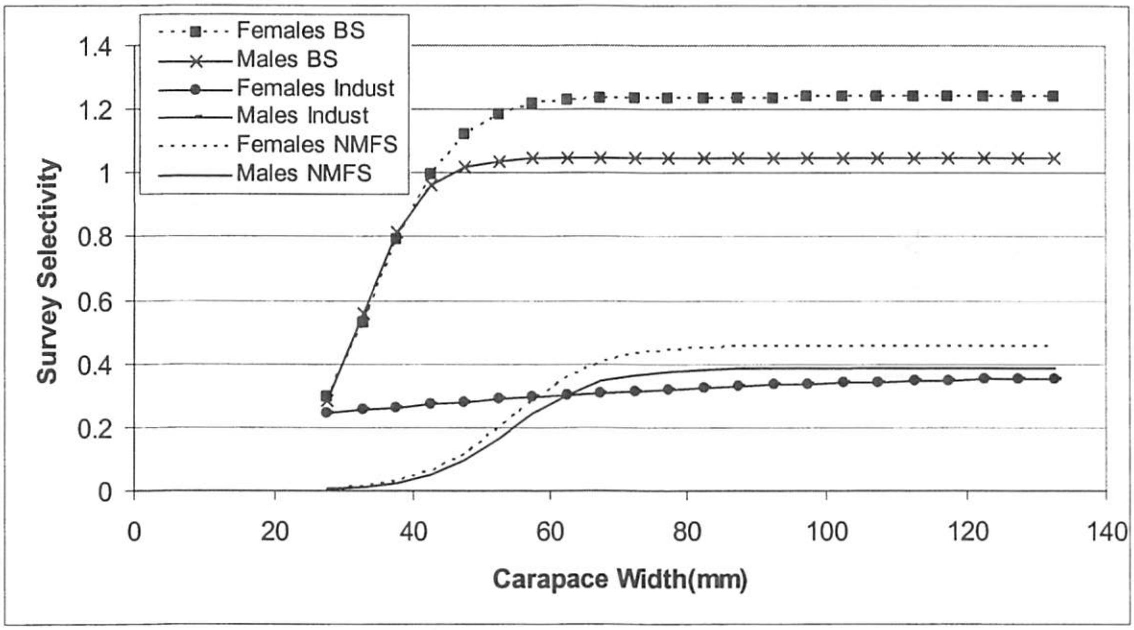

Figure 7. Survey selectivity curves fit to NMFS entire Bering sea by sex (Females BS and Males BS), the Industry study area survey (Females Indust, Males Indust) and the NMFS survey in the study area (Females NMFS, Males NMFS). Survey biomass likelihood weight 1.0.

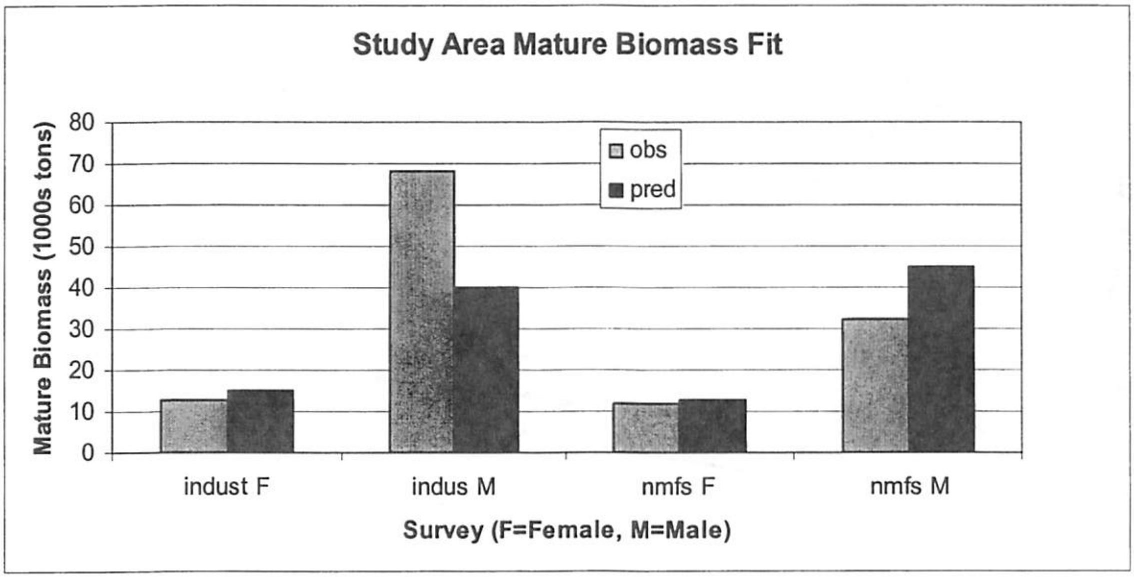

Figure 8. Fit to mature biomass by sex in the Study area for the Industry net (indust F females and Indus M males) and the NMFS net (nmfs F females and nmfs M males). Survey biomass likelihood weight 1.0.

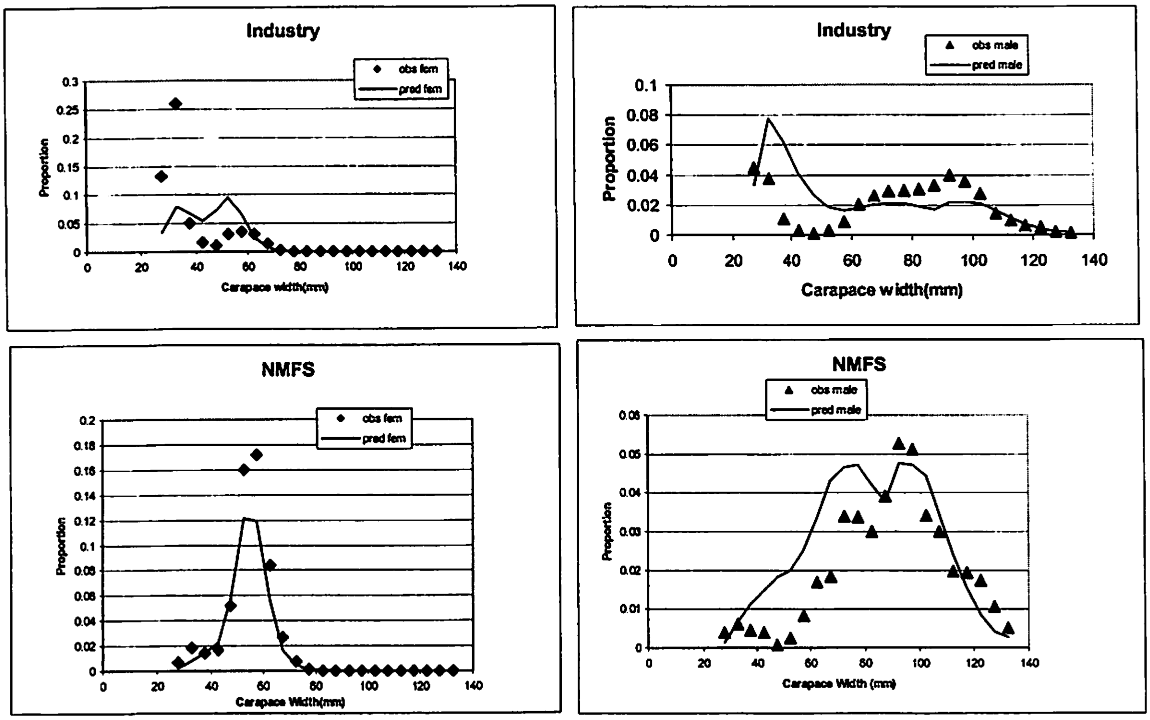

Figure 9. Fits to study area length frequency for industry and NMFS tows female and male crab. Weight study area biomass 1.0.

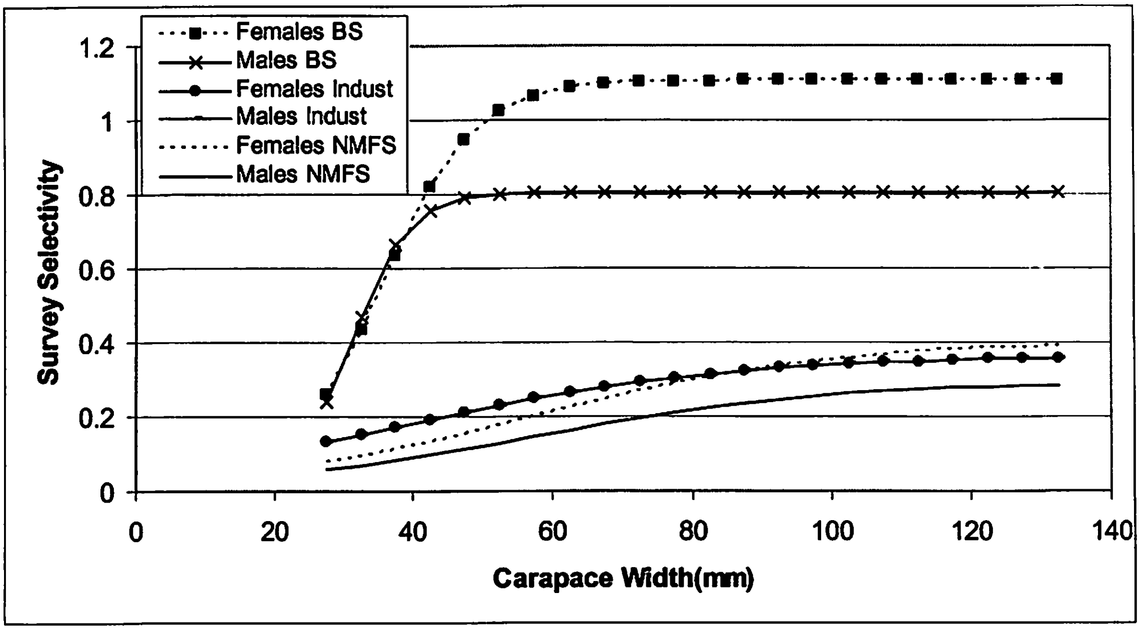

Figure 10. Survey selectivity curves fit to NMFS entire Bering sea by sex (Females BS and Males BS), the Industry study area survey (Females Indust, Males Indust) and the

NMFS survey in the study area (Females NMFS, Males NMFS). Survey biomass likelihood weight 50.

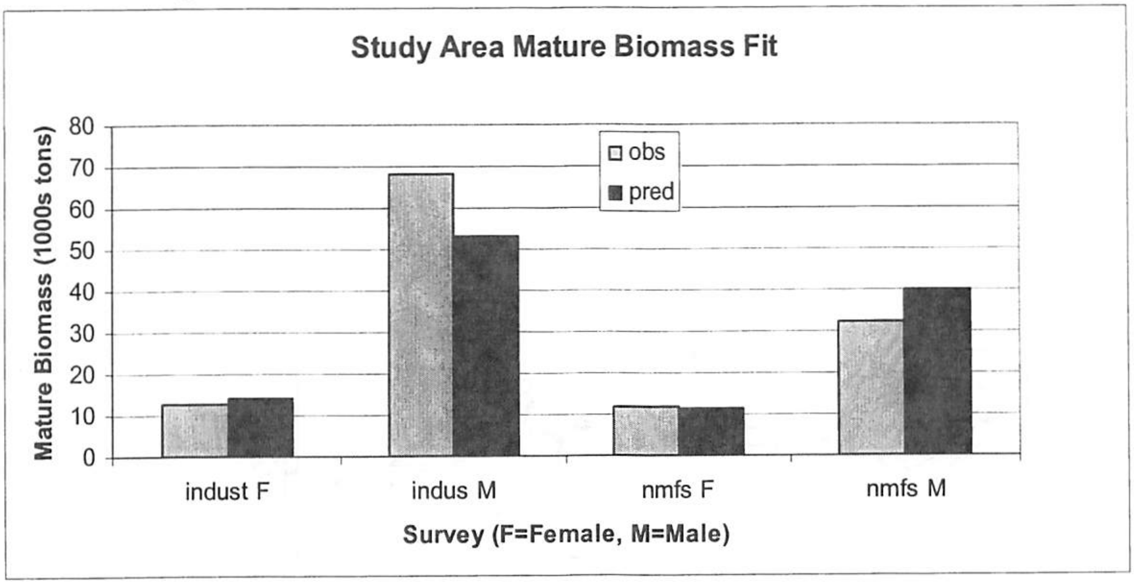

Figure 11. Fit to mature biomass by sex in the Study area for the Industry net (indust F females and Indus M males) and the NMFS net (nmfs F females and nmfs M males). Survey biomass likelihood weight 50.

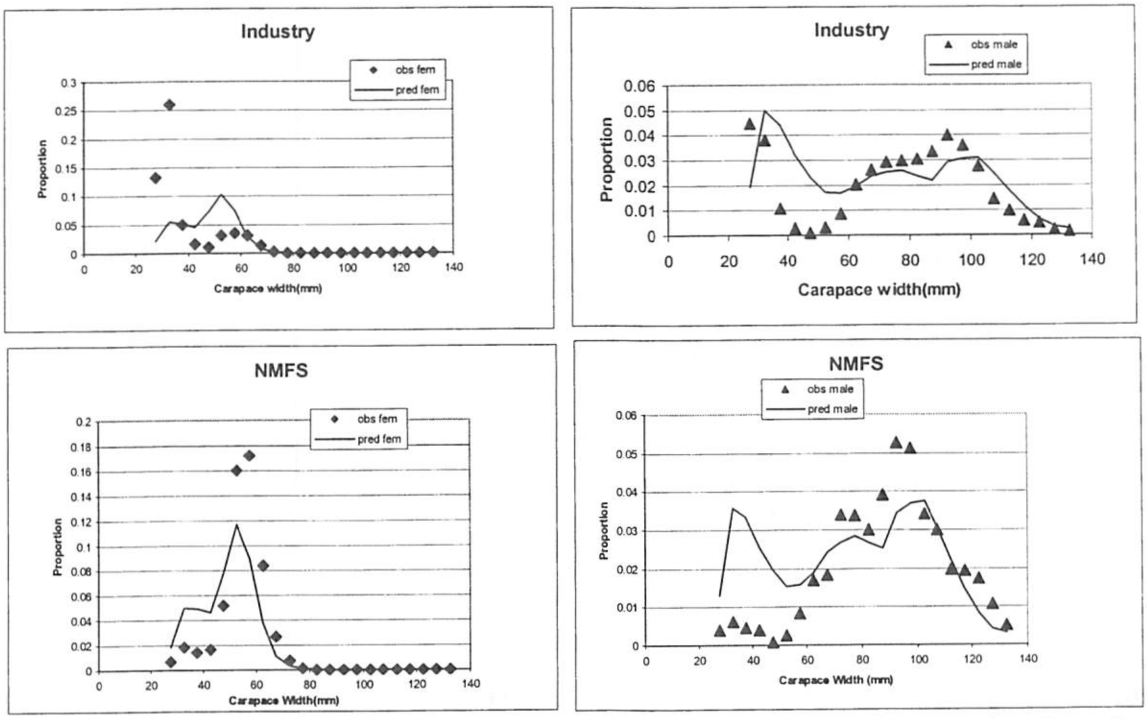

Figure 12. Fits to study area length frequency for industry and NMFS tows female and male crab. Weight study area biomass 50.0.

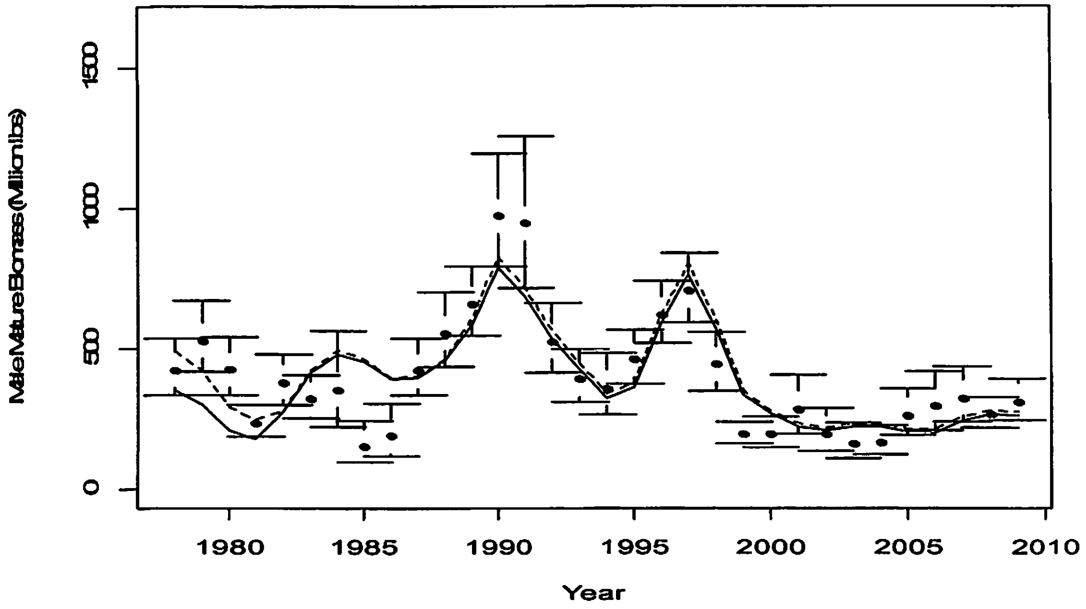

Figure 13. Fit to female mature biomass. Study area survey biomass likelihood weight 1.0.

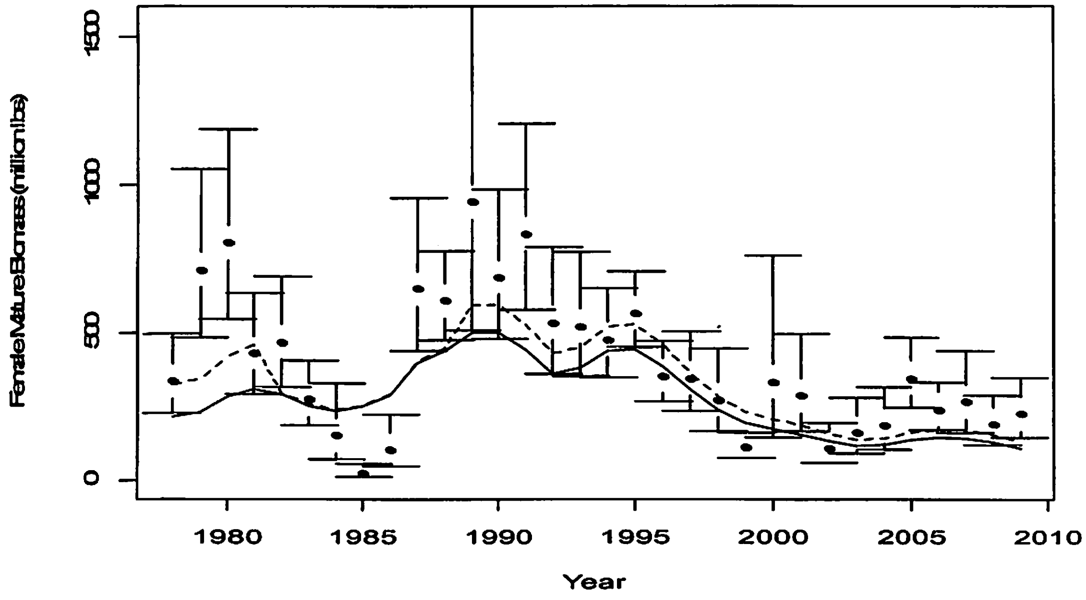

Figure 14. Fit to the female mature biomass. Study area survey biomass likelihood weight 1.0.

2 Description of Alternatives

This Chapter provides an overview of the alternatives and options under consideration in this analysis as well as those considered but not carried forward for further analysis at this time.

2.1 Alternative 1: status quo

Alternative 1 continues the current practice of annually established OFLs for the 10 BSAI stocks and does not establish annual catch limits below these values. All catch levels (TACs and GHLs) for those stocks are established by the State of Alaska using the management categories outlined in the BSAI Crab FMP. Note this alternative is considered for comparative purposes against other alternatives in this analysis but per revised federal guidelines as specified in Chapter 1would not comply with statutory requirements.

2.2 Alternative 2: Constant buffer approach

The ACL is set equal to the total-catch acceptable biological catch (ABC). The ABC for each stock would be set to the product of a constant pre-specified buffer less than 1 and the established OFL. Once the buffer value is selected, the ABC would be annually established below the annually updated OFL based upon the most recent stock assessment using this fixed buffer.

Buffer values under consideration in this alternative include the following[1]:

Option 1:	ABC = OFL (no buffer)
Option 2:	ABC = 90% of OFL
Option 3:	ABC = 80% of OFL
Option 4:	ABC = 70% of OFL
Option 5:	ABC = 60% of OFL
Option 6:	ABC = 50% of OFL
Option 7:	ABC = 40% of OFL
Option 8:	ABC = 30% of OFL
Option 9:	ABC = 20% of OFL
Option 10:	ABC = 10% of OFL

2.3 Alternative 3: Variable buffer

The ACL is set equal to the total-catch acceptable biological catch (ABC). The ABC is established based upon a pre-specified percentile of the distribution for the OFL which accounts for scientific uncertainty regarding the OFL. Here the probability of the ABC exceeding the OFL (P(ABC>OFL) is equal to a specified value, P*. A range of P* values are considered and result in stock-specific percentage buffer values which vary over time depending on the assessed extent of scientific uncertainty. Once the P* value is selected, the ABC would be annually established below the annually updated OFL using the buffer which corresponds to the selected P* and taking account of the assessed extent of scientific uncertainty. The OFL is based upon the most recent stock assessment.

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[1] note that other buffer values may be selected within these ranges.

P* values under consideration in this alternative include the following[2]:

Option 1: P* = 0.5
Option 2: P* = 0.4
Option 3: P* = 0.3
Option 4: P* = 0.2
Option 5: P* = 0.1

Actual ABC values corresponding to the P* options based upon calculation of the appropriate buffer value below OFL by stock are listed in the individual chapters of impacts of the alternatives by stock.

2.4 Rebuilding options for EBS snow crab and EBS Tanner crab stocks (apply to both alternatives)

These options apply to EBS snow crab and EBS Tanner crab stocks only. One of the options for each stock must be selected in order to rebuild the stock. This will be in addition to the ACL alternative that is selected for the stock. Rebuilding options may be more constraining than the ABC control rule for these stocks. The harvest strategy necessary to rebuild the stock under each option below will inform the maximum ACL for each of these stocks. Once each stock is rebuilt these measures will no longer be necessary and the ABC control rule will apply for each stock.

2.4.1 Snow Crab

The options below represent different target years for rebuilding the snow crab stock to the proxy for B_{MSY} with a pre-specified probability (values for T_{target})[3]. Sub-options (applicable to each option) establish probabilities for rebuilding by T_{target} (either fixed probabilities or increasing probabilities by year until T_{target}). The maximum permissible year for rebuilding[4] (denoted T_{end}) is set at 8 years (based on preliminary information included in Table 1, note that the actual end date for T_{end} will be set based on the best available information in the analysis of the rebuilding alternatives) in order to increase the probability of rebuilding (from interim T_{target} Option 4 established as the number of years to achieve greater than 50% probability of rebuilding over the time frame) to greater than 70% over the rebuilding time frame if the total catch fishing mortality in each year was set to the maximum permissible level of 75% of F_{OFL}[5].

Option 1: Set T_{target} based on minimum number of years necessary to rebuild under the current best assessment of the snow crab stock if all sources of fishing-related mortality are set to zero[6].

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[2] note that other P* values may be selected within these ranges.

[3] No less than 50%.

[4] The maximum permissible year is denoted T_{end} rather than T_{max} because T_{max} (10 years or T_{min} plus one generation time) appears in the NS1 Guidelines and clearly pertains to a new rebuilding plan. This is a revised rebuilding plan so although there is needs to be a maximum rebuilding time, the rules which define T_{max} do not apply (i.e. the revised plan cannot allow a further ten years for rebuilding).

[5] The year corresponding to this level of fishing mortality will be calculated by projecting the current best assessment of the snow crab stock ahead under the average fishing mortality for the groundfish fishery and the maximum permissible level of fishing mortality for the directed crab fishery.

[6] Recovery by the minimum T_{target} could occur with low levels of catch although this would decrease the probability of rebuilding by T_{end}. See attached table for probability of rebuilding under low levels of catch (equivalent to incidental catch in other fisheries)

For example, the current estimate of the minimum number of years (see Table 1) to recover to $B_{35\%}$ for two consecutive is 2 years (i.e. under assumption of catch at 75% of F_{OFL} through 2010/11 and implementing F=0 beginning in 2011/12 fishing year). The minimum number of years is the same with very low levels of catch (equivalent to estimated incidental catch in other fisheries). However the probability of rebuilding is higher under F=0.

Option 2 –Option 7[actual number TBD based on T_{end} calculation]: Set T_{target} above the minimum number of years (between 1 above the minimum and T_{end}). Here each separate options (numbered consecutively starting from Option 2) represent a time increment in one year intervals to T_{end}.

For example, using the current estimate of the minimum number of years under Option 1 (2 years) and the maximum number of years (T_{end}= 8 years, see Table 1) there with be 6 additional options (to Option 1) considered.
The timeframes associated with these would be the following:

- Option 2: 3 years to rebuild[7]
- Option 3: 4 years to rebuild[7]
- Option 4: 5 years to rebuild[7]
- Option 5: 6 years to rebuild[8]
- Option 6: 7 years to rebuild[8]
- Option 7: 8 years to rebuild[8] (= T_{end})

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[7] Rebuilding in this time frame would occur with a 50% probability based on a strategy in which the fishing mortality is initially projected to remain constant over the rebuilding time frame. In practice, however, the fishing mortality may change from year to year in response to changes in abundance. The probability of rebuilding by the chosen Ttarget will remain fixed at 50% for Options 2-4.

[8] Options 5-7 initially assume a constant fishing mortality of 75% F_{OFL}. In practice, however, the fishing mortality may change from one year to the next in response to changes in abundance. Rebuilding in these time frames would occur with different fixed probabilities, each greater than 50%. (The precise probabilities associated with options 5, 6 and 7 have not yet been determined, Table 1 is preliminary and will be recalculated in the rebuilding analysis)

Table 1 Estimated catch and probability of rebuilding (defined as mature male biomass being above $B_{35\%}$ for consecutive two years) for three catch scenarios: Catch scenarios in each year = 75% F_{OFL}, F=0 directed and total F=0. All scenarios assume catch = 75% F_{OFL} in 2010/11 fishing year and the listed strategy thereafter. In bold is the year in which the probability of being rebuilt is greater than 50% for the first time for each catch scenario.

Year	Catch: 75% F_{OFL}	Probability: 75% F_{OFL}	Catch: directed[1] F=0	Probability: directed[1] F=0	Catch: Total F=0	Probability: Total F=0
2009/10	56.95	0.000	56.95	0	56.95	0
2010/11	73.53	0.090	73.88	0.088	73.88	0.088
2011/12	77.85	0.156	1.05	0.167	0.00	0.167
2012/13	73.44	0.194	1.27	**0.770**	0.00	**0.782**
2013/14	83.06	0.227	1.52	0.957	0.00	0.961
2014/15	93.45	0.382	1.79	0.999	0.00	0.999
2015/16	97.09	**0.529**	2.01	1	0.00	1
2016/17	99.35	0.593	2.18	1	0.00	1
2017/18	101.81	0.646	2.34	1	0.00	1
2018/19	107.07	0.697	2.50	1	0.00	1

1-estimated incidental catch only included, no directed fishery

Sub-options (applies to each option above: Increased probability of rebuilding by the agreed T_{target}.

1. 75% probability of rebuilding by T_{target}.
2. 90% probability of rebuilding by T_{target}.
3. Annually increasing probability of rebuilding by T_{target}. The annual fishing mortality rate would be calculated so that the probability of rebuilding by T_{target} increases annually according to an agreed schedule. Note that if F=0 is necessary to achieve agreed probability in a given year then closures in groundfish fisheries and crab fisheries would be necessary. Under this option, T_{target} would be the year in which the probability of rebuilding is 50%.

   Sub-options below refer to different annual and end-point probabilities of rebuilding.
   - a. Range from 50% in first year of rebuilding to 70% by T_{target}.
   - b. Range from 50% in first year of rebuilding to 90% by T_{target}.

For all options, the values for the probability of rebuilding for each year of the rebuilding period and the associated rebuild fishing mortality rate would be updated annually using the best assessment of the snow crab stock, as recommended by the SSC. The CPT, SSC and Council will review progress to rebuilding annually and recommend annual adjustments to the fishing mortality rates on which management decisions are based consistent with the intent of the chosen alternative and progress towards rebuilding. If rebuilding to the proxy for B_{MSY} does not occur by T_{end}, then the maximum F will be the *rebuilding F*, the F of the final year, or 75% of F_{OFL}, whichever is lower, until a new rebuilding plan is developed.

2.4.2 Tanner crab

The rebuilding options below represent different target years for rebuilding the Tanner crab stock to the proxy for B_{MSY} with a pre-specified probability (values for T_{target})[9]. Options (applicable to each alternative) establish probabilities for rebuilding by T_{arget} (either fixed probabilities or increasing probabilities by year to T_{max}). The maximum permissible year for rebuilding (denoted T_{max}) is defined as 10 years (or T_{min}[10] plus one generation time if rebuilding cannot occur with 50% probability within 10 years).

Option 1: Set T_{target} equal to T_{min}[11].

Option 2 –Option [#TBD]: Set T_{target} above the minimum number of years (between T_{min}+1 and T_{max}). Rebuilding in this time frame would occur with 50% probability based on a strategy in which the fishing mortality by the directed fishery is constant during the rebuilding period and the bycatch in the snow crab fishery is based on the alternative selected in the snow crab rebuilding plan. Each separate option (numbered consecutively starting from Option 2) represents a time increment in one year intervals to T_{max}.

Sub-options (applies to each option above): Increased probability of rebuilding by the agreed T_{target}.

4. 75% probability of rebuilding by T_{target}.
5. 90% probability of rebuilding by T_{target}.
6. Annually increasing probability of rebuilding by T_{target}. The annual fishing mortality rate would be calculated so that the probability of rebuilding by T_{target} increases annually according to an agreed schedule. Note that closures in groundfish, scallop and crab fisheries may be necessary to achieve some annual probabilities. Under this option, T_{target} would be the year in which the probability of rebuilding is 50% given the agreed probability of rebuilding by T_{max}.
   Sub-options below refer to different annual and end-point probabilities of rebuilding.
   a. Range from 50% in first year of rebuilding to 70% by T_{target}.
   b. Range from 50% in first year of rebuilding to 90% by T_{target}.

For all rebuilding options, the values for the probability of rebuilding for each year of the rebuild period and the associated rebuild fishing mortality rate would be updated annually using the best assessment of the snow crab stock, as recommended by the SSC. The CPT, SSC and Council will review progress to rebuilding annually and recommend annual adjustments to the fishing mortality rates on which management decisions are based consistent with the intent of the chosen alternative and progress towards rebuilding. If rebuilding to the proxy for B_{MSY} does not occur by T_{max}, then the maximum F will be the rebuilding F, the F of the final year, or 75% of F_{OFL}, whichever is lower, until a new rebuilding plan is developed.

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[9] No less than 50%.

[10] T_{min} is the lowest year in which rebuilding to the proxy for B_{MSY} could occur with 50% probability.

[11] Recovery by the minimum T_{target} could occur with low levels of catch although this would decrease the probability of rebuilding by T_{max}. Catch levels in non-directed fisheries (e.g. snow crab, groundfish and scallop fisheries) may need to be constrained under this alternative.

5.0 Bristol Bay red king crab

This section provides a draft impact analysis for assessing the biological and economic impacts of the ACL alternatives (alternatives 2 and 3 as described previously) on the Bristol Bay red king crab stock. This section will comprise section 5.3 of the analysis. Some of the information provided below will be moved to sections on methodology and assessment information when the preliminary review draft is made available in March 2010.

5.3 Impacts of alternatives

Overview of OFL calculation and status determination

When compared to the Overfishing Limit (OFL) control rule, adopted as part of Amendment 24, the fishing mortality rates on retained legal males associated with the catches of Bristol Bay red king crab (BBRKC) (Fig. X.1) have often exceeded the OFL (Fig. X.2). This did not constitute overfishing in the past because Amendment 24 was only implemented in 2008. Moreover, the harvest strategy used to make recommendations for TACs has changed over time in response to changes in knowledge regarding the dynamics of the resource.

The most recent assessment of BBRKC (Zheng *et al.* 2009) is based on a sex- and size-structured population dynamics model which also considers the dynamics of shell-condition and maturity state[1]. The values for the parameters of this model are estimated using data on catch length-compositions, survey indices of abundance (assumed to be absolute indices of the survey-selected component of the population) as well as length-compositions from the surveys. The model is also fitted to discard length-frequency data, length-frequencies for the bycatch in the trawl fishery, and length frequency data for catches in Tanner crab fishery.

The OFL for BBRKC is currently based on the Tier 3 control rule, i.e. the proxy for F_{MSY} is taken to be $F_{35\%}$ while the proxy for B_{MSY} is taken to be B_{35}[2] (NPFMC, 2008). The OFL is a total-catch OFL and is computed as the sum of catches by five different sources of removals: (a) the retained legal males in directed (pot) fishery for Bristol Bay red king crab, (b) discards of males and females in the directed fishery, (c) bycatch in the Tanner crab fishery, and (d) bycatch in the trawl fishery.

The calculation of the OFL is based on the assumptions that: (a) the F_{OFL} pertains to the directed fishery for legal males (full-selection fishing mortality), (b) future full-selection discard mortality (males and females) in the directed fishery is given by F_{OFL} multiplied by the average ratio of discard fishing mortality to fishing mortality on legal males over the most-recent five years (2004/05 – 2008/09 for the analyses of this chapter), (c) fishing mortality by the Tanner crab fishery equals the average value over these last five years, and (d) fishing mortality by the trawl fishery equals the average value over these five years. Thus changes to F_{OFL} directly impact the predicted catches of legal males in the directed fishery as well as the predicted discard of males and females in the directed fishery, while the fishing mortality rates leading to bycatch in the Tanner and trawl fisheries are constant and independent of F_{OFL}.

As described in Chapter 2, there are two alternatives under consideration for computing a total-catch Acceptable Biological Catch (ABC) for BBRKC: (a) the OFL can be multiplied by a pre-specified buffer (Alternative 2), (b) a distribution can be computed for the OFL which accounts for uncertainty, and the ABC set to a pre-specified percentile of that distribution (Alternative 3).

The analyses of this chapter are based on the assumption that the ACL equals the ABC (i.e. no sector-specific Annual Catch Limits (ACLs) are implemented), that the ACL applies to all removals of BBRKC (a total-catch ACL), and that the Total Allowable Catch (TAC) (which pertains to catches of legal male crab in the directed fishery) is lower than the ABC to allow for discards and catches in the trawl and Tanner crab fisheries.

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[1] The analyses of this chapter are based on an updated version of the assessment model. The results are therefore not identical to those in Zheng *et al.* (2009).

[2] The biomass corresponding to $F_{35\%}$ and not 35% of the average unfished biomass.

Evaluation of alternatives

The short- and medium-term implications of the alternatives for calculating the ABC are evaluated in this chapter. The short-term implications are assessed by impact of the alternatives for the buffer and P* on the ABC which would have been advised for the 2009/10 fishery (assuming that ABCs had been specified for that fishery) while the medium-term implications are evaluated by projecting the population ahead 30 years[3] under the assumptions that the catch equals the ABC (this is equivalent to assuming that the TAC is set equal to the component of the ABC which is estimated to consist of legal male crab caught by the directed fishery), and that the catch equals to the ABC.

Analyses to determine the extent of "additional variability" (the uncertainty associated with sources of uncertainty not captured within the stock assessment) have yet to be finalized. Results are therefore provided for three levels for the extent of additional uncertainty (none, σ_b=0.2, and σ_b=0.4), which should bound the true value for this quantity. The general structure of the algorithm used to conduct the medium-term projections is outlined in Appendix XX. The methods used for economic analysis of the catch projections is outlined in Appendix XY.

Results

Short-term implications

Table X.1 lists the ABC values for the 2009/10 fishing year for each of the alternatives, along with the corresponding estimate of the catch in the directed fishery. The difference between $\mathrm{ABC}_{\mathrm{tot}}$ and $\mathrm{ABC}_{\mathrm{dir}}$ reflects the losses to discard in the directed fishery, and bycatch in the Tanner crab and trawl fisheries. The gross revenue from the directed fishery associated with each of the alternatives is also shown.

There is a linear relationship between the ABC and buffer (Table X.1a, Figure X.3a) with the ABC set equal to the OFL for a buffer of 1 and being 10% of the ABC for a buffer of 0.1. The relationship between the buffer and P* is, however, not simple linear proportionality (Table X.1b, Figure X.3b). Moreover, the impact of the (assumed) extent of additional variance is substantial given that the variability of the OFL estimated from the assessment is low (Figure X.4a). Specifically, the buffer (and hence the ABC for 2009/10) gets smaller for the same value for P* as the value for σ_b is increased. For example, the buffer for a P* of 0.4 (40% probability that the ABC will exceed the true OFL) is 0.95 if there is no uncertainty that is not captured by the stock assessment, but is 0.91 and 0.81 if σ_b is 0.2 or 0.4 (Tables X.4b-d; Figure X.3b). The relationship between P* and the buffer based on the OFL calculated for 2009 is given in the "P* (additional uncertainty)" column of Table X.1a.

Medium-term implications

Table X.2 lists summaries of the posterior distributions for the key parameters which determine the productivity of the population for the two stock-recruitment relationships. The distributions for F_{MSY} and B_{MSY} are the same for the two stock-recruitment relationships which is expected given the way the values for R_0 and steepness are set (see step 3 of Appendix XX). Note that B_{35} is not 35% of the unfished mature male biomass at mating. This is because recruitment is not independent of mature male biomass at mating. The extent of uncertainty captured within the stock assessment, σ_w, is 0.061 based on the 2009 assessment.

Tables X.3 and X.4 summarize the results of the medium-term projections in terms of (a) the probability of the mature male biomass at mating dropping below the overfished level at least once over the 30-year period (column "Prob (overfished)"), (b) the annual probability of the catch exceeding the true OFL (column "Prob (overfishing)"), (c) the mean and 90% intervals for the catch of legal males by the directed fishery in the last year of the projection period, and (d) the revenue estimated for 2038, and (d) the present value of the stream of revenue from projected catch in the directed fishery projected from 2009-2038 and discounted to 2009 dollar value at alternative discount

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[3] 30 years is sufficiently long so the resource equilibrates close to the proxy for B_{MSY} under deterministic conditions (no fluctuations in recruitment about the assumed stock-recruitment relationship).

rates r=2.7% and 7%. Figures X.5a and X.6a show the time-trajectories of catch and mature male biomass at mating relative to B_{35} for two illustrative choices for the buffer (1; ABC=OFL; 0.5; the ABC is half of the OFL) for the two stock-recruitment relationships. As expected, the mature male biomass equals B_{MSY} in average terms when the buffer equals 1, while the mature male biomass increases over time if the buffer is set to 0.5. The mature male biomass drops over the early years of the projection period because the current mature male biomass is substantially larger than B_{MSY} at present and setting the ABC to the OFL (without a buffer) would be expected to drive the stock back (down) to B_{MSY}. The decline in mature male biomass also occurs owing to some poorer-than-average recruitments in recent years. The projections based on the Ricker stock-recruitment relationship are much less variable than those based on the Beverton-Holt stock-recruitment relationship due primarily to the tighter distributions for R_0 and B_{MSY} (Table X.2). Figures X.5b and X.6b show the projected gross revenues in the directed fishery for median and 95% confidence intervals catch projections, discounted to 2009 present value using discount rates r=2.7% and 7%.

Figures X.7a and X.8a illustrate the differences among the 10 buffers in terms of the median time-trajectory of mature male biomass at mating relative to B_{MSY} and the median time-trajectory of the catch of legal males in the directed fishery, and Figures X.7b and X.8b illustrate the associated gross revenue projections. The ratio of mature male biomass to B_{MSY} increases essentially continuously with changes in the buffer. The rate at which catch drops with increasing buffer sizes is, however, not the same as that at which biomass increases (Figures X.7 and X.8; Tables X.3 and X.4) with the catch in 2038 essentially the same for buffers between 0.6 and 1.0 (Beverton-Holt) and between 0.8 and 1.0 (Ricker) (Tables X.3 and X.4).

Unlike the median trajectories in Figures X.7 and X.8, the probability of being overfished and overfishing occurring is very sensitive to the extent of additional uncertainty, with these probabilities dropping rapidly with decreasing buffer sizes when there is no additional uncertainty, but remaining higher when there is greater additional uncertainty (Tables X.3 and X.4).

The current analyses are unable to predict the extent to which the uncertainty in terminal biomass will change over time (the next 30 years) nor whether estimates of the extent of uncertainty not captured by the assessment will change over time. The results in Tables X.3-X.4 and Figures X.5-X.8 are based on pre-specified buffers. There is, however, a direct relationship between buffer values and choices for P* under the assumption that estimates of σ_b and σ_w do not change over time (Table X.5). The results in Table X.5 combined with those in Table X.3 and X.4 provide a basis to evaluate different choices for P*.

References

NPFMC 2008. Amendment 24. Final Environmental Assessment for amendment 24 to the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. Prepared by staff of the Alaska Department of Fish and Game, National Marine Fisheries Service, and the North Pacific Fishery Management Council. North Pacific Fishery Management Council, 605 West 4^th Ave, Anchorage, AK. 99501.

Zheng, J. and M.S.M. Siddeek. 2009. Bristol Bay Red King Crab Stock Assessment in Fall 2009. North Pacific Fishery Management Council. 605 W. 4th Avenue, Suite 306, Anchorage, AK 99501-2252. 139pp,

Table X.1. The values for catch-related quantities for 2009/10 for each of the alternatives. The column P* in Table X.1a shows the relationship between each buffer and P* for different values for the extent of additional uncertainty.

(a) ACL = OFL * Buffer

Alternative	**ABC$_{tot}$ (t)**	**ABC$_{dir}$ (t)**	**P * (additional uncertainty**			**Revenue Millions $**
			None	**0.2**	**0.4**	
Buffer = 1	12,423	11,067	0.5	0.5	0.5	155.52
Buffer = 0.9	11,181	9,960	0.11	0.38	0.50	139.97
Buffer = 0.8	9,938	8,853	0	0.21	0.38	124.41
Buffer = 0.7	8,696	7,747	0	0.07	0.28	108.87
Buffer =0.6	7,454	6,640	0	0.02	0.16	93.31
Buffer = 0.5	6,211	5,533	0	0.00	0.07	77.75
Buffer = 0.4	4,969	4,427	0	0	0.03	62.21
Buffer = 0.3	3,727	3,320	0	0	0.03	46.66
Buffer = 0.2	2,485	2,213	0	0	0	31.10
Buffer = 0.1	1,242	1,107	0	0	0	15.56

(b) ACL defined by P* (no additional uncertainty)

Alternative	**ABC$_{tot}$**	**ABC$_{dir}$**	**Buffer**	**Revenue**
$P^* = 0.5^{\&}$	12,423	11,067	1	155.52
$P^* = 0.4$	11,837	10,544	0.95	148.17
$P^* = 0.3$	11,654	10,377	0.94	145.83
$P^* = 0.2$	11,425	10,199	0.92	143.33
$P^* = 0.1$	11,089	9,845	0.89	138.35

& - set to the point estimate

(c) ACL defined by P* (additional uncertainty = 0.2)

Alternative	**ABC$_{tot}$**	**ABC$_{dir}$**	**Buffer**	**Revenue**
$P^* = 0.5^{\&}$	12,423	11,067	1	155.52
$P^* = 0.4$	11,266	9,988	0.91	140.36
$P^* = 0.3$	10,610	9,407	0.85	132.20
$P^* = 0.2$	9,843	8,773	0.79	123.29
$P^* = 0.1$	9,020	8,004	0.73	112.48

& - set to the point estimate

(d) ACL defined by P* (additional uncertainty = 0.4)

Alternative	**ABC$_{tot}$**	**ABC$_{dir}$**	**Buffer**	**Revenue**
$P^* = 0.5^{\&}$	12,423	11,067	1	155.52
$P^* = 0.4$	10,116	8,994	0.81	126.39
$P^* = 0.3$	9,036	8,036	0.73	112.93
$P^* = 0.2$	7,945	7,103	0.64	99.82
$P^* = 0.1$	6,671	5,967	0.54	83.85

& - set to the point estimate

Table X.2. Posterior means and 90% intervals for key parameters of the population dynamics model used for projection purposes.

Parameter	**Distribution**
Ricker stock-recruitment relationship	
Virgin recruitment, R_0 (/1000)	9,676 (9,146 – 10,245)
Virgin MMB	76.4 (72.4 – 80.9)
Steepness, h	1.002 (0.989 – 1.013)
F_{MSY} ($F_{35\%}$)	0.439 (0.427 - 0.451)
B_{MSY} ($B_{35\%}$)	29.2 (27.6 – 30.9)
σ_R	0.923 (0.859 – 0.997)
Beverton-Holt stock-recruitment relationship	
Virgin recruitment, R_0 (/1000)	15,577 (14,758 – 16,478)
Virgin MMB	123.2 (116.9 – 130.3)
Steepness, h	0.790 (0.785 – 0.794)
F_{MSY} ($F_{35\%}$)	0.439 (0.427 - 0.451)
B_{MSY} ($B_{35\%}$)	29.2 (27.6 – 30.9)
σ_R	0.930 (0.867 – 1.004)

Table X.3 Summary of the medium-term consequences of the alternatives (Beverton-Holt stock-recruitment relationship). The column "directed catch" lists the posterior mean and 90% intervals for the catch of legal males in the directed fishery in 2038.

(a) No additional uncertainty

Alternative	**Prob (Overfished)**	**Prob (overfishing)**	**Directed catch (2038) (t)**	**Present value of Catch Revenue (2009-2038) ($millions)**	
				R=2.7%	**R=7%**
Buffer = 1	0.092	0.486	8.2 (3.8 – 17.8)	2428.04 (1499.85 - 4321.79)	1675.59 (1122.11 - 2781.54)
Buffer = 0.9	0.033	0.041	8.3 (3.8 – 17.6)	2376.53 (1461.47 - 4183.42)	1624.08 (1081.71 - 2674.48)
Buffer = 0.8	0.010	0.000	8.2 (3.8 – 17.3)	2310.88 (1418.04 - 4027.88)	1562.47 (1036.26 - 2556.31)
Buffer = 0.7	0.005	0.000	8.2 (3.9 – 16.7)	2225.03 (1363.5 - 3824.87)	1486.72 (983.74 - 2408.85)
Buffer = 0.6	0.001	0.000	8.1 (4.0 – 15.8)	2104.84 (1301.89 - 3578.43)	1390.77 (924.15 - 2234.12)
Buffer = 0.5	0.000	0.000	7.7 (4.0 – 14.8)	1942.23 (1219.07 - 3271.39)	1268.56 (850.42 - 2025.05)
Buffer = 0.4	0.000	0.000	7.1 (3.9 – 13.4)	1732.15 (1111 - 2884.56)	1118.07 (760.53 - 1767.5)
Buffer = 0.3	0.000	0.000	6.2 (3.6 – 11.6)	1452.38 (956.47 - 2391.68)	925.16 (642.36 - 1449.35)
Buffer = 0.2	0.000	0.000	4.9 (2.9 – 8.8)	1085.75 (731.24 - 1766.49)	681.75 (481.77 - 1058.48)
Buffer = 0.1	0.000	0.000	2.8 (1.7 – 4.9)	597.92 (408.04 - 963.54)	369.66 (263.61 - 570.65)

(b) Additional uncertainty = 0.2

Alternative	**Prob (Overfished)**	**Prob (overfishing)**	**Directed catch (2038) (t)**	**Present value of Catch Revenue (2009-2038) ($millions)**	
				R=2.7%	**R=7%**
Buffer = 1	0.201	0.469	8.2 (3.8 – 17.2)	2398.75 (1370.57 - 4406.63)	1654.38 (1000.91 - 2886.58)
Buffer = 0.9	0.115	0.278	8.2 (3.8 – 17.0)	2344.21 (1346.33 - 4279.37)	1600.85 (973.64 - 2781.54)
Buffer = 0.8	0.044	0.134	8.2 (3.8 – 16.7)	2275.53 (1310.98 - 4115.75)	1538.23 (936.27 - 2654.28)
Buffer = 0.7	0.015	0.049	8.1 (3.9 – 16.3)	2187.66 (1264.52 - 3927.89)	1461.47 (890.82 - 2511.87)
Buffer = 0.6	0.001	0.008	7.9 (4.0 – 15.6)	2064.44 (1204.93 - 3676.4)	1364.51 (836.28 - 2333.1)
Buffer = 0.5	0.000	0.000	7.6 (4.0 – 14.5)	1907.89 (1128.17 - 3372.39)	1247.35 (769.62 - 2121)
Buffer = 0.4	0.000	0.000	7.0 (3.8 – 13.2)	1700.84 (1015.05 - 2998.69)	1097.87 (680.74 - 1866.48)
Buffer = 0.3	0.000	0.000	6.1 (3.4 – 11.7)	1426.12 (859.51 - 2513.89)	909 (565.6 - 1548.33)
Buffer = 0.2	0.000	0.000	4.8 (2.7 – 8.6)	1067.57 (643.37 - 1885.67)	670.64 (415.11 - 1148.37)
Buffer = 0.1	0.000	0.000	2.7 (1.6 – 4.9)	588.83 (348.45 - 1055.45)	364.61 (220.18 - 634.28)

(c) Additional uncertainty = 0.4

Alternative	**Prob (Overfished)**	**Prob (overfishing)**	**Directed catch (2038) (t)**	**Present value of Catch Revenue (2009-2038) ($millions)**	
				R=2.7%	**R=7%**
Buffer = 1	0.260	0.431	8.0 (3.7 – 16.5)	2302.8 (1179.68 - 4541.97)	1582.67 (826.18 - 3058.28)
Buffer = 0.9	0.201	0.327	7.9 (3.7 – 16.5)	2245.23 (1162.51 - 4385.42)	1529.14 (805.98 - 2931.02)
Buffer = 0.8	0.138	0.232	7.9 (3.8 – 16.4)	2172.51 (1135.24 - 4230.89)	1465.51 (779.72 - 2803.76)
Buffer = 0.7	0.080	0.155	7.8 (3.9 – 16.1)	2076.56 (1097.87 - 4045.05)	1386.73 (745.38 - 2655.29)
Buffer = 0.6	0.034	0.087	7.5 (3.7 – 15.4)	1961.42 (1037.27 - 3814.77)	1295.83 (693.87 - 2481.57)
Buffer = 0.5	0.015	0.042	7.2 (3.7 – 14.6)	1807.9 (954.45 - 3527.93)	1181.7 (629.23 - 2274.52)
Buffer = 0.4	0.006	0.010	6.7 (3.4 – 13.3)	1611.96 (841.33 - 3175.44)	1040.3 (547.42 - 2026.06)
Buffer = 0.3	0.000	0.001	5.8 (3.0 – 11.5)	1353.4 (692.86 - 2717.91)	862.54 (443.39 - 1713.97)
Buffer = 0.2	0.000	0.000	4.5 (2.2 – 9.1)	1014.04 (497.93 - 2108.88)	636.3 (313.1 - 1313)
Buffer = 0.1	0.000	0.000	2.6 (1.2 – 5.6)	555.5 (250.48 - 1242.3)	343.4 (155.54 - 759.52)

Table X.4 Summary of the medium-term consequences of the alternatives (Ricker stock-recruitment relationship). The column "directed catch" lists the posterior mean and 90% intervals for the catch of legal males in the directed fishery in 2038.

(a) No additional uncertainty

Alternative	**Prob (Overfished)**	**Prob (overfishing)**	**Directed catch (2038) (t)**	**Present value of Catch Revenue (2009-2038) ($millions)**	
				R=2.7%	**R=7%**
Buffer = 1	0.000	0.486	9.0 (8.0 – 10.1)	2603.78 (2281.59 - 2964.35)	1774.57 (1550.35 - 2026.06)
Buffer = 0.9	0.001	0.041	9.0 (8.0 – 10.1)	2541.16 (2233.11 - 2887.59)	1715.99 (1502.88 - 1956.37)
Buffer = 0.8	0.000	0.000	8.9 (8.0 – 10.0)	2453.29 (2159.38 - 2783.56)	1642.26 (1440.26 - 1869.51)
Buffer = 0.7	0.000	0.000	8.6 (7.7 – 9.7)	2336.13 (2057.37 - 2648.22)	1550.35 (1360.47 - 1762.45)
Buffer = 0.6	0.000	0.000	8.1 (7.3 – 9.1)	2182.61 (1925.06 - 2472.48)	1436.22 (1262.5 - 1633.17)
Buffer = 0.5	0.000	0.000	7.4 (6.7 – 8.4)	1985.66 (1752.35 - 2249.27)	1297.85 (1141.3 - 1474.6)
Buffer = 0.4	0.000	0.000	6.5 (5.8 – 7.3)	1736.19 (1532.17 - 1966.47)	1127.16 (990.81 - 1279.67)
Buffer = 0.3	0.000	0.000	5.3 (4.7 – 5.9)	1420.06 (1254.42 - 1606.91)	916.07 (806.99 - 1039.29)
Buffer = 0.2	0.000	0.000	3.8 (3.4 – 4.3)	1028.18 (906.98 - 1163.52)	658.52 (579.74 - 747.4)
Buffer = 0.1	0.000	0.000	2.0 (1.8 – 2.3)	544.39 (477.73 - 619.13)	346.43 (304.01 - 394.91)

(b) Additional uncertainty = 0.2

Alternative	**Prob (Overfished)**	**Prob (overfishing)**	**Directed catch (2038) (t)**	**Present value of Catch Revenue (2009-2038) ($millions)**	
				R=2.7%	**R=7%**
Buffer = 1	0.058	0.468	8.8 (7.8 – 10.0)	2563.38 (2106.86 - 3088.58)	1748.31 (1402.89 - 2154.33)
Buffer = 0.9	0.015	0.278	8.8 (7.7 – 10.0)	2499.75 (2064.44 - 3007.78)	1688.72 (1364.51 - 2078.58)
Buffer = 0.8	0.003	0.134	8.7 (7.5 – 9.9)	2413.9 (1985.66 - 2909.81)	1616 (1302.9 - 1990.71)
Buffer = 0.7	0.000	0.049	8.5 (7.1 – 9.8)	2300.78 (1872.54 - 2788.61)	1527.12 (1221.09 - 1888.7)
Buffer = 0.6	0.000	0.008	8.0 (6.5 – 9.5)	2153.32 (1722.05 - 2637.11)	1417.03 (1117.06 - 1767.5)
Buffer = 0.5	0.000	0.000	7.3 (5.8 – 9.0)	1961.42 (1537.22 - 2441.17)	1281.69 (993.84 - 1619.03)
Buffer = 0.4	0.000	0.000	6.4 (4.9 – 8.2)	1714.98 (1313 - 2184.63)	1113.02 (845.37 - 1433.19)
Buffer = 0.3	0.000	0.000	5.2 (3.9 – 7.0)	1402.89 (1045.35 - 1841.23)	904.96 (669.63 - 1196.85)
Buffer = 0.2	0.000	0.000	3.7 (2.7 – 5.2)	1015.05 (733.26 - 1382.69)	650.44 (467.63 - 890.82)
Buffer = 0.1	0.000	0.000	2.0 (1.4 – 2.8)	536.31 (370.67 - 767.6)	341.38 (235.33 - 489.85)

(c) Additional uncertainty = 0.4

Alternative	**Prob (Overfished)**	**Prob (overfishing)**	**Directed catch (2038) (t)**	**Present value of Catch Revenue (2009-2038) ($millions)**	
				R=2.7%	**R=7%**
Buffer = 1	0.170	0.432	8.5 (6.5 – 9.9)	2464.4 (1736.19 - 3296.64)	1675.59 (1131.2 - 2368.45)
Buffer = 0.9	0.114	0.326	8.5 (6.5 – 9.9)	2398.75 (1687.71 - 3202.71)	1618.02 (1092.82 - 2278.56)
Buffer = 0.8	0.069	0.232	8.4 (6.1 – 9.8)	2318.96 (1604.89 - 3098.68)	1549.34 (1036.26 - 2182.61)
Buffer = 0.7	0.041	0.155	8.2 (5.7 – 9.7)	2213.92 (1486.72 - 2975.46)	1465.51 (958.49 - 2072.52)
Buffer = 0.6	0.014	0.087	7.8 (5.1 – 9.6)	2076.56 (1336.23 - 2842.14)	1362.49 (859.51 - 1954.35)
Buffer = 0.5	0.004	0.041	7.2 (4.4 – 9.4)	1891.73 (1163.52 - 2675.49)	1232.2 (746.39 - 1814.97)
Buffer = 0.4	0.001	0.010	6.2 (3.6 – 8.9)	1649.33 (967.58 - 2462.38)	1068.58 (619.13 - 1644.28)
Buffer = 0.3	0.000	0.001	5.1 (2.8 – 8.1)	1345.32 (751.44 - 2155.34)	865.57 (479.75 - 1418.04)
Buffer = 0.2	0.000	0.000	3.6 (1.9 – 6.4)	967.58 (511.06 - 1697.81)	619.13 (325.22 - 1100.9)
Buffer = 0.1	0.000	0.000	1.9 (0.9 – 3.7)	508.03 (245.43 - 995.86)	323.2 (155.54 - 638.32)

Table X.5. Relationship between P* and the size of the buffer between the OFL and the ABC for different values for the extent of additional variability, σ_b, when $\sigma_w = 0.061$, based on the assumption that the OFL is log-normally distributed about its best estimate.

	Additional uncertainty, σ_b		
P*	0	0.2	0.4
0.5	1	1	1
0.4	0.985	0.949	0.906
0.3	0.969	0.897	0.815
0.2	0.950	0.840	0.721
0.1	0.925	0.767	0.607

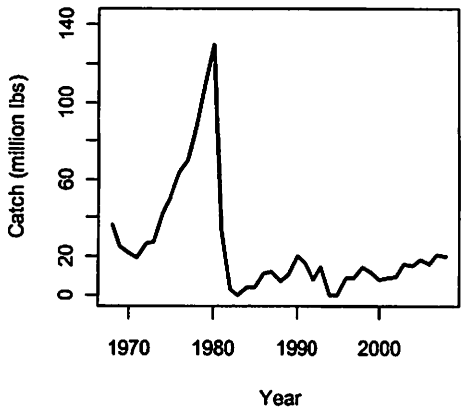


Figure X.1. Total retained catches of Bristol Bay red king crab (million lbs) [source: Zheng *et al.* (2009)]

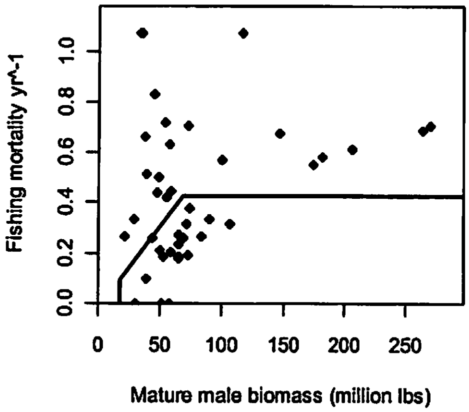


Figure X.2. Fully-selected fishing mortality by the directed (pot) fishery on legal males and the mature male biomass on Feb 15 (dots). The solid line denotes the Tier 3 OFL control rule.

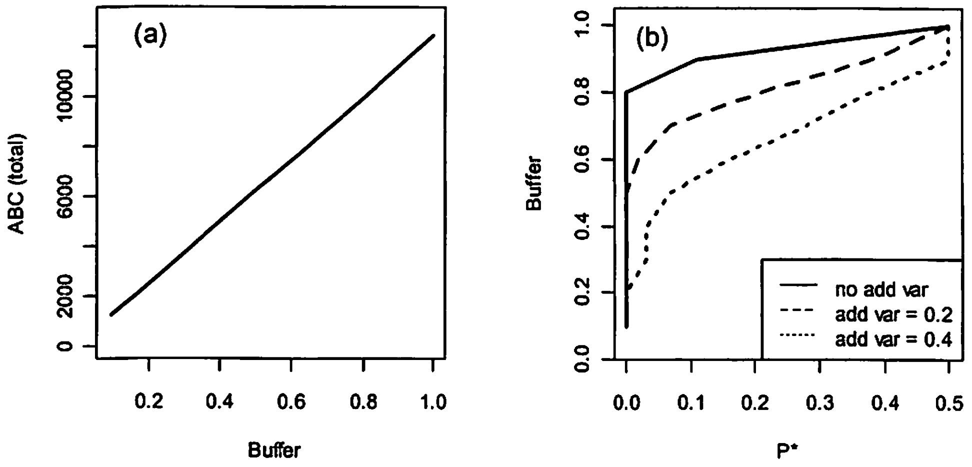


Figure X.3. Relationship between the buffer and the ABC (a) and the relationships between P* and the buffer for three values for the extent of additional uncertainty (b).

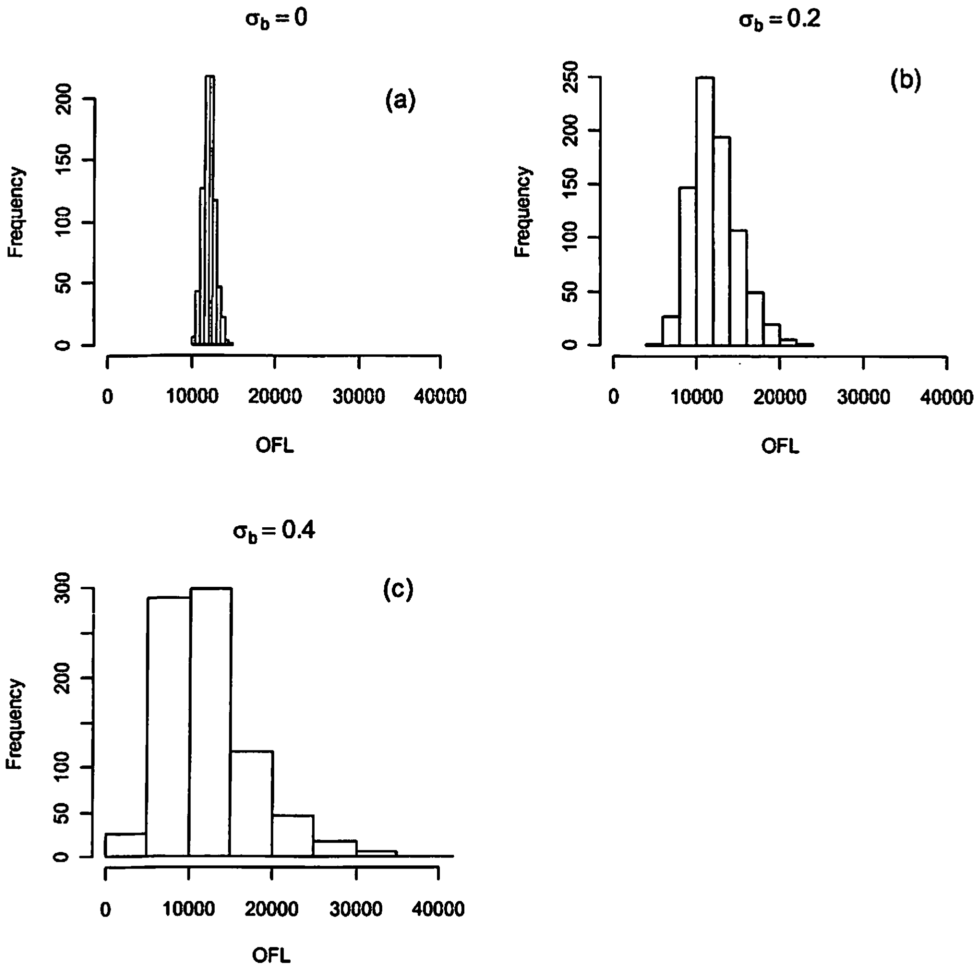


Figure X.4. Distribution of OFL values as a function of the assumed extent of additional uncertainty (σ_b).

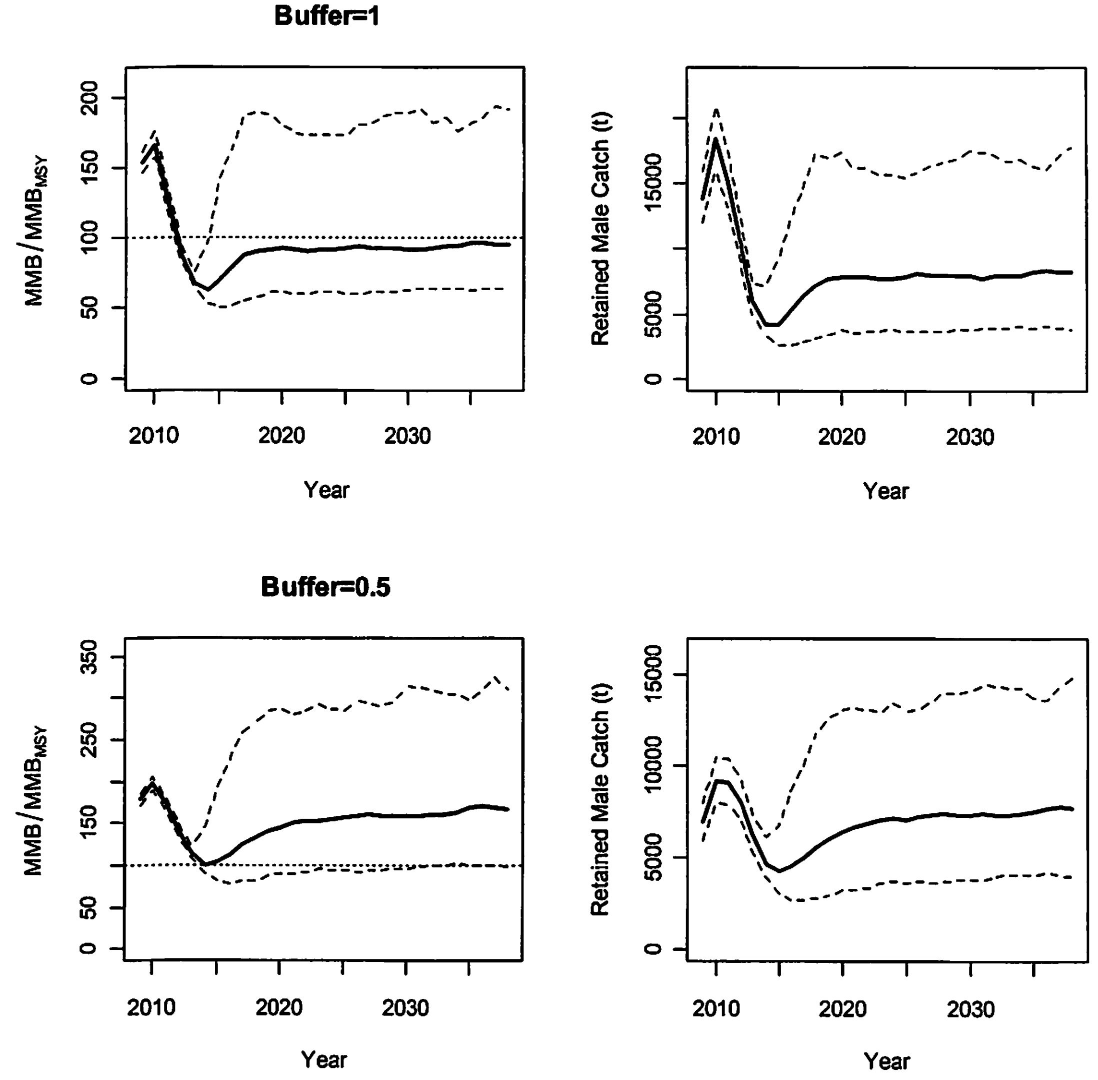
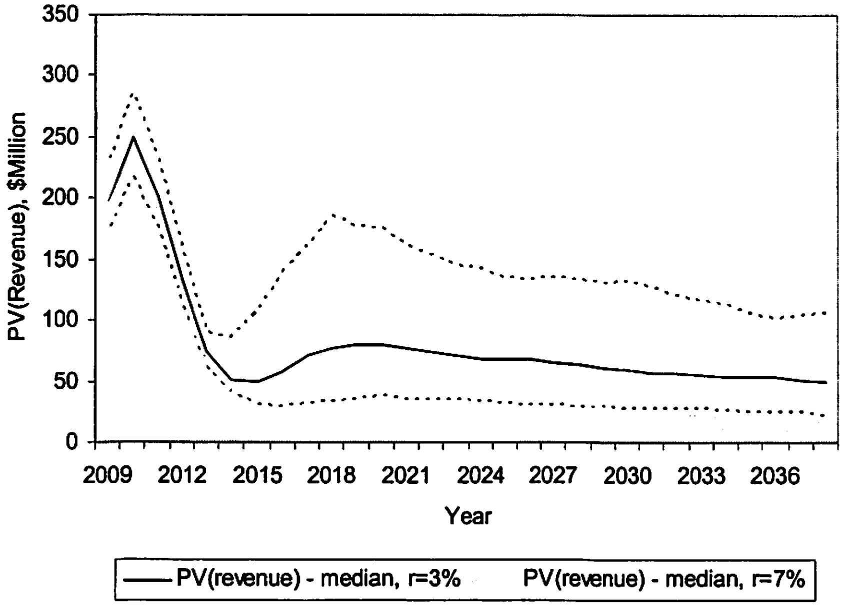


Figure X.5a. Time-trajectories of mature male biomass at mating relative to B_{35} (the proxy for B_{MSY}) and catch, for projections based on two choices for the buffer between the OFL and the ABC. The results in this figure are based on the Beverton-Holt stock-recruitment relationship.

Buffer=1.0



Buffer=0.5

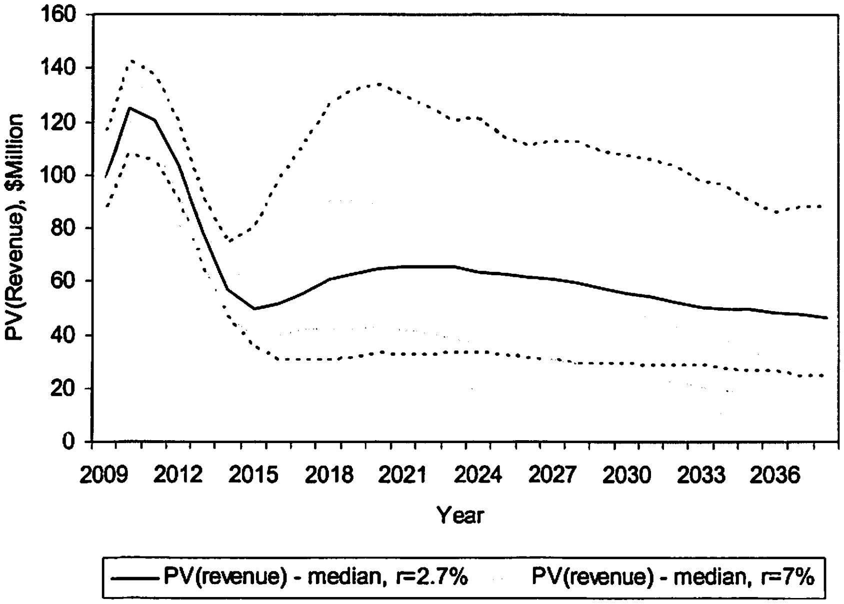


Figure X.5b. Time-trajectories of projected gross revenues in the directed fishery for median and 95% confidence interval catch projections based on two choices for the buffer between the OFL and the ABC. The results in this figure are based on the Beverton-Holt stock-recruitment relationship.

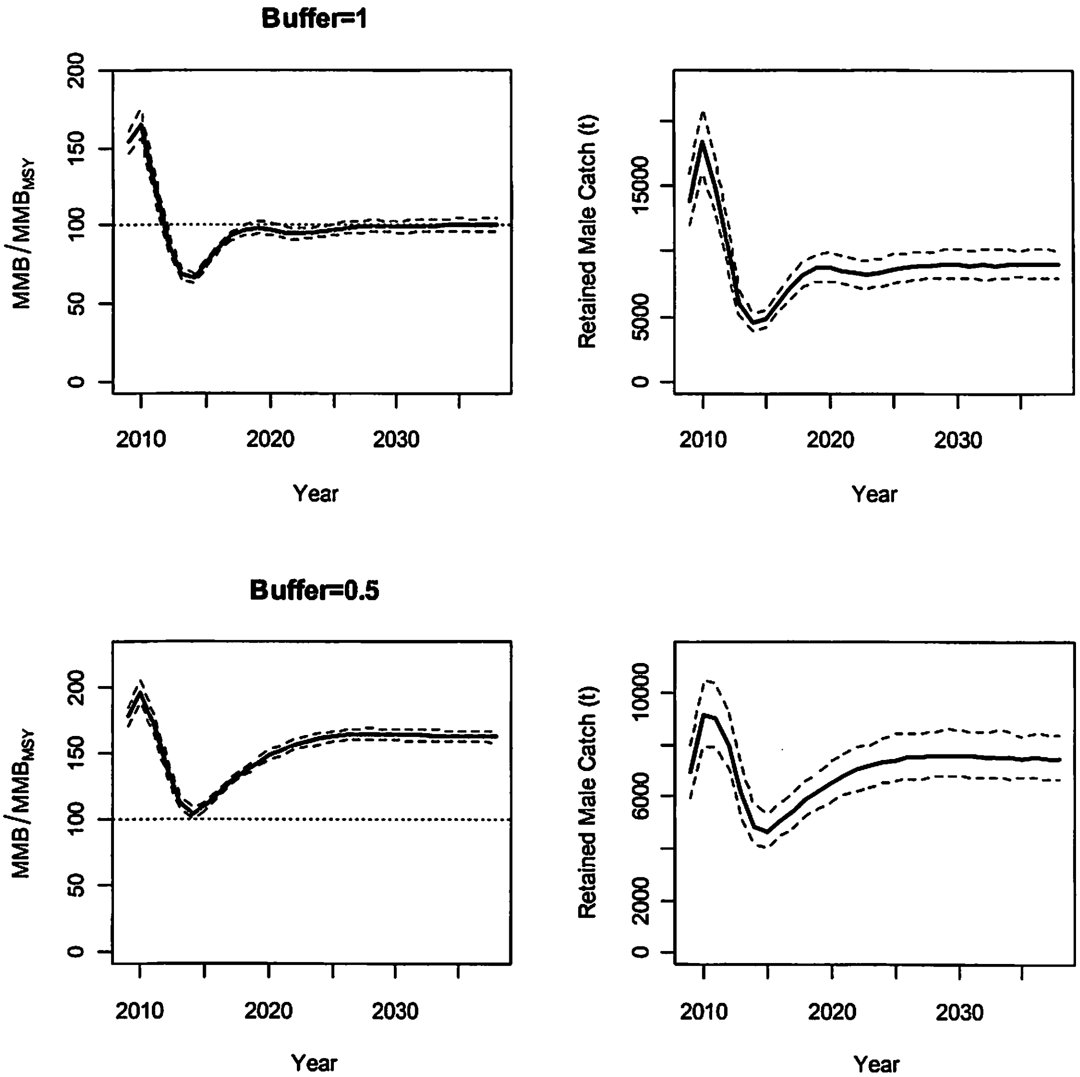
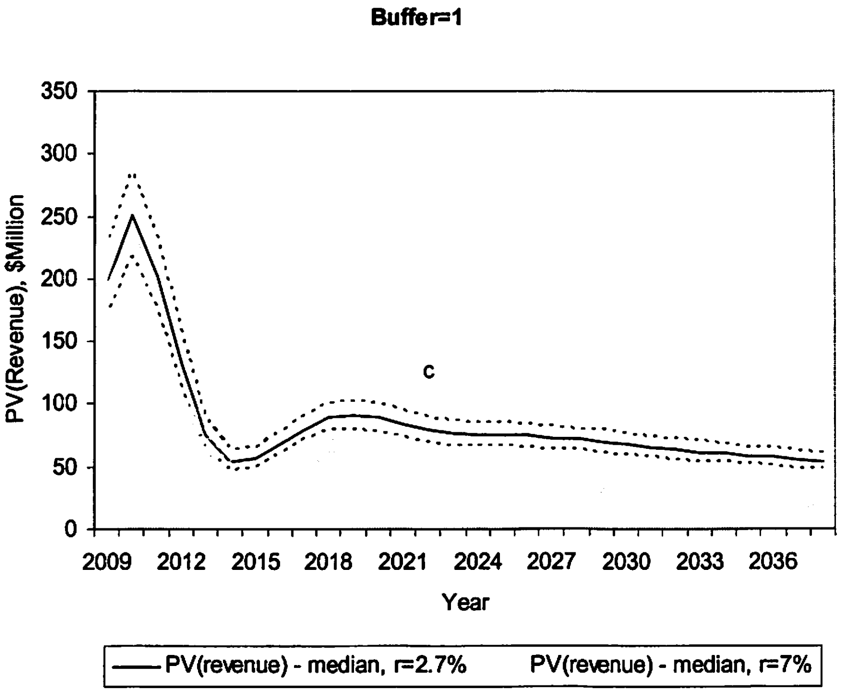


Figure X.6a. Time-trajectories of mature male biomass at mating relative to B_{35} (the proxy for B_{MSY}) and catch for projections, based on two choices for the buffer between the OFL and the ABC. The results in this figure are based on the Ricker stock-recruitment relationship.



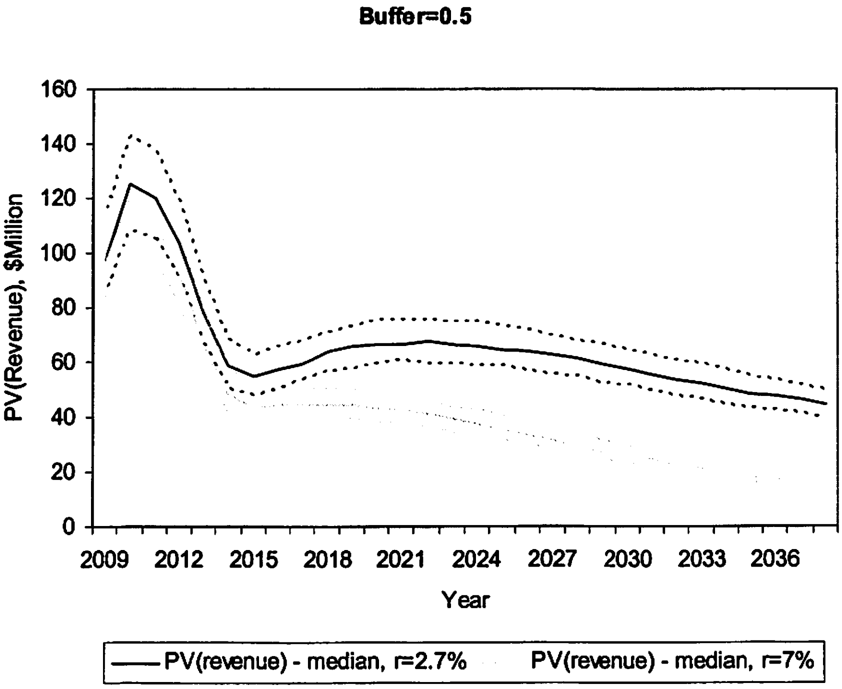


Figure X.6b. Time-trajectories of projected gross revenues in the directed fishery for median and 95% confidence interval catch projections based on two choices for the buffer between the OFL and the ABC. The results in this figure are based on the Ricker stock-recruitment relationship.

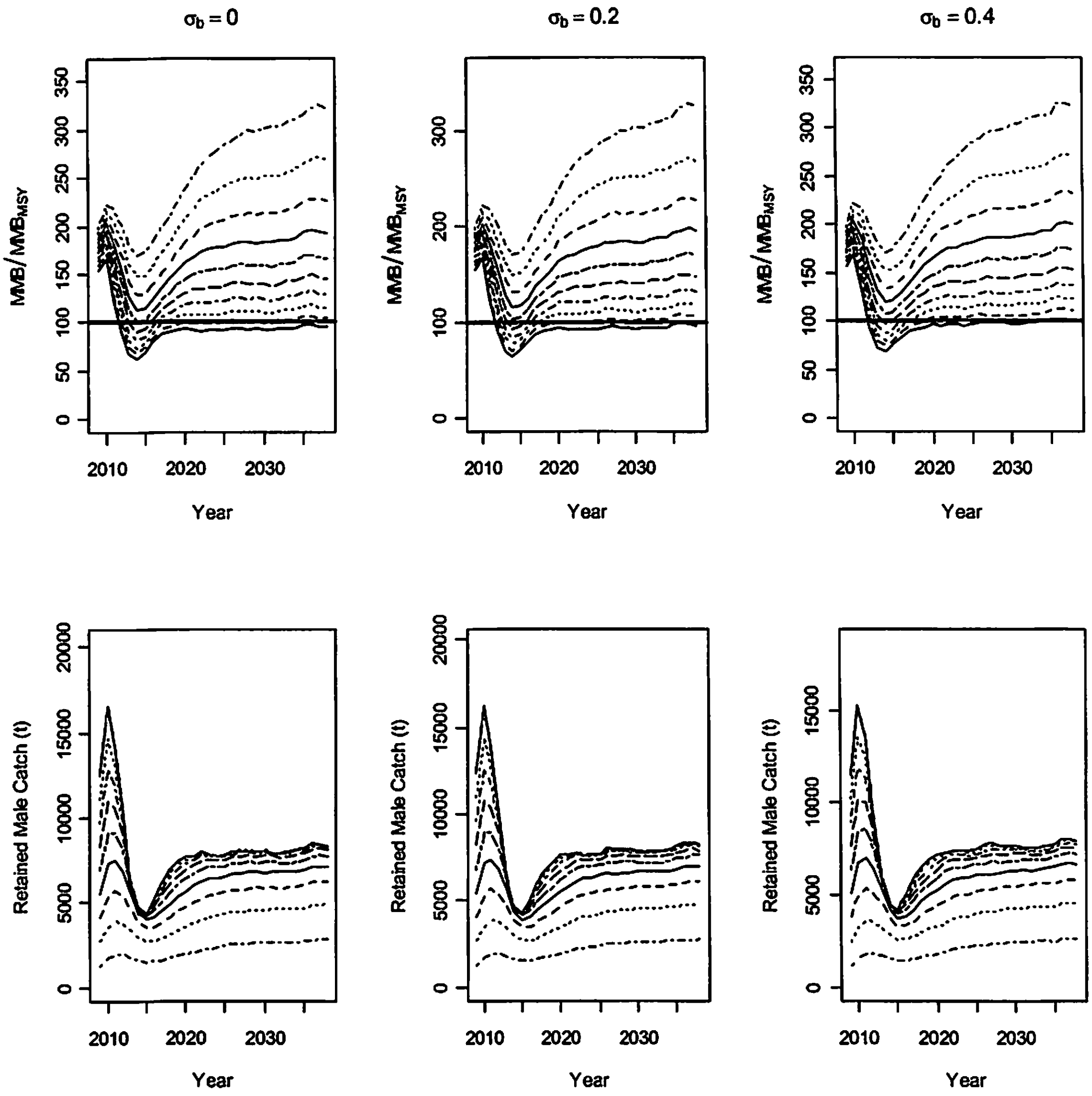


Figure X.7a. Median time-trajectories of mature male biomass (at the time of mating) relative to the proxy for B_{MSY} (B_{35}) and median time-trajectories of the catch of legal males in the directed fishery for different buffer values (0.1 to 1) and values for the extent of additional variability (σ_b=0, 0.2, 0.4). The results in this figure are based on the Beverton-Holt stock-recruitment relationship. The three columns in this figure correspond to the results in Tables X.3a-c respective

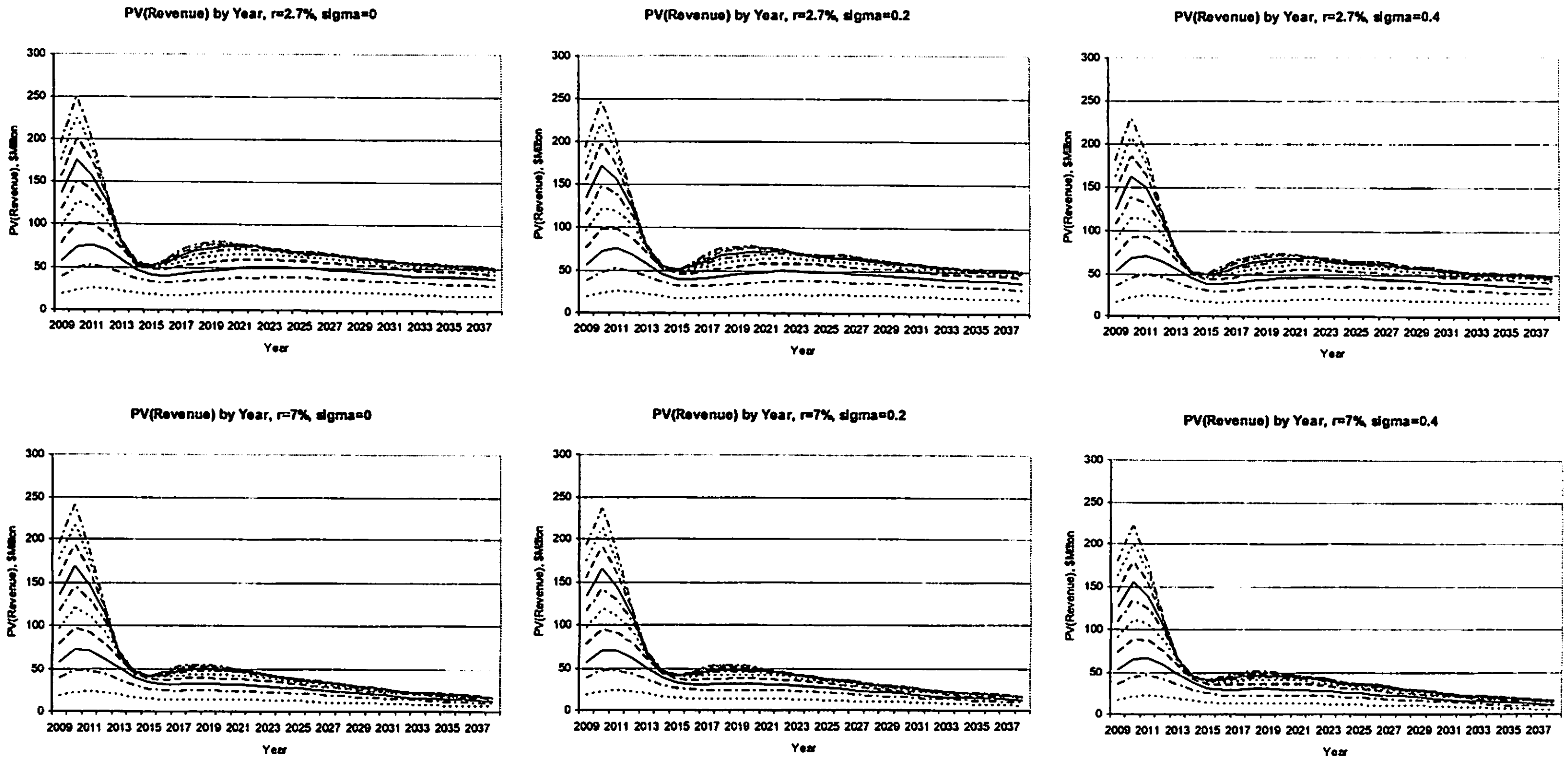


Figure X.7b. Median time-trajectories of projected gross revenues in the directed fishery for median and 95% confidence interval catch projections for different buffer values (0.1 to 1) and values for the extent of additional variability (σ_b=0, 0.2, 0.4). The results in this figure are based on the Beverton-Holt stock-recruitment relationship. The three columns in this figure correspond to the revenue columns in Tables X.3a-c respectively.

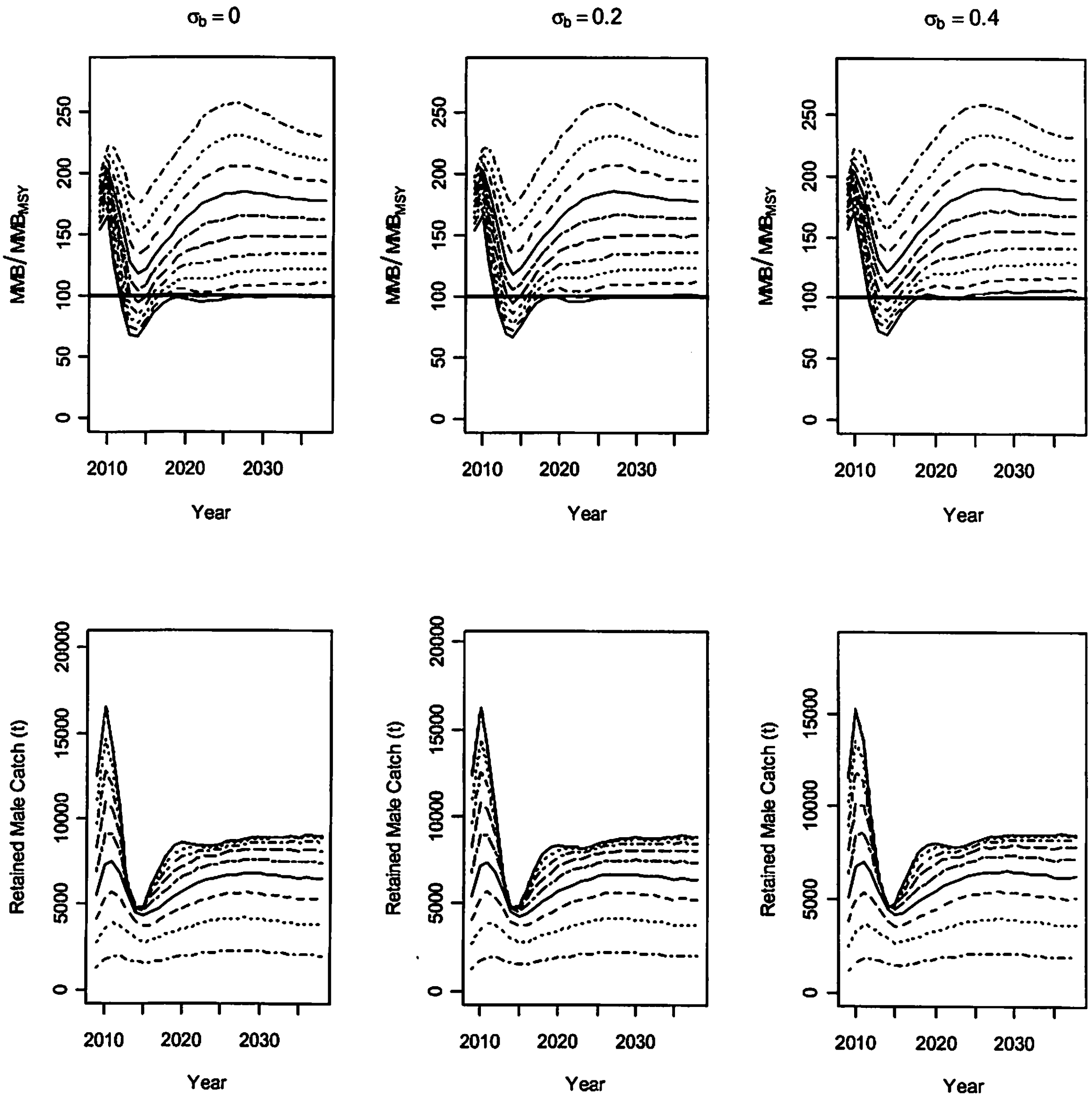


Figure X.8a. Median time-trajectories of mature male biomass (at the time of mating) relative to the proxy for B_{MSY} (B_{35}) and median time-trajectories of the bcatch of legal males in the directed fishery for different buffer values (0.1 to 1) and values for the extent of additional variability (σ_b=0, 0.2, 0.4). The results in this figure are based on the Ricker stock-recruitment relationship. The three columns in this figure correspond to the results in Tables X.4a-c respectively.

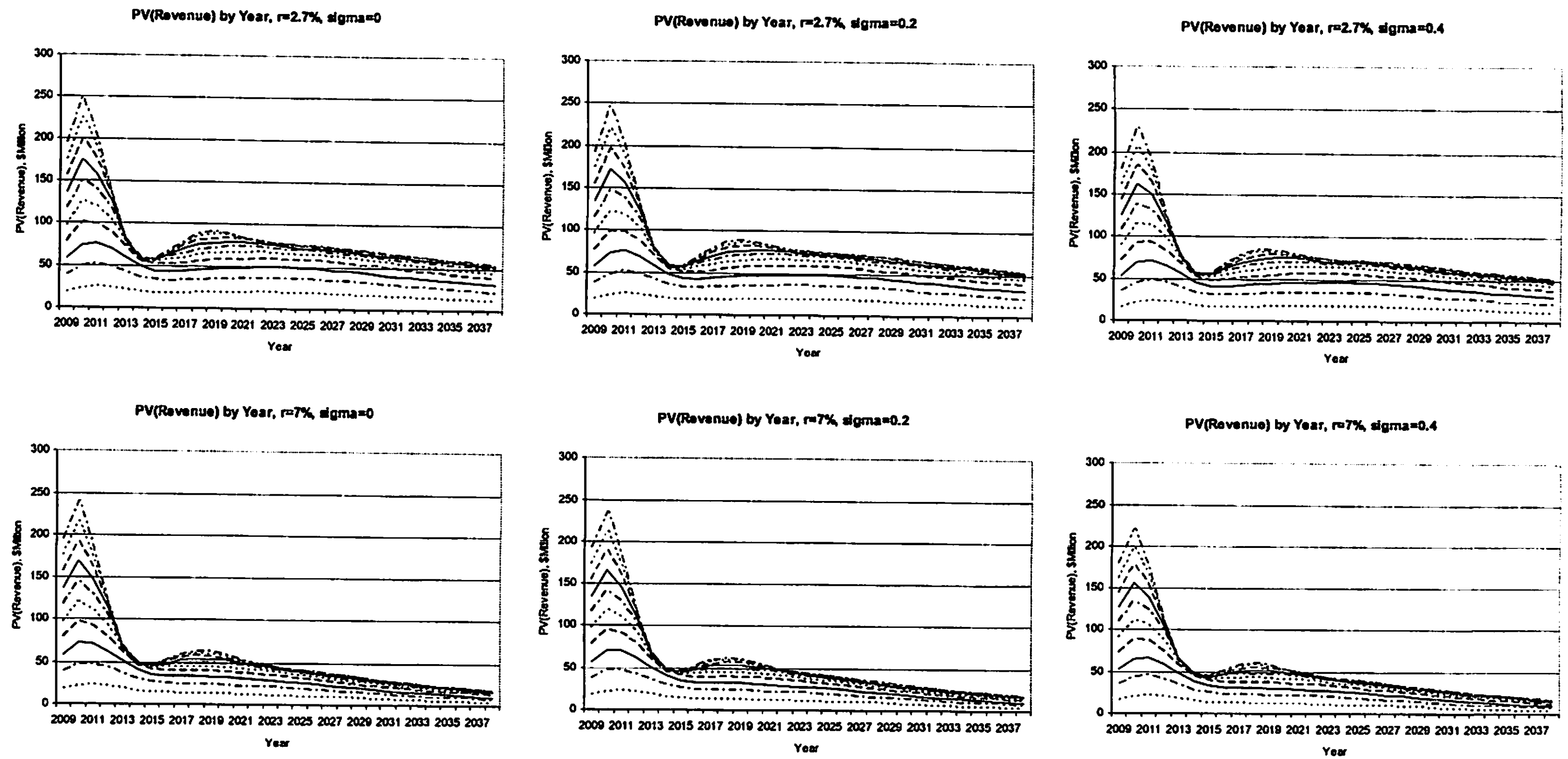


Figure X.8b. Median time-trajectories of projected gross revenues in the directed fishery for median and 95% confidence interval catch projections for different buffer values (0.1 to 1) and values for the extent of additional variability (σ_b =0, 0.2, 0.4). The results in this figure are based on the Ricker stock-recruitment relationship. The three columns in this figure correspond to the revenue columns in Tables X.3a-c respectively

APPENDIX XX: METHOD USED TO CONDUCT THE MEDIUM-TERM PROJECTIONS

Thirty-year projections are conducted to evaluate the medium-term implications of the different buffers in terms of their impact on stock status (measured in terms of mature male biomass at the time of mating relative to B_{35}, the probability of overfishing, and the probability of the stock becomes overfished, $B < 0.5B_{35}$) as well as socio-economic impacts. The projections account for uncertainty related to: (a) the values for the parameters of the population dynamics model used to model the stock, (b) the recruitment to the modelled population for each future year, (c) the form of the stock-recruitment relationship, and (d) the stock assessment models used for population size estimation. These sources of uncertainty reflect the scientific uncertainty which the buffer between the OFL and ABC (and hence ACL) is meant to account for.

The algorithm used is as follows:

1) Fit the stock assessment model to the data for the stock to obtain the "best estimates" of parameters of the model.
2) Apply the Markov chain Monte Carlo (MCMC) method to obtain a set of 800 equally likely sets of parameter vectors from the posterior distribution for these parameters. This step quantifies source (a) outlined above.
3) For each draw from the posterior distribution:
    a. Calculate $F_{35\%}$ and set F_{MSY} to $F_{35\%}$.
    b. Given F_{MSY} and the assumed form of the stock-recruitment relationship (Ricker or Beverton-Holt) find the value for the steepness of the stock-recruitment relationship so that MSY occurs at $F_{35\%}$.
    c. Set R_0 (the virgin recruitment) so that B_{MSY} occurs at the proxy for B_{MSY} selected by the Crab PLAN team if full-selection fishing mortality on legal male crab in the directed fishery equals $F_{35\%}$.
    d. Calculate the extent of variability (quantified using a standard deviation, i.e. σ_R) between the actual recruitment estimates and the values predicted by the stock-recruitment relationship for the years corresponding to B_{MSY}.
4) Set the value for $F_{35\%}$ used when setting the OFL to the median of the values for $F_{35\%}$ across the draws from the posterior (i.e., the projections are undertaken under the assumption that $F_{35\%}$ is correct on average when setting OFLs).
5) Set the value for σ_R used when generating future recruitment to the median of the values for σ_R across the draws from the posterior.
6) For each draw from the posterior distribution and choice of a buffer:
    a. Generate an assessment bias, b, based on a normal distribution with mean zero and standard deviation σ_b[4].
    b. For each year of the thirty-year projection period:
        i. Compute the true OFL (the OFL based on the parameters generated from the posterior distribution).
        ii. Generate the data on which the ACL will be based by generating a random variable ε_y from $N(0;\sigma_w^2)$[5] which represents the annual deviation in the assessment result from the true value and then multiplying all of the

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[4] This source of uncertainty reflects the "additional uncertainty" not captured within the assessment.

[5] The value for σ_w is set to the standard deviation of the logarithm of the estimate of mature male biomass at mating in the last year of the assessment.

population-related information needed to set the ABC (mature male biomass at mating, numbers-at-length) by $\exp(b+\varepsilon_y-\sigma_b^2/2-\sigma_w^2/2)$ to generate the data used when setting the ABC[6].

iii. Compute the OFL based on the data generated at step ii) and multiply it by the buffer to compute the ABC (and hence the catch).
iv. Project the population ahead one year and generate the recruitment for the next year.

Economic analysis of catch projections

Economic figures used in the analysis are presented in Table XX1. Preliminary economic analysis of the 30 year projections applies a constant price through the time trajectory and presents results as the present value of projected gross revenues, based on the projected catch estimates in the directed fishery. Estimated first wholesale production volume is derived by multiplying directed catch projections by mean product recovery rate (volume weighted mean over all product forms, averaged over available time series). The projected revenue figures use the average first wholesale price for 2008, calculated as the volume-weighted mean over all product forms and all processing plants in the rationalized fishery. Projected revenues are discounted to present value using OMB-specified values for regulatory impact analysis (7%;OMB, 1996) and benefit cost analysis (2.7%, based on 30-year bond rate; OMB, 2009).

For further analysis of ACL alternatives to be presented in the preliminary review draft for March 2010, we plan to improve this preliminary analysis following guidance from the SSC regarding the preliminary economic analysis of snow crab rebuilding presented at the October 2009 NPFMC meeting (October 2009 SSC Minutes), by providing more detailed economic results for both the processing and harvest sectors, both in terms of projected gross revenues and likely net revenue effects, and effects on participants in the fisheries relative to estimated dependency on affected crab fishery resources. In addition, we will employ the price forecasting model developed by Dalton (2008), revised per SSC recommendations provided at the October 2008 SSC meeting (SSC, 2008).

Dalton, M. (2008). "A Time Series Analysis of U.S. Import Prices and Alaska Processors' Wholesale Prices for King Crab." Report to the North Pacific Fishery Management Council, September 10.

Garber-Yonts, Brian. 2009. BSAI Crab Economic Data Report Database Metadata Documentation. NOAA, Alaska Fisheries Science Center, Seattle, WA. http://www.fakr.noaa.gov/sustainablefisheries/crab/rat/edr/metadata_013009.xls.

OMB. 1996. "Economic Analysis of Federal Regulations Under Executive Order 12866." URL: http://www.whitehouse.gov/omb/inforeg_riaguide/#iii.

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[6] The data used when setting the ABC thus differ from the true values due to a random component which is common across years and a random component which varies among years,

SSC. 2008. "Draft report of the Scientific and Statistical Committee to the North Pacific Fishery Management Council, September 29-October 1, 2008."

OMB. 2009. "Circular No. A-94: Discount rates for cost-effectiveness, lease purchase, and related analyses." URL: http://www.whitehouse.gov/omb/circulars_a094_a94_appx-c/.

Table XX1: Economic Production and First Wholesale Price in the Bristol Bay Red King Crab Fishery, 1998-2008[1].

Year	Finished pounds	Processed raw pounds	Mean product recovery	RKC sales revenues	Pounds sold	RKC sales ratio	Mean First Wholesale Price
1998	8785470	13242789	0.659	64191960.99	8929813	0.11	7.12
2001	5339217	8200864	0.652	61270915.9	5259166	0.14	11.68
2004	9636167	14541382	0.642	91862793.37	9032394	0.22	10.31
2005	11248089	18390112	0.618	60211049.93	6814143	0.23	9.52
2006	9168267	14164626	0.647	66705181.21	8367762	0.16	8.11
2007	13084503	17598503	0.678	82323008.61	9598092	0.17	8.70
2008	13314414	20101781	0.662	97729170.68	10179241	0.12	**9.79**
		Average PRR:	**0.651**				

[1] Data are from the BSAI Crab Economic Data Reports; dollar values are CPI-adjusted to base year 2009

An Approach to P*-based ACLs for BSAI FMP Crab Stocks,

With a Comparison to the Constant-Buffer ACLs

Three BSAI FMP crab stocks are currently classified as Tier 5 stocks (NPFMC 2009):

- Western Aleutian ("Adak") red king crab
- Aleutian Islands golden king crab
- Pribilof golden king crab.

Note that the Aleutian Islands golden king crab stock is anticipated to be re-classified as a Tier 4 stock, pending adoption of a stock-assessment model that has been developed for the stock (NPFMC 2009, p. 23).

The overfishing limit (OFL) for each of the Tier 5 stocks "is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information" (NPFMC 2009, p. 3):

> "The OFL represents the average retained catch from a time period determined to be representative of the production potential of the stock. The time period selected for computing the average catch, hence the OFL would be based on the best scientific information available and provide the appropriate risk aversion for stock conservation and utilization goals. In Tier 5, the OFL is specified in terms of an average catch value over a time period determined to be representative of the production potential of the stock, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information.
>
> "For most Tier 5 stocks, only retained catch information is available so the OFL will be estimated for the retained catch portion only, with the corresponding overfishing comparison on the retained catch only. In the future, as information improves, the OFL calculation could include discard losses, at which point the OFL would be applied to the retained catch plus the discard losses from directed and non-directed fisheries" (NPFMC 2009, p. 5)."

Note that, due to insufficient history and confidentiality of data on discards and bycatch, the OFL for the BSAI crab Tier 5 stocks has been defined in terms of the retained catch only.

The 2009/10 OFLs for the three Tier 5 stocks were as follows:

Stock	Catch years (retained)	2009/10 OFL (retained catch)
Western Aleutian Is red king crab	24 years: 1984/85–2007/08	0.50-million pounds
Aleutian Islands golden king crab	11 years: 1985/86–1995/96	9.18-million pounds[a]
Pribilof Islands golden king crab	6 years: 1993-1998	0.176-million pounds

a. The CPT recommended 1990/91–995/96 as the years for computing average retained catch for an OFL of 6.93-million pounds (NPFMC 2009), but the SSC recommended 1985/86–1995/96 and 9.18-million pounds (June 2009 SSC minutes).

<u>Recommended method for to computing P*-based ACL for the Tier 5 stocks</u>.

Assuming that the average retained catch is an "appropriate proxy for the long-term average production potential" (June 2008 SSC minutes, p. 15) and that the years chosen to compute the long-term average are from a time period that is, in fact, "representative of the production potential of the stock," one could conceptualize the catch in each year during the chosen time period as a random observation from an imaginary infinite sequence of annual catches during which the "long-term average production potential" was maintained. In that case, ACLs based on the P* approach can be determined from the distribution of the sample mean; I am suggesting that be done by using a t-distribution to compute the lower bound of the approximate (1-2P*) confidence interval for the mean (i.e., of the "long-term average production potential"). That is, the ACL could be computed as,

$$ACL = \bar{x} - t_{(P*, df=n-1)} s_{\bar{x}}$$

where,

$\bar{x} = \textit{sample mean of n annual catches in time period,}$

$t_{(P*, df=n-1)} = \textit{the } P* \textit{ percentile of a t distribution with } n-1 \textit{ degrees of freedom, and}$

$s_{\bar{x}} = \textit{the standard error of the mean computed from the sample of n annual catches.}$

Data and Analysis

Data and relevant sample statistics for each of the three Tier 5 stocks are in Table 1.

The sample distributions of retained catch for each of the stocks show some strong departures from what would be expected from a normal distribution (Figure 1). Given that and the small sample sizes (as few as 6 years for the Pribilof Islands golden king crab sample and up to 24 years for the Western Aleutian Islands red king crab sample), it's worthwhile to give some consideration to the sampling distribution of the mean and to investigate whether a t distribution can, for our purposes, provide a useful approximation to that sampling distribution. The sampling distribution of the mean was investigated by generating 1,000 bootstrapped sample means for each of the three samples of annual retained catches and comparing the distribution of those bootstrapped sample means to a t-distribution with the appropriate degrees of freedom. Additionally the P*-based ACLs determined according to the percentiles of the distribution of the bootstrapped means were compared with those determined from the t distribution.

The bootstrap-generated sampling distributions of the mean were in each case unimodal (Figure 2, top row). Comparisons of the boot-strapped sampling distributions of the mean with the appropriate t distribution (Figure 2, second and third row) suggest that the sampling distribution of the mean may have shorter left tails than expected for the t distribution and that the t distribution provides a good approximation except for at the tails of the distribution (e.g., for percentiles < ~10th percentile). This analysis suggests that errors in determining ACLs by using the t distribution would be more conservative than the nominal P* level; i.e., if anything, the ACL so determined would be smaller than needed for a value of P*, particularly for smaller values of P* (Figure 2, bottom row).

Results

P*-based ACLs determined using the recommended (t-distribution) approach for each of the three stocks for values of P* ranging from 0.10 to 0.50 in increments of 0.10 are given and compared with the 2009/10 OFL and with the (P*x100)th percentiles of the bootstrapped sampling distribution of the mean in Table 2. The P*-based ACLs are compared with values for a constant-buffer approach to determining ACLs (i.e., percent of OFL) in Table 3.

Table 1. Values of retained catch and sample statistics (mean, standard deviation, and standard error of the mean) for the time periods used to determine the 2009/10 retained-catch OFL for the Western Aleutian Islands ("Adak") red king crab, Aleutian Islands golden king crab, and Pribilof Islands golden king crab stocks.

Western Aleutian Islands Red King Crab		Aleutian Islands Golden King Crab		Pribilof Islands Golden King crab	
Years	Retained Catch	Years	Retained Catch	Years	Retained Catch
1984/85	1,296,385	1985/86	12,734,212	1993	67,458
1985/86	868,828	1986/87	14,738,744	1994	88,985
1986/87	712,543	1987/88	9,257,005	1995	341,908
1987/88	1,213,892	1988/89	10,627,042	1996	329,009
1988/89	1,567,314	1989/90	12,022,052	1997	179,249
1989/90	1,105,971	1990/91	6,950,362	1998	35,722
1990/91	828,105	1991/92	7,702,141		
1991/92	951,278	1992/93	6,291,197		
1992/93	1,286,424	1993/94	5,551,143		
1993/94	698,077	1994/95	8,128,511		
1994/95	196,967	1995/96	6,960,406		
1995/96	38,941				
1996/97	0				
1997/98	0				
1998/99	5,900				
1999/00	0				
2000/01	76,562				
2001/02	153,961				
2002/03	505,642				
2003/04	479,113				
2004/05	0				
2005/06	0				
2006/07	0				
2007/08	0				
n	24	N	11	n	6
Mean	499,413	Mean	9,178,438	Mean	173,722
Std. dev.	527,442	Std. dev.	2,973,391	Std. dev.	134,125
Std. error	107,664	Std. error	896,511	Std. error	54,756

Table 2. 2009/10 overfishing level (OFL, pounds of retained catch) for the Western Aleutian Islands ("Adak") red king crab (WAI RKC), Aleutian Islands golden king crab (AI GKC), and Pribilof Islands golden king crab (PI GKC) stocks and the retained-catch ACLs (pounds) for alternative values of P* between 0.10 and 0.50 computed by assuming that the sample mean of retained catch for the chosen period of n years has a t distribution with n-1 degrees of freedom, with (P*x100)th percentiles of the bootstrapped sampling distribution of the mean for comparison.

	WAI RKC		AI GKC		PI GKC	
OFL	499,413		9,178,438		173,722	
	ACL		ACL		ACL	
P*	t, df=23	Bootstrap	t, df=10	Bootstrap	t, df=5	Bootstrap
0.10	357,355	359,184	7,948,260	8,176,708	92,908	112,936
0.20	407,088	406,578	8,390,353	8,505,180	123,371	131,568
0.30	442,163	445,518	8,692,952	8,764,822	143,090	148,363
0.40	471,819	471,463	8,945,179	8,995,717	159,092	161,656
0.50	499,413	497,076	9,178,438	9,196,835	173,722	173,722

Table 3. Comparison of the P*-based (i.e., Alternative 3) and constant-buffer-based (i.e., Alternative 2) ACLs: the P*-based ACLs are computed from percentiles of t distribution with appropriate degrees of freedom (see text) and the buffers are defined as (ACL/OFL) x 100%.

	WAI RKC		AI GKC		PI GKC	
OFL	499,413		9,178,438		173,722	
P*	ACL (t, df=23)	Buffer	ACL (t, df=10)	Buffer	ACL (t, df=5)	Buffer
0.10	357,355	72%	7,948,260	87%	92,908	53%
0.20	407,088	82%	8,390,353	91%	123,371	71%
0.30	442,163	89%	8,692,952	95%	143,090	82%
0.40	471,819	94%	8,945,179	97%	159,092	92%
0.50	499,413	100%	9,178,438	100%	173,722	100%

Buffer	ACL	P* (t, df=23)	ACL	P* (t, df=10)	ACL	P* (t, df=5)
100%	499,413	0.50	9,178,438	0.50	173,722	0.50
90%	449,472	0.32	8,260,594	0.17	156,350	0.38
80%	399,530	0.18	7,342,750	0.03	138,978	0.28
70%	349,589	0.09	6,424,907	0.01	121,605	0.19
60%	299,648	0.04	5,507,063	0.001	104,233	0.13
50%	249,707	0.01	4,589,219	0.000	86,861	0.09
40%	199,765	0.01	3,671,375	0.000	69,489	0.06
30%	149,824	0.00	2,753,531	0.000	52,117	0.04
20%	99,883	0.00	1,835,688	0.000	34,744	0.03
10%	49,941	0.00	917,844	0.000	17,372	0.02

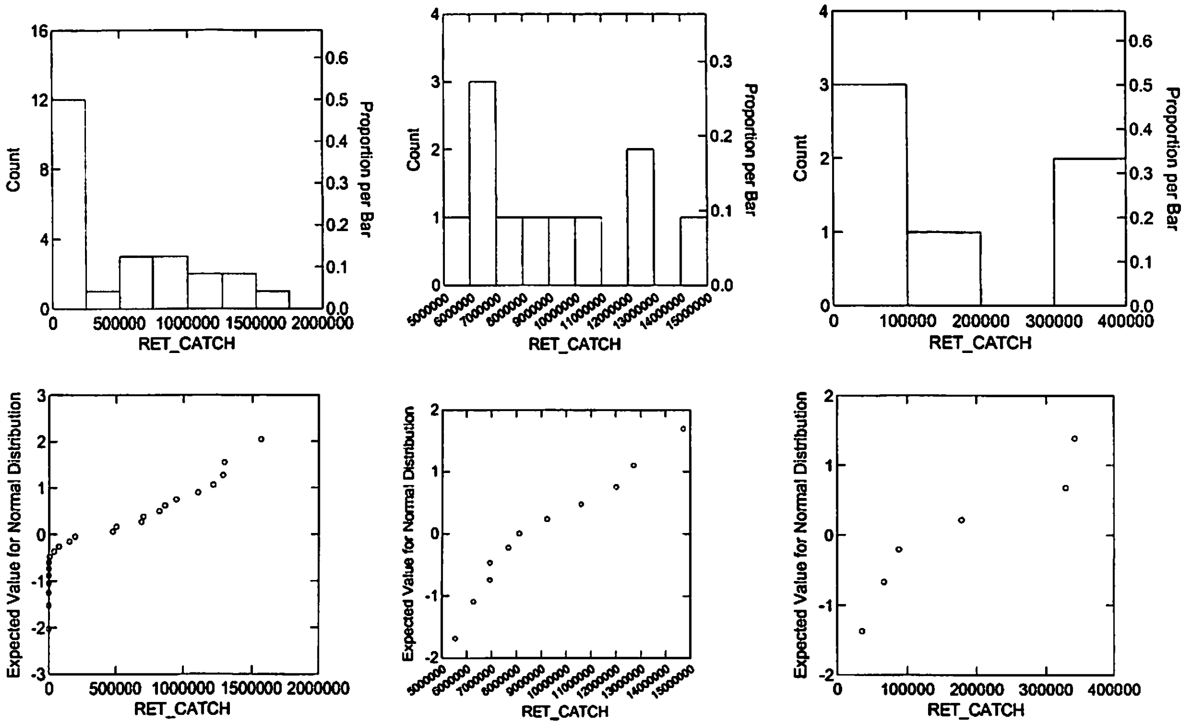

Figure 1. Frequency distribution histograms (top row) and normal probability plots (bottom row) of the annual retained catch values in the time periods used to estimate the retained-catch overfishing limits (OFLs) for each of the Western Aleutian Islands red king crab stock (left column), Aleutian Island golden king crab stock (middle column), and Pribilof Island golden king crab stock (right column).

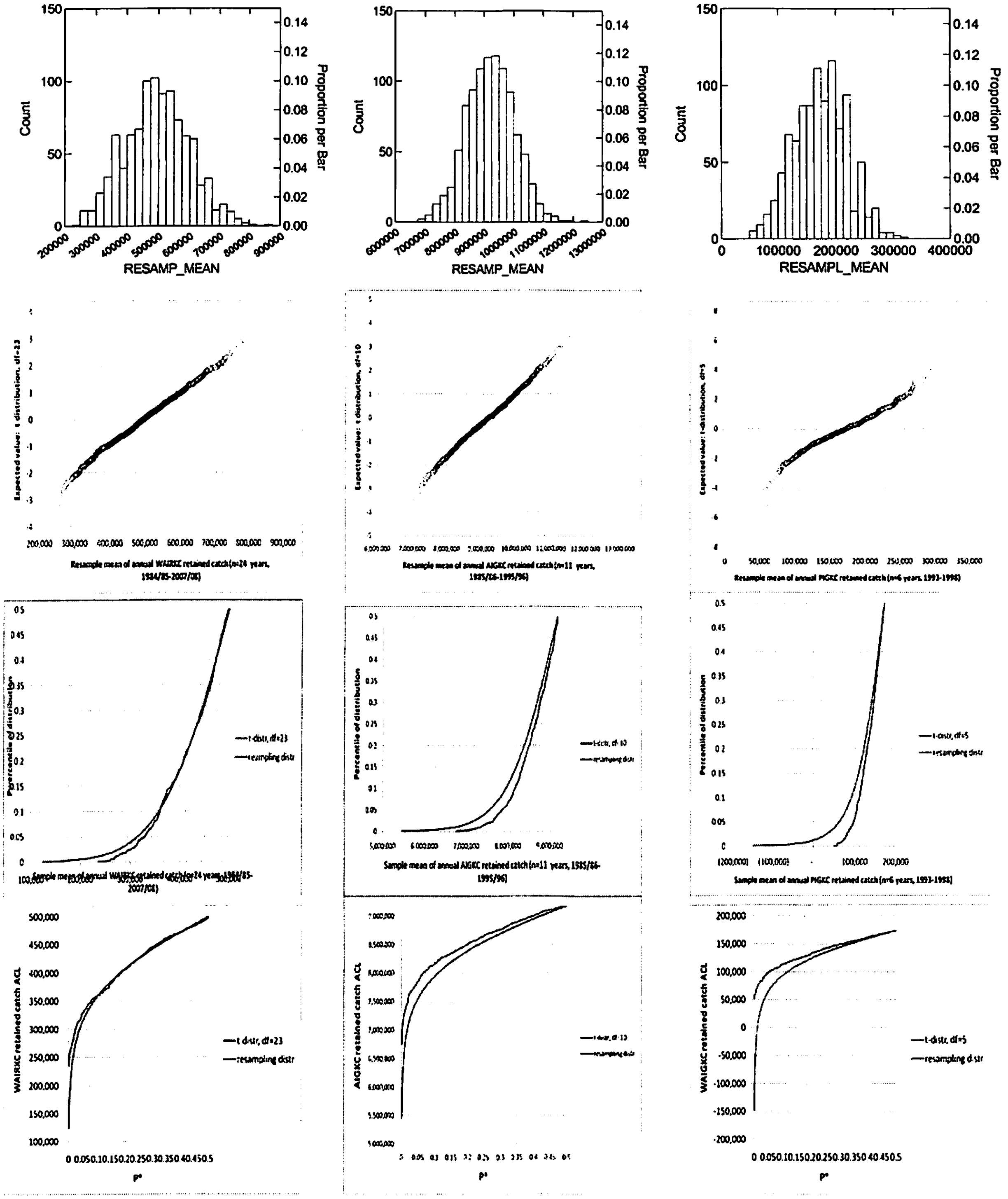

Figure 2. Bootstrap distribution of sample means for WAI RKC (left column), AI GKC (middle column) and PI GKC (right column) data: histograms (top row), probability plots (relative expected for t distribution with n-1 degrees of freedom; 2nd row), percentiles of distribution in comparison to t distribution with n-1 degrees of freedom (3rd row), and resulting ACLs for given value of P* in comparison to ACLs for given value of P* computed assuming t distribution with n-1 degrees of freedom (bottom row).

Henderschedt

add H' rev, with the following changes

C-3(a) BSAI Crab Right of First Refusal

The AP recommends the following actions and alternatives move forward for analysis, noting the changes (bold and strikeout) to Action 2, Alternative 2 below:

Action 1: Increase a right holding entity's time to exercise the right and perform as required.

Alternative 1 – status quo

1) Maintain current period for exercising the right of first refusal at 60 days from receipt of the contract.
2) Maintain current period for performing under the right of first refusal contract at 120 days from receipt of the contract.

Alternative 2: Increase an entity's time to exercise the right and perform.

1) Require parties to rights of first refusal contracts to extend the period for exercising the right of first refusal from 60 days from receipt of the contract to 90 days from receipt of the contract.
2) Require parties to rights of first refusal contracts to extend the period for performing under the contract after exercising the right from 120 days from receipt of the contract to 150 days from receipt of the contract.

Action 2: Increase community protections by removing the ROFR lapse provisions.

Alternative 1 – status quo

1) Maintain current provision under which the right lapses, if IPQ are used outside the community of the entity holding the right for three consecutive years.
2) Maintain current provision, which allows rights to lapse, if the PQS is sold in a sale subject to the right (and the entity holding the right fails to exercise the right).

Alternative 2 – Strengthen community protections under circumstances where ROFR may lapse.
~~Increase community protections by removing the provisions under which the right lapses.~~

Option 1: Require parties to rights of first refusal contracts to remove the provision that rights lapse, if the IPQ are used outside the community for a period of three consecutive years

Option 2: If any entity with a right of first refusal chooses not to exercise its right, and the ~~IPQ~~ PQS is sold and used in another community, then the right of first refusal as to the original entity lapses and is acquired by the community entity where the IPQ is currently being used.
~~Require parties to right of first refusal contracts to remove any provision for the right to lapse, if an entity chooses not to exercise its right~~

a. after 3yrs
b. after 5yrs

Option 3: Require that any person holding PQS that met landing thresholds qualifying a community entity for a right of first refusal on program implementation to maintain a contract providing that right at all times

Action 3: Apply the right to only PQS and assets in the subject community.

Alternative 1 – status quo

The right of first refusal applies to all assets included in a sale of PQS subject to the right, with the price determined by the sale contract.

Alternative 2: Apply the right to only PQS.

Require parties to rights of first refusal contracts to provide that the right shall apply only to the PQS subject to the right of first refusal. In the event other assets are included in the proposed sale, the price

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of the PQS to which the price applies shall be determined by a) agreement of the parties or b) if the parties are unable to agree, an appraiser jointly selected by the PQS holder and the entity holding the right of first refusal. c. an arbitrator

Alternative 3: Apply the right to only PQS and assets in the subject community.

Require parties to rights of first refusal contracts to provide that the right shall apply only to the PQS and other assets physically present in the community benefiting from the right of first refusal. In the event other assets are included in the proposed sale, the price of the PQS to which the price applies shall be determined by a) agreement of the parties or b) if the parties are unable to agree, an appraiser jointly selected by the PQS holder and the entity holding the right of first refusal.

Motion passed 19/0

C-3(b) WAG King Crab Regional Delivery

The AP recommends the Council move the package forward for analysis. *Motion passed 19/0*

Minority Report: After a motion to delete Alternative 3 from the analysis failed (8/11), a motion was made to add an alternative to convert Western Alaska Golden King Crab QS to B shares (failed 3/16).

Converting WAG to a B share fishery accomplishes the same thing that removing the regional landing requirement does. Neither of these alternatives addresses the Council's Purpose and Need statement. The undersigned believe that if the Council is going to include an alternative as drastic as removing the regional landing requirement, consideration should be given to a B share conversion as well. Signed by: Beth Stewart, Jerry Downing, Chuck McCallum

C-4 Groundfish Annual Catch Limits

The AP recommends that the Council have the Non-target Species Committee convene to address this item prior to the April meeting and consider management measures that may be needed in a trailing amendment. *Passed 18/0*

The AP further recommends the Council move forward with this analysis. *Passed 18/0*

C-5(a) Amendment 80 Lost Vessel Replacement

The AP recommends the Council approve Staff Proposed Purpose and Need Statement as written. Further, the AP recommends the Council move the analysis forward for public review with the following modifications to the alternatives and options (bold and strikeout):

Staff Suggested Purpose and Need

Allowing Amendment 80 vessel owners to replace their vessels due to actual total loss, constructive total loss, permanently ineligibility to be used in a U.S. fishery, or for other reasons would allow vessel owners to improve vessel safety, meet international class and load line requirements that would allow a broader range of onboard processing options, or to otherwise improve the economic efficiency of their vessels. Allowing smaller vessels to be replaced with larger vessels could improve the ability of vessel owners to comply with the groundfish retention standard (GRS) applicable to all Amendment 80 vessels.

Feb 13, 2010

PUBLIC TESTIMONY SIGN-UP SHEET

Agenda Item: C-3(b) BSAI Crab WAG landing requirement

	NAME *(PLEASE PRINT)*	**TESTIFYING ON BEHALF OF:**
1	Dave Fraser	Adak Community Development Corp.
2	Clem Tillion	Aleut Corp
3	Everette Anderson	APICDA
4	(Joe Sullivan, Edward Poulsen,	} ICEPAC, ACC and
5	Gretar Gudmundsson, Margaret Wells)	} Crab Group - together
6	Jake Jacobsen	Inter-Cooperative Exchange
pass 7	Steve Minor	North Pacific Crab Assoc.
pass 8	Heather McCarty / Mateo Paz-Soldan	CBSFA / City of St. Paul
9	MIKE STANLEY	GKCHA
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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.

C-3(b)(2) West region exemption in WAI golden king crab fishery
Motion, February 13, 2010

Release for public review with the following revisions:

Remove Alternative 2, Option 2

Purpose and need statement:

The purpose of this proposal is to develop a regulation to allow waiver of the requirement that west-designated Western Aleutian Islands gold king crab (WAG) individual fishing quota (IFQ) be delivered west of 174 ° W. longitude.~~, in the event that no~~ A reliable shoreside processing facility ~~is open~~ may not be available each season to take delivery and process WAG IFQ. ~~In that circumstance,~~ Relaxing the regional landing requirement ~~needs to be relaxed to~~ would allow the IFQ to be delivered outside the west region, to promote full utilization of the TAC.