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OF TANNER CRAB (CHIONOECETES BAIRDI AND C. OPILIO)

IN THE EASTERN BERING SEA, AND ITS USE

IN DEFINING MANAGEMENT SUBAREAS

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October 1980

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*A program of research in methods for marine resource management
supported jointly by:*

WASHINGTON SEA GRANT PROGRAM   NATIONAL MARINE FISHERIES SERVICE

National Oceanic and Atmospheric Administration
U.S. Department of Commerce

WASHINGTON SEA GRANT PROGRAM

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REGIONAL VARIATION IN THE SIZE OF SEXUAL MATURITY OF TWO SPECIES OF TANNER CRAB

(CHIONOECETES BAIRDI AND C. OPILIO) IN THE EASTERN BERING SEA,

AND ITS USE IN DEFINING MANAGEMENT SUBAREAS

The United States catch of two tanner crab species (Chionoecetes
bairdi and C. opilio) in the eastern Bering Sea has rapidly increased from
a negligible amount in 1973 to approximately 34,000 metric tons in 1979.
C. bairdi was the first of the two species to be harvested both because
its major areas of abundance were closer to established fishing ports and
because it is larger, hence economically more desirable. C. opilio became
an important component of the domestic catch in 1978 when the tanner crab
fishery expanded northward in response to a decline in the abundance of
C. bairdi. In 1979, 43% of the domestic harvest of tanner crab was comprised
of C. opilio.

Current management regulations for eastern Bering Sea tanner crab
reflect the relatively recent origins of the fishery. Both species are
subject to: 1) sex restriction--only males may be taken, 2) gear restriction--
only pots may be used, and 3) harvest quotas. No substocks of either species
are recognized, however, two management areas, separated along 58°N latitude,
were established to segregate a Japanese fishery for C. opilio in the northern
area from the domestic fishery in the southern area. C. bairdi has a minimum
size limit, C. opilio does not.

The minimum size limit for C. bairdi of 140 mm maximum carapace width
(135 mm excluding lateral spines) was chosen such that males are allowed one
year after maturing for breeding purposes before being subjected to harvest.
This size was derived by adding an expected annual growth increment of 25 mm
to the 110 mm size of 50% maturity reported in Brown and Powell (1972) plus

an additional 5 mm to account for the maximum difference between the commercial measurement (width including spines) and the scientific measurement (width excluding spines) (W. Donaldson, per. comm.). Thus the minimum size limit is directly related to the size of sexual maturity.

The objectives of this paper are two-fold. Since the size of maturity of male C. bairdi upon which the present minimum size limit is based (Brown and Powell, 1972) was estimated from data collected outside the Bering Sea near Kodiak Island, the first objective is to determine a size of sexual maturity for each species which is more appropriate for the eastern Bering Sea. The second objective is to determine how much regional variability in the size of sexual maturity exists in the eastern Bering Sea, and, if it is significantly large, to minimize the effects of this variability by partitioning the area into relatively homogenous subunits.

Materials and Methods

All data, excluding bottom temperature, were collected on the 1975 to 1979 crab stock assessment surveys conducted by the National Marine Fisheries Service each year during the months of May through August. The area of the eastern Bering Sea sampled progressively expanded from 1975 to 1979 to include regions to the north and west of the 1975 survey area (Figure 1). Sampling sites were situated at the approximate centers of adjacent 37 km x 37 km quadrates in every year except 1979 when the sampling density was doubled in areas south of 58°N latitude and halved north of 61°30'N latitude. At each sampling site, a 400 mesh eastern fish trawl with a 32 mm stretched mesh cod end liner was towed for one-half hour. Crabs obtained in the trawl sample were sorted according to species and sex and processed as follows. First, maximum carapace width in millimeters, excluding lateral spines, was

measured using a vernier caliper. Second, shell condition, an index
of the relative time since a crab last molted, was estimated. Shell
condition was based on the amount of wear and accumulation of epifauna
on the exoskeleton and ranged from 1 for crabs still soft from molting
to 5 for crabs believed to have not molted for three years. Third,
the state of sexual maturity was determined for females by noting the
width of the abdomen relative to the carapace. Wide abdomens are in-
dicative of mature females. Fourth, on the 1979 survey only, the height
of the right chaela (see Brown and Powell (1972) for a description of this
measurement) and the maximum carapace width, including lateral spines,
were measured on a subsample of males using vernier calipers.

Bottom temperature measurements were obtained from Ingraham(1973).
These data are monthly averages of measurements taken sporadically over
a span of approximately 20 years and are reported for 1° latitude by
1° longitude quadrangles. A fifth order polynomial in latitude and longi-
tude was fit to these average temperatures to both smooth the data and
to allow interpolation of temperature at the positions of the crab sampling
stations. The data for August, shown in Figure 8, were chosen as
being representative of the conditions in late summer when the temperature
differences between the warm and cold areas of the eastern Bering Sea
are maximal.

Estimating the Size of Sexual Maturity

The methods used to differentiate mature from immature tanner crab
differ between sexes because the external morphological changes which
accompany sexual maturation are conspicuous for females but quite subtle
for males. Females undergo a true puberty molt (Hartnoll, 1978) during

which their abdomens increase in size disproportionately more than other body features. Males also abruptly increase the relative size of their appendages, especially the chaela, at maturity, however, these changes are slight and barely discernable in the field. Thus, mature females can be easily recognized whereas mature males cannot, without recourse to histological examination of their gonads, be individually separated from those still immature with any reliability. If a sufficiently large sample of males is available, however, immature and mature individuals can be separated using the pattern of chaela growth relative to carapace growth. The method used for doing this, which is described in Somerton (ms.), recognizes that when chaela measurements are plotted against carapace measurements on double logarithmic axes, the data typically lie along two straight lines, one line describing the relative growth of these estimates for juvenile crabs and the other describing the relative growth for adults. Using a computer algorithm similar to cluster analysis, this method iteratively fits two lines to the data until all values are classified as either adult or juvenile.

A measure of the size of sexual maturity which provides the most biological information is the mean size of a group of animals at the instant they reached sexual maturity (mean size of sexual maturity). This measure is often difficult to calculate and instead is approximated by either the size of 50% maturity or the mean size of mature individuals. The size of 50% maturity is typically estimated by dividing the size range of a species into a number of equal width size intervals, calculating the percent of the specimens within each interval which are mature, and determining the size at which maturity reaches 50%. Estimates of the size of 50%

maturity can be improved by fitting either a logistic or cumulative normal curve to percent maturity and size data using regression techniques and then evaluating the fitted equation at 50% maturity (Somerton, ms.). For animals with indeterminate growth, the size of 50% maturity is a fairly good approximation of the mean size of sexual maturity. For animals, such as female tanner crab, which cease growth upon reaching sexual maturity (Watson, 1970), the mean size of sexual maturity is best estimated by the mean size of a sample of mature individuals because, on the average, these two measures of the size of sexual maturity must be the same.

Previous studies have reported the size of sexual maturity of both female and male tanner crab as the size of 50% maturity (Watson, 1970). I will deviate from this convention by expressing the female size of sexual maturity as the mean size of mature individuals both because this measure is a better approximation of the mean size of sexual maturity and, as will be shown later, because it is less affected by annual fluctuations in year class strength and because it is independent of mortality rate.

Regional Variation in the Mean Size of Mature Female Tanner Crab

Considering that the area of the eastern Bering Sea in which tanner crabs are found spans more than 500 miles from north to south and an equal distance from east to west, and that within this region there exist several oceanographic domains with quite different thermal regimes (Kinder and Schumacher, in press), it was anticipated that the size of sexual maturity should show regional variation.

To determine whether or not such variation was significant, the mean size of the mature females sampled at each site on the 1979 survey was regressed against the latitude and longitude of the site using stepwise multiple regression (Nie et al., 1975). Only longitude was significant (P < .001) for C. bairdi and only latitude was significant (P < .001) for C. opilio. In both cases, the coefficient of the significant variable was negative indicating that as one progresses westward (C. bairdi) or northward (C. opilio) the mean size of adult females decreased.

Mean size of mature females at each site was also regressed against the depth and mean August bottom temperature at the site using stepwise multiple regression. For both species, depth and temperature were highly significant (P <.001). The regression coefficients were all negative, implying that smaller crabs are found in colder and deeper water.

Regional variation in the mean size of mature male tanner crab cannot be examined in the same manner as above, because unlike females the size of maturity for males cannot be calculated at each sampling site. To estimate the size of 50% maturity a sample containing both adults and juveniles is necessary. Tanner crab tend to be segregated by size, consequently a typical sample from the eastern Bering Sea contain adults or juveniles but rarely both (per. ob.). Henceforth, it is assumed that the size of 50% maturity for males varies spatially in a manner similar to the mean size of mature females. This assumption is probably valid, because male and female tanner crab have an identical rate of growth while they are both juveniles (Sinoda, 1968).

Partitioning the Eastern Bering Sea into Subareas
Which Minimize the Regional Variation in Mean Size of Mature Females

The regional variation in the size of sexual maturity that both species
of tanner crab display in the eastern Bering Sea complicates the problem of
establishing minimum size limits because a mean size of maturity for the
entire area would be too large for some regions and too small for others.
Thus, an attempt was made to partition the eastern Bering Sea into subareas
which are relatively homogenous with respect to the mean size of mature females.

As a first step toward this partitioning, frequency histograms of the
mean size of mature females at each site on the 1979 survey were made (Figure 2).
Notice that the frequency histogram for each species is roughly bimodal with
the separation point between the modal groups occurring at 85 mm for C. bairdi
and 59 mm for C. opilio. This bimodality suggests that partitioning would
be effective in reducing the total variability in the mean size of mature
females if each modal group were distributed in a distinct region of the
eastern Bering Sea.

The two modal groups are indeed spatially segregated. This is shown
in Figure 3, where sampling sites associated with the smaller modal group
(mean size ≤ 85 mm, C. bairdi; ≤ 59 mm, C. opilio) are indicated by squares,
and sites associated with the larger group are indicated by pluses. Large
mature C. bairdi females are located primarily east of 167°W longitude; large
mature C. opilio females are located in two areas, one east of 167°W longi-
tude and the other south of 60°N latitude and west of 172°W longitude.

A simple partitioning of the eastern Bering Sea into two subareas along
a longitude line appeared to be an effective way of explaining much of the
variability in mean size of mature females. To find the longitude of best
partitioning, a line accounting for most of the variability in mean size, a

computer technique was developed which searched for the longitude which minimized the sum of squares about each of two subarea means pooled over both sub-areas. The algorithm started by dividing the survey region into two groups at 163°W longitude. The mean and sum of squares for each subroup, and the pooled sum of squares were calculated. The longitude was then increased by 15', and the process repeated iteratively until 179°W longitude was reached. In Figure 4, is shown the pooled sum of squares divided by the total sum of squares about a single mean plotted against longitude for the years 1975 to 1979. The longitude which results in the best partitioning of the eastern Bering Sea into two subareas is the one corresponding to the minimum pooled residual sum of squares. Results of this analysis are summarized in Table 1 where the longitude of best partitioning, the mean size of mature females in each subarea, and the percent of the total sum of squares unexplained by partitioning are shown.

For C. bairdi, a pronounced minimum in the pooled sum of squares occurs at 167°15'W longitude in all five years. This indicates that the abrupt spatial segregation between large and small modal groups seen in Figure 3 is, in fact, a persistent feature of their distributions. The mean size of mature females was quite constant in the eastern subarea (east of 167°15'W longitude) but decreased steadily in the western subarea from 1976 onwards as the survey expanded north and west into regions of smaller crabs. The decrease in mean size in the western subarea resulted in a progressively greater difference in mean size between subareas. As a consequence, the partitioning of the survey area accounted for an increasingly greater amount of the total variability in mean size of mature females (Table 1). In the 1979 survey, which covered the entire distribution of C. bairdi in the eastern Bering Sea, more than 50% of the total variability was removed by this partitioning.

For C̲. o̲p̲i̲l̲i̲o̲, partitioning the survey area into two subareas along a
longitude line appears to be less useful for delineating management areas
than it is for C̲. b̲a̲i̲r̲d̲i̲. First, the partitioning was not as effective in
explaining the variation in mean size of mature females. The reduction in
unexplained sum of squares was comparable to C̲. b̲a̲i̲r̲d̲i̲ in only three of five
survey years and there was no tendency for the unexplained sum of squares
to be reduced as the survey area expanded. Second, the longitude of best
partitioning was not constant as it was for C̲. b̲a̲i̲r̲d̲i̲, but showed considerable
variability between survey years. Third, the longitude of best partitioning
did not separate subareas that are useful for management purposes. Figure 3
shows that the five year average longitude of best partitioning, 167°00'W
longitude, does separate an eastern region of larger females from the remainder
of the survey area. However, Figure 5 shows that the abundance of mature
female C̲. o̲p̲i̲l̲i̲o̲ in the eastern subarea is quite low relative to the western
subarea. Thus, the best longitudinal partitioning of C̲. o̲p̲i̲l̲i̲o̲ merely
separates a small area containing large but relatively few mature females from
the major portion of the population.

A partitioning by latitude was also attempted for C̲. o̲p̲i̲l̲i̲o̲ but it was
equally ineffective for defining management subareas. For the two survey
years examined, 1978 and 1979, the average latitude of best partitioning
occurred at 59°30'N latitude. This partitioning, however, only reduced the
unexplained sum of squares to an average of 73% of the total.

Comparing the Size of 50% Maturity to the Mean
Size of Mature Female Tanner Crab

The size of 50% maturity is a less useful measure of the size of maturity
of female tanner crab than is the mean size of mature females for two reasons.

First, the size of 50% maturity is affected by variations in year class
strength whereas the mean size of maturity is, except for possible density
dependent effects on growth, independent of such variations. The difference
in the amount of variability associated with the two measures is clearly
seen by comparing the mean sizes of mature female C. bairdi in the eastern
subarea (Table 1) with estimates of the sizes of 50% maturity for the same
area (Table 2). The size of 50% maturity is a function of the relative
abundance of equal-sized mature and immature individuals. Since female
tanner crab cease growth at sexual maturity and may live several years there-
after (Watson, 1970), the maturing size range may contain immature females
from a single year class but mature females from several year classes. If a
particularly large year class enters the maturing size range, the immature
females will increase in abundance relatively more than mature females because
the number of mature females is buffered by the number that have matured
in previous years. As a consequence, the percent mature in any size
interval within the maturing size range will decrease and the size of 50%
maturity will increase.

The second reason why the size of 50% maturity is not a good measure
of the size of maturity of female tanner crab is that it varies with mortality
rate. This occurs because an increase in mortality rate decreases the number
of mature females relative to the number immature and, in turn, results in
an increase in the size of 50% maturity. This effect can be seen by comparing
Tables 1 and 2. The difference between the size of 50% maturity and the mean
size of mature female C. bairdi is less in the western subarea than in the
eastern subarea (1978-79 average difference: western subarea, 10.6 mm;
eastern subarea, 19.2 mm). To demonstrate that this difference is due to a
greater mortality rate in the western subarea, frequency histograms of adult

female shell condition in each subarea are shown in Figure 6. The shell
condition in the eastern subarea is greater than in the western subarea
for both the 1978 and 1979 survey years. If it is assumed that the factors
which lead to an increase of shell condition with time, that is, which
result in exoskeleton wear and the accumulation of epifauna, are the same
in the two areas, then the consistent difference in shell condition could
only be due to a greater mortality rate in the western subarea. Thus estimates
of 50% maturity reflect both variation in year class strength and differences
in adult mortality rate, and as a consequence, are less preferable than the
mean size of adult female tanner crabs.

Size of 50% Sexual Maturity for Male Tanner Crab

Sizes of 50% maturity for male tanner crab were estimated using a
computer technique described in Somerton (ms.) which first classified chaela
height and carapace width measurements into adult and juvenile categories,
then fit a logistic function to the percent mature by size. Since the
regional variation in the size of maturity was assumed to be the same for
both sexes, the male C. bairdi morphometric measurements were separated by
subarea before analysis. The classification of the data into adult and
juvenile groups and the logistic functions which were fit to percent maturity
estimates are shown in Figure 7. Male C. Bairdi reach 50% maturity at 110 mm
in the western subarea and at 118 mm in the eastern subarea. Male C. opilio
reach maturity at 67 mm.

Discussion

Regional Variation in Size of Maturity

A division of the eastern Bering Sea into two subareas along 167°15'W

longitude accounts for much of the regional variability in the mean size
of mature female C. bairdi and is therefore effective for defining stock
subunits for management purposes. A similar type of subdivision for C. opilio
is not justified using the same criteria. The reasons for this difference
between species are related to the temperature preferences of each species
and the distribution of temperature in the eastern Bering Sea.

C. opilio is a cold water species with a distribution that extends from
55°N latitude in the eastern Bering Sea northward to the Arctic Ocean and
along the east coast of Canada to Nova Scotia (Watson, 1969). By comparison,
C. bairdi is a warmer water species with a distribution that extends from
Oregon (Hosie, 1974) northward to 60°N latitude. Within the eastern Bering
Sea, C. opilio is most abundant in the cold central region of the continental
shelf which is characterized by small termal gradients and weak seasonal
temperature fluctuations (Kinder and Schumacher, in press). C. bairdi is
most abundant in the relatively warm area north of the Alaska peninsula
(eastern subarea), which is characterized by strong thermal gradients and
large seasonal temperature fluctuations as well as along the outer margin
of the continental shelf (western subarea), which is characterized by rela-
tively warm water with weak spatial and temporal variation.

An explanation for the abrupt change in the mean size of mature female
C. bairdi at 167°15'W longitude is not obvious. Although the variation in
the size of mature females was clearly related to the distribution of bottom
temperature in late summer, no large temperature gradients are located near
this longitude (Figure 8). Furthermore, there is no discontinuity in
abundance or species composition of either benthic infauna or epifauna in
this area (S. Jewett and C. Hafflinger, per. comm.). One possibility is
that the difference in the size of sexual maturity is genetically determined

and that the inhabitants of the two subareas defined earlier represent distinct subpopulations. However, further study is needed to test this hypothesis.

The two areas of the eastern Bering Sea in which mature female C. opilio are exceptionally large but low in abundance have two characteristics in common. First, compared to the remaining area of C. opilio distribution in the eastern Bering Sea, these two areas are relatively warm, especially the southern area in late summer. Second, these areas are the major areas of sympatry between C. opilio and C. bairdi. The larger sizes of C. opilio are quite likely due to higher temperatures in these areas and the low abundances suggest that competition with C. bairdi may be significant.

Size of 50% maturity for male C. bairdi

The current minimum size limit for C. bairdi in the eastern Bering Sea is based on a 110 mm size of 50% maturity estimated from data collected near Kodiak Island (Brown and Powell, 1972). The apparent difference between this value and the values estimated for each of the two Bering Sea subareas will now be examined.

The Bering Sea estimates of the size of 50% maturity are based on measurements of the maximum carapace width whereas the estimate of Brown and Powell (1972) is based on measurements of the carapace width excluding lateral spines. Data collected and analyzed by R. Otto (per. comm.) allows conversion from one type of measurement to the other. The carapace widths of 154 male C. bairdi, spanning a size range from 71 mm to 177 mm, were measured both inside and outside of the lateral spines. A regression of inside dimension (ID) against outside dimension (OD) produced the equation: ID = .9902·OD - .0882. This equation predicts that the 118.2 mm size of 50% maturity in the eastern subarea is equivalent to 117.0 mm measured inside the lateral spines, and 110.1 mm size in the western subarea is equivalent to 108.9 mm.

To statistically compare the Bering Sea sizes of 50% maturity with the size reported in Brown and Powell (1972), the variance of the two Bering Sea estimates must be determined. Estimating these variances is complicated by each estimate having two components of variability and only one of these is directly estimable. One component of variability is due to the probability of wrongly classifying chaela and carapace measurements into juvenile and adult categories (misclassification error). The other component is due to variability of percent maturity values about the fitted logistic equation (fitting error). Estimates of fitting error were obtained by using standard techniques of nonlinear regression to estimate the variance and covariance of the parameters of the logistic equation and by using the Delta method to obtain an approximate relationship between fitting error and these variance and covariance estimates (Somerton, ms.). If the two components of variability are assumed to be additive, misclassification error can be estimated by subtracting fitting error from an estimate of the total variability of the size of 50% maturity. Obtaining a reasonable estimate of total variability is then the crux of the statistical comparison.

The method used for estimating total variability of the size of 50% maturity for male C. bairdi consisted of determining the variance among independent estimates of the size of 50% maturity which were obtained by analyzing replicate randomly chosen subsamples of morphometric data. Preliminary experiments showed that both misclassification error and fitting error increased as sample size decreased. As a consequence, estimates of total variability could not be made by subsampling the C. bairdi data sets because the resulting subsamples would obviously be smaller than the data sets they were chosen from. The total amount of C. opilio morphometric data, however, was large enough to allow subsamples to be chosen that were approximately

the same size as the C. bairdi samples for each subarea. Therefore, it was assumed that misclassification error is equal between species, provided that sample size is equal. The C. opilio morphometric values were randomly distributed among N subsets, where N was chosen such that the average sample size was as close as possible to the size of a C. bairdi data set. An estimate of the size of 50% maturity and the fitting error associated with this estimate were calculated for each subsample. The variance about the N independent estimates of the size of 50% maturity and the average of the N estimates of fitting error were both calculated. This sequence of operations was repeated three times, and the three estimates of total variability and fitting error were averaged.

A summary of the calculations leading to a 95% confidence interval about the estimates of the size of 50% maturity for male C. bairdi in each subarea are shown in Table 3. An example of the calculations for the eastern subarea follows.

There were 243 morphometric values for C. bairdi in the eastern subarea, consequently the 1064 C. opilio values were separated into 4 subsets averaging 266 values each. The average of the three estimates of total variability of the estimated sizes of 50% maturity was 7.12 and the average of the estimates of fitting error was 2.56. Misclassification error was then equal to 7.12 - 2.56 = 4.56. The estimated fitting error for the C. bairdi data was .90. Estimated total variability was equal to .90 + 4.56 = 5.46. The 95% confidence interval (expressed as width excluding lateral spines) is equal to 117.0 ± 1.96$\sqrt{5.46}$.

The 110 mm size of 50% maturity reported in Brown and Powell (1972) clearly falls outside of the 95% confidence interval for the eastern subarea in the Bering Sea but is included within the confidence interval for the

western subarea. Although the test is admittedly crude, it can be concluded that the size of 50% maturity for male $\underline{C}$. $\underline{bairdi}$ in the eastern subarea is larger than the 110 mm value upon which the current minimum size limit is based. A difference between the size of 50% maturity in the western subarea and the 110 mm value lacks statistical significance.

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Species	Year	Mean Size of Mature Females		% of Total SS Unexplained By Partioning at λ_{min}	Longitude of Best Partitioning (λ_{min})
		E. of λ_{min}	W. of λ_{min}		
C. bairdi	1975	92.0	80.1	63.6	167°15'
	1976	93.1	82.0	65.9	167°15'
	1977	93.6	81.0	59.0	167°15'
	1978	93.5	79.8	51.7	167°15'
	1979	93.6	78.0	49.1	167°15'
C. opilio	1975	66.5	58.1	74.0	167°00'
	1976	71.7	58.3	54.6	168°15'
	1977	67.5	57.0	51.7	165°30'
	1978	68.6	56.5	59.9	167°00'
	1979	63.3	54.5	82.3	168°30'

Table 1

Shown are the longitude of best partitioning, or the longitude resulting in the minimum pooled residual sum of squares (λ_{min}), the percent of the total between station sum of squares unexplained by partitioning (pooled residual sum of squares x 100/total sum of squares), and the mean size (carapace width in mm) for mature females in the survey area east and west of λ_{min}.

Size of 50% Sexual Maturity

	C. bairdi		C. opilio
Year	E. of 167°15'	W. of 167°15'	Entire Survey Area
1975	83.0		
1976	71.8		
1977	76.6		
1978	72.9	69.4	44.0
1979	75.8	67.3	47.1

Table 2

Shown are sizes of 50% sexual maturity for females of each species of tanner crab summarized by area and year. Values for C. opilio and C. bairdi west of 167°15' before 1978 are not included because the surveys in earlier years did not have sufficient coverage of the eastern Bering Sea.

C. opilio

Number of samples	4	7
Average sample size	266	152
$\overline{\hat{S}^2_T}$	7.12	8.84
$\overline{\hat{S}^2_F}$	2.56	3.83
$\hat{S}^2_M$	4.56	5.01

C. bairdi

Subarea	Eastern	Western
Sample size	243	141
$\hat{S}^2_F$	.90	1.73
$\hat{S}^2_T$	5.46	6.74
Size of 50% maturity including spines	118.2	110.1
Size of 50% maturity excluding spines	117.0	108.9
95% Confidence interval	$117.0 \pm 1.96\sqrt{5.46}$	$108.9 \pm 1.96\sqrt{6.74}$
	112.4 - 121.6	103.8 - 114.0

Table 3

Shown are the sequence of calculations used in constructing 95% confidence intervals about estimates of the size of 50% maturity for male C. bairdi in the eastern and western subareas of the eastern Bering Sea. The three types of error are: total variability (S^2_T), fitting error (S^2_F), misclassification error (S^2_M).
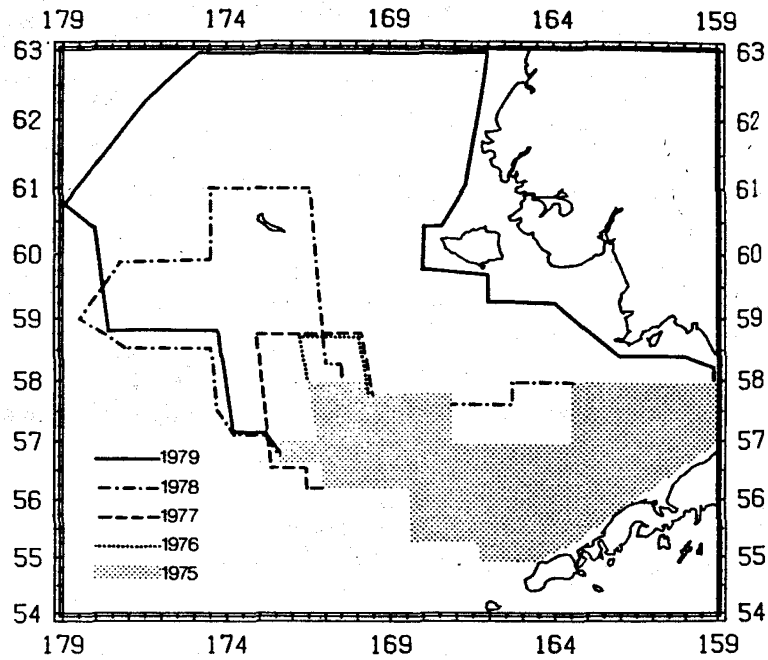
Figure 1

Shown are the areas sampled on the annual Bering Sea crab
survey from 1975 to 1979. The shaded area was sampled in every
year. In addition, the 1976 and succeeding surveys included
the areas indicated by the appropriate perimeter lines.

C. bairdi

C. opilio
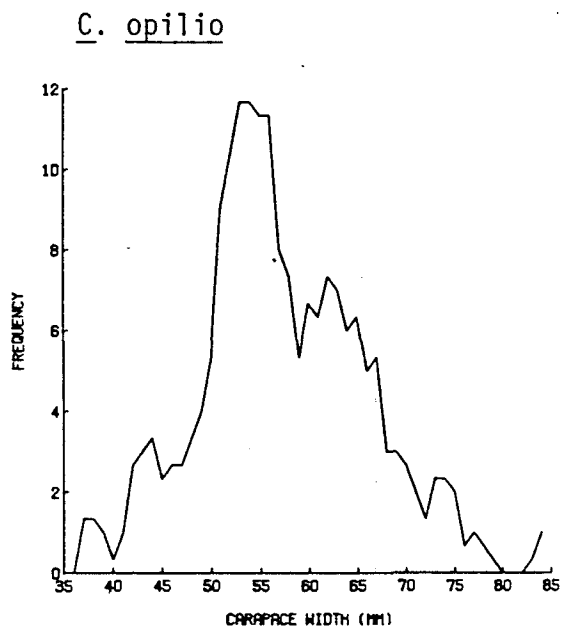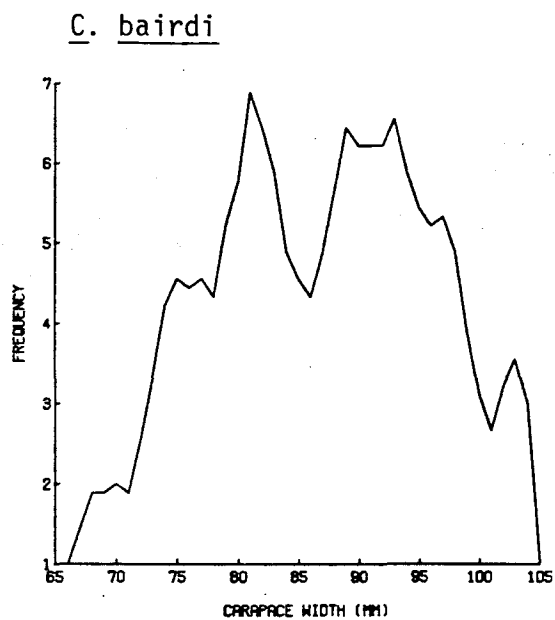
Figure 2

For each species is shown a histogram of the mean size of adult females at every sampling site on the 1979 survey. To enhance the visibility of modes, the frequencies were smoothed using a moving average of three values.
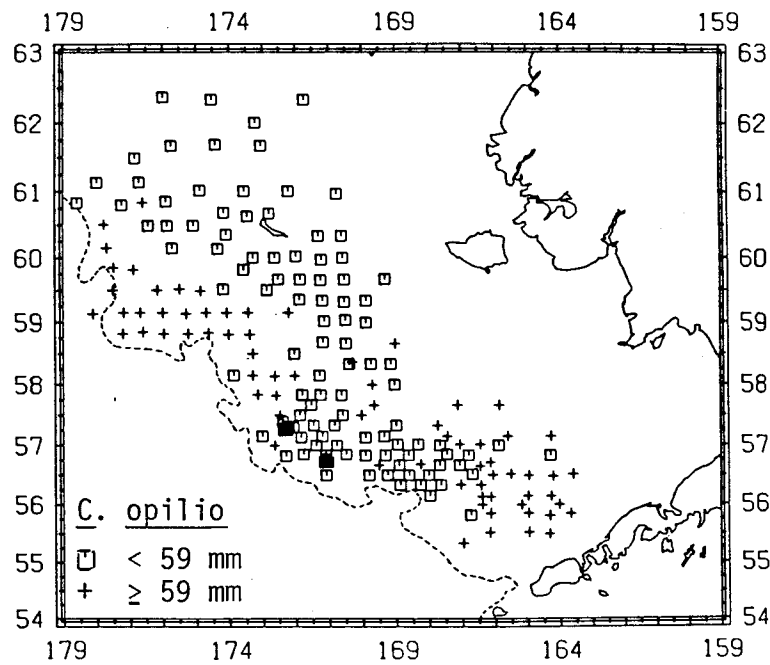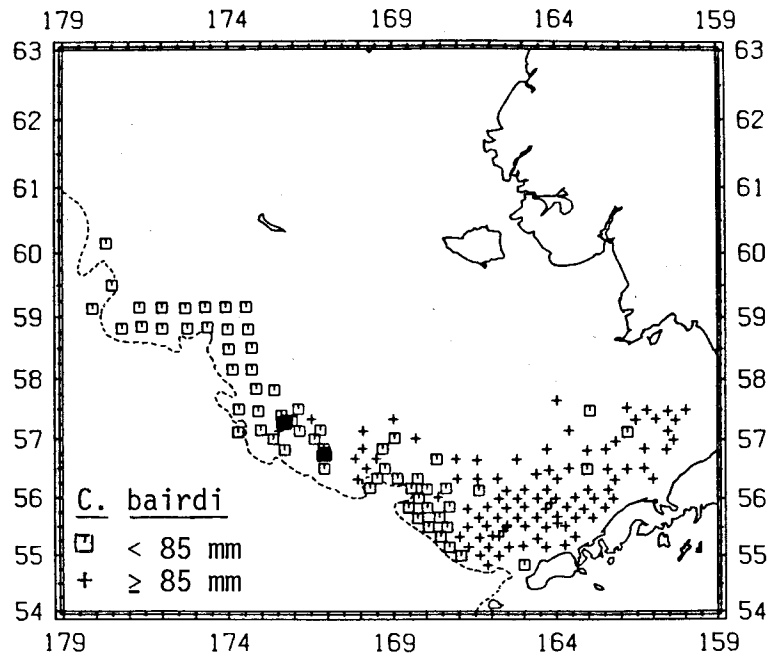
Figure 3

The distribution of each of two modal size groups of mature female tanner crabs is shown. Stations where the mean sizes of adult females were greater or less than the size chosen to separate modes are indicated by the appropriate symbols. Stations lacking adult females are not shown.
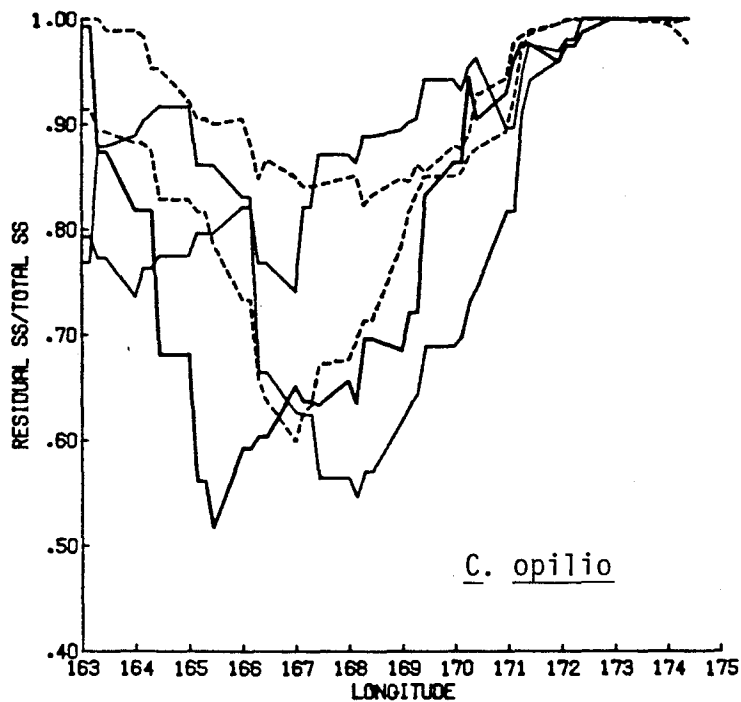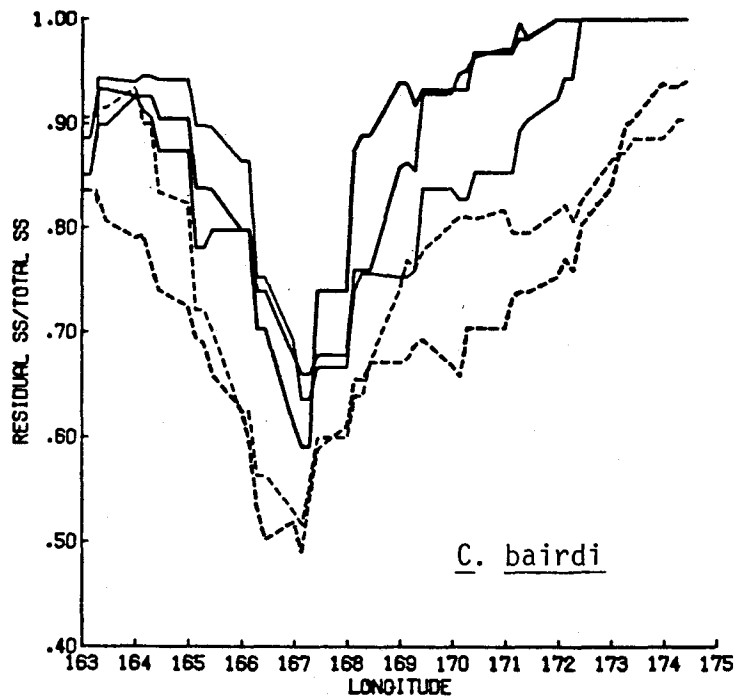
Figure 4

Proportion of the total variability between station mean sizes of
mature females unexplained by partitioning (Residual SS/Total SS) is
shown plotted against longitude for the years 1975 to 1979. The
longitude of best partitioning is indicated by the minimum value of
each plot.
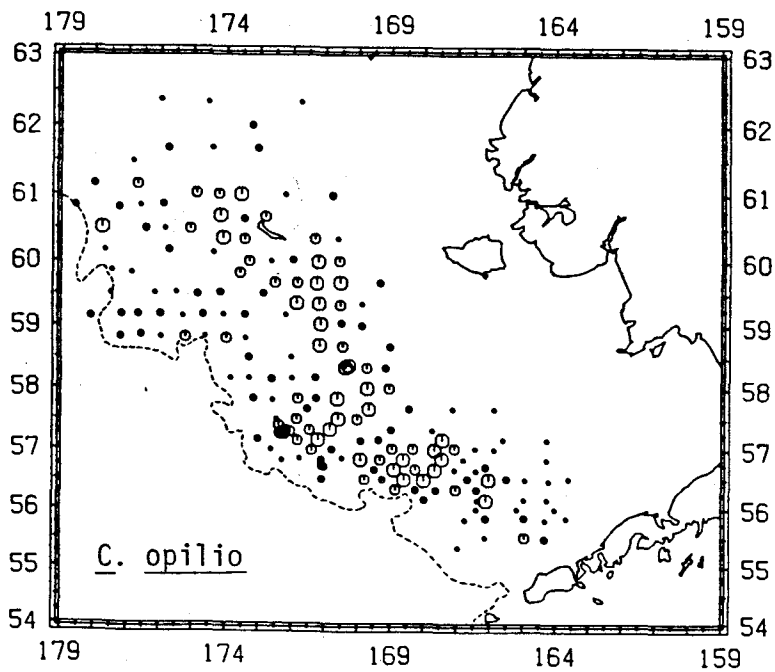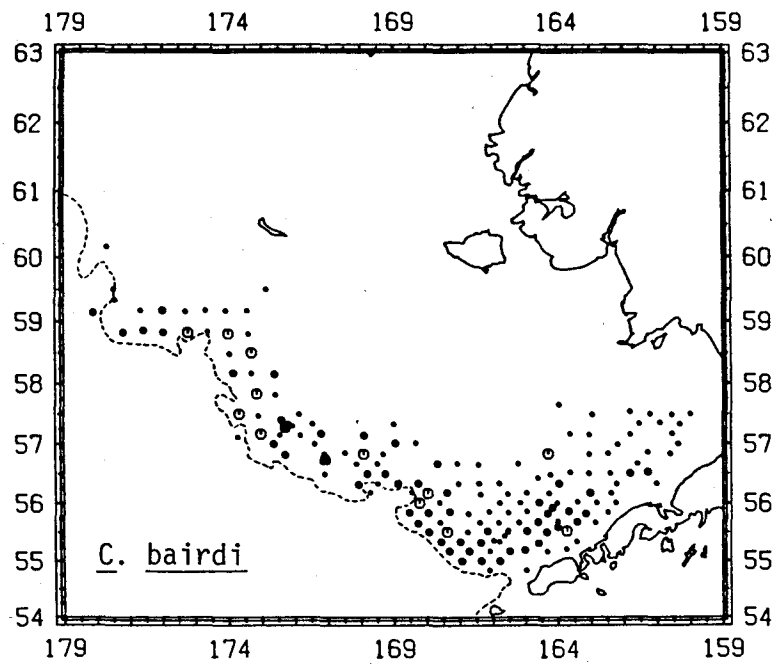
Figure 5

Number of adult female tanner crab caught at each sampling site is indicated by a variable sized hexagon. Stations lacking adult females are not shown.

WESTERN   EASTERN

1978

1979
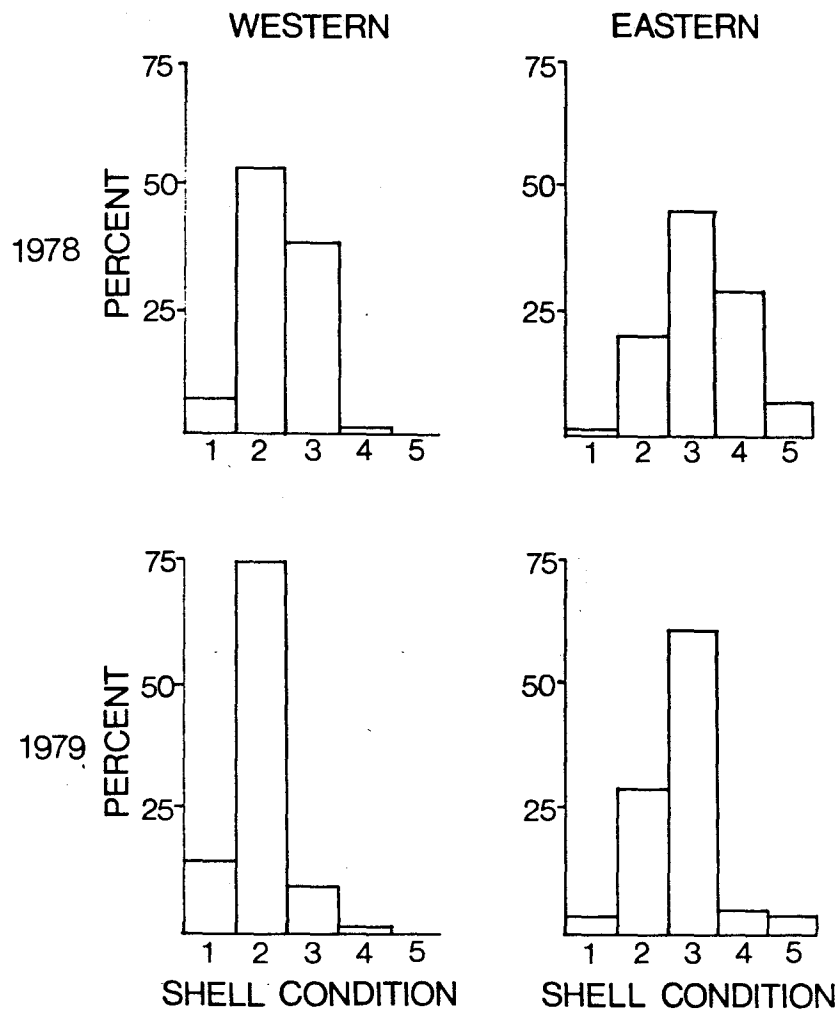
Figure 6

Shown are histograms of the percent of mature female <u>C</u>. <u>bairdi</u> in each of five shell condition categories arranged according to survey year and subarea.
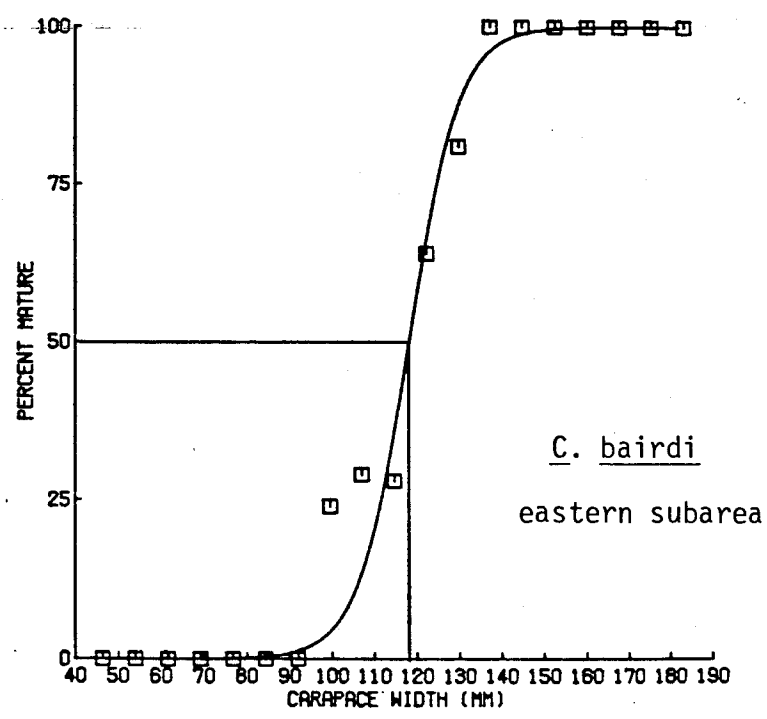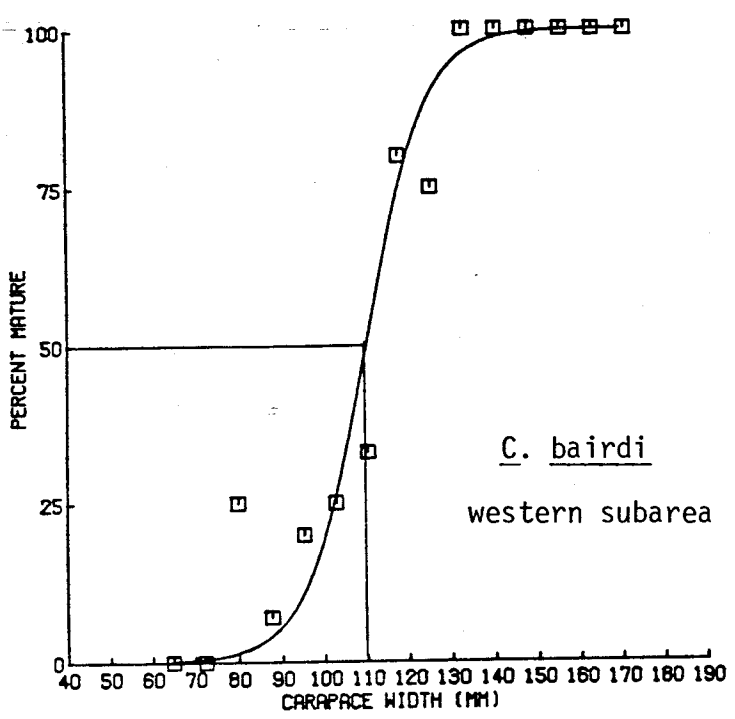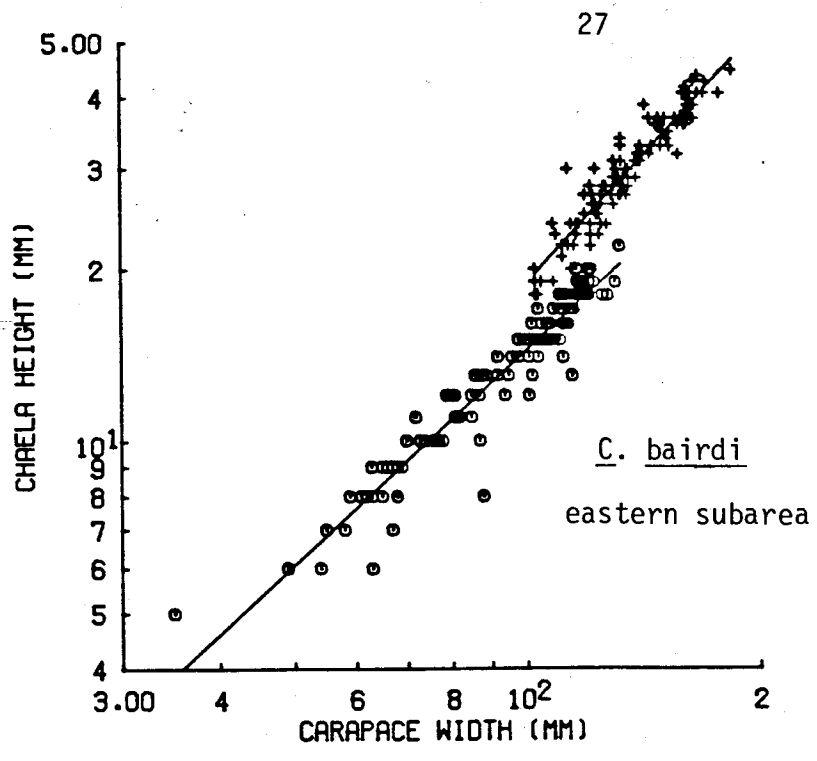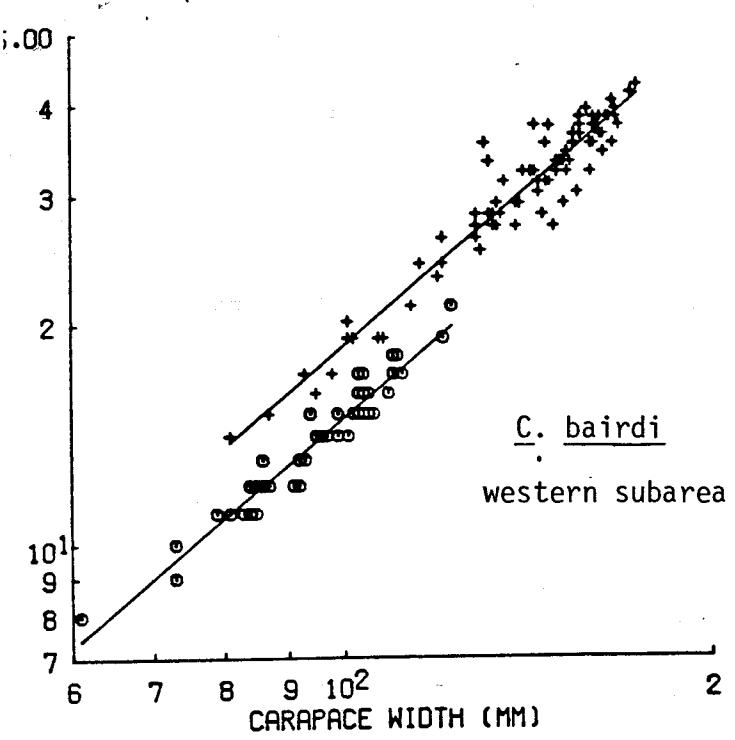
Figure 7

This figure shows the various steps in the estimation of the size
of 50% maturity for male C. opilio and for male C. bairdi in each of the
two subareas. The upper figures show the classification of chaela
and carapace width measurements into adult (indicated by pluses) and
juvenile (indicated by circles) categories. The lower figures show
the fit of a logistic function to estimated percent maturity values.
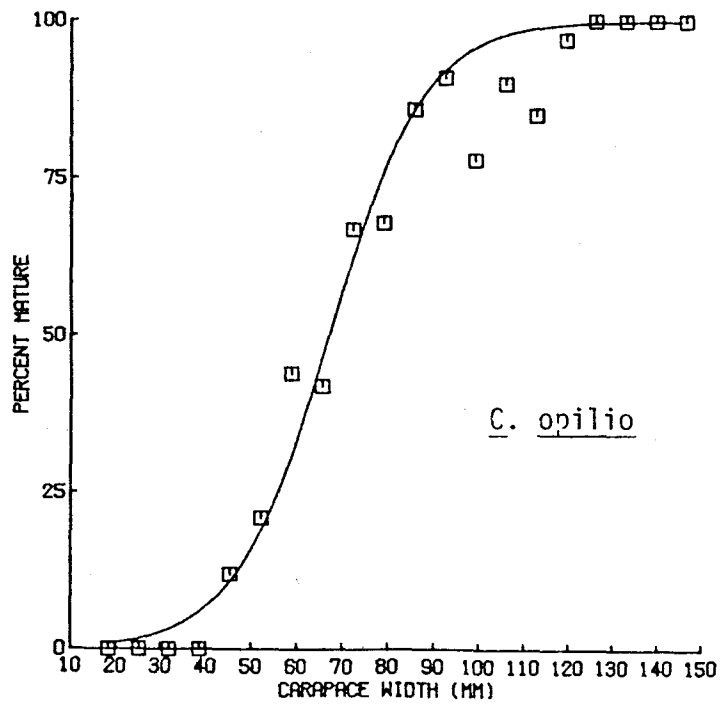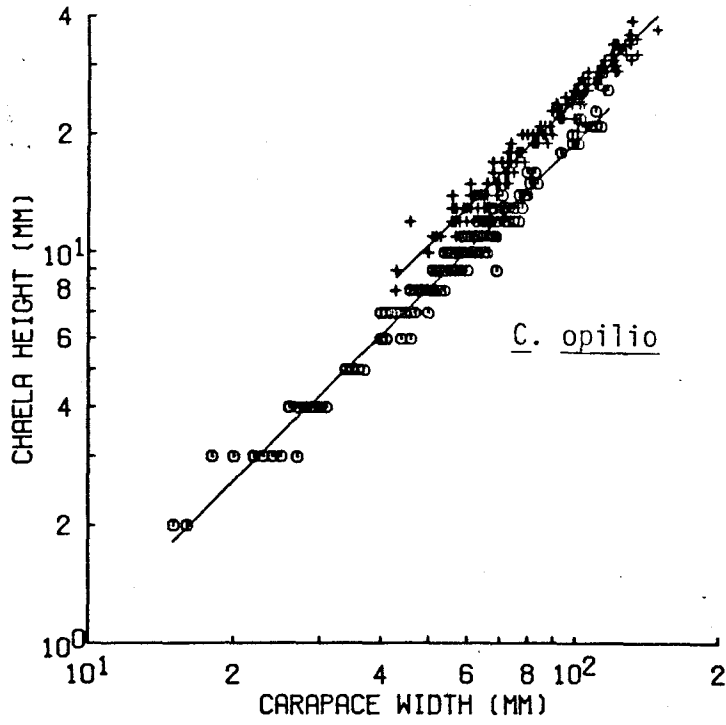The estimated sizes of 50% maturity are indicated by straight lines.
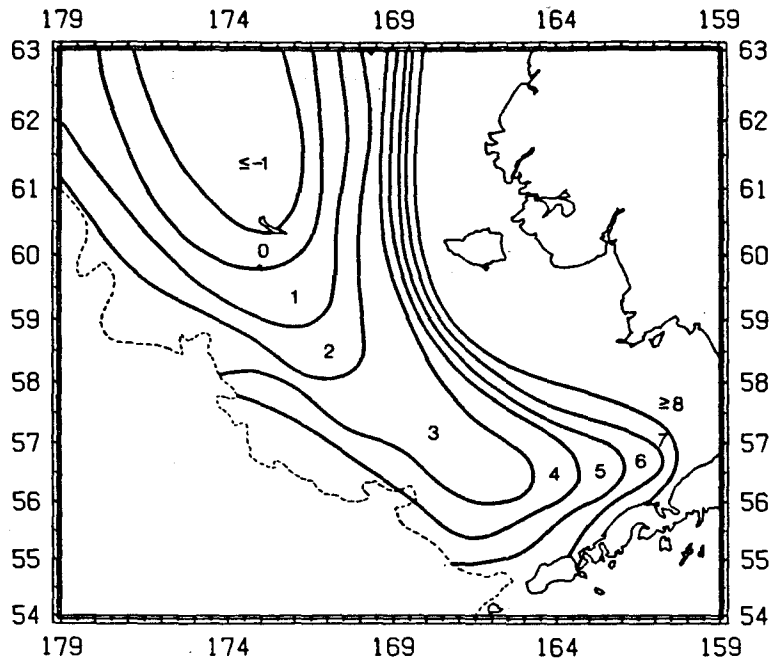
Figure 7. (continued)

Figure 8

This figure shows contours of bottom temperature in °C for the month of August. The 200 m isobath is indicated by the dashed line.