Selectivity correction for Shelikof Strait acoustic trawl survey data

Background: Shelikof Strait has been surveyed annually starting in 1981, primarily to monitor the pollock spawning aggregation that occurs in the strait in March. Acoustic survey methodology relies on midwater trawl sampling to scale backscatter into abundance at length. Trawl catch samples are assumed to be representative of the species and size composition of the acoustically sampled population. As trawls are generally selective in what they catch, this assumption can impart errors on the acoustic survey results.

Midwater trawl selectivity was assessed during the Shelikof Strait survey on four occasions; in 2007, 2008, 2013 and most recently in 2018. Selectivity was estimated by placing small recapture nets ("pocket nets") on the outside of the midwater trawl surface to sample escaping fish. In 2007, this work was carried out on the NOAA ship Miller Freeman (MF), and in 2008, the experiment was repeated using the new noise quieted NOAA ship Oscar Dyson (DY). The experiment consisted of eight back-to-back trawl operations taken opportunistically on fish populations that featured a large range of fish sizes, from 8 – 65 cm, with multiple size modes. These results were used to fit a hierarchical Bayesian model (HBM), separately for each experiment year. Details on the pocket net experimental design and the model specifics can be found in Williams et al 2010.

In 2013, two similar dedicated trawling experiments were carried out, but consisting of only four trawls each. In addition, pocket nets were placed on every trawl sample taken throughout the strait, regardless of the fish size composition. In each of these pocket net trawling events, the pocket nets were attached to the trawl as it was being deployed, and removed from the trawl as it was being retrieved onto the net reel. This method was used because the pocket nets were manufactured from low strength materials and were not sufficiently robust to prevent damage when being rolled up with the trawl onto the net reel. In 2018, pocket nets were manufactured from a more durable material identical to the codend liner (0.5" / 12 mm mesh) and permanently attached to the trawl at the onset of the cruise. This approach greatly reduced the trawling time by removing the laborious attaching and detaching of the nets, resulting in a safer and significantly more practical method.

The dedicated selectivity experiments conducted in 2007, 2008 and in 2013 aimed to estimate the values of the selectivity coefficients L50 (length at 50% retention in cm) and selection range (SR, distance from the 25% and 75% retention points on the logistic function in cm) as well as "directionality" parameters that described the pattern of fish escapement from the trawl. Bayesian posteriors for provided an estimate of within-and between haul variability of these parameters, which were then used to assess the sensitivity of abundance estimates to "selectivity corrected" trawl catch data (see Williams, 2013).

A critical shortcoming of the dedicated experimental design was that it was constrained spatially and temporally to the experimental locations and times, assuming that selectivity was constant and did not vary by location or other environmental factors such as temperature, fish depth, light levels, and fish size structure. For this reason, the non-dedicated datasets collected throughout the survey area where pocket nets were attached to each survey trawl event were thought to provide a better basis for estimating survey-wide selectivity. When the HBM was applied to these data (2013 and 2018), a successful convergence could not be achieved. This may be in part due to reduced signal in escapement in non-opportunistically chosen sample populations, or higher inherent variability in the data.

A new more pragmatic model was sought to fit these data, with the following objectives, 1) reduce the complexity of the model by removing "directional" parameters and using a binomial likelihood in place of the Poisson approach used in the HBM , 2) prioritize estimating of unbiased point estimates over a rigorous treatment of variance estimation, as the latter was not directly used in providing survey estimates for stock assessment, 3) improve robustness and practicality of model runs by taking a frequentist maximum likelihood approach over the necessity for deriving posterior distributions via MCMC. A proposed modified model (hierarchical selectivity model = HSM) is outlined below. The total number of fish *d* at length *l* escaping the trawl though the meshes (termed "mesh selection") is defined as

$$d_l = \sum_p {}^{n_{p.l}}/_{s_p}$$

where *n* is the number caught at length *l* in pocket *p* and *s* is the sampling proportion of pocket *p*. Sampling proportion is the # of meshes in a given trawl portion covered by the pocket net divided by the total number of meshes in that portion (see Williams et al 2011 for more details). A logistic selectivity function re-parameterized in terms of L_{50} and *SR* is

$$S_l = {}^{1}\Big/\left(1 + 9^{((L_{50}-l)/SR)}\right)$$

and the binomial negative log likelihood function is

$$-logL(L_{50}, SR) = \textstyle\sum_l (c_l \log(S_l) + d_l \log(1 - S_l)).$$

To estimate a multi-haul mean parameter value, haul specific estimates of L50 and SR are assumed to be random values drawn an underlying normal distribution as

$${L_{50}}_h \sim N(\mu L_{50}, \sigma L_{50})$$

and

$$SR_h \sim N(\mu SR, \sigma SR)$$

for each haul h. the values of $\mu L_{50}, \sigma L_{50}, \mu SR, \sigma SR$ are jointly estimated by normal likelihood as

$$-logL(\mu L_{50}, \sigma L_{50}) = Nlog(\sigma L_{50}) + \sum_h \frac{({L_{50}}_h - \mu L_{50})^2}{2\sigma {L_{50}}^2}$$

and

$$-logL(\mu SR, \sigma SR) = Nlog(\sigma SR) + \sum_h \frac{(SR_h - \mu SR)^2}{2\sigma SR^2}$$

where N is the number of hauls. The three likelihood components are combined for estimating the model parameters using maximum likelihood (*mle* function in R stats4 package). An inverse chi square penalty function is placed on the estimates of σL_{50} and σSR to prevent degenerate solutions where these parameter estimates become very small, similar to Williams et al. (2011). For the purposes of correcting the time series, the maximum likelihood of the posterior density is assumed to be an adequate point estimate for the selectivity correction. The correction is implemented as

$$\widehat{n_l} = {}^{n_l}/_{S_l}$$

where $\hat{n}$ is the selectivity corrected number of fish at length l to enter the trawl, n is the number retained in the codend, and S is the selection function based on model outputs μL_{50} and μSR.

While this model formulation does not directly account for inter haul variability due to pocket net sampling, the model readily converges and yields stable estimates with all datasets (dedicated experiments and survey-wide samples). The parameter estimates for L50 and SR are similar to outcomes of HBM's in the 2008 case (Oscar Dyson), while the outcome differed somewhat for 2007 EBS (Oscar Dyson) and substantially for the 2007 GOA set Miller Freeman, Fig. 1.

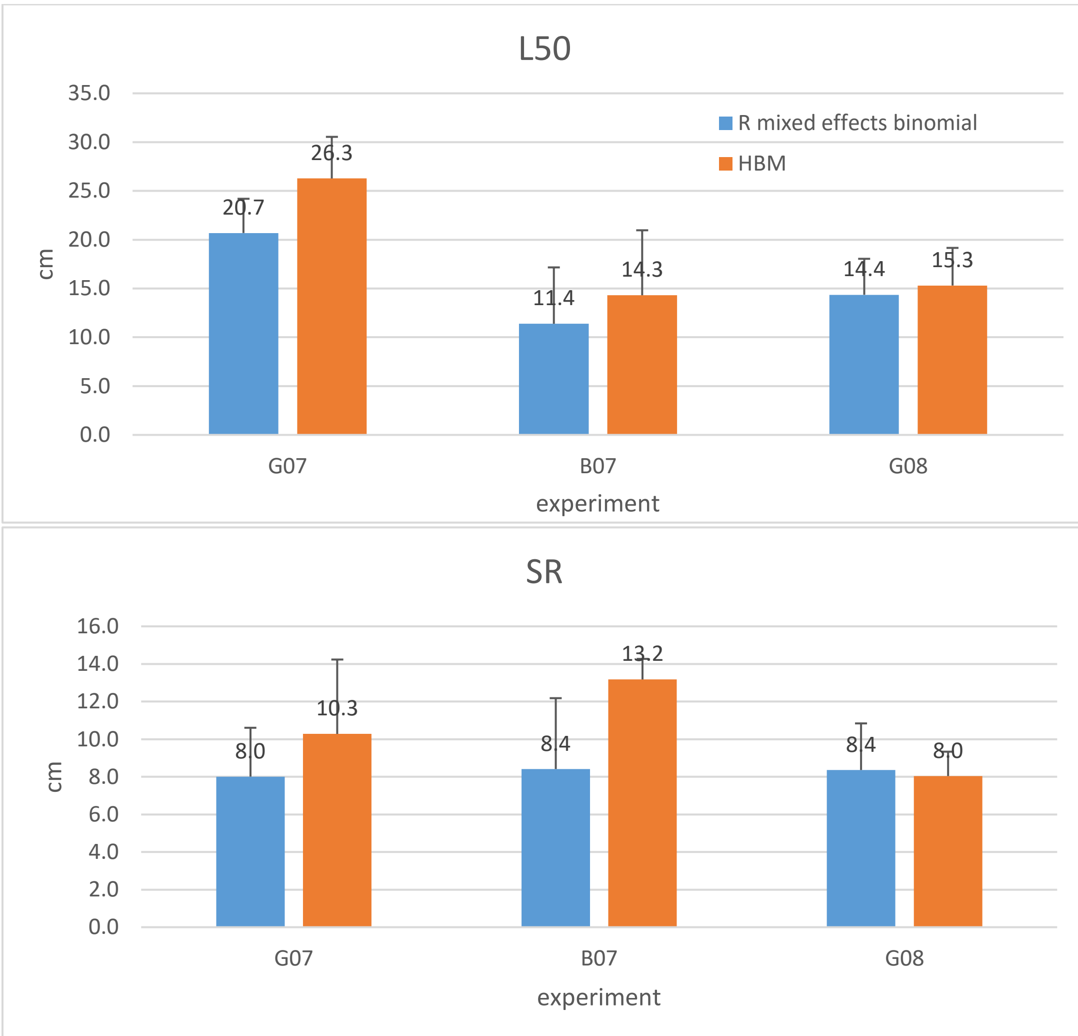


Figure 1. Comparison of parameter estimates using two different modeling approaches for midwater trawl selectivity.

In both cases the HBM results for L50 were higher, indicating a stronger selectivity effect. Overall, the variance about the estimates was similar, despite the new model not correctly incorporating within – haul variability.

To examine the potential effects of within-haul variability on the HSM, a sensitivity analysis was carried out by resampling the pocket net data collected in 2018 and repeating the model run (n = 500). For each pocket net sample, individual fish length measurements were chosen at random from the data (with replacement) and the total number of fish in each pocket net n was assumed to randomly vary with a distribution

$$n \sim N(1, \sigma).$$

The value of sigma was varied from 0 to 0.4, equivalent to CV of 0 - 40 %. The results (Fig.2) show that

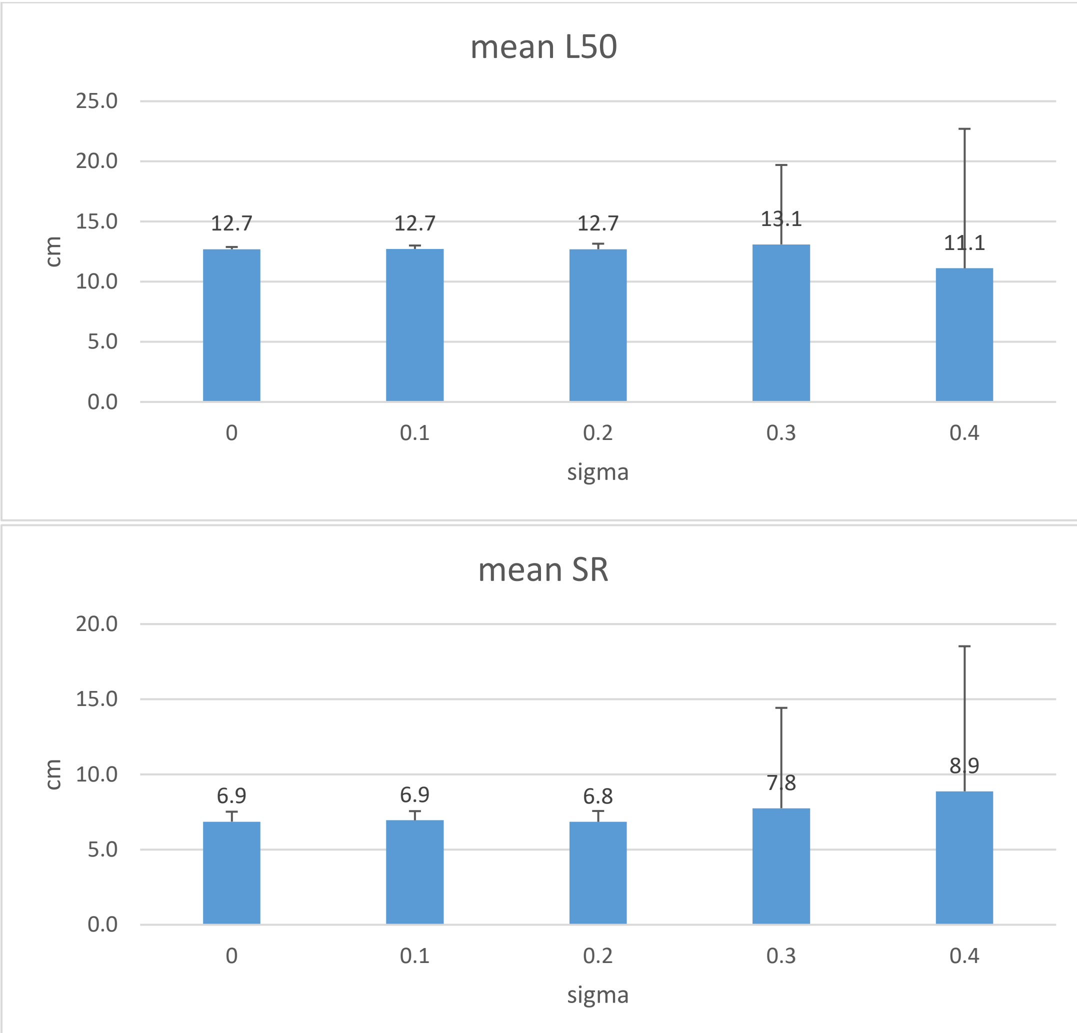


Figure 2. Results of sensitivity of HSM to individual pocket net sampling error.

The selectivity run results indicate that the mean L50 and SR mean are relatively robust to random sampling error of the type that could be expected to occur with pocket net sampling.

Proposed action on devising a selectivity correction for Shelikof Strait and other GOA winter surveys is as follows:

1). Estimation of trawl selectivity will become a routine survey activity, with pocket nets becoming a permanent gear accessory for the midwater trawls used in the survey. Mean survey selectivity parameters will be estimated for each survey and applied to the survey trawl catch data. For past surveys, a single model run that incorporates all past GOA pocket net samples will be estimated, and this correction applied to the past survey time series for surveys conducted with the Oscar Dyson (2008 – present). The large difference between OD and MF findings, and the larger volume of OD data suggests that the 2007

GOA MF experimental result may be an outlier and therefore the MF survey time series where the current midwater trawl (Aleutian Wing Trawl) was used (1993 – 2007) will not be corrected.

The 2018 selectivity function estimates for individual hauls were similar, with the exception of a single haul which yielded a larger L50 and SR estimate (Fig. 3). The overall mean was slightly influenced by this single tow although the overall effect of this is not likely to substantively influence the results.

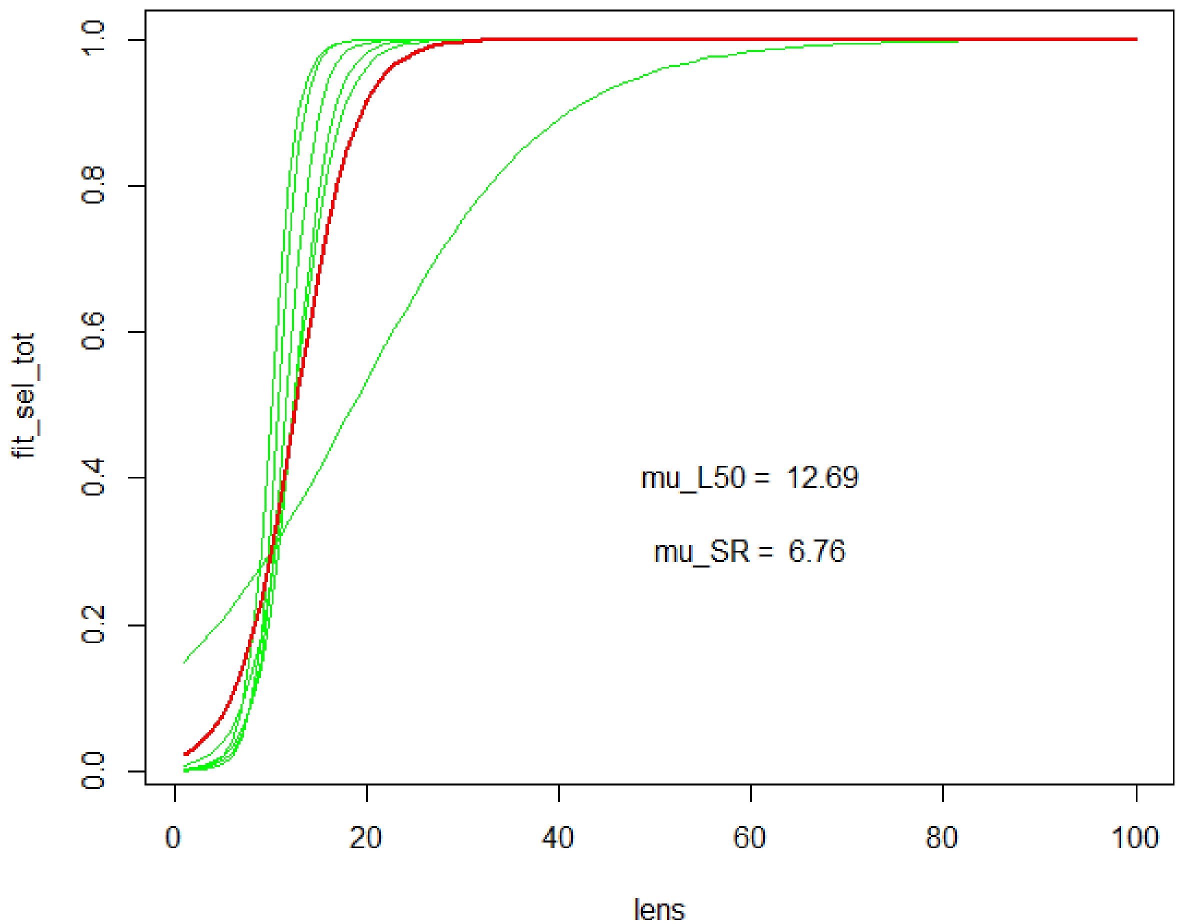
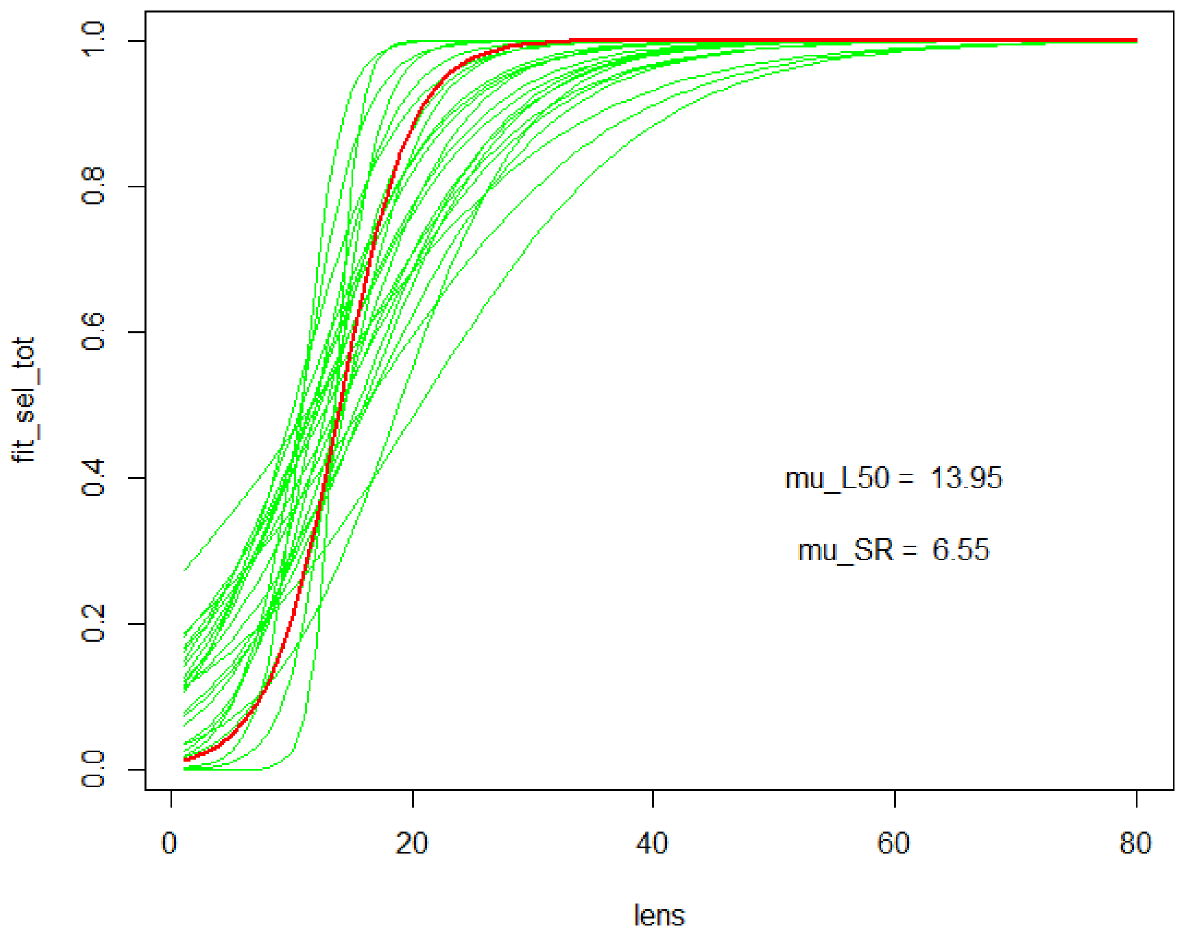


Figure 3. Results of fitting the HSM to the 2018 survey pocket net data.

For the survey years prior to 2018, the model was fit to all the pocket net hauls (n=40) collected in the winter GOA (Fig. 4).



In conclusion, the new model formulation represents a pragmatic shift from the HBM to allow for more reliable and stable model behavior, while yielding largely comparable results and exhibiting stability with simulated increasing pocket net sampling error. The analysis results in a historical correction function, applied to the 2008 – 2017 Shelikof time series, and a survey specific correction applied to 2018.The recommendation going forward is to install pocket net gear as a standard survey practice, and estimate a selectivity correction each year.

References

Williams, K., Punt, A.E., Wilson, C.D. and Horne, J.K., 2010. Length-selective retention of walleye pollock, *Theragra chalcogramma*, by midwater trawls. ICES Journal of Marine Science, 68(1), pp.119-129.