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

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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

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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.

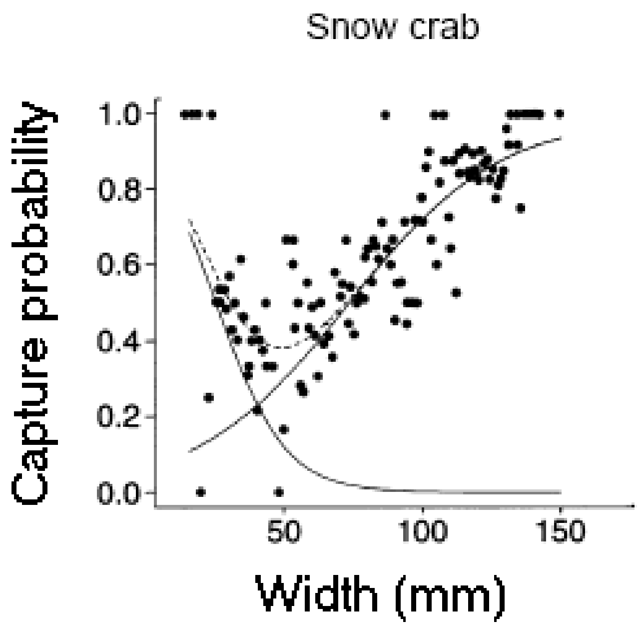

Figure 2. Location of the side-by-side trawling areas (shown with pink shading) and the 3 BSFRF survey areas encompassing the 27 NMFS survey blocks (shown with a red line). Location of the 1998 auxiliary bag experiment sampling areas (blue circles).

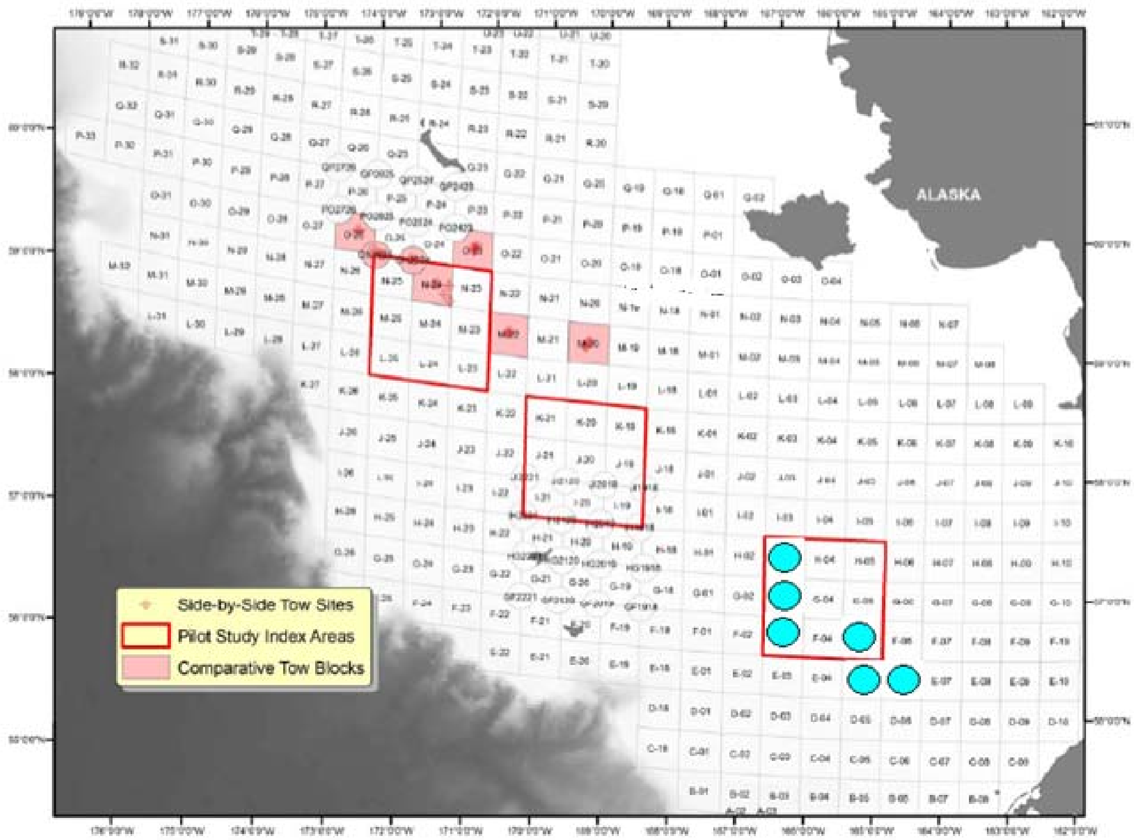

Figure 3. The cpue ratio (NMFS cpue / BSFRF cpue) by 5 mm width interval is shown with the fitted model evaluated at the mean (over the 27 NMFS stations in the 3 BSFRF blocks), maximum and minimum net widths. Also shown is the fitted model ignoring net width. Note, for clarity, ratios > 1.2 were omitted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

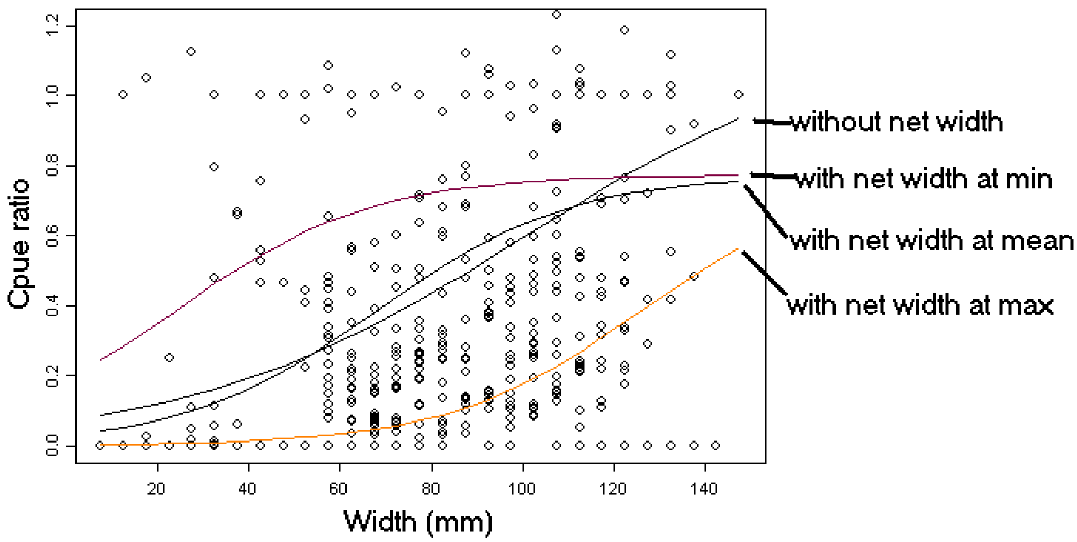

Figure 4. A possible estimator of survey selectivity from trawl selectivity that is spatially varying. This estimate was produced by evaluating the trawl selectivity function, by 5 mm width increments, at each NMFS station using the measured value of net width, then for each increment computing the weighted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

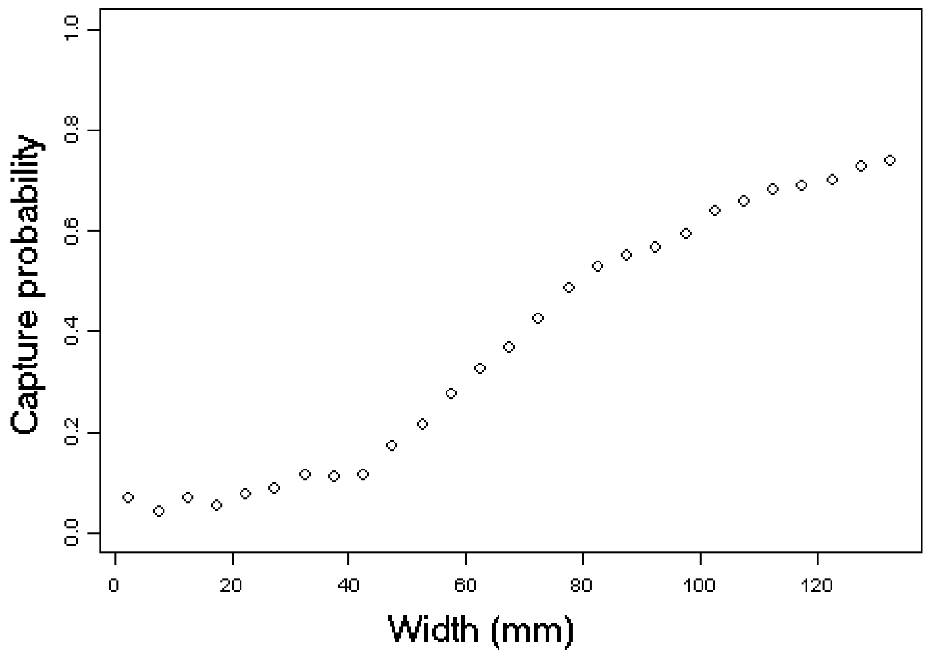

Figure 5. Plot of the mean catch ratio (NMFS/BSFRF) in the 27 NMFS survey areas by 5 mm width intervals and the fit of a logistic function. Also shown are the 95% confidence intervals on the mean selection determined using a process known as bootstrapping.