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Estimation of Harvest Rates in the Spot Shrimp (*Pandalus platyceros*) Pot Fishery in Southeast Alaska Using Pre- and Post-Fishery Stock Assessment Surveys

by

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Abstract

The pot shrimp fishery in Southeast Alaska harvested an annual average of 355 metric tons of shrimp since 1990/91 season with an average ex-vessel value of almost 2 million dollars (U. S.). Spot shrimp (*Pandalus platyceros*) comprise over 95% of the landed weight. Information on abundance, size and sex composition, and distribution of spot shrimp populations and evaluation of the cumulative impact of fishing effort on the abundance and biology of this resource is essential to achieving an optimum sustainable harvest. Stock assessment surveys were conducted in limited areas two weeks prior to the fishery in 1997 and 1998 to collect this information. In February, 1999, a post-season survey was conducted approximately 4 months after the area was closed to evaluate the effects of the commercial fishery on the abundance and composition of the stocks and to determine if a harvest rate could be reliably estimated for spot shrimp stocks in two areas.

The basic catch statistics of total catch per pot, mean size of catch and variance in size of catch provide an adequate method of summarizing and comparing the size frequency distributions. A more complex model which estimates the selectivity of the gear and the underlying abundance of shrimp by size interval didn’t substantially improve the detection of differences between areas, survey years, or pot types, but did provide estimates for selectivity coefficients. Two models were used to estimate harvest rates in the 1998 District 3 fishery, a full model which estimates abundance for each size interval and a reduced model which assumes decreasing abundance with increasing size. Estimates of harvest rates on shrimp 40 mm and greater and associated variability were comparable, averaging between 30% and 40% for both areas. However, the large amount of uncertainty associated with these estimates due to sampling variability indicate that a more extensive survey is needed to more precisely estimate future harvest rates. The results also illustrate the importance of knowing the selectivity of gear in addition to the harvest rate on fully recruited individuals to the gear.

Introduction

The pot shrimp fishery in Southeast Alaska has developed over the last decade to become one of the most important shellfish fisheries in the region. The small and sporadic catches in the 1970’s by a handfull of fishers (a seasonal average of 6.8 metric tons by 7 permitees) increased to an average of 112 mt and 85 permits in the 1980’s, and an average 356 mt worth an average ex-vessel value of almost 2 million dollars (U. S.) harvested by 203 permits since the 1989/90 season (Figure 1)(Koeneman and Botelho1997). Spot shrimp (*Pandalus platyceros*) comprise over 95 percent of the landed weight with minimal catches of coonstripe sheimp (*P. goniurus*) also landed. The majority of catch is harvested in Districts 3 (26%), 1 (18%) and 7 (14%) (Figure 2). Harvests from Districts 2, 6, 13, 10, and 12 are also significant, totaling an average of 31% of the total catch.

Management of the pot shrimp fishery has rapidly developed in the last 5 years in response to the rapid growth in number of participants and increase in fishing effectiveness (Bishop et al, these proceedings). The most effective change was implementation of a limited entry program which effectively ended growth in number of commercial pot fishery permits. Guideline harvest levels, based on historical catches, were set for each fishing district in 1995. Other management measures which served to limit growth in fishing effectiveness include limits on size and number of pots and restricting the fishery to only daytime hours. Minimum mesh size restrictions are intended to allow escapement of the smaller, less valuable segment of the shrimp stocks.

Information on the life history of spot shrimp, abundance, size and sex composition, and distribution of spot shrimp populations and of the catch removed from these populations, and evaluation of the cumulative impact of fishing effort on the abundance and biology of this resource in Southeast Alaska is very limited but essential to achieving optimum sustainable harvests. Three stock assessment and catch monitoring programs have recently been initiated to collect this type of information and provide a basis for evaluating and revising guideline harvest levels. In 1996, a spot shrimp stock assessment pilot survey was conducted in district 7 to ascertain the feasibility of annual assessment surveys and collect information on the size and sex composition of the district 7 stocks. In 1997 and 1998, similar surveys were conducted in District 3. Beginning in the 1997/98 season, floating processors were required to accommodate Alaska Department of Fish and Game (ADF&G) onboard observers. These observers collected information on size and sex composition of the catch and verified discard rate and fishticket information. A dockside sampling program was also initiated in 1997 and significantly expanded in the 1998/99 season. Samplers also collect information on size and sex composition of the landed catches.

This paper summarizes the catch and size distribution information collected in these programs and uses this information to evaluate differences in survey catch and length frequency distributions between areas, years, and pot-types. We also develop a simple model to estimate the selectivity of different pot-types and use this model to estimate harvest rates from data collected in a survey and subsequent resurvey after commercial harvest experiment. The pilot stock assessment surveys described in this report were undertaken with the long-term goal of developing methods and a stock assessment program to gauge stock strength prior to commercial fishing, estimate harvest rates and their impacts on the spot shrimp stocks, and developing appropriate guidelines for harvest and harvest rates.

Survey Methods

In September, 1997, a pilot stock assessment survey was conducted in Jackson Island, Grand Island, Hetta Inlet, and Nutkwa Inlet areas in Southeast Alaska district 3 (Figure 2). These areas were chosen because either they are among the top producers by weight for district 3 or because they lie adjacent to these areas, minimizing running time. The areas were also well protected from wind and ocean swell, minimizing the effects of inclement weather. The objectives of the pilot survey were to evaluate the feasibility of conducting a cost-effective survey, to collect information on size distribution and catch rates, size/weight conversions, size at female maturity, and other biological information, and to define the primary areas of spot shrimp abundance. In September, 1998, Hetta Inlet and Nutkwa Inlet were surveyed and resurveyed in February of 1999, following the commercial removal of 3,735 kilograms of spot shrimp from Nutkwa Inlet and 11,957 kg of shrimp from Hetta Inlet in October. The objectives of this pair of surveys was to collect representative information on size distribution and catch rates in these index areas and investigate the effect of commercial removal on these values. Sampling effort in the 1998 survey and 1999 resurvey was more randomly allocated within an area. The number of pots sampled by area and year ranged from 58 to 101, and 900 to over 2,400 spot shrimp sampled by area and year (Table 1).

Three types of pots were used in 1997; a 107 cm diameter with 2.86 cm (1 1/8 inch) mesh and four tunnels (small mesh research pot), a 107 cm diameter with 4.445 cm (1 ¾ inch) mesh and three tunnels (large mesh research pot), and a 96.5 cm diameter 4.445 cm mesh cone pots which belonged to the contractor (commercial pot). The additional commercial pots were used to increase harvest for cost recovery purposes, but catches were also counted and sampled. A set consisted of 15 pots spaced 10 fathoms apart and systematically ordered as: CCLCSCLCSCLCSCC, where C is a commercial pot, L is a large mesh research pot, and S is an small mesh research pot. This ordering was chosen to intersperse pots in a systematic fashion, and to put our large and small mesh research pots away from ends where pots are most likely to be lost by snagging or not to touch bottom due to insufficient buoy line. Pots were baited with bait jars filled to 1/3 capacity with chopped herring and hanging bait of 1/3 of a chum salmon. Pots were snapped onto loops of hollow core line spliced in at 18.3 m (10 fathom) intervals on a floating groundline. In the 1998/99 survey, only large and small mesh research pots were used. A set consisted of 10 pots, with small mesh and large mesh pots alternating on the groundline.

Shrimp habitat was mapped prior to the 1997 survey by the skipper of the charter vessel. In general, commercial densities of spot shrimp are found on steep-sided rock edges in depths from 91 to 128 m, but sometimes as shallow as 46 m at the head of inlets. We attempted to stratify sets by prime and sub-optimal spot shrimp habitat, as determined by our interview of the charter skipper and 9 of the 59 sets were in sub-optimal habitat. Although we had prior knowledge of which stretch of rocky bottom edge was prime spot shrimp habitat, we did not know *a priori* which isobath had the highest spot shrimp density. On the first day, all of the sets targeting optimal habitat were set so as to cover the depth range of 91 to 128 m. On following days, the isobathymetric contour line with highest spot shrimp density was targeted for optimal habitat sets. Sets were made one quarter to a half-mile apart along the isobathymetric contour line. Bottom depth was recorded as each fifth pot was set. Set end locations were determined by recording the GPS position of both end buoys immediately prior to pulling each set. From 6 to 10 sets were retrieved and reset each day.

In the 1998 survey and 1999 resurvey, 12 sets each were made for two areas (Nutkwa Inlet and Hetta Inlet), only large and small mesh research pots were sampled and the selection of location of sets was systematically chosen. The extent of good spot shrimp habitat was determined based on the 1997 survey and divided into 12 segments. A random starting point was selected within the first set, and subsequent sets were equal-distant from the first set. Locations were recorded with GPS. The location of the sets in the 1999 resurvey were the same locations in the 1998 survey. Chen et al (1998) has shown substantial increases in precision may be achieved when the same locations are resurveyed.

In all surveys, the contents of each pot were emptied into a numbered basket and set into an aerated tote of seawater on deck. Pot contents were sorted by species, bycatch counted, recorded and released. In 1997, we planned to sample 6 of the 15 pots in each set (2 commercial, 2 large mesh and 2 small mesh research pots). In the 1998 and 1999 surveys, 3 large mesh and 3 small mesh research pots were selected for sampling. For shrimp from pots that had been randomly selected for sampling, spot shrimp were sub-sampled by number or weight at a rate varying from every shrimp sampled to 1 in 40 shrimp sampled. The order of pots to be sampled from all strings for that date was determined prior to beginning pulling. The sub-sampled shrimp were measured for carapace length to the nearest 0.1 mm and examined for presence or absence of eggs, parasites and soft-shells.

Basic Catch Statistics

One challenge in evaluating the diversity of size distributions was to summarize these distributions in terms of simple statistics which provide a comprehensive summary of the shape, location and size of these distributions. Three statistics were used to characterize the size distribution of spot shrimp caught by pot type and area in the three surveys; mean size of shrimp, variance of size of shrimp, and total pot catch. Size frequency distributions were first compiled by calculating T_L, the estimated catch per pot of shrimp of size L, as the sum of the sampling rates for each shrimp sampled by each millimeter size interval over all pot catches within an area, survey year, and pot type divided by the number of pots sampled:

$$T_L = \frac{\sum_{s}^{n_s} \sum_{p_s}^{n_{p(s)}} \sum_{i_{p,s}}^{n_{L(p,s)}} R_{L,i,p,s}}{\sum_{s}^{n_s} \sum_{p_s}^{n_{p(s)}} 1} \qquad (1)$$

where n_s is the total number of s sets, $n_{p(s)}$ is the total number of p_s pots in set s, $n_{L(p,s)}$ is the total number of shrimp of size L in pot p of set s, and $R_{L,i(p,s)}$ is the sampling rate associated with shrimp $i_{L(p,s)}$. Each pot is assumed to represent 1 unit of sampling effort.

Total catch (T.) is the sum over all carapace intervals from the smallest carapace length measured (min L) to the largest carapace length measured (max L) of the estimated shrimp caught per pot:

$$T. = \sum_{L=\min L}^{\max L} T_L \qquad (2)$$

The mean size (μ) of shrimp is estimated as

$$m = \sum_{L=\min L}^{\max L} L \frac{T_L}{T.} \qquad (3)$$

and the variance (σ^2) as

$$s^2 = \sum_{L=\min L}^{\max L} (L-m)^2 \frac{T_L}{T.} \qquad (4)$$

These three statistics provide a summary of the overall shape, location, and magnitude of the size distribution for each pot-type, area, and survey year combination.

Descriptive Model

The mean, variance, and total catch per pot provide a simple and robust means to summarize the size distributions obtained in survey catches. However, each statistic is dependent on both the selectivity of the gear (mesh size) and the abundance and size composition of the shrimp population in the area where the pots are fishing. A simple model that estimates the selectivity of the mesh size and the underlying pattern in size distribution was constructed. This model is based on two premises; the selectivity of the gear can be described by an inverse exponential function $q/(1+e^{(-(\alpha+\beta L))})$, and abundance exponentially decreases with increasing size, or $A_0 e^{-bL}$. These assumptions are reasonably supported by population dynamics theory if growth is slow and variable and total mortality is moderate to high, and by the decreasing abundance of larger shrimp which are fully recuited to the gear. Combining these two assumptions results in the size distribution being described according to the 'bell-shaped' curve:

$$T_L = \frac{e^{a+bL}}{1+e^{-(a+bL)}} \qquad (5)$$

where a, b, α, and β are coefficients defining the shape of the size distribution (note that a = $Ln(qA_0)$). The mid-point of the selectivity curve, or mean selectivity (point at which 50% of the shrimp of a given carapace length are caught), is calculated as $-(\alpha/\beta)$ and the variance of the curve is defined as $\pi^2/(3\beta^2)$, which is the variance of the derivative of the selectivity function with respect to length.

For the size distribution of each area, survey, and pot type, these parameters were estimated by minimizing the sum of squares using the SAS Model procedure (SAS Institute Inc. 1993). Because of a large number of zero counts between 15 mm and 51 mm, a square-root transformation was selected over a log transformation to lessen the influence of large counts on the estimation procedure. A number of problems can arise from log transformed abundance when sampling effort is fixed and abundance is often small or zero (Stewart-Oaten, 1996).

Estimation of Harvest Rate

A change in the catch rate by size class from a pre-fishery to a post-fishery survey can be used as a measure of the harvest rate by size class and absolute abundance if the catch and size composition of the catch is known (Chen et al, 1998). The pre-fishery survey in September of 1998 and a post-fishery survey following the closure of the commercial fishery October 30 were conducted to provide such an estimate. In addition to providing estimates of harvest rates, data from these surveys may be used to evaluate the feasibility and benefits of using a number of harvest rate estimators. The simplest (i.e. fewer assumptions but more parameters to estimate) was derived from the abundance estimators of Chen et al, 1998 (termed the Full Model in the following discussion). If we define α_F

and β_F as the selectivity coefficients of the commercial fishery pots, α_Z and β_Z as the selectivity coefficients of the survey gear, u as the harvest rate on shrimp which are fully recruited to the fishing gear (maximum harvest rate), and $A_L=qN_L$ is the fraction (or catchability coefficient q) of the total abundance N_L that is available to a survey pot, the catch of size L shrimp in the prefishery survey pots is

$$T_{L(Prefishery)} = \frac{A_L}{1+e^{-(a_z+b_z L)}} \tag{6}$$

the catch (C_L) in the fishery is

$$C_L = \frac{uN_L}{1+e^{-(a_F+b_F L)}} \tag{7}$$

and the subsequent catch in the postfishery survey will be

$$T_{L(Postfishery)} = \frac{q\left(N_L - \frac{uN_L}{1+e^{-(a_F+b_F L)}}\right)}{1+e^{-(a_Z+b_Z L)}} = \frac{\left(A_L - \frac{uA_L}{1+e^{-(a_F+b_F L)}}\right)}{1+e^{-(a_Z+b_Z L)}} \tag{8}$$

In the following analysis, the selectivity coefficients of pots used in the commercial fishery were set equal to the selectivity coefficients of the commercial and large mesh research pots used in the survey, or $\alpha_F=\alpha_L$ and $\beta_F=\beta_L$. Small mesh research pot parameters will be designated as α_s and β_s as in the previous discussion. The parameters to be estimated using small mesh and large mesh size frequency data from the presurvey and postsurvey catches $A_{min\ L}$ to $A_{max\ L}$, α_L , α_s ,= β_L , β_s, and μ.

The previous equations were modified to incorporate the structure of the descriptive model into the analysis. This model is refered to as the Reduced Model. This is accomplished by replacing each A_L in equations 6 and 8 by the function e^{a+bL}. The Reduced Model is defined by the 4 equations for large mesh and small mesh research pot presurvey catch and the large mesh and small mesh research postsurvey catch:

$$T_{L(Prefishery/LargeMesh)} = \frac{e^{a+bL}}{1+e^{-(a_L+b_L L)}} \tag{9}$$

$$T_{L(Prefishery/SmallMesh)} = \frac{e^{a+bL}}{1+e^{-(a_s+b_s L)}} \tag{10}$$

$$T_{L(Postfishery/LargeMesh)} = \frac{\left(e^{a+bL} - \frac{ue^{a+bL}}{1+e^{-(a_L+b_L L)}}\right)}{1+e^{-(a_L+b_L L)}} \tag{11}$$

$$T_{L(Postfishery/SmallMesh)} = \frac{\left(e^{a+bL} - \frac{ue^{a+bL}}{1+e^{-(a_L+b_L L)}}\right)}{1+e^{-(a_s+b_s L)}} \tag{12}$$

As with the descriptive model, parameters were estimated by minimizing the sum of squares of square-root transformed variables.

Bootstrap Methods

The survey design was a stratified sampling design with sets being systematically located within an area with a random starting point, pots of a given type being randomly chosen within a set, and shrimp within a pot being subsampled and measured at a rate dependent on total number of shrimp in the pot. However, logistical limitations and infrequent unavoidable mistakes in selecting the correct pot resulted in differing numbers of pots within a set being sampled and different subsample rates for each pot. Because of the diversity and complexity of the sampling design, we decided that the best approach for evaluating the variability in abundance and size distributions and significance of differences in parameter estimates was a bootstrap approach. A critical assumption in the bootstrap methods used in the analysis is that the population of shrimp in the survey area is large enough that the selection of a set, pot, or individual shrimp is independent of other samples, resulting in sampling with replacement in the selection process.

We define n_s as the number of sets and s as an individual set (s = 1 to n_s), $n_{p(s)}$ to be the number of pots of a certain pot type sampled in set s and p_s as an individual pot in set s (p_s= 1 to $n_{p(s)}$), $n_{c(p,s)}$ to be the number of shrimp sampled in pot p_s and i,p,s to be the ith individual shrimp sampled in pot p_s, $L_{i,p,s}$ as the length of shrimp i,p,s and $R_{i,p,s}$ as the sampling rate associated with i,p,s. For each bootstrap simulation b, n_s set numbers were randomly selected with replacement (designated as s*) from the n_s sets; within each s*, $n_{p(s^*)}$ pot numbers were randomly selected with replacement (designated as $p^*_{s^*}$); and within each $p^*_{s^*}$, $n_{c(p^*,s^*)}$ shrimp numbers were randomly chosen (i*,p*,s*), each with an associated carapace length (L_{i^*,p^*,s^*}) and sampling rate R_{i^*,p^*,s^*}. Therefore each bootstrap simulation results in a set of sampling rates and associated lengths which can be summed using equation 1 to obtain the length frequency distribution T_L^* with L ranging from min L to max L.

One thousand bootstrap simulations were generated, resulting in 1000 size frequency distributions for each area, survey, and pot type. General statistics and parameter values were estimated for each size frequency distribution within a bootstrap simulation. The median bootstrap estimate provided a measure of the expected value for each statistic or parameter value and the upper 95% and lower 5% quantiles provided a measure of the sampling variability in estimates. Significant differences in estimates were determined by looking at the percentage of time a given estimate was greater than or less than another estimate for the 1000 bootstrap simulations. For example, if the mean size of shrimp of one survey, area, and pot type was larger than the mean size of shrimp of another survey, area and pot type in either 975 or 25 of the 1000 bootstrap generated size frequency distributions, the significance of the difference between the means would be estimated as 5% or 1-(absolute value of (.5-*Number Larger/1000))*2).

Results

Basic Catch Statistics

Average catch per pot of spot shrimp by survey, area, and pot type ranged from 50 shrimp per pot (1997 commercial pots from Grand Island, Jackson Island, and Nutkwa Inlet all averaged from 50 to 52 shrimp per pot) to 205 shrimp per pot (Grand Island small mesh research pot) (Figure 3). The average catch per pot was 124 shrimp per pot. Small mesh research pots caught the most shrimp, followed by large mesh research pots. Commercial pots overall caught the fewest shrimp. The 1997 Grand Island, 1998 Hetta Inlet, and 1998 and 1999 Nutkwa Inlet small mesh research pot catches were the largest catch per pot, averaging over 150 shrimp per pot. Other small and large mesh research pot catches generally averaged between 100 and 150 shrimp per pot. The 5% to 95% quantile range of median values average 50% of the median value.

There was a very large and significant difference between catches in commercial pots and catches in small mesh and large mesh research pots (Table 2). In the bootstrap simulations, all of the median catches of the large and small mesh research pots were significantly greater than corresponding median catches in commercial pots. The totals of catch per pot of commercial pots were smaller for every bootstrap simulation in 5 of the 8 comparisons. The catch in Nutkwa Inlet 1998 small mesh research pots were significantly greater (<.01%) than catches in large mesh research pots and catches in the Nutkwa Inlet 1999 resurvey small mesh research pots were significantly greater (3.8%) than catches in the large mesh pots. Comparisons within pot type across areas and surveys for large mesh research and commercial pots resulted in 3 significant differences in 34 comparisons of total catch per pot (Table 3). Grand Island small mesh research pots in 1997 caught significantly more shrimp than small mesh research pots in Hetta Inlet and Nutkwa Inlet and small mesh research pots in Nutkwa Inlet caught significantly more shrimp than small mesh research pots in Hetta Inlet in the 1999 resurvey.

Mean size of shrimp by area, survey, and pot type ranged from 32 mm to 41 mm and averaged 36.7 mm (Figure 3). The mean size of shrimp caught in small mesh research pots was less than 35 mm for all areas except Hetta Inlet. The mean size of shrimp caught in large mesh research and commercial pots in Hetta Inlet was equal to or greater than 39 mm. The mean size of pots from other area-survey-pot-type combinations was between 35mm and 39 mm. The 5% to 95% quantile range of mean size values averaged about 5% of the median value.

With the exception of Hetta Inlet in 1997 and 1999 resurvey, there were large and significant differences in mean size of shrimp caught in small mesh research pots and shrimp caught in both large mesh research and commercial pots (Table 2). The abundance of large shrimp in Hetta Inlet resulted in a similar size of shrimp being caught in all pot types. The mean size of shrimp caught in commercial pots was not significantly different than shrimp caught in large mesh research pots, averaging about a 1 mm difference in mean sizes. Hetta Inlet had significantly larger shrimp in all 13 comparisons of Hetta Inlet to other areas within the same survey and pot type(Table 3). The mean size of Nutkwa Inlet small mesh research pots was significantly smaller than Grand Island and Jackson Island small mesh research pots. There was a significant decrease in mean size of shrimp caught in small mesh research pots in Hetta Inlet 1997 survey to the 1998 and 1999 resurvey catches and in Nutkwa Inlet from the 1998 to the 1999 resurvey, but a significant increase in mean size from the Nutkwa Inlet 1997 to 1998 survey.

Variances ranged from 12 mm^2 to 29 mm^2 and averaged 18 mm^2 (Figure 3). Except for the 1997 Nutkwa Inlet survey, the largest variances of 21 mm^2 or greater were obtained for the small mesh research pots. The 5% to 95% quantile range averaged 46% of the median variance. There were significant differences between the variances of small mesh research pots and large mesh research and commercial pots for 8 of the 12 comparisons (Table 2). There were no significant differences between large mesh research and commercial pots. The only significant difference between variances across areas within surveys and pot types, or across surveys within areas and pot types was a difference between Jackson Island and Hetta Inlet small mesh research pots (Table 3).

Descriptive Model

The estimates of the mean and variance of the selectivity curve were compared for the 1000 bootstrap simulations. Median values for the mean of the selectivity curve ranged from 28 mm to 44 mm, with 15 of the 20 survey, area, pot type medians being between 32 mm and 42 mm(Figure 4). The 5% - 95% quantile ranges averaged 14% of the median values. A comparison of means of the selectivity curve by pot type resulted in 7 of the 12 small mesh vs large mesh research and commercial pot comparisons being significant (Table 4). None of the large mesh research and commercial pot comparisons were significant different. Comparisons across areas or survey years within a pot type found significantly differences between small mesh research pots in 1997 surveys in Hetta Inlet and in Nutkwa Inlet and Grand Island. Significant differences were also detected between small mesh research pots in Hetta Inlet in 1997 and 1999 (Table 5). The mean of the selectivity curve for 1997 Hetta Inlet small mesh pots was the highest and most variable. There was also a significant difference between the 1997 Grand Island and Nutkwa Inlet small mesh research pots. Means of the selectivity curves for Nutkwa Inlet small mesh research pots were the smallest values estimated.

The variance of the selectivity curve ranged between 2.7 and 8.2 mm^2 and averaged 4.7 mm^2 (Figure 4). Estimates of the variance were extremely variable, with 5% to 95% quantile ranges averaging 96% of the median values. The 1997 Hetta Inlet and Grand Island small mesh research pot variances were the most variable. Except for the 1998 Hetta Inlet small mesh research pot variance estimates, the variances estimated for the 1998 survey and 1999 resurvey have smaller quantile ranges than those in the 1997 survey. The large variability associated with estimates of the β parameter, and therefore the variance calculated from the β parameter, precluded any significant differences being detected between either mesh sizes, areas, or surveys (Table 4 and 5).

The estimates for the two parameters which quantify the underlying abundance available to the pots (parameters a and b) were compared (Figure 5). The values for the initial abundance parameter a averaged 19 and estimates ranged from 10 to 40. Values for the exponential decrease parameter b averaged –0.42 and ranged from –0.19 to –0.84. Estimates of these parameters were highly variable, with the 5% - 95% quantile ranges averaging 98% and

105% of the median bootstrap simulation values for parameters a and b respectively. However, this variability was much less for the estimates calculated from the 1998 survey and 1999 resurvey data. Significant differences in both parameters were found between small mesh and large mesh research pots in Nutkwa Inlet in the 1997 and 1998 surveys and 1999 resurvey and between Nutkwa Inlet small mesh research and commercial pots in 1997 (Table 4). A significant difference was also obtained between small mesh research and commercial pots in the 1997 Jackson Island survey. No differences between parameter estimates were obtained in comparisons within pot types between years or between areas (Table 5).

Estimation of Harvest Rate

The number of survey, area, and pot type size distributions available and the feasibility of combining aspects of the full and reduced model to estimate abundance and selectivity parameters indicate that a number of ways of estimating harvest rates can be developed and evaluated. For example, selectivity coefficients can be estimated for small mesh and large mesh research pots (Equation 5) and set into the full model to estimate the abundance by carapace length parameters (A_L) and the harvest rate u (Equations 9 and 10). An approach which proved to be a poor estimator of the selectivity and harvest rate parameters was to fit only Equations 9 and 10 to the 1998 survey and 1999 resurvey data. This analysis resulted in extremely variable estimates and a failure of the fitting algorithm to converge in 35% of the bootstrap simulations for both Hetta and Nutkwa Inlet survey data. The full model was modified such that the small mesh research pot selectivity coefficients were estimated from the 1998 survey and 1999 resurvey small mesh research pot size distributions by area. These parameter values were then averaged and entered into Equations 9 and 10 as known parameters. Large mesh selectivity coefficients, individual carapace length abundance parameters, and harvest rates were then estimated using Equations 6 and 8. The reduced model estimated the selectivity coefficients for large mesh and small mesh pots, the abundance parameters for each survey area, and the maximum harvest rate coefficient using data from the 1997 and 1998 surveys and 1999 resurvey. Size distributions from the1997 Hetta Inlet small mesh research pots were not used due to the large amount of variability in estimates. Different abundance parameters were estimated for the commercial pots in the different areas because the commercial pots caught significantly fewer shrimp than the research pots. Different abundance parameters were also estimated for Nutkwa Inlet small mesh and large mesh research pots in 1997 and 1998 due to the large and significant differences observed in the descriptive models. A summary of the parameters estimated and size distributions used is summarized in Table 6.

The three parameter of most interest are the maximum harvest rate, u, and mean and variance of the large mesh research and commercial pot selectivity curve. These three parameters determine the harvest rate by size class in the fishery. The estimated mean of the large mesh selectivity curve using the reduced model was the largest and significantly larger than the Nutkwa Inlet full model estimated mean (Figure 6). The median Hetta Inlet full model estimated mean of selectivity curve was between the other two median, but estimates were much more variable. The estimated variances of the selectivity curve were not significantly different between the two models (Figure 6). The median estimated variance of the full model Hetta Inlet large mesh selectivity curve was smaller than the full model or Nutkwa Inlet reduced model median variance. The reduced model estimates were the least variable. All estimates of the maximum harvest rates were similar between models and areas and highly variable. Median maximum harvest rate estimates were 37.5% for Hetta Inlet reduced model compared to 40.0% for the Hetta Inlet full model. The Nutkwa Inlet reduced model median estimate of 36.2% was larger than the median estimate of 30.6% for the Nutkwa Inlet full model median estimate. The 5% to 95% quantiles ranged from 7% for Nutkwa Inlet full model to 58% for the Nutkwa Inlet reduced model.

Figures 7 depicts the median estimated harvest rate and the 5% to 95% quantile range about this median by 1 mm carapace lengths for the Hetta Inlet and Nutkwa Inlet reduced models. The median harvest rate values for both Hetta Inlet and Nutkwa Inlet become significantly different from 0% at about 33 mm and reach the maximum harvest rate value at about 40 mm. The variability in harvest rate estimates also increases over this same range in carapace length. The change in harvest rate median values over carapace lengths and the range in estimates between the 5% to 95% quantiles for Hetta Inlet and Nutkwa Inlet full model and reduced model estimates are compared in Figure 8. The full model estimates that the maximum harvest rate is achieved at 37 and 40 mm carapace length for Nutkwa Inlet and Hetta Inlet respectively, and harvest rate estimates are larger and more variable from 32 mm to carapace length at maximum harvest rate than the corresponding estimates of the reduced model. For example, at 35 mm carapace length, the full model median harvest rates for Hetta Inlet and Nutkwa

Inlet are 22% and 26% respectively, compared to the full model estimate of 10% for both areas. The 5% to 95% quantiles are larger for both the Hetta Inlet and Nutkwa Inlet full models estimates from 32mm to 38 mm when compared to corresponding reduced models estimates. The quantile ranges are slightly less for maximum harvest rates for full model estimates when compared to reduced model estimates.

Discussion

There are a number of ways of studying size frequency distributions of spot shrimp caught in pot gear of different mesh sizes, in different areas, and in different years. The simpliest and most straight forward way is to graph the average catch per pot by carapace length. This provides an excellent means of visualizing the size selectivity of each type of pot and the relative abundance and possible population structure of the shrimp in the proximity of the pot. However, describing these size frequencies in terms of a few meaningful statistics or model parameters allows for easier comparison of many size frequencies across time, area, or gear. If the parameters are directly related to the effectiveness of the gear or the size and abundance of the unseen shrimp population, they may provide additional insight into the overall impact of commercial removal on shrimp abundance.

The basic statistics of mean, variance, and average total catch per pot were found to be adequate in looking at differences between areas, years, and mesh sizes. These statistics also provide a simple means to summarize size distributions and provide index measurements of stock condition prior to the fishery. A substantial change in catch per pot or mean carapace length for a given mesh size might be indicative of major changes in recruitment or effect of past fishing effort on population age structure and abundance. However it is difficult to interprete changes in these statistics between mesh sizes.

The more conceptual model of describing the size frequency distribution in terms of abundance and selectivity of the gear did not detect as many differences as the simple statistics, and some of the differences call into question the underlying assumptions in the model. For example, the highly significant differences between the abundance parameters of large mesh and small mesh pots estimated for Nutkwa Inlet in 1997 and 1998 suggest that the shrimp are vulnerable to the gear differently other than that specified by the selectivity curve. This suggest other factors may be responsible for different catches of shrimp, including exclusion of small shrimp from the pot when a high abundance of large shrimp is present. These methods did provide estimates of the selectivity by carapace length of research and commercial pots. The high variability in parameter estimates also suggest that more sampling effort is required to better resolve these questions.

Harvest rates were estimated using methods adapted from Chen et al (1998) and modification of these methods to more parsimoniously describe the underlying abundance of shrimp. Variability of the maximum harvest rate estimates due to sampling design and effort were similar for the full and reduced model. Estimates of the selectivity coefficients for the commercial and large mesh research pots were less variable than those of the full model, resulting in more precise estimates of harvest rates for shrimp not fully recruited to the pot gear. However, variability for all harvest rate estimates was unacceptably high, indicating that more sampling effort is required in future surveys. A closed population is a necessary condition for unbiased estimates of a harvest rate. The 3 month interval of time between the closure of the fishery (October 30) and the following resurvey (February, 1999) may have resulted in growth or migration, which would likely bias the harvest rate estimates low. However Kimker et al (1996) cited unpublished observations the found growth was minimal during the winter months. Uncertainty about the equality of catchabilities between pre- and post-surveys can be accounted for by estimating separate parameters for the two time intervals as was done with the reduced model.

The results also illustrate the importance of knowing the selectivity of gear in addition to the harvest rate on fully recruited individuals to the gear. The impact of fishing effort will be much different if the maximum harvest rate promptly decreases to zero with decreasing size below 40 mm, or if harvest rates remain relatively high for smaller shrimp. Discussion of harvest rates should necessary include the distribution of harvest rates over all size segments of the population. The decision on which model provides the best estimate of harvest rate needs to be evaluated in consideration of estimating the harvest rate on fully recruited shrimp and the selectivity curve and harvest rate on shrimp that are partially recruited to the gear.

Measurement of variability using bootstrap resampling methods (Efron 1982) is a reasonable alternative when the sampling design is complex and distributional properties of the estimates are unknown. The advantage of using bootstrap simulations is that the inherient variability in the data itself governs the variability of parameter estimates and fewer assumptions are required concerning the underlying distribution of the data. Bootstrap methods have been used in fisheries related studies for principally trawl survey analyses (Kimura and Balsinger 1985; Stanley 1992; Smith 1997). The application of bootstrap methodology to complex survey design when sample sizes are small or sampling is without replacement is often not as straightforward as the simple 'naive' bootstrap methods employed in the current study (Smith 1997). However the extremely small fraction of area and shrimp sampled during the surveys supports the assumption of sampling with replacement used in the current bootstrap methods. Development of maximum likelihood estimators, possibly using Poisson or negative binomially distributed catch rates (Chen et al 1998) could be validated by comparing variability from these methods with bootstrap values.

Acknowledgements

We acknowledge the help of number of people have participated in the collection and analysis of survey data. The charter fishing vessel operators, Brad and Debbie Johnson of F/V Cape Blanco readily shared their knowledge of the biology and fishing know-how relating to spot shrimp and expertly managed the setting and retrieval of shrimp pots. Don House, Gordie Woods, and Matt Lichtenstein also participated in the survey. Doug Woodby offered many helpful comments on earlier drafts of this paper.

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Table 1. Summary of distribution of sampling effort by area and year for the 1997 and 1998/99 pot shrimp surveys.

Area	Subdistrict	Date	Number of Sets	Number of Pots Sampled			
				Large	Small	Skipper	Total
Jackson/Long Isl.	10321/10330	Sep-97	17	27	37	37	101
Grand Island	10340	Sep-97	12	23	20	22	65
Hetta Inlet	10325	Sep-97	18	22	25	23	70
Hetta Inlet	10325	Sep-98	12	35	36	0	71
Hetta Inlet	10325	Feb-99	12	35	37	0	72
Nutkwa Inlet	10321/10323	Sep-97	12	24	23	23	70
Nutkwa Inlet	10323	Sep-98	12	36	36	0	72
Nutkwa Inlet	10323	Feb-99	12	33	35	0	68
Total			107	235	249	105	589

Area	Subdistrict	Date	Number of Sets	Number of Spot Shrimp Sampled			
				Large	Small	Skipper	Total
Jackson/Long Isl.	10321/10330	Sep-97	17	341	509	395	1245
Grand Island	10340	Sep-97	12	364	341	255	960
Hetta Inlet	10325	Sep-97	18	274	699	220	1193
Hetta Inlet	10325	Sep-98	12	980	1095	0	2075
Hetta Inlet	10325	Feb-99	12	817	969	0	1786
Nutkwa Inlet	10321/10323	Sep-97	12	299	315	261	875
Nutkwa Inlet	10323	Sep-98	12	1029	1370	0	2399
Nutkwa Inlet	10323	Feb-99	12	788	1219	0	2007
Total			107	4892	6517	1131	12540

Table 2. Summary of comparison of different pot types within an area and survey year of total catch per pot, mean carapace length, and variance of carapace length for 1000 bootstrap simulations. Only differences with a significance level less than or equal to 5% (i.e. a 2.5% overlap) are listed. Level of significance of <.1% designates that all of the estimates for one pot type were greater than corresponding estimates of the other pot type. There were a total of 16 comparisons in each of the basic catch statistics: 8 ADF&G large mesh vs ADF&G small mesh pot comparisons, 4 ADF&G large mesh vs Vessel pots, and 4 ADF&G small mesh vs Vessel pots

	Median Difference	Level of Significance
Total Catch per pot Comparisons		
Nutkwa Inlet 1998 Survey ADF&G Small Mesh/ADF&G Large Mesh	81.3	<0.1%
Nutkwa Inlet 1999 Resurvey ADF&G Small Mesh/ADF&G Large Mesh	65.3	3.8%
Grand Island 1997 Survey ADF&G Large Mesh/Vessel	103.6	<0.1%
Jackson Island 1997 Survey ADF&G Large Mesh/Vessel	55.7	0.6%
Hetta Inlet 1997 Survey ADF&G Large Mesh/Vessel	57.4	1.0%
Nutkwa Inlet 1997 Survey ADF&G Large Mesh/Vessel	50.4	<0.1%
Grand Island 1997 Survey ADF&G Small Mesh/Vessel	153.9	<0.1%
Jackson Island 1997 Survey ADF&G Small Mesh/Vessel	95.5	<0.1%
Hetta Inlet 1997 Survey ADF&G Small Mesh/Vessel	59.0	0.8%
Nutkwa Inlet 1997 Survey ADF&G Small Mesh/Vessel	75.9	<0.1%
Mean Carapace Length Comparisons		
Grand Island 1997 Survey ADF&G Large Mesh/ADF&G Small Mesh	2.58	1.0%
Jackson Island 1997 Survey ADF&G Large Mesh/ADF&G Small Mesh	2.69	1.0%
Nutkwa Inlet 1997 Survey ADF&G Large Mesh/ADF&G Small Mesh	4.90	<0.1%
Hetta Inlet 1998 Survey ADF&G Large Mesh/ADF&G Small Mesh	2.17	0.2%
Nutkwa Inlet 1998 Survey ADF&G Large Mesh/ADF&G Small Mesh	2.92	<0.1%
Nutkwa Inlet 1999 Resurvey ADF&G Large Mesh/ADF&G Small Mesh	6.55	<0.1%
Grand Island 1997 Survey ADF&G Vessel/Small Mesh	3.26	<0.1%
Jackson Island 1997 Survey ADF&G Vessel/Small Mesh	3.59	<0.1%
Hetta Inlet 1997 Survey ADF&G Vessel/Small Mesh	2.31	<0.1%
Nutkwa Inlet 1997 Survey ADF&G Vessel/Small Mesh	5.61	<0.1%
Variance of Carapace Comparisons		
Grand Island 1997 Survey ADF&G Small Mesh/ADF&G Large Mesh	11.71	0.8%
Hetta Inlet 1997 Survey ADF&G Small Mesh/ADF&G Large Mesh	11.05	1.4%
Hetta Inlet 1998 Survey ADF&G Small Mesh/ADF&G Large Mesh	9.66	<0.1%
Nutkwa Inlet 1998 Survey ADF&G Small Mesh/ADF&G Large Mesh	7.7	0.2%
Hetta Inlet 1999 Resurvey ADF&G Small Mesh/ADF&G Large Mesh	9.27	0.2%
Nutkwa Inlet 1999 Resurvey ADF&G Small Mesh/ADF&G Large Mesh	6.99	0.8%
Grand Island 1997 Survey ADF&G Small Mesh/Vessel	12.85	1.0%
Hetta Inlet 1997 Survey ADF&G Small Mesh/Vessel	12.16	<0.1%

Table 3. Summary of comparison of different areas within same pot type and survey year and different survey years within same area and pot type. Comparisons are of total catch per pot, mean carapace length, and variance of carapace length for 1000 bootstrap simulations. Only differences with a significance level less than or equal to 5% (i.e. a 2.5% overlap) are listed. Level of significance of <.1% designates that all of the estimates for one pot type were greater than corresponding estimates of the other pot type. There were a total of 22 comparisons in each of the basic catch statistics across areas within a survey year and pot type and 12 comparisons across survey years within an area and pot type.

	Median Difference	Level of Significance
Total Catch per pot Across Areas Comparisons		
1997 Survey ADF&G small mesh pots Grand Island/Hetta Inlet	79.0	2.4%
1997 Survey ADF&G small mesh pots Grand Island/Nutkwa Inlet	75.4	3.8%
1999 Resurvey ADF&G small mesh pots Nutkwa Inlet/Hetta Inlet	61.7	4.6%
Total Catch per pot Across Survey Years Comparisons		
Hetta Inlet ADF&G small mesh pots 1998 Survey/1997 Survey	71.7	3.0%
Hetta Inlet ADF&G small mesh pots 1998 Survey/1999 Resurvey	77.7	2.6%
Nutkwa Inlet ADF&G small mesh pots 1998 Survey/1997 Survey	65.1	3.6%
Mean Carapace Length Across Areas Comparisons		
1997 Survey ADF&G large mesh pots Hetta Inlet/Grand Island	-2.57	0.2%
1997 Survey ADF&G large mesh pots Hetta Inlet/Jackson Island	-3.23	<0.1%
1997 Survey ADF&G large mesh pots Hetta Inlet/Nutkwa Inlet	3.11	<0.1%
1998 Survey ADF&G large mesh pots Hetta Inlet/Nutkwa Inlet	2.00	<0.1%
1999 Resurvey ADF&G large mesh pots Hetta Inlet/Nutkwa Inlet	2.60	<0.1%
1997 Survey ADF&G small mesh pots Hetta Inlet/Grand Island	-3.85	<0.1%
1997 Survey ADF&G small mesh pots Grand Island/Nutkwa Inlet	2.88	<0.1%
1997 Survey ADF&G small mesh pots Hetta Inlet/Jackson Island	-4.71	<0.1%
1997 Survey ADF&G small mesh pots Jackson Island/Nutkwa Inlet	2.10	0.6%
1997 Survey ADF&G small mesh pots Hetta Inlet/Nutkwa Inlet	6.76	<0.1%
1998 Survey ADF&G small mesh pots Hetta Inlet/Nutkwa Inlet	2.77	<0.1%
1999 Resurvey ADF&G small mesh pots Hetta Inlet/Nutkwa Inlet	3.76	<0.1%
1997 Survey Vessel pots Hetta Inlet/Grand Island	-2.91	<0.1%
1997 Survey Vessel pots Hetta Inlet/Jackson Island	-3.43	<0.1%
1997 Survey Vessel pots Hetta Inlet/Nutkwa Inlet	3.50	<0.1%
Mean Carapace Length Across Survey Years Comparisons		
Hetta Inlet ADF&G small mesh pots 1997 Survey/1998 Survey	1.71	2.2%
Hetta Inlet ADF&G small mesh pots 1997 Survey/1999 Resurvey	2.58	<0.1%
Nutkwa Inlet ADF&G small mesh pots 1998 Survey/1997 Survey	2.33	<0.1%
Nutkwa Inlet ADF&G small mesh pots 1998 Survey/1999 Resurvey	1.84	1.4%
Variance in Carapace Across Areas Comparisons		
1997 Survey ADF&G small mesh pots Hetta Inlet/Jackson Island	8.23	3.8%

Table 4. Summary of comparisons of different pot types within an area and survey year. Comparisons are of mean of selectivity curve, variance of selectivity function, abundance parameter a and exponential decrease parameter b for 1000 bootstrap simulations. Only differences with a significance level less than or equal ot 5% are listed. Level of significance of <0.1% designates that all of the estimates for one pot type were greater than corresponding estimates of the other pot type. There were a total of 16 comparisons for each estimated parameter or statistic.

	Median Difference	Level of Significance
Mean of Selectivity Curve Comparison		
Jackson Island 1997 Survey ADF&G large mesh/ADF&G small mesh	4.22	2.4%
Nutkwa Inlet 1997 Survey ADF&G large mesh/ADF&G small mesh	10.17	<0.1%
Nutkwa Inlet 1998 Survey ADF&G large mesh/ADF&G small mesh	6.34	<0.1%
Hetta Inlet 1999 Resurvey ADF&G large mesh/ADF&G small mesh	4.93	2.8%
Nutkwa Inlet 1999 Resurvey ADF&G large mesh/ADF&G small mesh	7.21	<0.1%
Jackson Island 1997 Survey Vessel/ADF&G small mesh	5.48	<0.1%
Nutkwa Inlet 1997 Survey Vessel/ADF&G small mesh	11.32	<0.1%
Variance of Selectivity Curve Comparison		
(No comparisons were found to be significant at the 5% level)		
Initial Abundance Parameter a Comparison		
Nutkwa Inlet 1997 Survey ADF&G large mesh/ADF&G small mesh	17.13	<0.1%
Nutkwa Inlet 1998 Survey ADF&G large mesh/ADF&G small mesh	6.90	<0.1%
Nutkwa Inlet 1999 Resurvey ADF&G large mesh/ADF&G small mesh	8.76	<0.1%
Jackson Island 1997 Survey Vessel/ADF&G small mesh	7.51	4.4%
Nutkwa Inlet 1997 Survey Vessel/ADF&G small mesh	20.74	0.6%
Exponential Decrease Parameter b Comparison		
Nutkwa Inlet 1997 Survey ADF&G small mesh/ADF&G large mesh	0.38	0.4%
Nutkwa Inlet 1998 Survey ADF&G small mesh/ADF&G large mesh	0.16	0.2%
Nutkwa Inlet 1999 Resurvey ADF&G small mesh/ADF&G large mesh	0.20	<0.1%
Jackson Island 1997 Survey ADF&G small mesh/Vessel	0.18	4.8%
Nutkwa Inlet 1997 Survey ADF&G small mesh/Vessel	0.47	0.6%

Table 5. Summary of comparisons of different areas within same pot type and survey year and different survey years within same area and pot type. Comparisons are of mean of selectivity function, variance of selectivity function, abundance parameter a and exponential decrease parameter b for 1000 bootstrap simulations. Only differences with a significance level less than or equal ot 5% are listed. Level of significance of <0.1% designates that all of the estimates for one pot type were greater than corresponding estimates of the other pot type. There were a total of 22 comparisons across areas within a survey year and pot type and 12 comparisons across survey years within an area and pot type for each estimated parameter or statistic.

	Median Difference	Level of Significance
Mean of Selectivity Curve Comparison		
1997 Survey ADF&G small mesh pots Grand Island/Nutkwa Inlet	6.05	2.0%
1997 Survey ADF&G small mesh pots Hetta Inlet/Jackson Island	-11.67	1.2%
1997 Survey ADF&G small mesh pots Hetta Inlet/Nutkwa Inlet	15.63	0.2%
1999 Resurvey ADF&G small mesh pots Hetta Inlet/Nutkwa Inlet	4.21	0.6%
Hetta Inlet ADF&G small mesh pots 1997 Survey/1999 Resurvey	10.19	2.0%
Variance of Selectivity Curve Comparison		
(No comparisons were found to be significant at the 5% level)		
Initial Abundance Parameter a Comparison		
(No comparisons were found to be significant at the 5% level)		
Exponential Decrease Parameter b Comparison		
(No comparisons were found to be significant at the 5% level)		

Table 6. Summary of data set used and parameters estimated for the full and reduced model.

<u>Full Model Hetta Inlet 1998 Survey and 1999 Resurvey:</u>

(1) Hetta Inlet parameters $_s$ and $_s$ are estimated as average selectivity coefficients from Hetta Inlet 1998 survey ADF&G small mesh pots and Hetta Inlet 1999 resurvey ADF&G small mesh pots using Equation 5.

(2) Parameters A_{15}, A_{16}, …, A_{50}, A_{51}, u, $_L$ and $_L$ were estimated from the 1998 survey Nutkwa Inlet ADF&G large and small mesh pots and Hetta Inlet 1999 resurvey ADF&G large and small mesh pots using Equations 6 and 8.

<u>Full Model Nutkwa Inlet 1998 Survey and 1999 Resurvey (similar to Hetta Inlet)</u>

(1) Nutkwa Inlet parameters $_s$ and $_s$ are estimated as average selectivity coefficients from Nutkwa Inlet 1998 survey ADF&G small mesh pots and Nutkwa Inlet 1999 resurvey ADF&G small mesh pots using Equation 5.

(2) Parameters A_{15}, A_{16}, …, A_{50}, A_{51}, u, $_L$ and $_L$ were estimated from the 1998 survey Nutkwa Inlet ADF&G large and small mesh pots and Nutkwa Inlet 1999 resurvey ADF&G large and small mesh pots using Equations 6 and 8.

<u>Reduced Model Nutkwa Inlet and Hetta Inlet Combined.</u>

The following Parameters were estimated:
Abundance parameters a and b for Hetta Inlet 1997 ADF&G Large Mesh Pots
Abundance parameters a and b for Hetta Inlet 1997 ADF&G Large and Small Mesh Pots
Abundance parameters a and b for Jackson Island 1997 ADF&G Large and Small Mesh Pots
Abundance parameters a and b for Grand Island 1997 ADF&G Large and Small Mesh Pots
Abundance parameters a and b for Hetta Inlet 1997 Vessel Pots
Abundance parameters a and b for Nutkwa Inlet 1997 Vessel Pots
Abundance parameters a and b for Jackson Island 1997 Vessel Pots
Abundance parameters a and b for Grand Island 1997 Vessel Pots
Abundance parameters a and b for Nutkwa Inlet 1997 ADF&G Small Mesh Pots
Abundance parameters a and b for Nutkwa Inlet 1997 ADF&G Large Mesh Pots
Abundance parameters a and b for Nutkwa Inlet 1998 ADF&G Small Mesh Pots
Abundance parameters a and b for Nutkwa Inlet 1998 ADF&G Large Mesh Pots
Selectivity Coefficient $_s$ and $_s$ for all Small Mesh Pots
Selectivity Coefficient $_L$ and $_L$ for all Large Mesh Pots
Harvest rate u_H for Hetta Inlet 1999 Resurvey Pots
Harvest rate u_N for Nutkwa Inlet 1999 Resurvey Pots

All size frequencies were used except Hetta Inlet 1997 ADF&G small mesh pots.

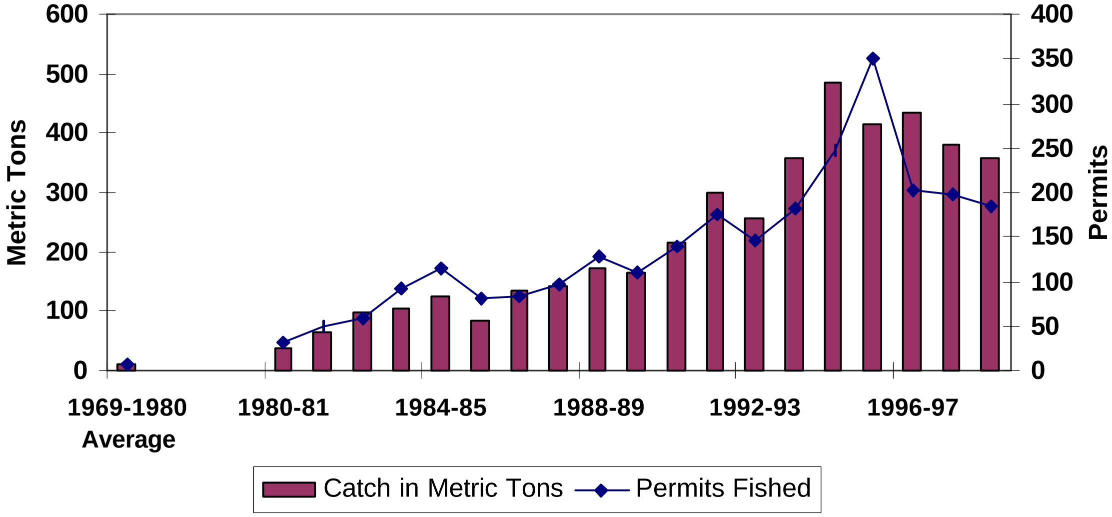

Figure 1. Commercial catch in the pot shrimp fishery in Southeast Alaska.

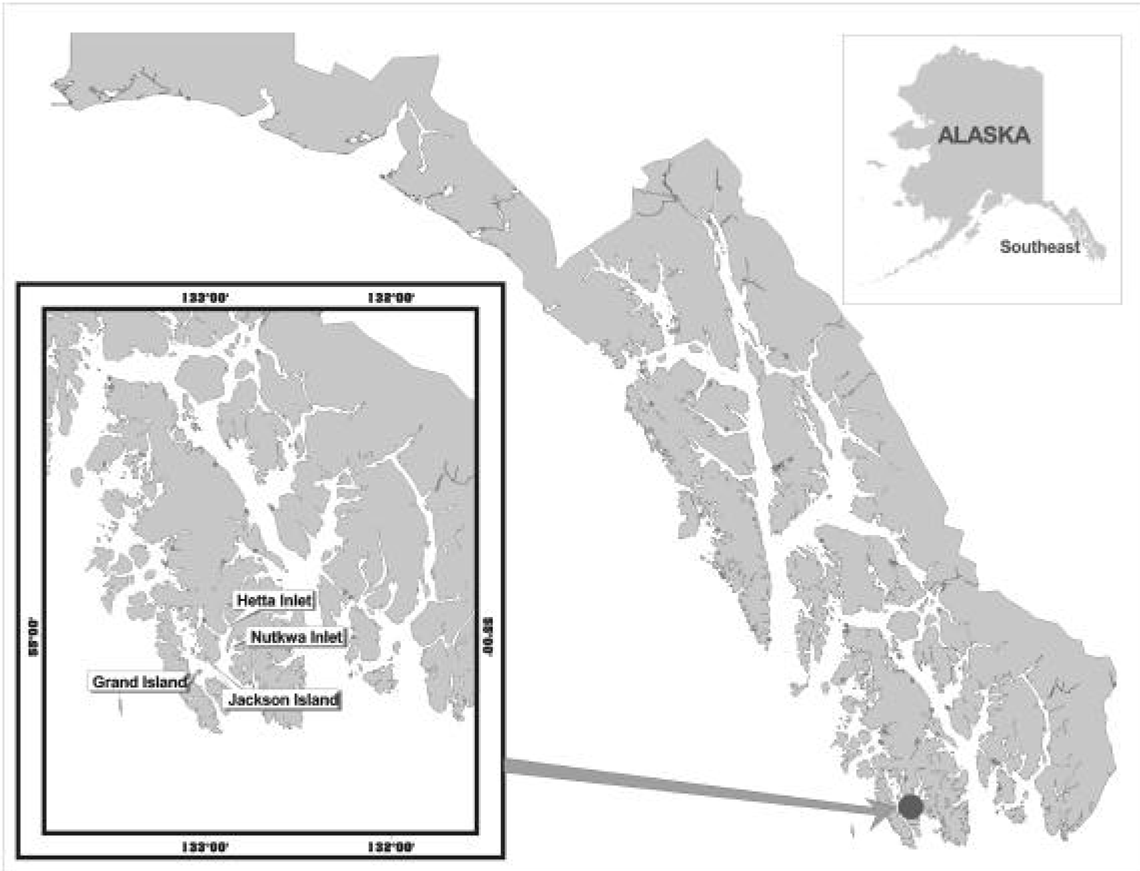

Fig. 2. Location of survey areas in District 3.

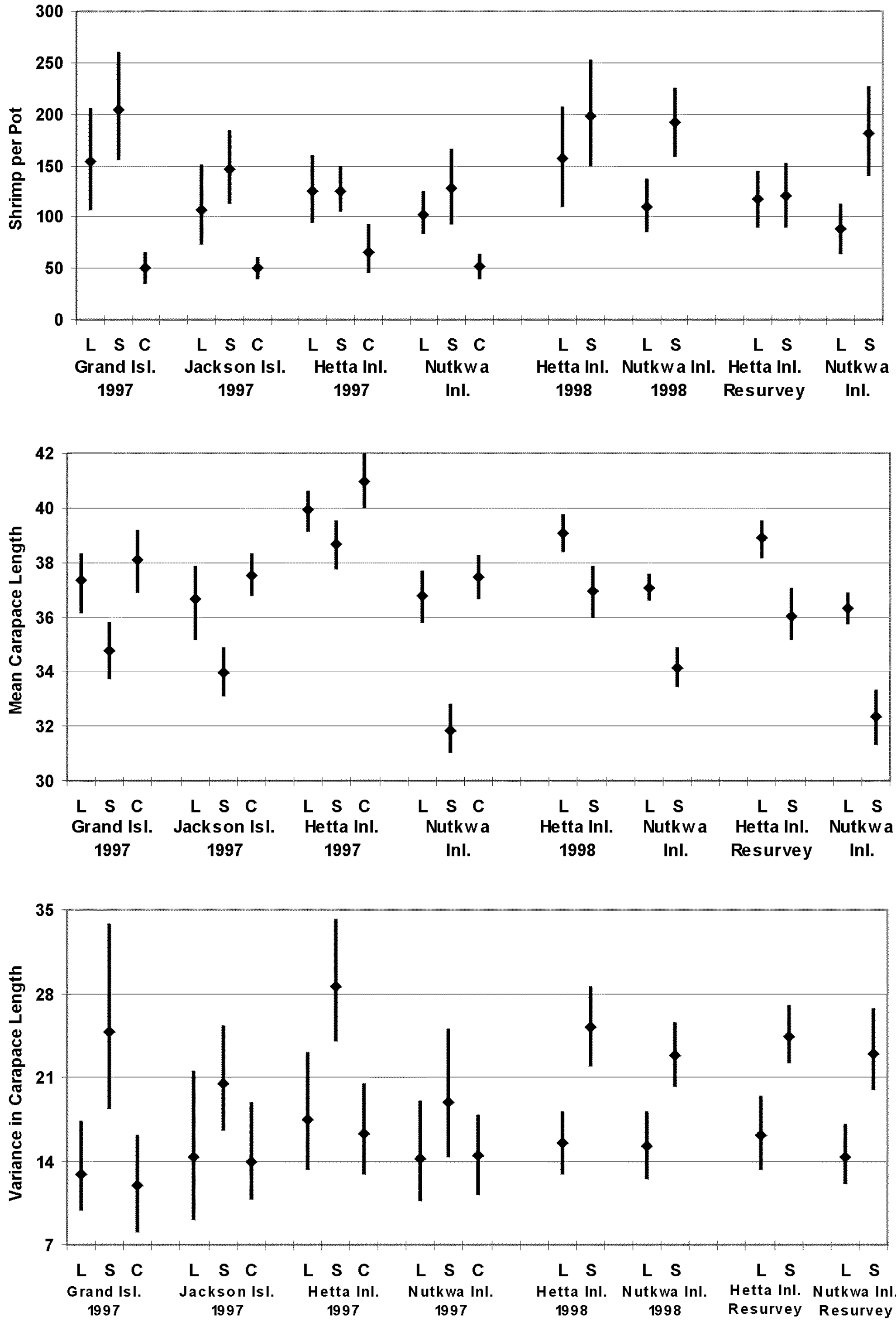

Figure 3. Median total catch per pot, mean carapace length and variance of carapace length and associated 5% and 95% quantiles for the 1997 Grand Island, Jackson Island, Hetta Inlet, and Nutkwa Inlet research and commercial pots, the 1998 Hetta Inlet and Nutkwa Inlet research and commercial pots, and the 1999 Hetta Inlet and Nutkwa Inlet resurvey. The L , S, and C designate large mesh research pots, small mesh research pots, and commercial pots respectively.

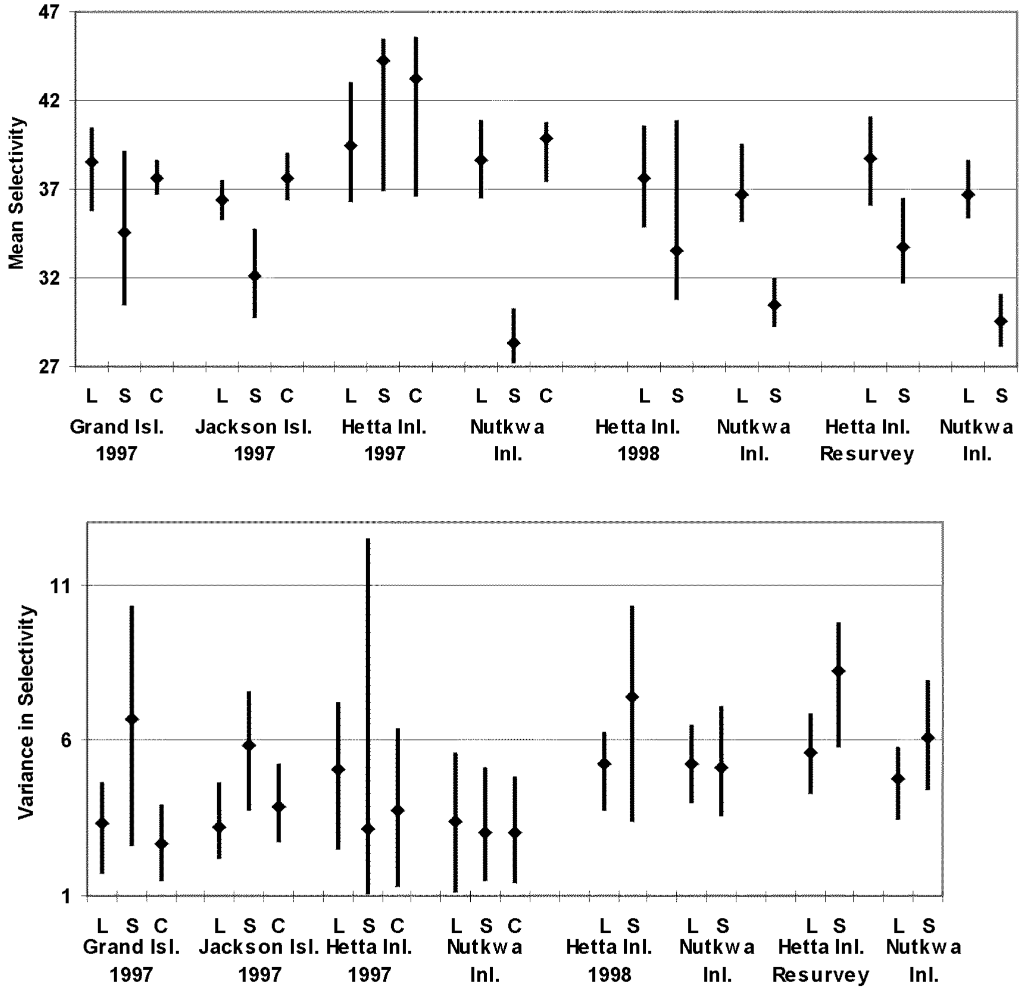

Figure 4. Median estimated mean and variance of the selectivity of shrimp pots and associated 5% and 95% quantiles for the 1997 Grand Island, Jackson Island, Hetta Inlet, and Nutkwa Inlet research and commercial pots, the 1998 Hetta Inlet and Nutkwa Inlet research and commercial pots, and the 1999 Hetta Inlet and Nutkwa Inlet resurvey. The L , S, and C designate large mesh research pots, small mesh research pots, and commercial pots respectively.

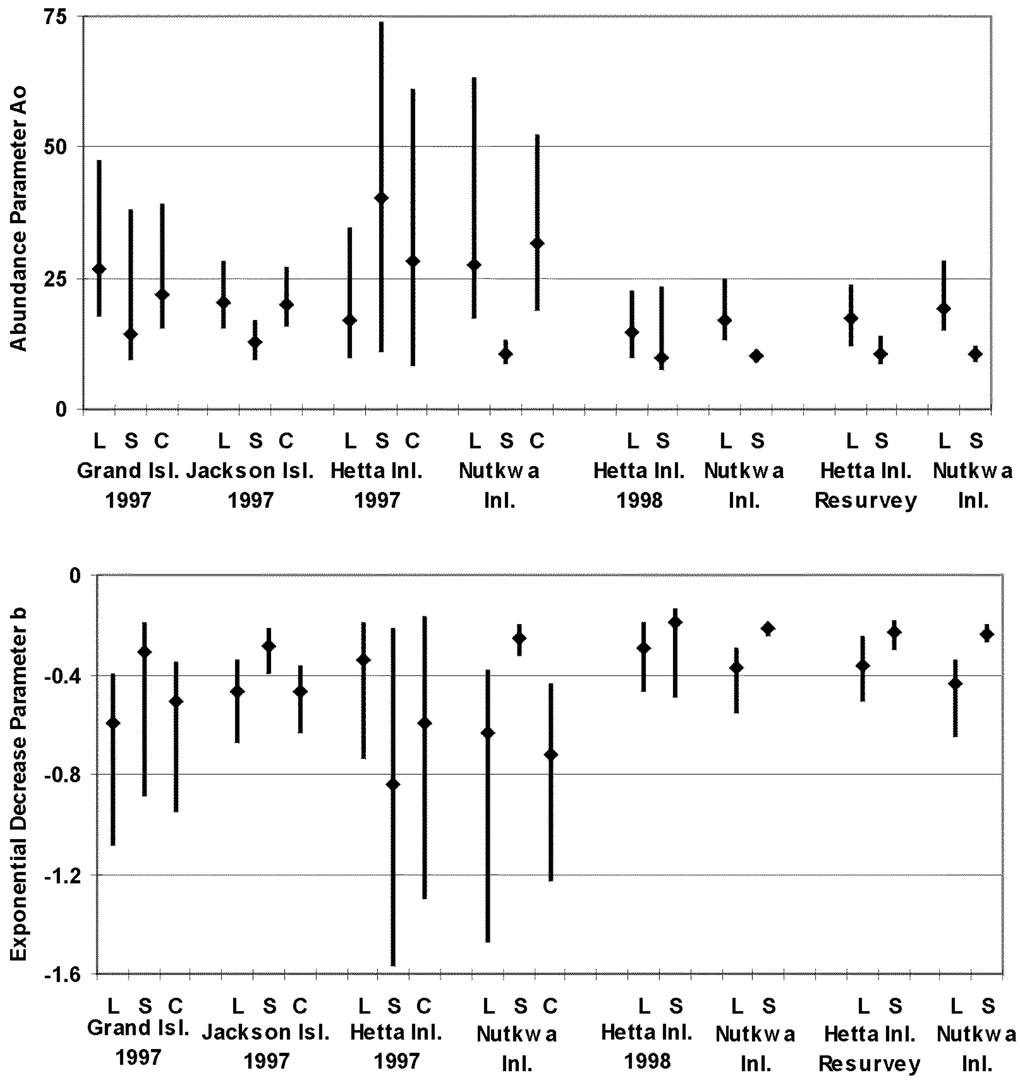

Figure 5. Median estimated abundance and exponential decrease parameters a and b of Equation 5 estimate of size frequency and associated 5% and 95% quantiles for the 1997 Grand Island, Jackson Island, Hetta Inlet, and Nutkwa Inlet research and commercial pots, the 1998 Hetta Inlet and Nutkwa Inlet research and commercial pots, and the 1999 Hetta Inlet and Nutkwa Inlet resurvey. The L , S, and C designate large mesh research pots, small mesh research pots, and commercial pots respectively.

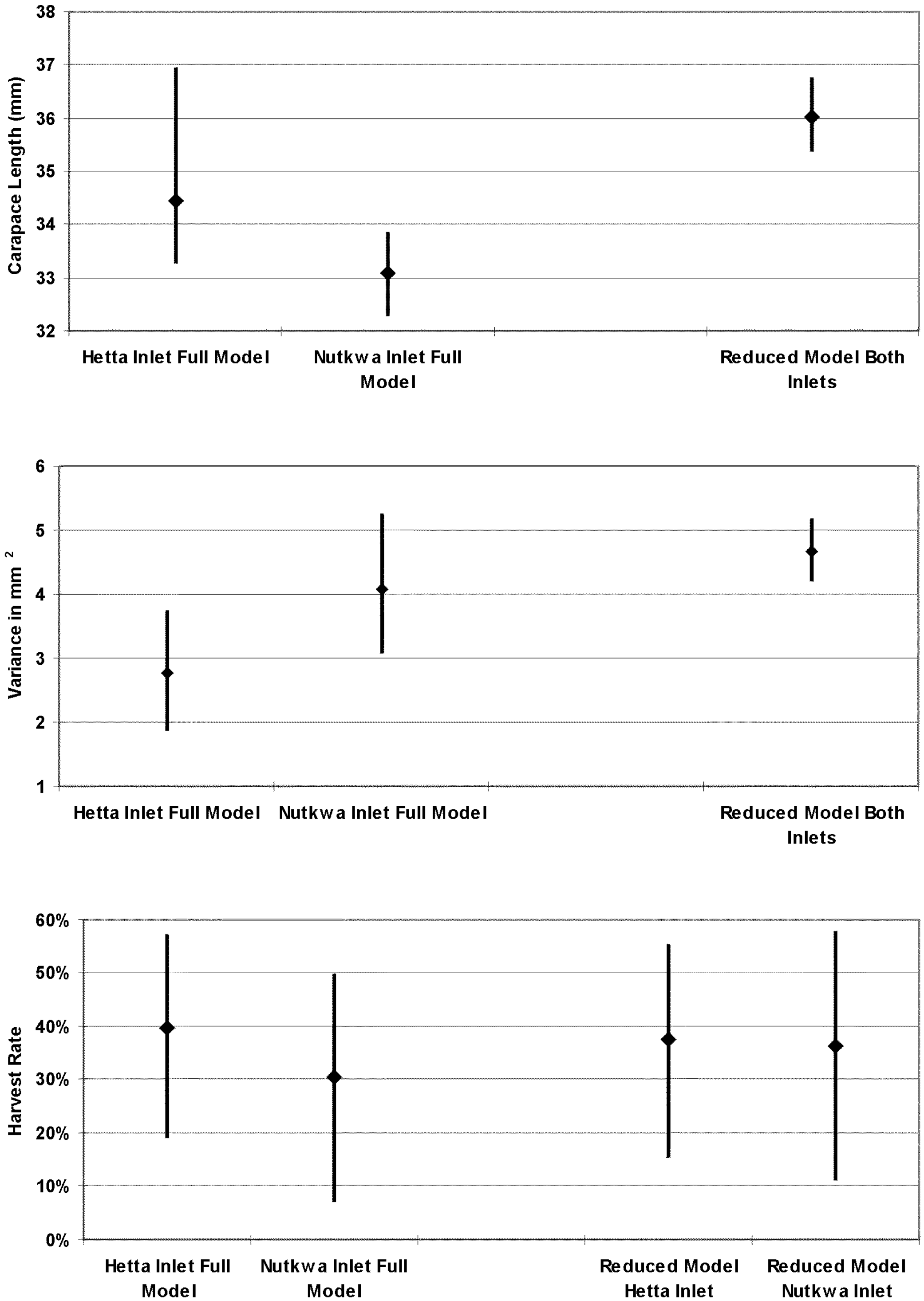

Figure 6. Median estimates of the large mesh and commercial pot selectivity coefficients, expressed as mean and variance of the selectivity of the pots, the maximum harvest rate, and associated 5% and 95% quantiles for the full and reduced models.

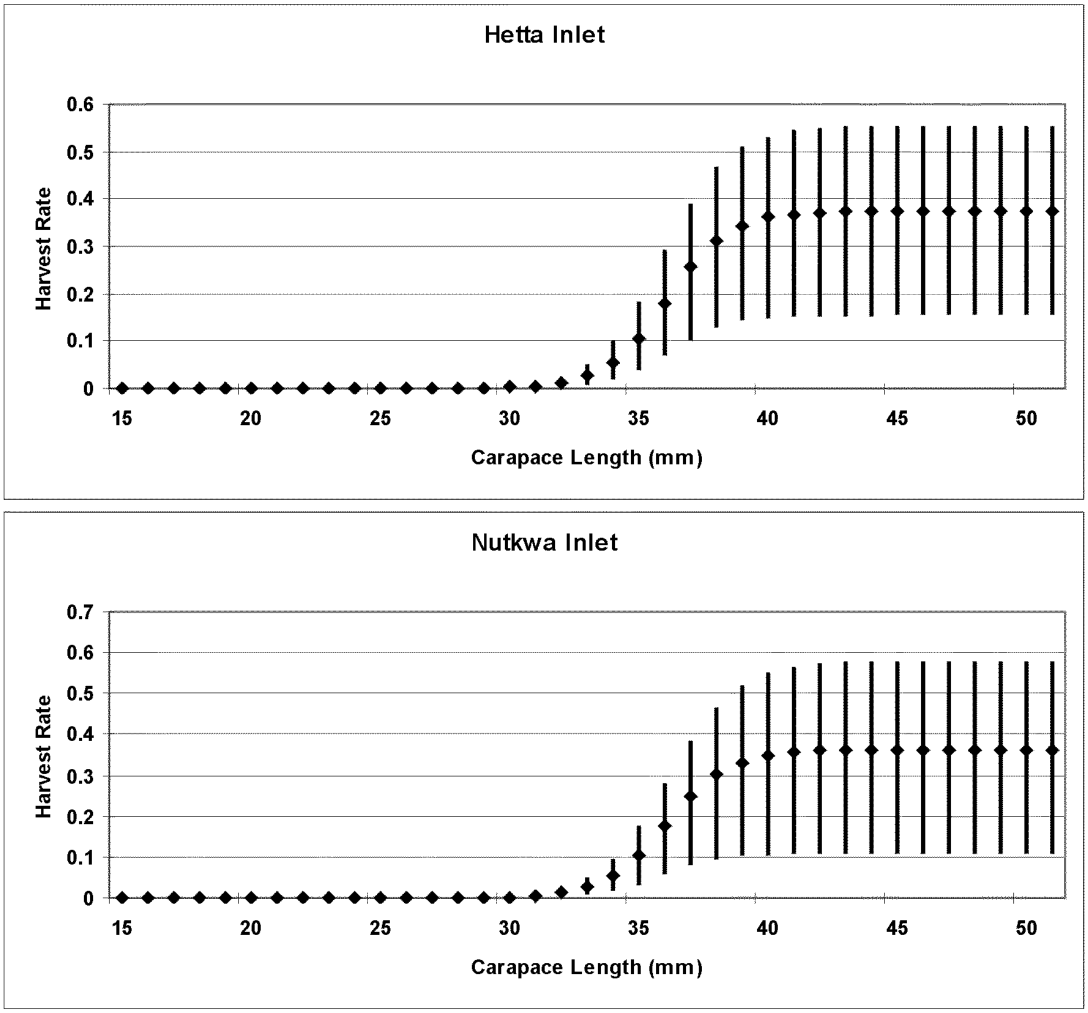

Figure 7. Median of estimated harvest rates in Hetta Inlet and Nutkwa Inlet for each millimeter carapace length and the associated 5% and 95% quantiles using the reduced model estimates.

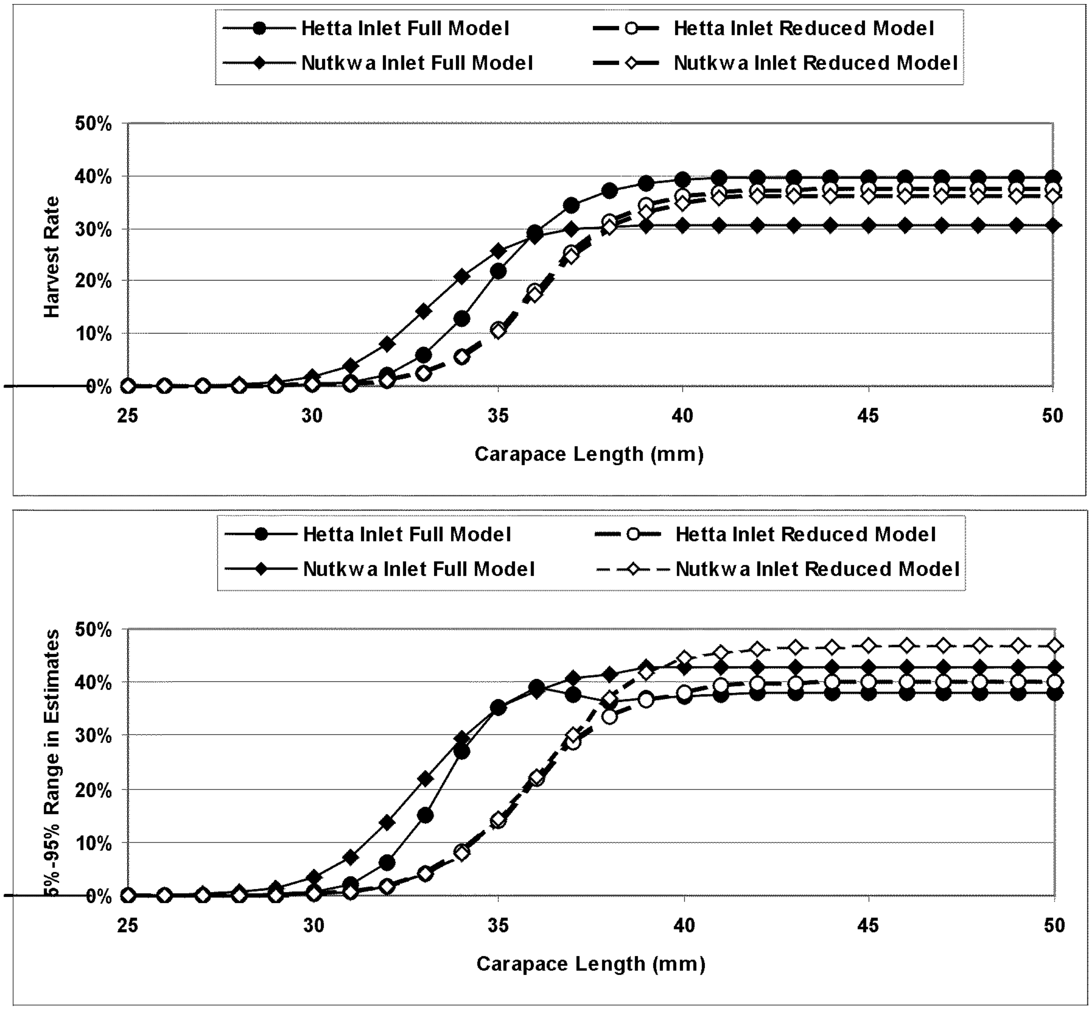

Figure 8. Comparison of harvest rate estimates by carapace length for the Hetta Inlet and Nutkwa Inlet full and reduced models. Harvest rate is the median estimated harvest rate over the 1000 bootstrap estimates and the 5% - 95% range value is the 95% quantile minue the 5% quantile range in estimates.