

## NOTES

### THE SIZE AT SEXUAL MATURITY OF BLUE KING CRAB, *PARALITHODES* *PLATYPUS*, IN ALASKA<sup>1</sup>

The blue king crab, *Paralithodes platypus*, is similar in size and general morphology to the better known and commercially more important red king crab, *P. camtschatica*. Unlike the red king crab, which is generally distributed throughout most of coastal Alaska, the blue king crab only occurs in small isolated populations. The principal fisheries for blue king crab occur in the eastern Bering Sea, where most populations are associated with offshore islands; minor, but locally important, fisheries occur south of the Alaska Peninsula, where populations are found in a number of widely scattered, enclosed bays.

Harvest of both species of king crab is restricted to males larger than minimum size. For red king crab, the minimum size is set at the average size of a male 3 yr after reaching sexual maturity in an attempt to assure that each male will have at least one opportunity to mate before becoming available for harvest (North Pacific Fishery Management Council 1981). For blue king crab, however, the size at maturity is not well known, and in some areas the minimum size limit is set at the same size as red king crab.

In this paper we estimate the size at maturity of female and male blue king crab in each of four populations. For females, the size at sexual maturity is based on the change in the presence of eggs or egg remnants on the pleopod setae as a function of size. For males, the size at maturity is based on chela allometry, using a new computer technique to estimate the size at which chela growth increases relative to carapace growth.

#### Materials and Methods of Collection

Samples of blue king crab were collected from each of four populations: St. Matthew Island, Pribilof Islands, Olga Bay, and Prince William Sound (Fig. 1). Sampling methods differed somewhat between populations. The populations from St. Matthew Island and Pribilof Islands were sampled with bottom trawls on cruises conducted by the National Marine

Fisheries Service during the months of June and July of each year from 1976 to 1981. Sampling depths ranged from 30 to 180 m. The Olga Bay population was sampled by scuba divers and with hand operated ring nets in March, June, and October 1980 and January 1981. Sampling depths ranged from 1 to 50 m. The Prince William Sound population was sampled with bottom trawls in September 1980 and with commercial king crab pots in September 1979 and December 1980. Sampling depths ranged from 80 to 150 m.

Carapace length of both sexes and the major (righthand) chela height of males were measured to the nearest 1 mm using sliding jaw calipers (see Wallace et al. 1949 for definitions of these measurements). Reproductive condition of females was classified as either

virgin—no eggs or egg remnants attached to the pleopod setae,  
attached eggs—eggs attached to the pleopods, or  
hatched eggs—egg remnants, consisting of egg membranes and egg funiculi, attached to the pleopod setae.

#### Female Size at Maturity

Female blue king crab mate and extrude eggs quite soon after every adult molt (a pathological exception to this is discussed in Somerton and MacIntosh<sup>2</sup>); therefore, females can be classified as mature or immature based on the presence or absence of eggs or egg remnants on the pleopods. Using this classification criterion, the percent of females that were mature was calculated for each 3 mm size interval. Percent mature is plotted against carapace length in Figure 2.

The size at 50% maturity (SM50) was chosen as an appropriate measure of the size at maturity [see Somerton (1981) for a discussion of the strengths and weaknesses of this particular measure]. SM50 was estimated for each population by fitting a logistic equation to percent mature by size, using weighted nonlinear least squares (Somerton 1980a), then

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<sup>2</sup>Somerton, D. A., and R. A. MacIntosh. In prep. Reproductive biology of the blue king crab, *Paralithodes platypus*. Center for Quantitative Science in Forestry, Fisheries, and Wildlife, University of Washington, Seattle, WA 98195.

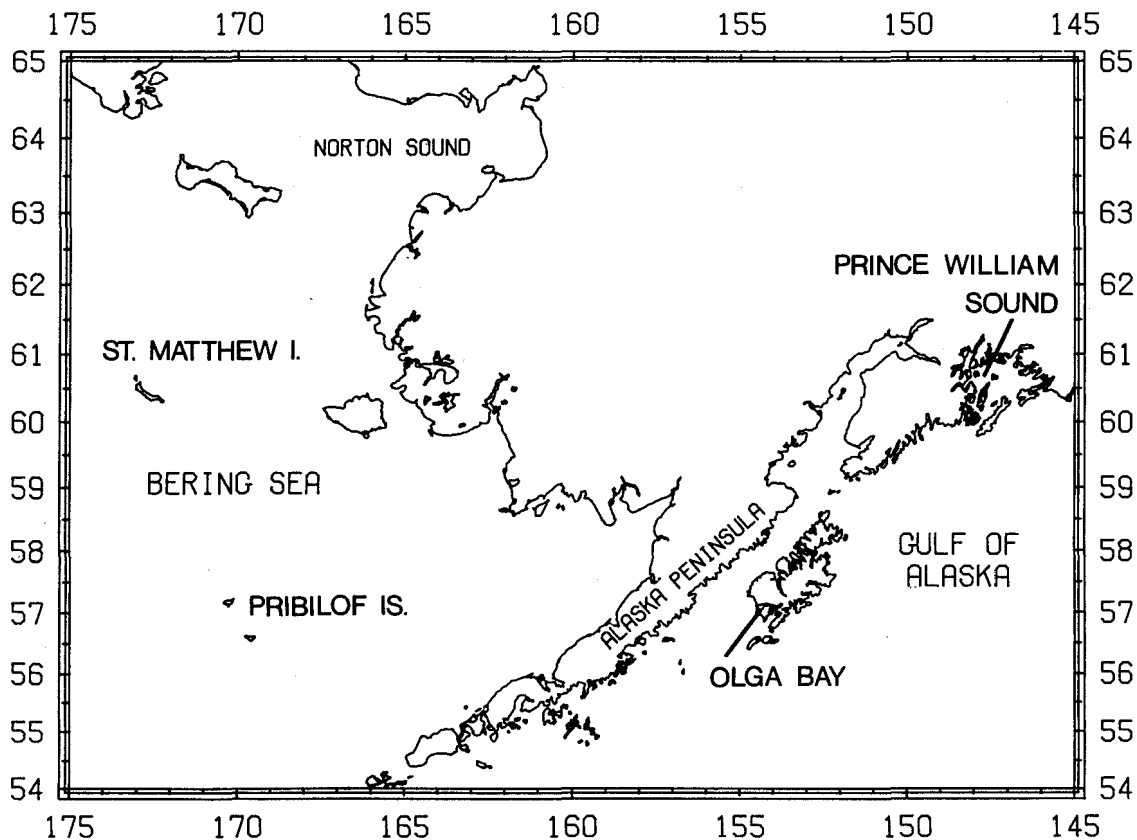


FIGURE 1.—Locations of the four blue king crab populations: St. Matthew Island, Pribilof Islands, Olga Bay, and Prince William Sound.

evaluating the fitted equation to find the size corresponding to 50% maturity. Variance of SM50 was estimated using the technique described in Somerton (1980a). Estimates of SM50, standard deviations, and 95% confidence intervals are shown in Table 1.

TABLE 1.—Female size at 50% maturity (SM50), standard deviation, and 95% confidence intervals for each of the four blue king crab populations studied.

Area	SM50 (mm)	Standard deviation	95% confidence interval
St. Matthew Island	80.6	0.6	79.4-82.6
Pribilof Islands	96.3	0.3	95.7-96.9
Olga Bay	93.7	0.4	92.9-94.5
Prince William Sound	87.4	0.5	86.4-88.4

### Male Size at Maturity

Male blue king crab do not display external features that unambiguously indicate maturity; however, at maturity the growth of the major chela may increase relative to the growth of the carapace. Although this relationship has not been established for blue king

crab, for tanner crab, *Chionoecetes bairdi*, the size of maturity based on chela allometry was almost identical to that based on a change in reproductive tract weights (Brown and Powell 1972). If this is also true for blue king crab, then the size at maturity can be estimated by the size at which chela growth increases.

When chela measurements are plotted against carapace measurements on log-log axes, the data assume a pattern consisting of two straight lines. These lines describe the juvenile and adult phases of relative growth (Hartnoll 1978). For some species of crab, especially brachyuran crabs, the two lines have similar slopes but different intercepts. Somerton (1980a) described a technique for estimating the size of maturity for species with this pattern of relative growth. For other species, including blue king crab, the two lines have different slopes and intersect at the size at maturity. In this case, the problem of estimating the size at maturity is one of estimating the intersection point of the two phase lines.

The intersection point can be estimated from morphometric data by finding the best fit of a model

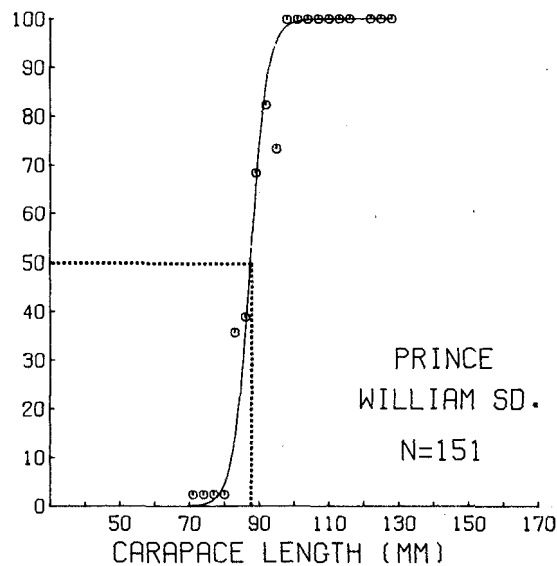
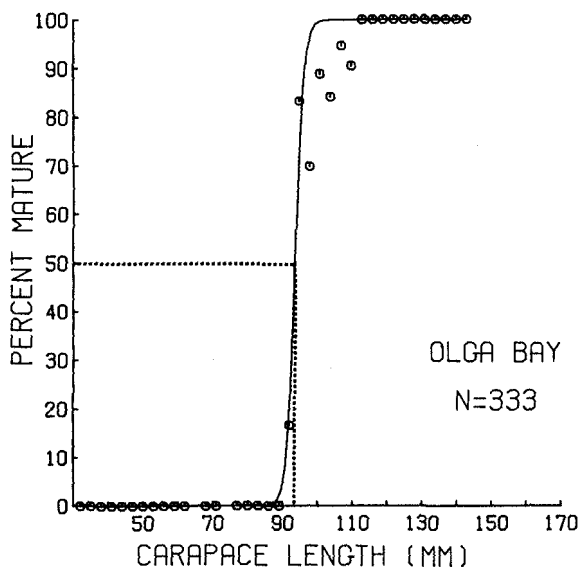
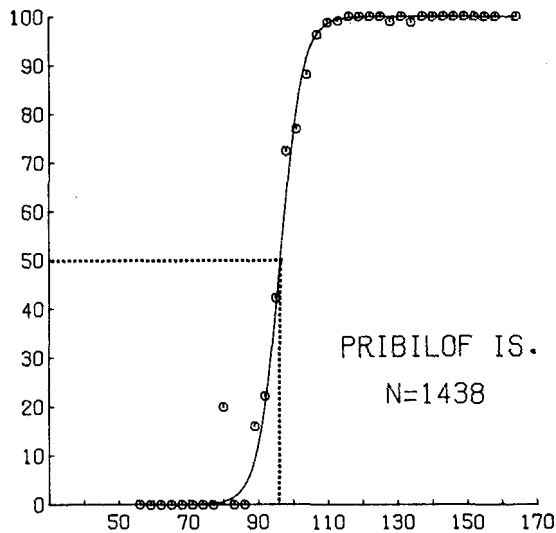
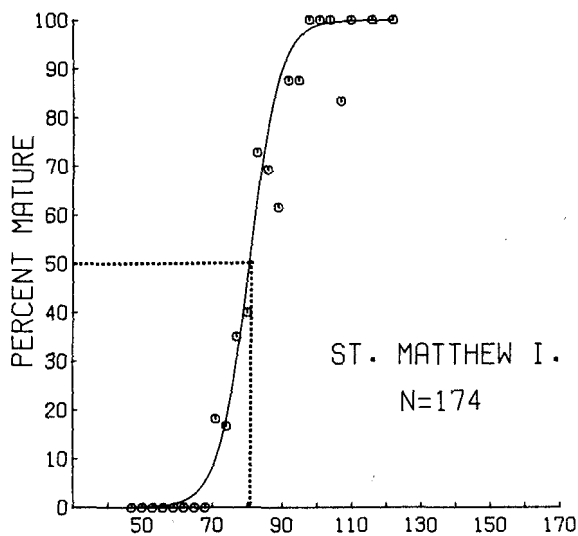


FIGURE 2.—Percent of blue king crab females that were mature, within 3 mm size intervals, as a function of size. Dotted lines indicate the carapace lengths corresponding to the 50% maturity levels on the fitted logistic functions (solid lines). Sample sizes (N) are indicated.

which describes a pair of intersecting straight lines and has the intersection point as a parameter. One such model, which has been previously used (Somerton 1980b) to describe the relation between premolt and postmolt carapace size, is

$$\begin{aligned}
 Y &= A + BX & X &\leq X^* \\
 Y &= Y^* + C(X - X^*) & X &> X^*
 \end{aligned}$$

where  $Y$  and  $X$  are the logarithms of chela height and

carapace length,  $X^*$  is the intersection point on the  $X$  axis, and  $Y^*$  is the intersection point on the  $Y$  axis, ( $Y^* = A + BX^*$ ). The model has four parameters.  $A$ ,  $B$ ,  $C$ , and  $X^*$ .

This model was fit to morphometric data using an iterative computer technique (FORTRAN program MATURE2 is available from the senior author). First, a lower and an upper bound of an interval on the  $X$  axis are chosen such that the intersection point is contained within the interval. Second,  $X^*$  is set

equal to the lower bound and linear regression is used to fit a lower line ( $X \leq X^*$ ), then an upper line ( $X > X^*$ ) to the data. Third,  $X^*$  is increased by some small amount and the model is fit to the data iteratively until  $X^*$  equals the upper bound. The size of sexual maturity is then equal to the antilog of the  $X^*$  value, which produced the minimum residual sum of squares about the model. Chela and carapace measurements and the best fitting pair of lines are shown in Figure 3.

Although this technique will always find the best fit of the model, the fit may not be statistically significant, that is, the fit of the two line model may not be significantly better than the fit of a single straight line. Therefore a single straight line was fit to the data and the residual sum of squares (RSS) of the two line model was tested against the RSS from the single line using a partial  $F$  test (Draper and Smith 1981). The partial  $F$  test was significant ( $P < 0.05$ ) for all four sets of blue king crab data. In cases where the fit of the two

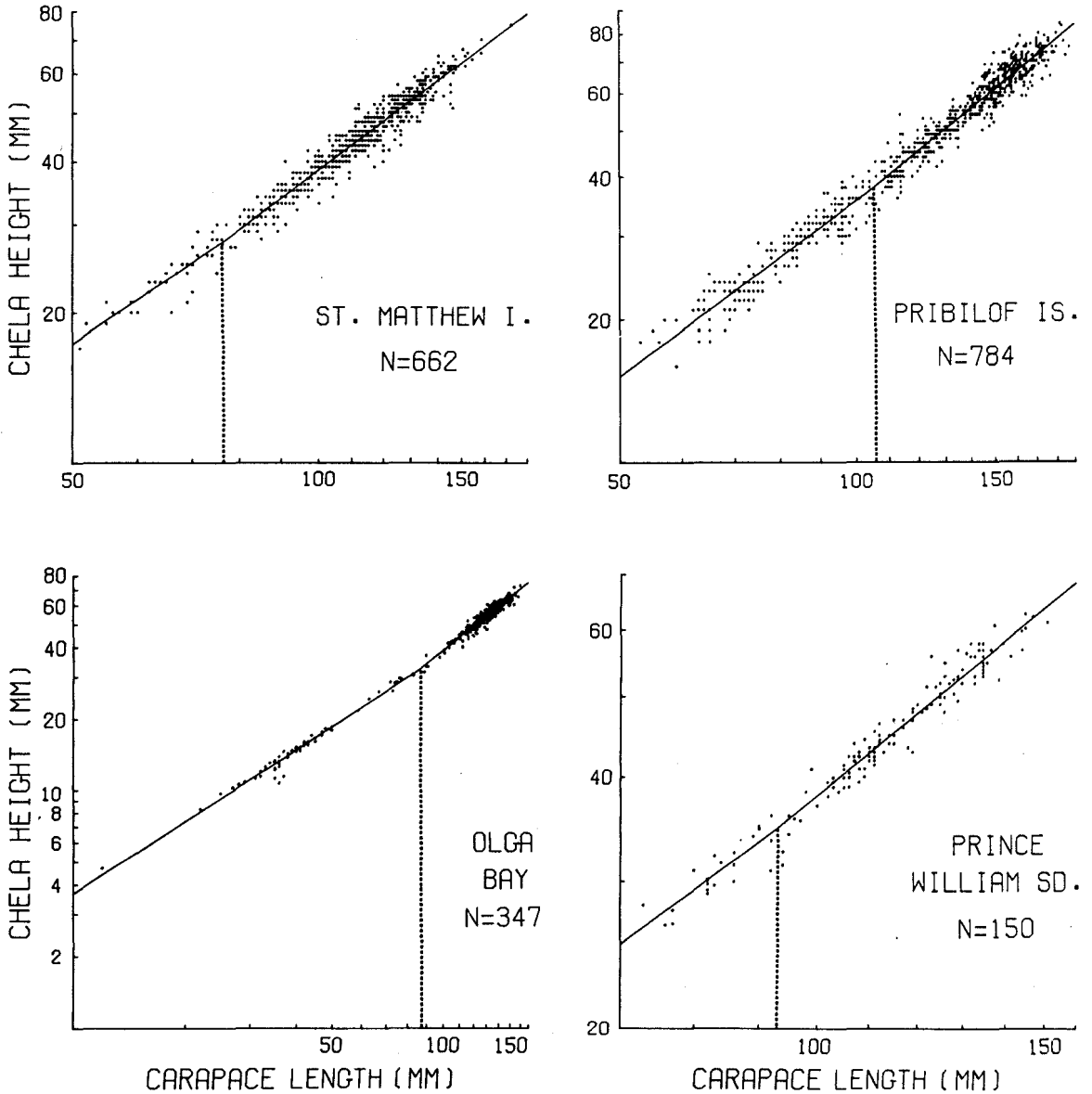


FIGURE 3.—Male chela heights and carapace lengths of the blue king crabs. The X axis intersection points of the two line model, or the estimated sizes of maturity, are shown by dotted lines. Sample sizes (N) are indicated.

line model is not significantly better than the fit of a single line, either more data or a broader size range of data is needed or some other procedure for estimating the size of maturity should be considered.

The standard deviation of  $X^*$  was estimated using Monte Carlo simulation (Hammersley and Handscomb 1964), which, in this particular application, consisted of 1) generating sets of synthetic morphometric data, 2) estimating  $X^*$  for each data set by fitting the two line model, and 3) calculating the standard deviation between the estimates of  $X^*$ . Each synthetic data set was constructed by generating a new chela measurement for each carapace measurement in the original sample. The new chela measurement was computed as

$$Y = E(Y) + Z \cdot SD$$

where  $Y$  is the logarithm of chela height,  $E(Y)$  is the expected value of log chela height given carapace length and the parameters of the appropriate phase line,  $Z$  is a randomly generated standard normal deviate, and  $SD$  is the standard deviation about the appropriate phase line. For carapace widths  $\leq X^*$ , the parameters and  $SD$  for the juvenile phase line were used; for carapace widths  $> X^*$ , the parameters and  $SD$  for the adult phase line were used. Thirty samples of morphometric data were generated for each population.  $X^*$  was estimated for each sample and the

standard deviation among the 30 independent estimates of  $X^*$  was calculated. The estimates of  $X^*$ , standard deviations, and 95% confidence intervals are shown in Table 2.

Samples from the populations of St. Matthew Island and Pribilof Islands contained some chela measurements that were unusually small compared with other measurements from crabs with similar carapace lengths (Fig. 4). These atypical measurements were probably obtained from crabs in the process of regenerating lost chelipeds. For crabs which are bilaterally symmetric, the inadvertent measurement of partially regenerated chelae should not be a problem, because the sizes of left and right chelae can be compared in the field, and, if different, the measurement can be rejected. For crabs, such as blue king crab, which are not bilaterally symmetric, partially regenerated chelae are harder to detect and thus are likely to be included in the sample. For red king crab, the

TABLE 2.—Male size at maturity, standard deviation, and 95% confidence intervals for each of the four blue king crab populations studied.

Area	Size at maturity (mm)	Standard deviation	95% confidence interval
St. Matthew Island	77.0	9.8	57.8-96.2
Pribilof Islands	108.0	12.8	82.9-133.1
Olga Bay	87.0	7.2	72.9-101.1
Prince William Sound	93.0	13.9	65.7-120.2

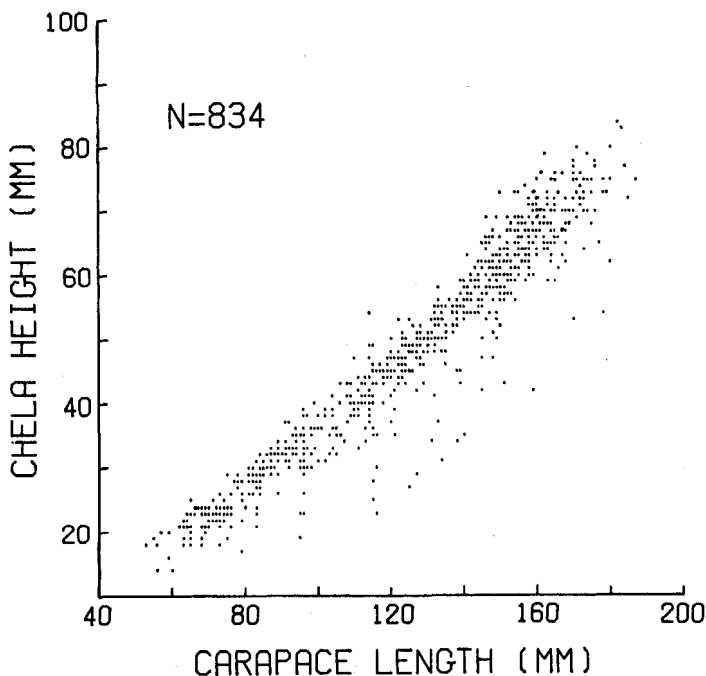


FIGURE 4.—Male chela height and carapace length measurements of the blue king crab from the Pribilof Islands before date deletion. Measurements of chela height which appear unusually small relative to the carapace length probably were obtained from crabs in the process of regenerating lost chela.

length of a limb after each of the five molts required for complete regeneration is 27, 45, 65, 85, and 100% of the length of a normal limb (Edwards 1972). Limbs in the last stages of regeneration are the hardest to detect.

Since measurements from regenerating chelae can be quite deviant from normal measurements, they can have a pronounced effect on the estimate of  $X^*$  and therefore must be detected and eliminated from the sample. The method we used for eliminating such outliers consisted of fitting a single straight line to the logarithms of chela height and carapace length (fitting the two line model is preferable if computer cost is not a consideration) then excluding the datum with the largest negative deviation. This is repeated iteratively until the mean square residual (MSR) is reduced to some level.

Two criteria were examined as a means of determining when MSR had been reduced sufficiently. The first criterion considered the change in MSR resulting from the deletion of each successive datum. Typically the change in MSR was initially large, then decreased almost asymptotically as additional data were deleted (Fig. 5). Elimination of regenerating chela measurements was assumed to be complete when the change in MSR became nearly constant. For the Pribilof Islands population, data deletion was halted after 50 values (6% of the sample) were removed (Fig. 6).

The second criterion was based on a comparison of the MSR of the contaminated sample with the MSR of a sample assumed to be free of regenerating chela measurements. Deletion was halted when the MSR of the contaminated sample was not significantly different from the uncontaminated sample, based on an  $F$  ratio, at some probability level. Although this criterion is more objective than the first, it requires an uncontaminated sample and it assumes that the true variance is identical between populations. For the Pribilof Islands data, to achieve an MSR that was not significantly different from the average MSR for the Olga Bay and Prince William Sound data (both of these data sets did not contain regenerating chelae measurements) at the 0.001 probability level, 114 values (14% of the sample) had to be excluded (Fig. 7). Even with this low probability level, the deletion of data was too severe, because the distribution of chela measurements about the fitted line appeared to have a positive skew. Since we believe that the true variance is probably less in the Olga Bay and Prince William Sound populations than in the Pribilof Islands population, the first criterion was used to determine when the deletion of data should be halted.

The number of data deleted by these methods may be too large, that is, some crabs with small, but otherwise normal, chela may have been excluded. In one study of limb regeneration in male red king crab, 14.7% of the adults and 25.6% of the juveniles had

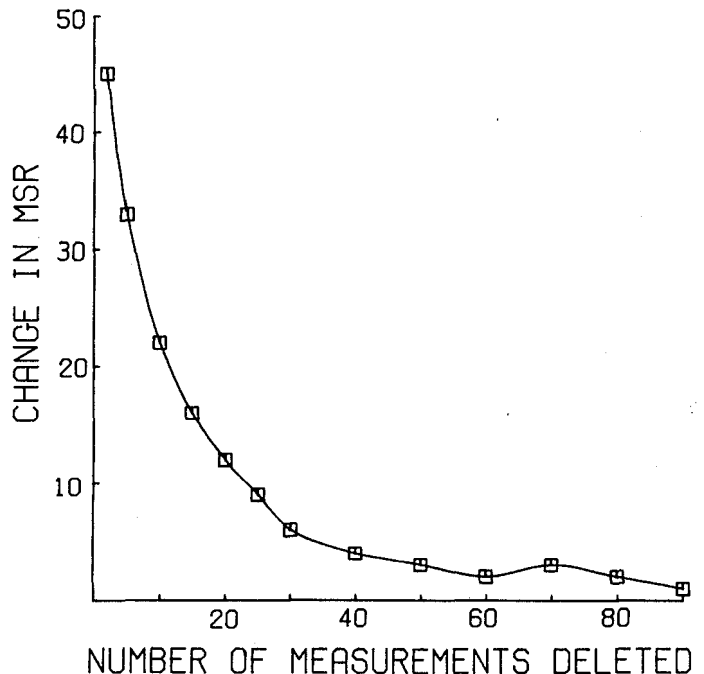


FIGURE 5.—Change in mean square error (MSR) about a single straight line fit to the data of the blue king crab from the Pribilof Islands as a function of the number of values deleted. Note that the change in MSR becomes nearly constant after deleting 50 values.

FIGURE 6.—Chela height and carapace length data of the blue king crab from the Pribilof Islands after the deletion of 50 values.

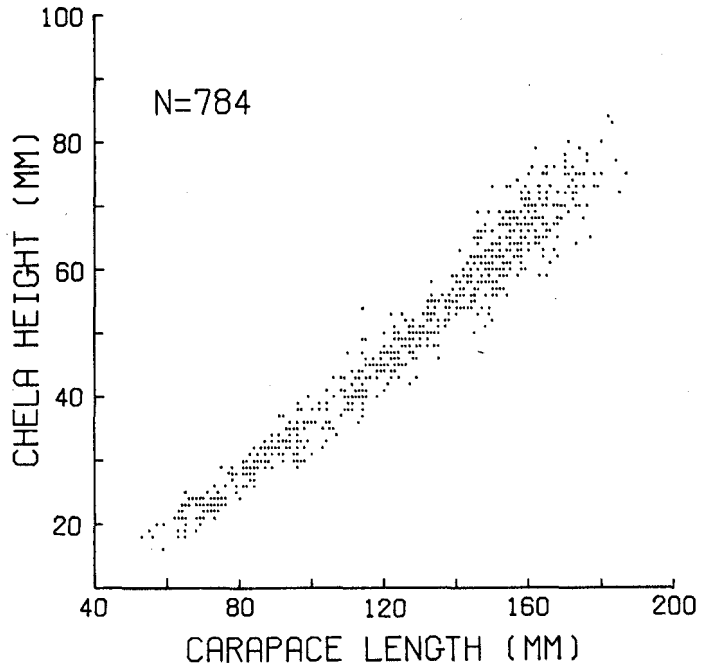
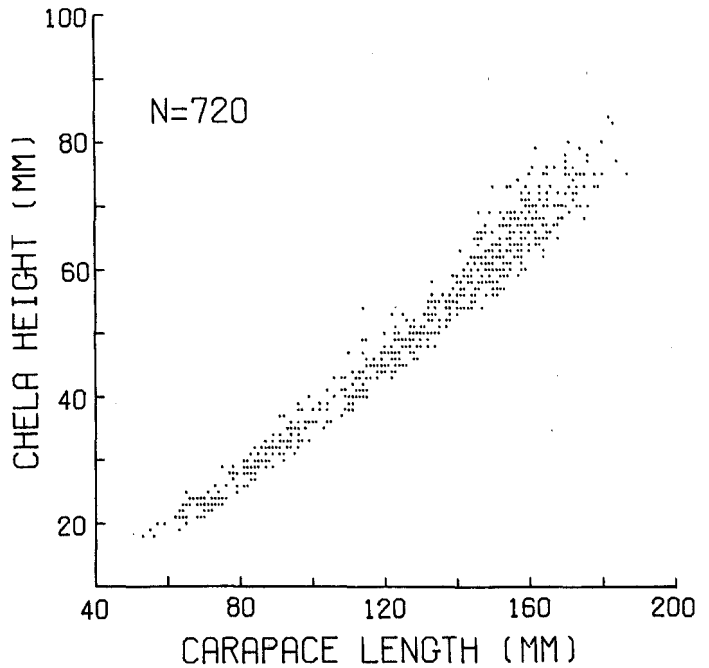


FIGURE 7.—Chela height and carapace length data of the blue king crab from the Pribilof Islands after the deletion of 114 values.



missing or regenerating limbs and 8.4% of the missing or regenerating limbs were the right cheliped (Edwards 1972). Thus 1.2% of all adult males and 2.2% of all juvenile males had missing or regenerating right

chela. For the Pribilof Islands sample, 6.0% of the total sample was deleted. Although some valid measurements may have been rejected, the loss of these measurements should bias the estimate of  $X^*$  less

than the inclusion of measurements from regenerating chela.

### Results and Discussion

For both sexes of blue king crab, estimates of the size at sexual maturity were largest at Pribilof Islands, smallest at St. Matthew Island, and intermediate between these extremes at Olga Bay and Prince William Sound (Tables 1, 2). Precision in the estimates of the size at maturity of blue king crab differs markedly between sexes. For females, the average standard deviation was 0.45 mm, whereas, for males, the average standard deviation was 10.93 mm, about 24 times larger. Because of this difference, the estimates for females differed significantly ( $Z$  test,  $P < 0.5$ ) between all areas, but the estimates for males did not differ between areas even though their range was nearly double that of females.

Much of the imprecision in the estimates of male size at maturity is the result of the pattern of relative growth. Standard deviation of an estimate of male size at maturity depends largely on the angle at which the two phase lines meet. As the included angle increases, uncertainty in the position of each phase line is progressively magnified in the uncertainty of the estimate of the size of maturity. Species, such as blue king crab, which exhibit a large angle between phase lines, inherently have a large standard deviation.

Future studies of male crabs with a similar pattern of relative growth should insure that samples include a broad range of sizes, because this will minimize the standard deviation of the estimates of size at maturity. The relationship between size range and standard deviation is exemplified by the two extreme cases examined here. The Olga Bay sample, which produced the smallest standard deviation, included individuals as small as 12 mm, whereas the Prince William Sound sample, which produced the largest standard deviation, included no individuals smaller than 72 mm.

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