INFORMATIONAL LEAFLET NO. 265

KING CRAB STOCK ASSESSMENT STUDIES IN LOWER COOK INLET, ALASKA, IN 1984 AND 1985 AND CALCULATION OF VARIANCE IN THE HISTORICAL SURVEY MEAN CATCH PER POT

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March 1988

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March 1988

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ABSTRACT

Population surveys were conducted on red king crab *(Paralithodes camtschatica)* in Lower Cook Inlet, Alaska during 1984 and 1985. Estimated variance in the historical survey mean catch per pot of prerecruit-1, recruit, postrecruit, legal male and mature female king were calculated to estimate the precision of these relative population abundance estimators. Formulae for stratified systematic sampling were used in the calculation of mean catch per pot and its variance.

Low survey catches in 1984 and 1985 were used to justify continued closure of the king crab commercial fishery in Lower Cook Inlet. Bounds on the error estimation for prerecruit-1's are large and contribute to the survey's inability to forecast recruits in both districts. Minimization of variance through stratification produced estimates of mean catch per pot equal to or less than estimates obtained without stratification, indicating significant overestimation of legal male relative abundance in some years.

Recommended survey design modifications to decrease variance in the mean include decreased sampling frequency of stations with consistent zero or rare captures within strata and sampling more stations adjacent to those with high catches. We present a formula for calculating the optimum number of pots set per station, given the cost of sampling stations relative to sampling pots and within station variance relative to among station variance.

KEY WORDS: King crab, *Paralithodes camtschatica*, abundance surveys, Cook Inlet, variance, stratification

INTRODUCTION

Statistical Area H includes Cook Inlet, Alaska south to 58° 52' N latitude and east to Cape Fairfield at 148° 50' W longitude. The major commercial fisheries for king crabs in this area occur in the Southern, Kamishak and Barren Islands Districts (Figure 1). Annual surveys for red king crab (*Paralithodes camtschatica*) have been conducted in the Southern and Kamishak Districts of Cook Inlet since 1974 and 1975, respectively (Hennick 1974, Davis 1975, 1976, 1977a, 1979, 1980, 1981, 1983, Merritt 1985). The purposes of these surveys were to collect information important to the annual management of these king crab fisheries. Specifically our objectives were to estimate: (1) an index of relative abundance of females and prerecruit, recruit and postrecruit males; (2) absolute population abundance of legal crabs; (3) fishing mortality rates; and (4) average fecundity. Fishery closures in 1984 and 1985 prevented the recovery of tags required for the Petersen mark-recapture technique (Ricker 1975). Consequently, we could not estimate absolute legal male abundance for these years.

A secondary purpose of this report was to estimate variance in the historical king crab survey mean catch per pot of male prerecruit-1, recruit, postrecruit, legal and mature female size categories, in order to determine the precision of these relative abundance estimates in Lower Cook Inlet. The smaller the variance, the greater the reliability of the relative abundance index. Generating reliable abundance estimates are crucial for management of fisheries which are based on a maximum sustainable yield strategy, as are the king crab fisheries in Lower Cook Inlet (NPFMC, 1977). We present minimum variance estimates as dictated by survey design, and suggest modifications in the survey to increase precision in estimates of mean catch per pot.

METHODS

Survey Design and Sampling Procedures

Surveys in the Southern District were conducted during 9-26 July 1984 and 8-18 July 1985. Sixty stations were selected from a 1.9-km^2 (1-nm^2) grid pattern which was overlaid onto a chart of Kachemak Bay. The sides of the grid were approximately parallel to lines of equal latitude and longitude, with waters less than 18.3 m (10 fa) in depth excluded from consideration. One 1.9-km^2 station was randomly chosen as a starting point, and subsequent stations were selected in a systematic manner to form a checkerboard-like pattern. Within each station four crab pots were placed in a line 0.2 km apart. Direction of the line was generally determined by the following three factors: 1) bottom topography (pot depth within a station was desired to be as similiar as contours allowed); 2) tidal flow; and 3) the most efficient vessel course required to survey all stations in as short a time as possible. This station and pot placement pattern has been used since 1974 with only minor annual adjustments associated with changes in crab distributions.

Surveys in Kamishak District were conducted from 22 June to 2 July 1984 and 17-27 June 1985. The survey design differed from that of the Southern District in that 40 stations were selected adjacent to one another from a 9.3-km^2 (5-nm^2) grid. Within each station five pots were placed in a line ("string") 0.6 km apart. Direction of the line was determined by bottom topography, tidal flow, and the most efficient vessel course. This survey design has been used since 1977, although eight to 16 pots per station were fished prior to 1980.

Crabs were surveyed using the state's *R/V PANDALUS* with king crab pots similiar to those used in the commercial fishery. Pots measured 2.1 x 2.1 x 0.8 m (7 x 7 x 2.5 ft) and were covered with 8.9 cm (3.5 in) stretched nylon mesh. Each pot had two entry tunnels with 88.9 x 17.8 cm (38 x 7 in) openings. Chopped frozen herring were placed in two 1.9-liter (2-qt) perforated plastic containers and hung inside each pot. Pots were placed on the ocean bottom, marked with floats, and retrieved after approximately 24 hrs.

Crab were sorted by sex and shell age. All males were sampled; systematic subsampling of females occurred when the catch exceeded about 40 females per pot. Crab shell age (new, old, very old) was noted, carapace length measurements were taken to the nearest millimeter using Vernier calipers, and percent egg clutch size was noted in mature females. Individual data forms for each sex were used for recording the catches from each pot. Data were edited and keypunched for data storage and analysis on the University of Alaska Computer Network.

<u>Calculation of Mean Catch per Pot and its Variance</u>

B. Alan Johnson (Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak, personal communication, 1986) suggested the methods for calculating mean catch per pot and variances of the means by district. The methods were programmed as a Lotus 1-2-3 spreadsheet program for use on IBM-compatible microcomputers. Formula for stratified systematic sampling were used, where the strata were selected separately for each year using a post-stratification scheme which minimized the coefficient of variation, or CV, (Steel and Torrie, 1960. p. 20) in mean catch for the district. The CV gives a relative measure of variation in mean catch per pot, and is more useful than the variance for evaluating interannual differences. The calculation of stratum means and variances was treated as a two-stage sampling problem; stations were the primary units and pots were the subunits. This procedure was used to calculate means and variances for each of five crab categories (legal, recruit, postrecruit, prerecruit-1, and mature female). Legal crabs were males greater than 177 mm in carapace width (7 in), or 145 mm in carapace length. Recruits were defined as exuviant males (new shell crabs which molted in the current year) between 145 - 163 mm carapace length. Postrecruits were legals minus recruits. Prerecruits were distinguished as 4's, 3's, 2's, and 1's, which denote the number of molts required to reach legal size, assuming a molt increment of 18 mm. The corresponding size categories were < 90, 91-108, 109-126 and 127-144 mm, respectively. Mature females were at least 90 mm in carapace length and had extruded eggs. Barren females had indications of sloughed eggs on the pleopods, and/or are very old shelled. Females less than 90 mm in carapace length with no eggs were defined as juvenile.

We did not calculate catch per pot statistics for prerecruits 2 through 4 because it is possible that such statistics may not be meaningful for these young crabs, due to inadequate capture and/or retention in the survey gear. Secondly, abundances of these young crabs are not used to formulate management decisions, because they will not be recruited to the fishery for two or more years. Also, we did not stratify the survey catches for 1977 in the Southern District because the data were not available in electronic form.

To obtain station and stratum statistics the methods of Johnson (Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak, personal communication, 1986) and Cochran (1977) were followed. We defined y_{jih} as the number of crab caught in pot j at station i of stratum h, m_{ih} is the number of pots at station i of stratum h, and n_h is the number of stations in stratum h. We calculated the mean catch per pot within station i in stratum h, $\bar{y}_{ih}$ and the overall mean catch per pot within stratum h, $\bar{\bar{y}}_h$ as:

$$\bar{y}_{ih} = m_{ih}^{-1} \sum_{j=1}^{m_{ih}} y_{jih} \qquad (1)$$

and

$$\bar{\bar{y}}_h = n_h^{-1} \sum_{i=1}^{n} \bar{y}_{ih} \qquad (2)$$

An unbiased estimator of the variance in Y_h is the sum of two variance components (Cochran 1977, p. 277):

$$\text{var}(\bar{\bar{y}}_h) = s_{1h}^2 n_h^{-1} + s_{2h}^2 n_h^{-1} \qquad (3)$$

The first term on the right hand side of equation 3 is the variance among station means and is estimated using mean squared error:

$$s_{1h}^2 = \sum_{i=1}^{n_h} \frac{(\bar{y}_{ih} - \bar{\bar{y}}_h)^2}{n_h - 1} \qquad (4)$$

The second term corresponds to the variance among pots within stations averaged over all stations and is estimated using:

$$s_{2h}^2 = \sum_{i=1}^{n_h} \text{var}(\bar{y}_{ih}) n_h^{-1} \qquad (5)$$

where

$$\text{var}(\bar{y}_{ih}) = m_{i-1,h}^{-1} \left[\sum_{j=2}^{m_{ih}} \frac{(y_{jih} - y_{j-1,i,h})^2}{2(m_{ih} - 1)} \right] \qquad (6)$$

Johnson suggested Eq. (6) to estimate within-station variance, $var(\bar{Y}_{ih})$, based on Wolter's (1984) finding that it partially protects against bias that can be caused by population patterns, such as autocorrelation and linear trends in the data.

Finally, formulae for stratified systematic sampling (Cochran 1977, were used to estimate the mean catch per pot within the district, $\bar{Y}_{stsy}$, and its variance, $var(\bar{Y}_{stsy})$:

$$\bar{Y}_{stsy} = \sum_{h=1}^{4} W_h \bar{\bar{y}}_h \qquad (7)$$

and

$$var(\bar{y}_{stsy}) = \sum_{h=1}^{4} W_h^2 var(\bar{\bar{y}}_h) \qquad (8)$$

where $W_h = n_h/N_h$, the stratum weight (total number of stations (n_h) within stratum h divided by the total number of stations (N) surveyed in the district).

Using post-stratification, stations were chosen to construct three or four strata that minimized the coefficient of variation in the district. Stations with zero catches comprised the first stratum. The optimum boundaries for the other strata were identified by minimizing the CV ($\bar{Y}_{stsy}$) through changes in the boundaries. Stations that were included in a strata were not necessarily adjacent.

Calculation of the Optimum Number of Pots per Station

Sukahtme et al. (1984, p. 314) describe methods to calculate the optimum number of pots per station (m_{opt}) and the optimum number of stations per stratum (n_{opt}), given the cost of locating a station (c_1) relative to the cost of locating a pot (c_2) and fixed precision levels. In Lower Cook Inlet crab surveys, it is likely for $c_1 > c_2$. That is, the costs (in terms of vessel time) are greater for adding a new station than for adding another pot within a station. Given this assumption, the formula for calculating m_{opt} is:

$$m_{opt} = [(c_1/c_2) \; (S_2^2 \; / \; S_1^2)]^{1/2} \qquad (9)$$

For example, if we assume c_1 costs approximately 1.4 hr of vessel time and c_2 costs approximately 0.1 hr of vessel time, then $(c_1/c_2)^{1/2} = 3.7$. If within stattion variance (S_2^2) in mean CPP is greater than among station variance (S_1^2) in strata of high catches, then a cost-adjusted m_{opt} would likely be equal to or greater than the 4 to 5 pots currently fished per station. In strata where catches are few or zero, it is likely that m_{opt} could be less than for strata with higher catches.

We did not calculate m_{opt} or n_{opt} in this paper because our estimates of variance were based on strata composed of stations which were not adjacent nor fixed in number or location among years. Instead, post-stratification of stations was designed to minimize variance in the estimated mean CPP without constraints. The formula for m_{opt} is presented here because we believe that the appropriate number of strata (with adjacent stations in fixed locations from year to year) can be determined by a subsequent full analysis of historical survey data. At that time, specific design recommendations can be addressed.

Calculation of Proportions

The proportion of male crabs in all size categories was calculated to provide a complete description of the size frequency data collected. We calculated $\hat{p}$, the estimated proportion of male crabs in size class z by:

$$\hat{p}_z = y_z Y^{-1} \qquad (10)$$

and estimated variance, $\hat{V}(\hat{p})$, by:

$$\hat{V}(\hat{p}) = \hat{p}_z \hat{q} / Y - 1 \qquad (11)$$

where y_z is the number of crabs in size class z, Y is the total number of crabs caught, $\hat{p}_z$ is the estimated proportion in sizeclass z, and $\hat{q}_z = 1 - \hat{p}_z$ (Scheaffer et al. 1986). Because sample size was judged small relative to the total population size, the finite population correction was ignored.

Calculation of Fecundity

The relative egg clutch size (hereafter termed ovigerity) of individual mature females is subjectively placed into four categories (0, 1-39, 40-89 and 90-100%) through visual inspection. These estimates are based both on the size of the egg mass relative to the abdominal flap and on the egg fullness of individual pleopods. Relative ovigerity estimates were converted to fecundity, being defined as the number of zoea eggs shortly before hatching (Matsuura et al. 1972).

This conversion was accomplished with an equation developed by Haynes (1968) who related carapace size and egg number from females sampled in Kachemak Bay:

$$\hat{F}_x = -247,400 + 3,318.8x \qquad (12)$$

where $\hat{F}_x$ is fecundity (number of eggs) and x is carapace length in millimeters. Egg mortality between extrusion and hatching is considered in the above regression.

We calculated the mean fecundity of mature females in the sampled population as:

$$\bar{F} = \sum_{all\ x} \sum_{all\ v} (\hat{F}_{x,b=100} b_v Y_{xv}) Y^{-1} \qquad (13)$$

where $\hat{F}_{x,b=100}$ is the mean fecundity of a female of length x with 100% ovigerity, $\bar{b}$ is the mean percent for ovigerity category v, y_{xv} is the number of mature females of length x in ovigerity category v, and Y is the total number of females captured in the survey. Estimated fecundity for each ovigerity category was summed across carapace lengths in 2-mm increments, and then divided by the total number of mature females captured.

We did not attempt to calculate confidence intervals for $\bar{F}$, but we did calculate a range. The lower bound of $\bar{F}$ was calculated by replacing b with the lower bound of each ovigerity category (i.e., 0, .01, .40 and .90) in eq. (13). The upper bound was calculated by using the upper bound of each ovigerity category (i.e., .39, .89, 1.0), in eq. (13).

RESULTS

Southern District

Males:

Abundance and Size Frequency. Totals of 1,195 and 610 males were captured in 1984 and 1985, respectively. Mean catch per pot and two standard errors of the mean for prerecruit-1, recruit, postrecruit and legal male king crab for the years 1974-1985 are shown in Table 1. No significant differences ($P \leq 0.05$) can be detected between the 1984 and 1985 mean catch per pot of prerecruit-1, postrecruit and legal male size categories. In 1985 significantly less ($P \leq 0.05$) recruit size king crab were captured compared to 1984. Thus, the predominance of older-aged males observed in 1985 is due to significantly less ($P \leq 0.05$) recruitment, relative to 1984.

Bounds (approximate 95% confidence intervals) on the error of the estimated mean catch per pot of prerecruit-1, recruit, postrecruit and legal males are shown in Figure 2. The coefficient of variation (CV) about the mean is less than 20% for all but two years (1982 and 1983) for legal male catch per pot, indicating this measure of relative abundance is more precise than the relative abundance indices for the other size categories. The prerecruit-1 and recruit mean catch per pot CV exceeds 20% in three years. The post-recruit measure of relative abundance is the least precise, with the CV exceeding 20% in five of 11 survey years.

Reduction of variance through stratification produced estimates of mean catch per pot equal to or less than estimates obtained without stratification (Figure 3). In the years 1976 and 1978, the mean catch per pot of legal male king crab was significantly overestimated, as indicated by non-overlapping 95% confidence intervals.

The mean carapace length of all males captured in 1984 was 131.6 mm (2 SE = 1.4; Figure 4), and in 1985 was 143.4 mm (2 SE = 1.8; Figure 4).

A greater mean carapace length was observed in 1985 because the proportion of postrecruits in the sampled catch doubled relative to 1984. The percentage ($\hat{p}_Z$ x 100) and two standard errors (2 SE) of males captured per size class in 1984 and 1985 are shown below:

Size Class (z)	1984		1985	
	p_Z x 100	2 SE	p_Z x 100	2 SE
Four	2.8	<0.1	1.0	<0.1
Three	18.6	0.1	4.0	0.1
Two	28.5	0.1	20.7	0.1
One	15.1	0.1	29.5	0.2
Recruit	18.2	0.1	12.0	0.1
Postrecruit	16.7	0.1	32.8	0.2
Total	99.9		100.0	

Distribution. The greatest catch of legals per pot in 1984 was 35.0 and occurred north of Seldovia Bay (Figure 5). In 1985 the greatest catch per pot was 20.0 and also occurred north of Seldovia Bay. No one station produced consistently high catches of legal males per pot across years 1974-1985. While legal males may tend to congregate in an area off Seldovia Bay in June and July, no one station can be predicted as producing the highest catch per pot in a given survey year. Several stations can be predicted to produce a zero or rare capture of legal males, and it is these stations which should be considered for reduced survey frequency.

In areas of relatively high crab abundance, distribution of captured crabs among pots tended to be aggregated, with one or two pots in the string of four producing the greatest catch and the remaining pots tending to produce few crab. This created greater variance between pots within a station than between stations in the same strata, as illustrated in Table 2. The mean among station variance (S_1^2) in legal male CPP across years for the stratum composed of highest catches was 18.8, while within station variance (S_2^2) was 63.5, or 3.4 times greater. In the stratum composed of moderate catches, the ratio of the mean within station variance to among station variance was 2.9 (Table 3). In the stratum composed of lowest non-zero catches, the mean within to among station variance ratio was estimated to be 0.3 (Table 4).

Highest catches tended to occur at depths ranging from 18 to 73 m (10 - 40 fa). No high catches occurred in the "holes" of Kachemak Bay: 90 to 165 m (50 - 90 fa), although legal males were present at those depths.

Females:

Abundance and Size Frequency. Totals of 2,100 and 841 females were captured in 1984 and 1985, respectively. Mean catch per pot and two standard errors of the mean for mature females for the years 1974-1985 are shown in Table 1. No significant differences can be detected between the 1984 and 1985 mean catch per pot.

Bounds (95% confidence) on the error of the estimated mean catch per pot of mature females are shown in Figure 6. The CV about the mean is less than 20% for all but four of 11 survey years (1975, 1976, 1984 and 1985).

The mean carapace length of all females captured in 1984 was 125.6 mm (2 SE = 0.6; Figure 7) and in 1985 was 129.2 mm (2 SE = 0.8; Figure 7).

Distribution. The greatest catch per pot of mature females in 1984 was 168.3 and occurred just off the Homer spit (Figure 8). In 1985, the greatest catch per pot was 57.3 and occurred about 4 km northeast of Homer spit. No one station produced consistently high catches of mature females per pot across years 1974-1985, so no station can be predicted as producing the highest catch per pot in a given year. Several stations can be predicted to produce zero or rare captures of females.

In areas of relatively high crab abundance, distribution of captured females among pots tended to be aggregated, with one or two pots in the string of four producing the greatest catch and the remaining catch tending to produce few crab. The mean among station variance (S_1^2) in mature female CPP across years for strata composed of highest catches was 611.0, while within station variance (S_2^2) was 2,466.5, or 4.0 times greater (Table 2). As with males, mean within station variance relative to among station variance in mature female CPP decreased as catches comprising each stratum declined (Tables 3 and 4).

Fecundity. In 1984 the greatest percentage (59.0%, 2 SE = 0.1) of females sampled had egg clutches in the 40-89% category. In 1985, the greatest percentage (53.0%, 2 SE = 0.1) of females sampled had egg clutches of 90-100% (Table 5). Estimated mean fecundity per mature female in 1984 was 160,000 eggs and in 1985 was 210,000 eggs (Table 5). However, because more females were captured in 1984, the estimated mean fecundity per pot was greater in 1984 than in 1985 (1.3 million and 750,000 eggs, respectively).

As part of the investigations on parasitic infestation of egg clutches in female king crab in the Southern District (Appendix C) females were inspected for ovigerity at periodic intervals from one location (Station P20) in 1984 and 1985. This provided information on timing of egg extrusion, egg mortality and timing of hatching; and, variation in these events within the sampled population. In 1984, egg extrusion appeared to commence in March, with 90-100% ovigerity noted in most females by June (Figure 9). Partial and barren egg clutches were noted from September to November. Observations in 1985 indicated a different timing of events. Barren females were noted in March and April, suggesting recent release of eggs. By July, all females had full or partial egg clutches, which they retained in approximately the same proportion through November. Females sampled in the fall of 1985 did not appear to suffer the extent of egg mortality as females sampled in the fall of 1984.

Kamishak District

Males:

Abundance and Size Frequency. Totals of 279 and 414 males were captured in 1984 and 1985, respectively. Mean catch per pot and two standard errors of the mean for prerecruit-1, recruit, postrecruit and legal male king crab for the years 1975-1985 are shown in Table 6. Mean prerecruit-1 catch per pot in 1984 and 1985 are the lowest on record. No significant differences can be detected between the 1984 and 1985 mean catch per pot of prerecruit-1 and recruit male size categories. In 1985 significantly more ($P \leq 0.05$) postrecruits and legal size king crab were captured compared to 1984.

Bounds (95% confidence) on the error of the estimated mean catch per pot of prerecruit-1, recruit, postrecruit and legal males are shown in Figure 10. The CV about the mean legal male catch per pot is less than 20% from 1975 to 1981, but from 1982 to 1985, precision in estimating the mean declines. Similarly, the CV about the mean postrecruit catch per pot exceeds 20% from 1981 to 1985. Recruit mean catch per pot CV exceeds 20% in five of 11 survey years. The prerecruit-1 measure of relative abundance is the least precise, with the CV exceeding 20% in six of 11 survey years. Error in estimating prerecruit-1's is so high, no difference from zero can be detected since 1982. Clearly, no forecast of recruits based on prerecruit-1's is possible.

Reduction of variance through stratification produced estimates of mean legal male catch per pot equal to or less than estimates obtained without stratification (Figure 11). In 1975, the estimated mean stratified catch per pot was 16, while the unstratified mean was 22. A significant overestimation of the mean occurred in 1978.

The mean carapace length of all males captured in 1984 was 107.7 mm (2 SE = 4.34; Figure 12), and in 1985 was 148.0 mm (2 SE = 3.12; Figure 12).

Similiar to the Southern District, a greater mean carapace length was observed in 1985 because the proportion of postrecruits in the sampled catch increased, relative to 1984. Percentage ($\hat{p}_z$ x 100) and two standard errors (2 SE) of males captured per size class in 1984 and 1985 are shown below:

Size Class (z)	1984		1985	
	p_z x 100	2 SE	p_z x 100	2 SE
Four	52.3	0.4	14.3	0.2
Three	9.0	0.2	4.3	0.1
Two	1.8	0.1	1.4	0.1
One	10.8	0.2	4.1	0.1
Recruit	16.8	0.3	13.8	0.2
Postrecruit	9.3	0.2	62.1	0.2
Total	100.0		100.0	

<u>Distribution</u>. The greatest catch of legals per pot in 1984 and 1985 was 5.0 and 32.8, respectively, and occurred north of Cape Douglas (Figure 13). No one station produced consistently high catches of legal males per pot across years 1975-1985. While legal males tend to congregate north of Cape Douglas and east of Augustine Island in June and July, no one station can

be predicted as producing the highest catch per pot in a given survey year. Several stations can be predicted to produce rare captures of legal males, and it is these stations which should be considered for reduced survey frequency.

As in the Southern District, distribution of captured crabs among pots tended to be aggregated, with one or two pots in the string of five producing the greatest catch and the remaining pots tending to produce few crab. The mean among station variance (S_1^2) in legal male CPP across years for the stratum composed of highest catches was 40.3, while within station variance (S_2^2) was 157.9, or 3.9 times greater (Table 2). In the stratum composed of moderate catches, the mean within station variance was 2.2 times greater than the mean among station variance (Table 3). The mean within station variance in the stratum composed of lowest non-zero catches did not decline, as observed in the Southern District, but rather increased to 3.4 times greater than the mean among station variance (Table 4).

Highest catches tended to occur at depths ranging from 37 to 73 m (20-40 fa). No high catches occurred along the 146+ m ridge (80 fa), although legal males were present at those depths.

Females:

Abundance and Size Frequency. Totals of 315 and 247 females were captured in 1984 and 1985, respectively. Mean catch per pot and two standard errors of the mean for mature females for the years 1974-1985 are shown in Table 6. No significant differences can be detected between the 1984 and 1985 mean catch per pot.

Bounds (95% confidence) on the error of the estimated mean catch per pot of mature females are shown in Figure 14. The CV about the mean is greater than 20% for five of 11 survey years. The lack of consistent precision in estimating the mean catch of mature females is similiar to the amount of precision found in male king crab estimates of relative abundance in the Kamishak District

The mean carapace length of all females captured in 1984 was 109.7 mm (2 SE = 2.8; Figure 15) and in 1985 was 113.5 mm (2 SE = 2.8; Figure 15).

Distribution. The greatest catch of mature females per pot in 1984 was 24.8 and occurred south of Augustine Island (Figure 16). In 1985 the greatest catch per pot was 9.3 and occurred northeast of Augustine Island (Figure 16). No one station produced consistently high catches of mature females per pot across years 1975-1985. Thus, no one station can be predicted as producing the highest catch per pot in a given year. Several stations can be predicted to produce zero or rare captures of females.

Distribution of captured females among pots tended to be aggregated, with one or two pots in the string of five producing the greatest catch and the remaining pots tending to produce few crab. The mean among station variance (S_1^2) in mature female CPP across years for strata composed of highest catches was 97.3, while within station variance (S_2^2) was 377.5, or 3.9 times greater. The mean within station variance for stratum 3 did not decline as observed in the other crab categories, but rather was 4.0 times greater than the mean among station variance (Table 3).

Fecundity. In 1984 and 1985 the greatest proportion of females sampled had egg clutches of an estimated 90-100% (46.0%, 2 SE = 0.3 and 45%, 2 SE = 0.4, respectively; Table 7). Estimated mean fecundity per mature female in 1984 was 220,000 eggs and in 1985 was 230,000 eggs (Table 7). Because more females were captured in 1984, the estimated mean fecundity per pot was greater in 1984 than in 1985 (220,000 and 190,000 eggs, respectively). The estimated fecundity per pot in the Kamishak District was considerably less than that estimated for the Southern District.

DISCUSSION

Abundance

Mean CPP of legal males showed a downward trend, so continued closure of the king crab fishery was recommended. Reopening of the fishery should be based upon estimates of relative and absolute abundance. While this paper contains only estimates of relative abundance, these data, along with catch statistics, can be used to estimate absolute abundance (Collie and Sissenwine 1983).

No harvest guidelines for king crab in statistical Area H are required under the Alaska Administrative Code 5 AAC 34.080. However, in its draft fishery management plan the North Pacific Fisheries Management Council (1977) recommended fixed harvest rates of 33% recruits and 50% post-recruits for king crab in Cook Inlet, similiar to harvest strategies for king crab in other state waters during the 1970's. Historical harvest strategies should be re-evaluated prior to reopening of the king crab fishery in Cook Inlet.

Abundance of prerecruit-1's cannot be used to forecast the abundance of recruits the following year, because of errors in estimating relative mean CPP. For example, the correlation coefficient between mean CPP of prerecruit-1's in year x on recruits in year x + 1 in the Southern District is r = 0.53, where prerecruit-1 abundance explains only 28% of the variation in recruit abundance.

Preseason surveys to estimate legal male relative abundance should be continued to be conducted on an annual basis. This is especially important because the survey is not currently successful in the forecast of recruits from the abundance of prerecruit-1's.

Distribution

Legal male and mature female king crab were captured in several discrete geographic regions; few or no captures of crabs in these two categories occurred between the aggregates (Figures 5, 8, 13 and 16). Aggregation in a population may be correlated to habitat heterogeneity, correlated to effects of currents on deposition of food sources, reflect social attractions, or be random. Patterns of dispersal may change with age and between seasons. While the causes of aggregation in legal males and mature females at the time of the survey are unknown, it is hypothesized that the number of aggregates found, and spacing between the aggregates, are related to population abundance. For example, decreasing abundance may result in retraction from range previously occupied. Certainly the incidence of stations with zero captures increased in the Kamishak District in 1984 and 1985, years of historic low abundance, compared to earlier years.

Catches within a string of pots indicates that legal males and mature females are distributed in a pattern termed "aggregated clumped" by Odum (1971). That is, within the aggregates dispersed among given geographic locations, groups of individuals appear to be clumped. King crab are frequently captured in one or two pots out of a string of four to five, creating greater variance between pots within a station than between stations in the same strata. Attraction to pot bait or to other crabs confined in a pot may tend to exaggerate grouping of king crab. Clusters of king crab have been observed to occur during the time of mating; however, abundance surveys in lower Cook Inlet are timed to avoid the mating season.

Historical survey data was examined for persistence of distributional patterns across years. No one station consistently produced the highest CPP across years, but groups of stations within geographic locations did. Distributional patterns of king crab in lower Cook Inlet should be more fully examined. It may be feasible to analyze the historical data base for frequency functions - the negative binomial, Poisson binomial, Neyman's type A and Thomas's double Poisson have been applied to aggregated populations (Pielou 1960). A greater understanding of king crab distributional patterns will promote greater efficiency and precision in abundance sampling.

Fecundity and Density Dependence

The objective of obtaining estimates of fecundity (as defined in Matsurra et al. 1972) is to examine if fecundity influences legal male population abundance. The National Marine Fisheries Service has found little evidence for density dependence in recruitment in the Adak, Dutch Harbor and Bering Sea areas (Bob Otto, National Marine Fisheries Service, Kodiak, pers. comm. 1986), by corresponding numbers of females to recruitment seven to eight years later. However, the lack of evidence is not conclusive, because recruitment is not knife-edged at age seven or eight, but occurs over a broad range of ages (McCaughran and Powell 1977). Also, the number of females may not directly correlate with fecundity. As seen in Table 3, estimated fecundity per female in 1985 was 76% greater than that observed in 1984.

There are several difficulties in estimating fecundity and relating it to population abundance. These include: (1) the relationship between female size and egg number, (2) egg mortality between the time of extrusion and larvae release, (3) differential fertilization and/or mortality between years, (4) inaccuracies inestimating true female abundance, and (5) differential mortality between hatch and recruitment.

Egg mortality between the time of extrusion and hatching normally occurs during the 11-12 month incubation period (Matsuura et al. 1972). Matsuura and Takeshita (1985) found 13-24% egg loss during incubation in laboratory-reared multiparous females and 53% loss in primiparous females. Egg loss appears closely related to embryo growth and structural changes. Additionally, egg loss is caused by parasites (Appendix C). Consequently, it is necessary to count the number of eggs just before hatching to obtain an estimate of the number of zoea released. Since surveys in lower Cook Inlet occur shortly after egg extrusion, ovigerity estimates obtained at that time should only be considered as fecundity after application of an egg mortality factor.

Fertilization of the eggs is influenced by the polygamous mating behavior of red king crab and elapsed time between ecdysis and mating. Powell and Nickerson (1965) found that while a male can mate with at least five females, it may not be capable of fertilizing all the eggs of subsequent females, resulting in unfertilized eggs. Thus, a highly skewed sex ratio, with males present in inadequate numbers, could influence reproductive capacity.

Age class structure can contribute to differences in ovigerity between years. Primiparous females appear to extrude smaller egg clutches and experience a greater percentage of egg mortality than multiparous spawners (Matsurra and Takeshita 1985). Thus, a large cohort of the smaller primiparous females could contribute to differences in observed ovigerity of the surveyed population between years. In the Southern District in 1984, the sampled age structure was composed of a lesser proportion of mature females than observed in 1985; this may in part explain the greater estimated fecundity in 1985.

Identification of population regulating factors for red king crab is difficult; even more difficult is the assessment of how these factors fluctuate in their influence. McLaren (1971) pointed out that density dependent and independent views of population growth are not mutually exclusive, and both can be involved in determining the size of a population. While an "index of fecundity" may now appear difficult to achieve, initialization of a data base on the reproductive capacity of females will aid in our understanding of red king crab population dynamics.

Effect of Post-Stratification on Abundance Estimates

While it is most desirable to set the number of stations per strata (and thus acceptable levels of precision) prior to a survey, post-stratification of data can be done. The estimators obtained by post-stratification are nearly as precise as stratified random sampling using proportional allocation (Scheaffer et al. 1986).

We used post-stratification to increase precision in relative abundance estimates by splitting the entire population (district) into strata according to mean CPP. The coefficient of variation about the mean of each strata was thus reduced and we became more confident of what was occurring in each strata. In most years, when strata means were combined, smaller bounds on the error of the district mean were obtained.

However, as Scheaffer et al. (1986) point out, stratification does not always produce an estimator with smaller variance. In the Southern

District, smaller bounds (not tested for significance) were obtained on legal male mean CPP estimates for all years, except 1977, 1981 and 1985 when the SE's appeared equivalent between the stratified and unstratified methods of calculation (Figure 3). In the Kamishak District, smaller bounds were obtained on legal male mean CPP estimates for 5 years, equivalent SE's were obtained for four years, and larger bounds were obtained for 1975 and 1982 (Figure 11). Larger bounds occurred with post-stratification because of a high degree of crab aggregation in those years and small numbers of stations surveyed. In both years, a larger portion of crab were captured at one station. To calculate among station variance (S) the post-stratification method required that each stratum be composed of at least two stations. This contributed to high among-station variance and higher bounds on the error of the district mean. This example emphasizes the importance of population distribution to survey design and resultant estimates of abundance.

Post-stratification produced district mean CPP estimates equal to or less than those obtained with the simple random sample method of calculation. We are more confident in the lower estimated means. Significant ($P \leq 0.05$) overestimation of legal male relative abundance occurred in the Southern District in 1976 and 1978, and in the Kamishak District in 1978, as evidenced by nonoverlapping approximate 95% confidence intervals. Substantial overestimation of mean CPP is also suggested in the Kamishak District in 1975 (Figures 3 and 11). This would have resulted in greater than expected exploitation rates for those years.

Survey Design

In Lower Cook Inlet, king crab surveys were originally designed as a systematic sample of stations in the Southern District and a random sample of adjacent stations in the Kamishak District, where stations were based on longitude and latitude. Information gathered since inception of the surveys now indicates that these survey designs should be modified for a population with an aggregated distribution pattern, because coefficient of variation about the mean CPP tends to be high. High C.V's in mean CPP were especially prominant in the Kamishak District. High C.V.'s produce imprecise relative abundance estimates, and indicate the necessity for survey redesign.

Comparisons of different sampling schemes on the precision of the population estimator have been conducted by several researchers. For anchovy, which aggregate in schools, Fieldler (1978) found that random sampling was the least precise method of estimating abundance. Stratified systematic surveys appeared to offer the most precision when schools were distributed in a nonrandom manner, and sampling density was low.

Iachan (1985) found gains in precision with stratification over simple random sampling. He found that clam surveys can be efficiently stratified based on contours of depth. An alternative is to stratify on catches from a previous survey, and to periodically redefine strata. He pointed out that systematic sampling (i.e., a grid pattern) of a population that is spatially autocorrelated (a slow change in abundance along a series) would automatically allocate stations proportional to stratum size. Note that systematic sampling of an aggregated population does not result in automatic strata definition.

Optimum allocation of sampling stations is one method which can reduce variance in the mean CPP in a stratum. We can do this by first reducing the survey frequency of stations showing consistent zero or rare captures of legal king crab. Additionally, stations adjacent to those of high catches should be sampled if they are not in the survey. For example, in the Southern District, off Seldovia Bay, there are stations which form an arc with relatively consistent high catches of legal males, yet adjacent stations (H7, H9, G6, etc.) are not regularly included in the survey.

Another method which can decrease variance is to alter the number of pots per station. Kimura and Balsiger (1985) evaluated the effect of varying the number of stations sampled and the number of sets made within each location on sablefish pot survey statistics. Their results indicated that the coefficient of variation about the mean catch per pot could be reduced by increasing the number of locations sampled and decreasing the number of sets per location. Increasing the number of sets had remarkably little effect.

The optimum number of survey stations and pots set per station can be determined so that the estimated population mean has maximum precision for the desired level of cost. Sukhatme et al. (1984) show that the optimal subsampling scheme is dependent on survey characteristics, including within station variance relative to among station variance and cost of sampling stations relative to sampling pots. In strata where the within station variance is low relative to the among station variance (e.g., for crab in the Southern District, Table 4), it is likely that the optimum number of pots set per station is less than 4 to 5. In strata of high catches, where within station variance is greater than among station variance (e.g., as in Table 2) and the cost of sampling a station is greater than sampling a pot, it is likely that the optimum number of pots is equal to or greater than 4 to 5.

When the C.V. does not vary between sampling units nor from year to year, then an optimum number of stations and pots per station can be calculated. As we have shown in this paper, C.V.'s vary considerably and tend to be rather high in some years, thus posing a problem in the design of an efficient two-stage sampling scheme. A solution to this problem lies in examining the historical survey data to determine if the same stratification can be applied to all years (that is, stations are adjacent within a strata and are fixed in location year to year). We believe that the survey can be redesigned to minimize the C.V. in the mean CPP at a given level of efficiency.

ACKNOWLEDGMENTS

We thank B. Alan Johnson for suggestions of variance formulae. Fred Jamson offered helpful advice in transferring data files from the University of Alaska Honeywell computer network. John Hilsinger and Al Kimker reviewed earlier versions of the manuscript. Lee Hammarstrom, Rich Gustufson, Rance Morrison and Paul Budge provided assistance in the field collection of data. The skipper of the R/V PANDALUS, Paul Desjardin, and his crew, Craig Forrest, Wes Humbyrd and Tom Coble, operated the vessel and gear during surveys.

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6/19/2002

Table 1. Mean catch per pot and two standard errors of the mean for size categories of male and female king crab captured during surveys in the Southern District, 1974-1985.

Year	Survey Date	Pot. No.	Station No.	Pre-Recruit One	Recruit	Post-Recruit	Legal	Mature Female
1974	13-27 Jun	240	60	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	1.2 ± 0.4	3.3 ± 1.2
1975	20-31 May	260	66	1.0 ± 0.2	1.1 ± 0.2	1.1 ± 0.4	2.2 ± 0.6	2.2 ± 0.6
1976	7-19 Jun	227	61	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.9 ± 0.2	3.4 ± 1.8
1977*	10-21 Jun	260	69	6.1 ± 1.6	0.8 ± 0.2	0.4 ± 0.1	1.1 ± 0.2	32.4 ± 4.6
1978	14-21 Jun	237	65	3.6 ± 0.6	1.7 ± 0.2	0.1 ±<0.1	3.4 ± 0.6	11.2 ± 2.8
1979	31- 7 Jun	255	66	4.2 ± 0.4	2.0 ± 0.2	0.3 ± 0.1	2.4 ± 0.4	8.5 ± 1.4
1980	8-25 Jul	367	96	7.5 ± 1.2	4.7 ± 0.6	0.4 ± 0.1	5.3 ± 0.8	34.1 ± 4.2
1981	10-19 Jul	238	60	2.7 ± 0.6	1.9 ± 0.4	0.5 ± 0.2	2.2 ± 0.6	10.5 ± 3.0
1982	8-19 Jul	222	60	1.1 ± 0.8	0.3 ± 0.2	0.1 ±<0.1	0.4 ± 0.2	7.6 ± 2.7
1983	28-15 Jul	230	60	0.8 ± 0.6	0.4 ± 0.4	0.2 ±<0.1	0.5 ± 0.4	2.5 ± 0.7
1984	9-26 Jul	234	59	0.8 ± 0.2	1.1 ± 0.4	0.7 ± 0.4	1.8 ± 0.8	8.0 ± 4.0
1985	8-18 Jul	231	60	0.8 ± 0.2	0.5 ± 0.2	0.6 ± 0.1	1.2 ± 0.4	3.4 ± 1.5

*unstratified

Table 2. Among (S_1^2) and within (S_2^2) station variance in mean CPP of legal male and mature female king crab in the Southern and Kamishak Districts by year for the stratum composed of highest catches (stratum 2).

Year	Southern District				Kamishak District			
	Male		Female		Male		Female	
	(S_1^2)	(S_2^2)	(S_1^2)	(S_2^2)	(S_1^2)	(S_2^2)	(S_1^2)	(S_2^2)
1974	12.1	15.3	36.7	635.9	--[a]	--[a]	--[a]	--[a]
1975	19.8	194.8	136.9	479.4	194.0	132.4	72.4	45.6
1976	0.3	3.6	427.9	940.7	0.7	25.2	196.4	536.0
1977	--[b]	--[b]	506.0	2,109.6	27.5	41.6	153.7	591.8
1978	0.8	14.8	291.8	5,110.4	5.0	31.9	121.2	482.0
1979	4.3	16.4	118.8	228.3	6.6	37.0	142.4	775.9
1980	18.9	53.8	1,370.9	2,696.8	29.4	94.2	11.0	133.6
1981	66.4	63.0	181.7	3,109.8	24.9	641.8	21.4	115.7
1982	5.3	9.9	1,188.3	6,835.4	93.9	345.7	174.4	584.5
1983	38.3	29.8	25.5	320.9	13.8	21.1	47.7	363.9
1984	7.0	202.8	2,838.9	5,846.8	1.3	9.1	128.0	504.9
1985	34.0	94.0	208.9	1,284.4	46.1	357.1	1.7	18.2
Mean	18.8	63.5	611.0	2,466.5	40.3	157.9	97.3	377.5
S_2^2 / S_1^2	3.4		4.0		3.9		3.9	

a No survey was conducted.
b An electronic copy of the data was not available.

Table 3. Among (S_1^2) and within (S_2^2) station variance in mean CPP of legal male and mature female king crab in the Southern and Kamishak Districts by year for the stratum composed of moderate catches (stratum 3).

Year	Southern District				Kamishak District			
	Male		Female		Male		Female	
	(S_1^2)	(S_2^2)	(S_1^2)	(S_2^2)	(S_1^2)	(S_2^2)	(S_1^2)	(S_2^2)
1974	0.6	2.6	0.5	11.6	--[a]	--[a]	--[a]	--[a]
1975	1.7	13.3	1.1	7.2	5.5	16.0	2.1	4.6
1976	0.1	1.5	2.0	16.7	1.2	12.9	16.1	29.0
1977	--[b]	--[b]	247.7	342.9	1.6	6.6	13.4	<0.1[c]
1978	0.4	2.0	114.5	475.3	0.5	3.4	20.6	79.0
1979	0.9	1.3	11.9	84.6	1.5	8.4	23.9	325.0
1980	12.8	19.2	437.6	1,051.3	5.8	15.1	14.1	<0.1[c]
1981	0.8	7.5	36.6	335.4	8.2	6.6	11.9	1.1
1982	<0.1[c]	3.2	27.6	351.4	4.7	6.6	2.6	3.5
1983	0.1	14.4	6.7	59.2	1.6	1.5	6.3	5.6
1984	12.8	16.2	65.2	83.1	0.2	1.7	0.8	0.9
1985	0.9	8.9	26.8	180.8	5.7	2.8	1.5	4.9
Mean	2.8	8.2	81.5	250.0	3.3	7.4	10.3	41.2
S_2^2/S_1^2	2.9		3.1		2.2		4.0	

a No survey was conducted.
b An electronic copy of the data was not available.
c For purposes of estimation, this fraction has been assigned a value of 0.04.

Table 4. Among (S_1^2) and within (S_2^2) station variance in mean CPP of legal male and mature female king crab in the Southern and Kamishak Districts by year for the stratum composed of lowest non-zero catches (stratum 4).[a]

Year	Southern District				Kamishak District			
	Male		Female		Male		Female[b]	
	(S_1^2)	(S_2^2)	(S_1^2)	(S_2^2)	(S_1^2)	(S_2^2)	(S_1^2)	(S_2^2)
1974	0.2	<0.1	1.1	1.7	--[c]	--[c]	--[c]	--[c]
1975	0.6	<0.1	0.2	0.7	0.8	4.5	--	--
1976	<0.1	<0.1	0.5	1.9	1.1	2.6	2.2	6.9
1977	--[d]	--[d]	11.6	27.2	0.3	1.8	--	--
1978	0.3	<0.1	15.4	21.8	0.1	0.4	--	--
1979	0.5	<0.1	3.3	9.1	0.4	1.9	0.7	<0.1
1980	5.3	<0.1	18.4	26.3	1.4	3.0	--	--
1981	0.4	<0.1	8.5	19.8	--[b]	--	--	--
1982	<0.1	<0.1	1.5	4.4	--[b]	--	--	--
1983	0.2	0.2	0.3	1.6	--[b]	--	--	--
1984	2.0	2.2	0.4	1.5	--[b]	--	--	--
1985	0.3	0.3	2.7	5.5	--[b]	--	--	--
Mean	0.9	0.3	5.3	10.1	0.7	2.4	10.3	41.2
S_2^2 / S_1^2	0.3		1.9		3.4		4.0	

a For purposes of estimation, the fraction <0.1 has been assigned a value of 0.04.
b Selection of a fourth stratum did not appreciably reduce the variance in the mean CPP.
c No survey was conducted.
d An electronic copy of the data was not available.

Table 5. Estimated percentage of female king crab per ovigerity category and standard errors for 1984 and 1985, Southern District. Estimated fecundity ($\bar{F}$) and range in the sampled population is standardized per female and per pot lift.

Ovigerity Category	1984 percentage	1984 2 SE	1985 percentage	1985 2 SE
Juvenile	11.0	<0.1	4.0	<0.1
Barren	2.0	<0.1	1.0	<0.1
1- 39%	13.0	<0.1	2.0	<0.1
40- 89%	59.0	<0.1	40.0	0.1
90-100%	15.0	<0.1	53.0	0.1
Total	100.0		100.0	
n	2100		841	

	1984 $\bar{F} \times 10^{-5}$	1984 Range	1985 $\bar{F} \times 10^{-5}$	1985 Range
Sample Total	3023	2035-4011	1733	1436-2031
/Mature Female	1.6	1.1- 2.1	2.1	1.8- 2.5
/Pot Lift	13.0	4.8-24.4	7.5	5.0-10.5

Table 6. Mean catch per pot and two standard errors of the mean for size categories of male and female king crab captured during surveys in the Kamishak District, 1975-1985.

Year	Survey Date	Pot No.	Station No.	Pre-Recruit One	Recruit	Post-Recruit	Legal	Mature Female
1975	2-11 Jun	96	8	6.0 + 1.2	11.2 + 3.2	5.2 + 2.0	16.3 + 5.2	8.6 + 3.9
1976	29-23 Jul	159	16	1.8 + 0.4	2.6 + 0.6	1.5 +<0.1	4.1 + 0.8	8.0 + 3.9
1977	8-23 Jul	199	33	1.0 + 0.6	0.9 + 0.6	0.8 +<0.1	2.6 + 0.8	16.5 + 3.3
1978	29-20 Jul	224	30	1.9 + 0.4	0.8 + 0.4	0.6 +<0.1	2.0 + 0.4	18.5 + 3.5
1979	8-27 Jul	261	34	5.3 + 0.8	2.9 + 0.6	0.3 +<0.1	3.0 + 0.6	10.2 + 2.5
1980	6-16 Jun	171	36	3.7 + 2.0	3.2 + 1.0	0.6 +<0.1	3.7 + 0.8	5.2 + 1.3
1981	23- 7 Jul	171	36	3.1 + 0.8	5.5 + 1.4	1.5 + 0.4	6.8 + 2.2	6.4 + 1.4
1982	24- 4 Jul	70	15	3.6 + 4.2	3.4 + 2.4	1.1 + 0.4	4.4 + 3.2	4.8 + 4.0
1983	15-25 Jun	192	40	1.0 + 1.4	0.6 + 0.2	0.3 +<0.1	0.9 + 0.4	2.1 + 1.1
1984	22- 2 Jul	185	40	0.1 + 0.1	0.4 + 0.2	0.1 +<0.1	0.4 + 0.2	1.0 + 1.1
1985	17-27 Jun	182	39	0.1 +<0.1	0.8 + 0.6	0.9 + 0.8	1.6 + 0.8	0.8 + 0.3

Table 7. Estimated percentage of female king crab per ovigerity category and standard errors for 1984 and 1985, Kamishak District. Estimated mean fecundity ($\bar{F}$) and range in the sampled population is standardized per female and per pot lift.

Ovigerity Category	1984 percentage	1984 2 SE	1985 percentage	1985 2 SE
Juvenile	38.0	0.3	40.0	0.4
Barren	0		1.0	0.1
1- 39%	0		0	
40- 89%	15.0	0.2	14.0	0.3
90-100%	46.0	0.3	45.0	0.4
Total	99.0		100.0	
n	315		247	

	1984 $\bar{F} \times 10^{-5}$	1984 Range	1985 $\bar{F} \times 10^{-5}$	1985 Range
Sample Total	438	388 - 489	344	307 - 390
/Mature Female	2.2	2.0 - 2.5	2.3	2.1 - 2.6
/Pot Lift	2.2	2.0 - 2.5	1.9	1.7 - 2.2

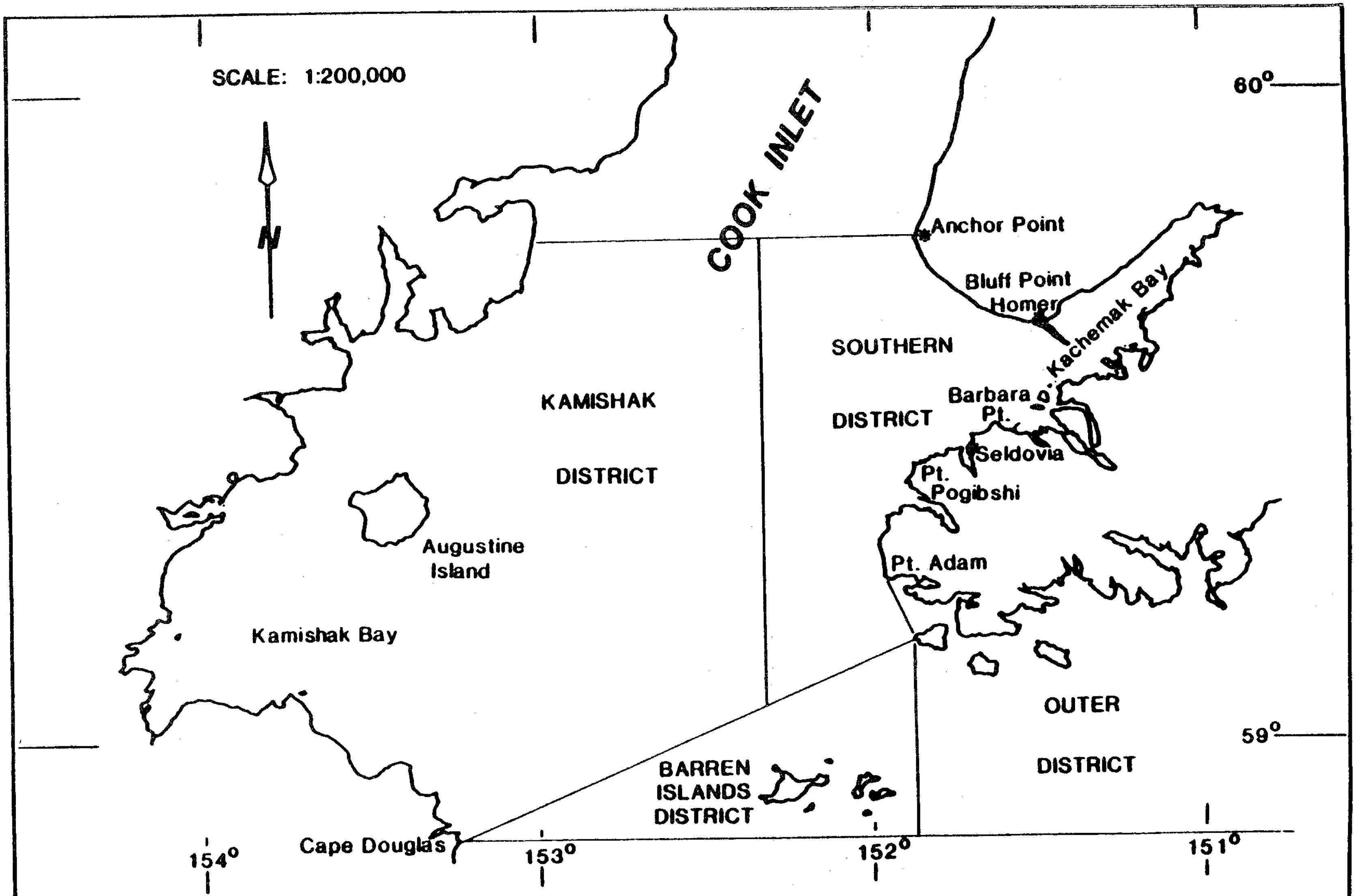

Figure 1. Lower Cook Inlet area district location chart.

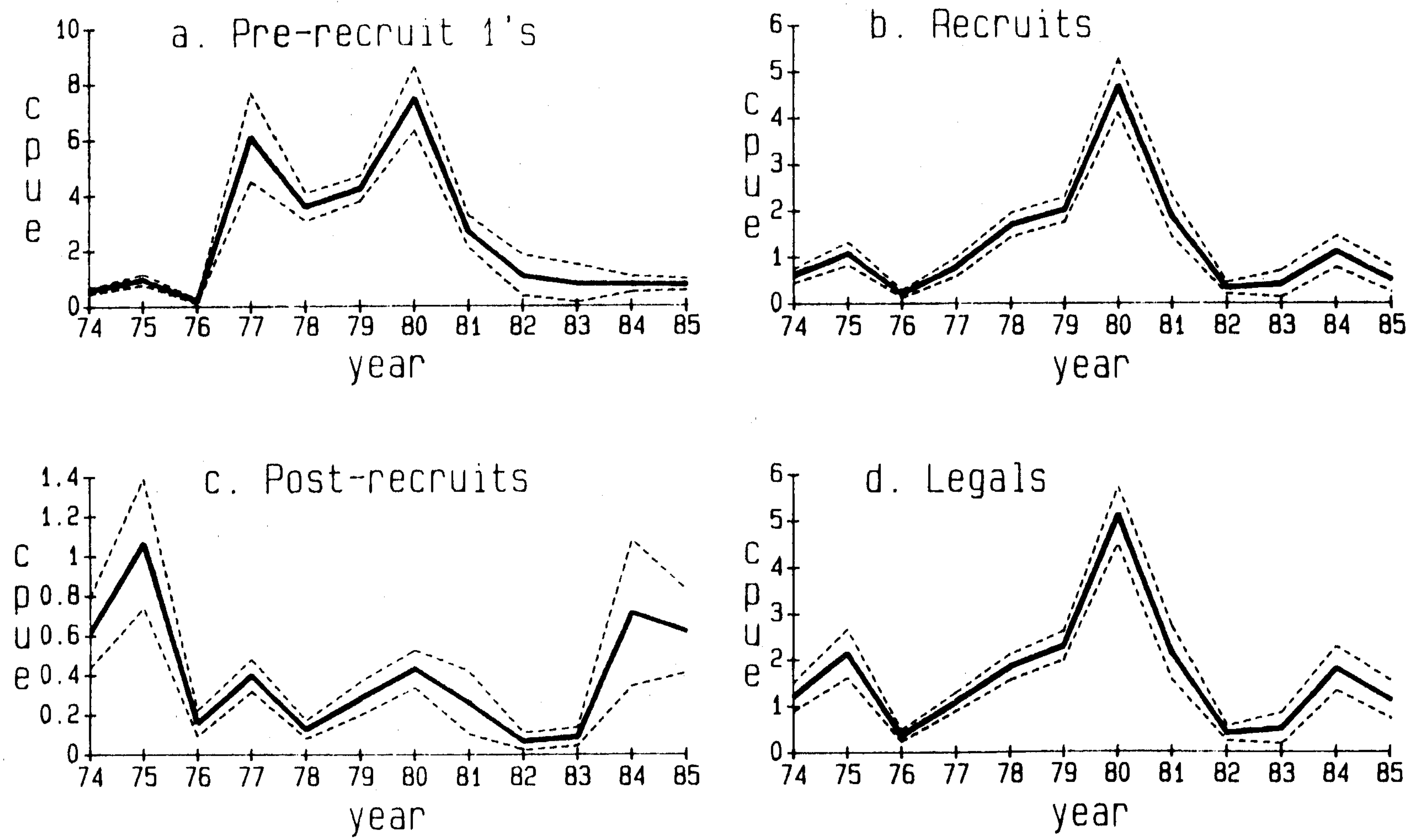

Figure 2. Mean stratified survey catch per pot and approximate 95% confidence interval (two standard errors) for male (a) prerecruit-1, (b) recruit, (c) postrecruit and (d) legal king crab, 1974-1985, Southern District.

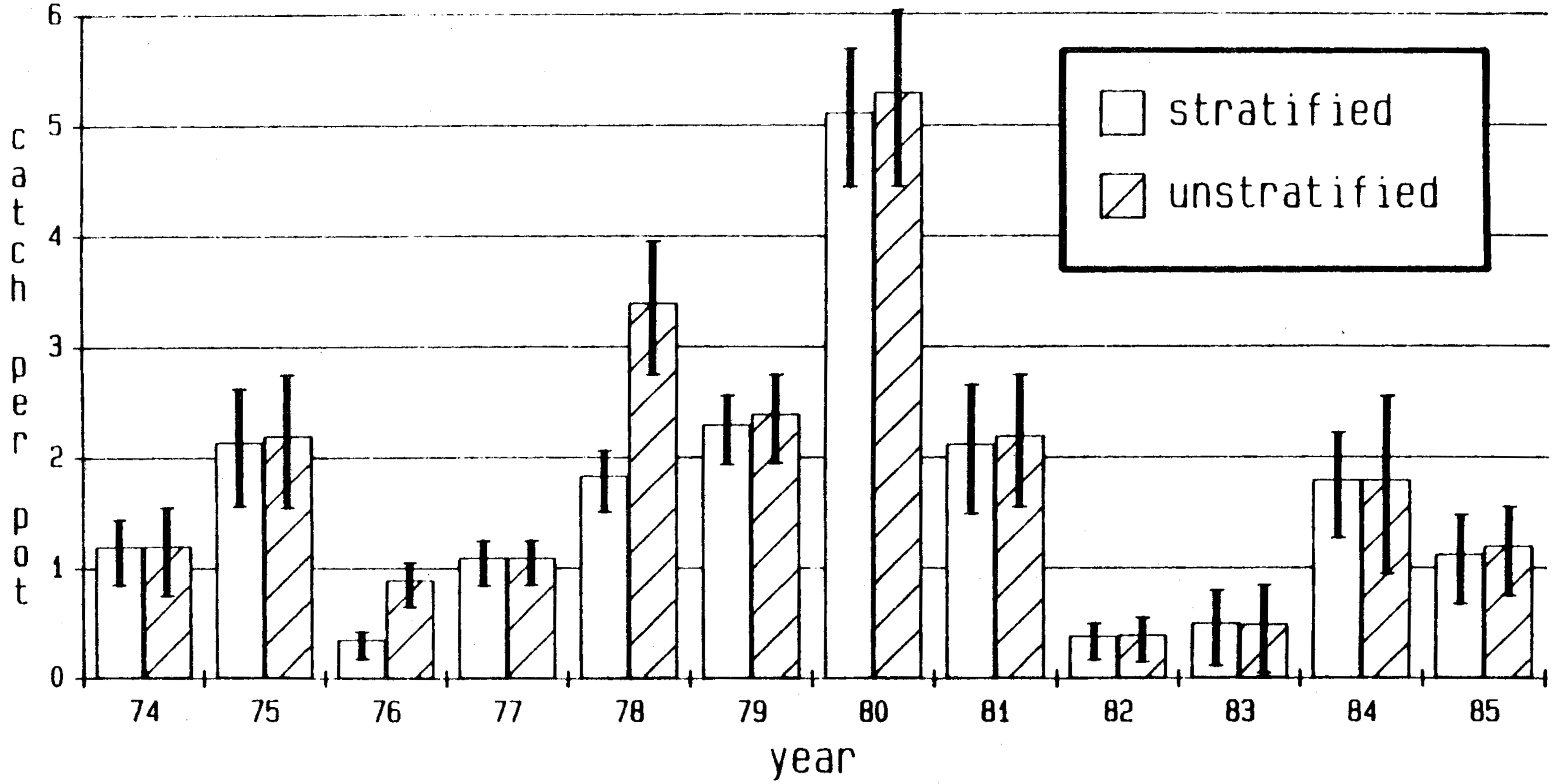

Figure 3. Comparisons between stratified and unstratified mean catch per pot and two standard errors (vertical bar) of legal male king crab in the Southern District by year(1977 is unstratified).

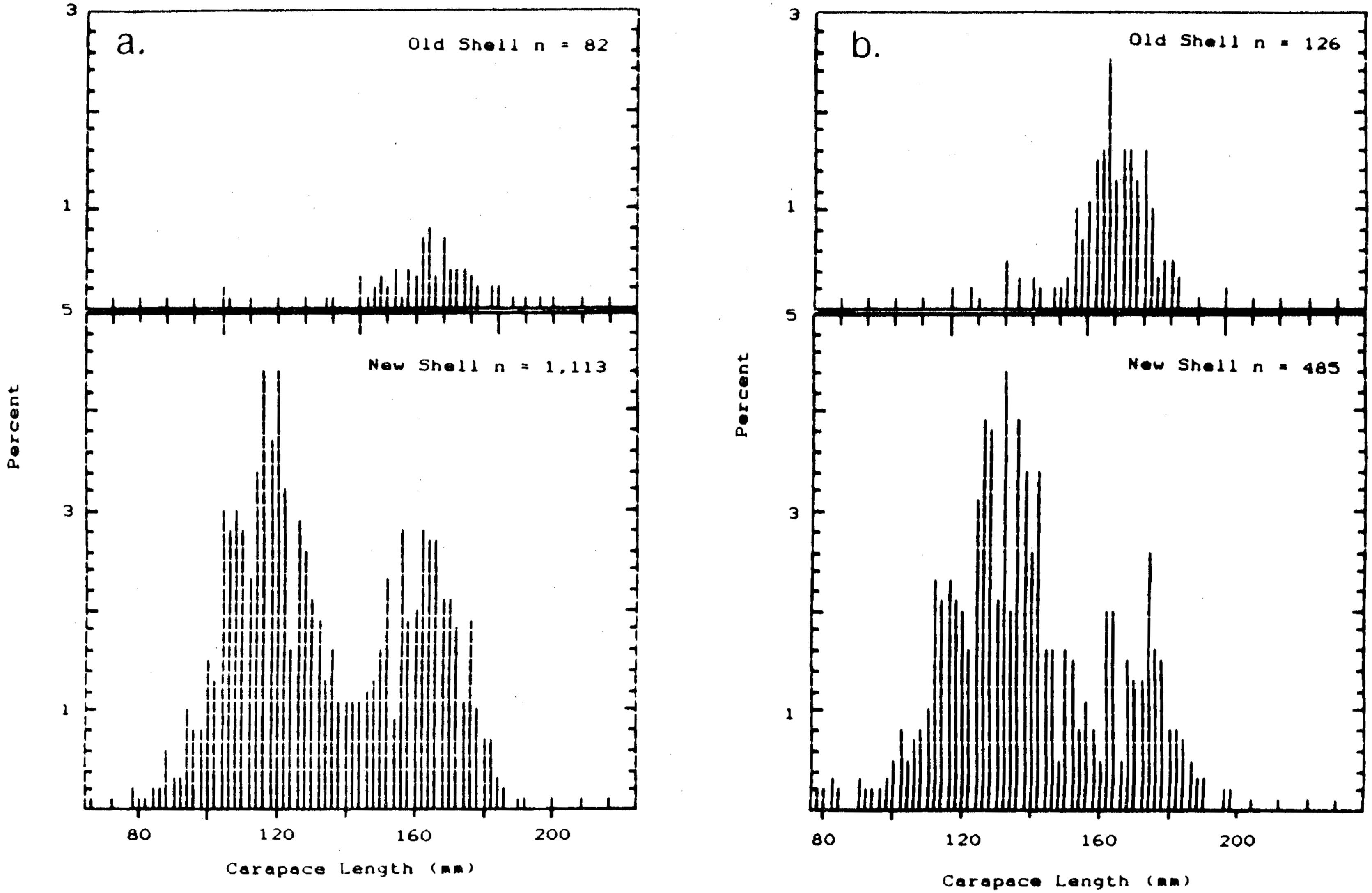

Figure 4. Male king crab carapace length frequency in 2-mm increments, Southern District index survey, (a) 1984 and (b) 1985.

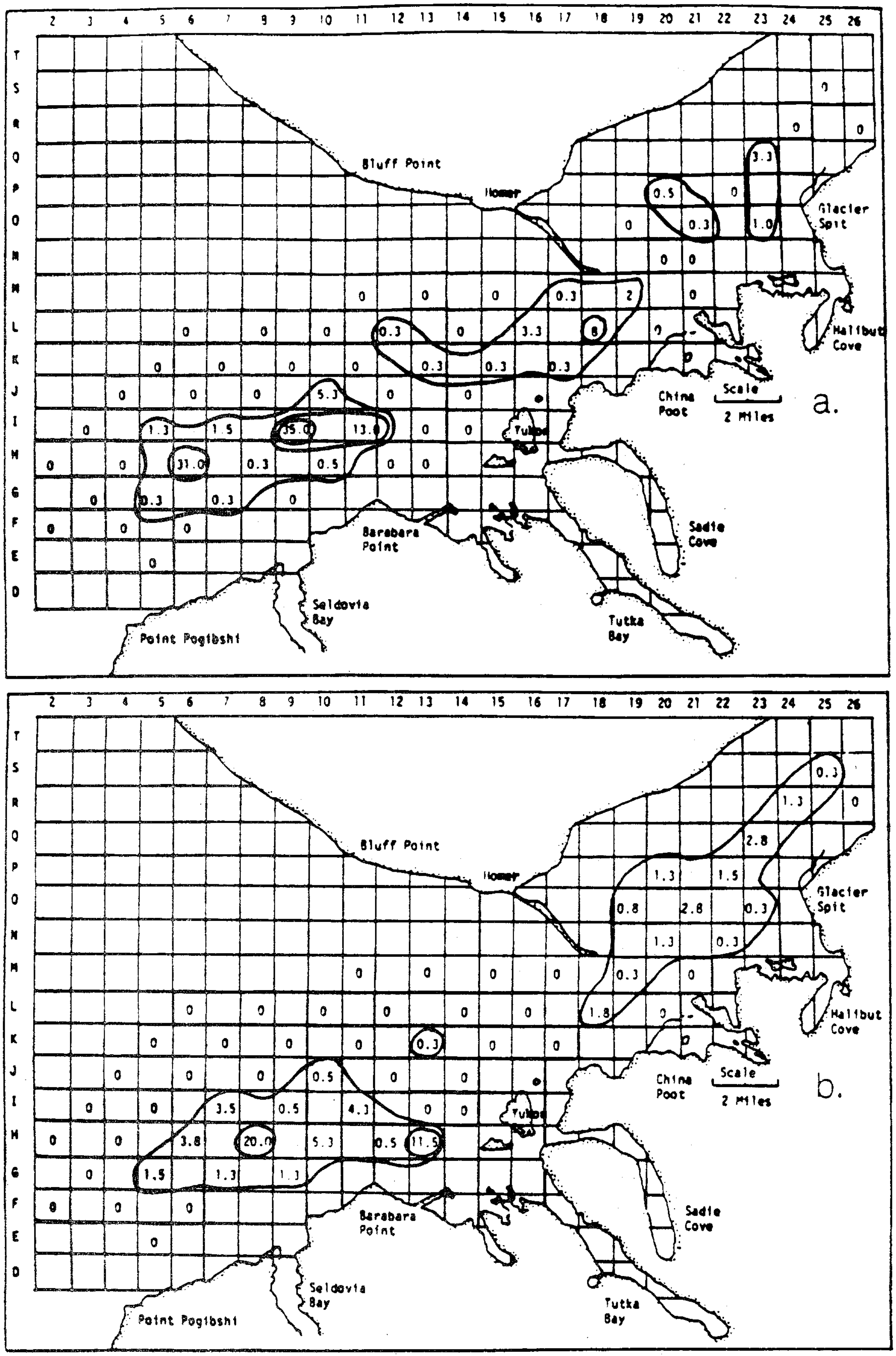

Figure 5. Average catch per pot of legal-sized male king crab captured during index fishing in the Southern District over (a) 9-26 July 1984 and (b) 8-18 July 1985.

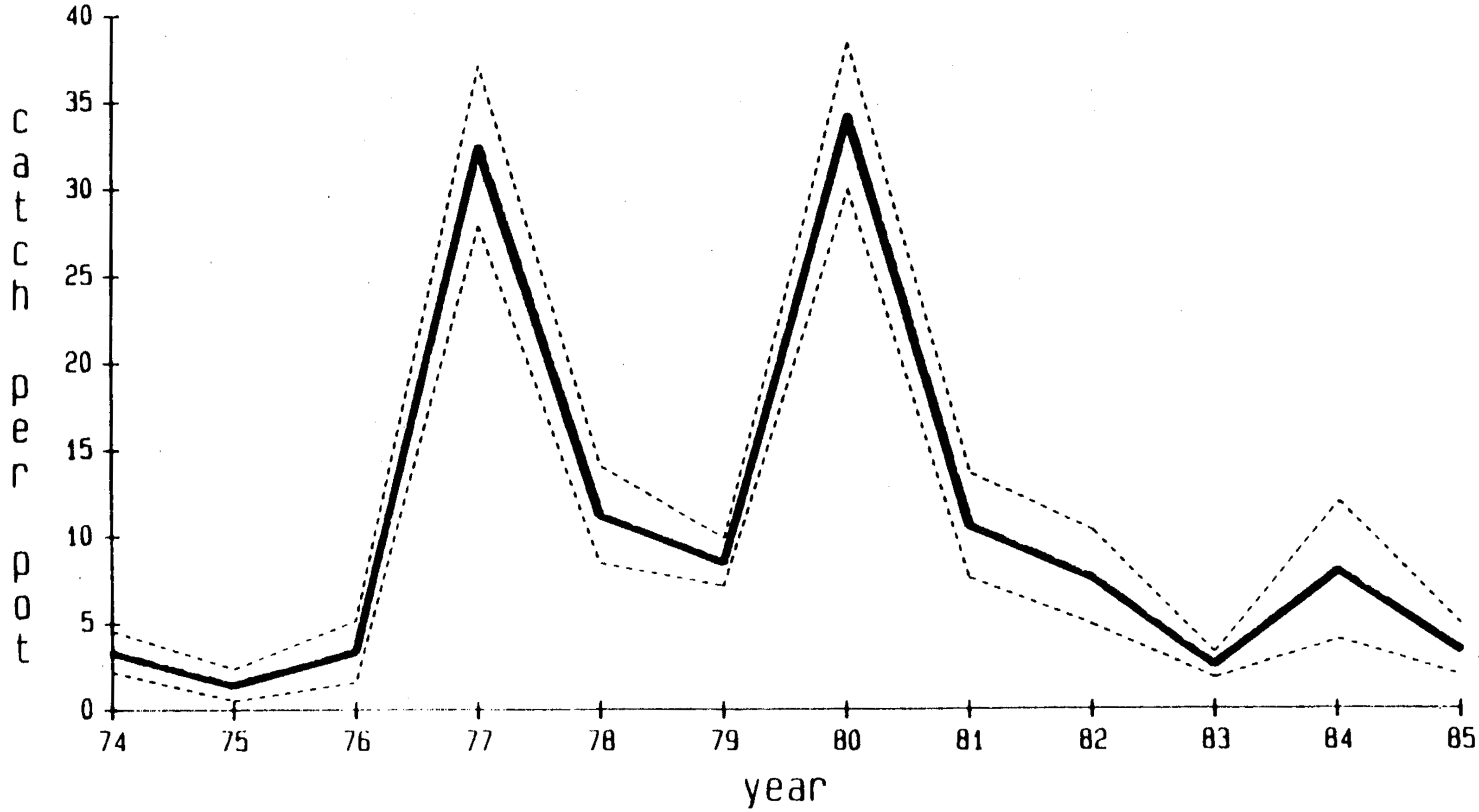

Figure 6. Mean stratified survey catch per pot and approximate 95% confidence interval (two standard errors) for mature female king crab, 1974-1985, Southern District.

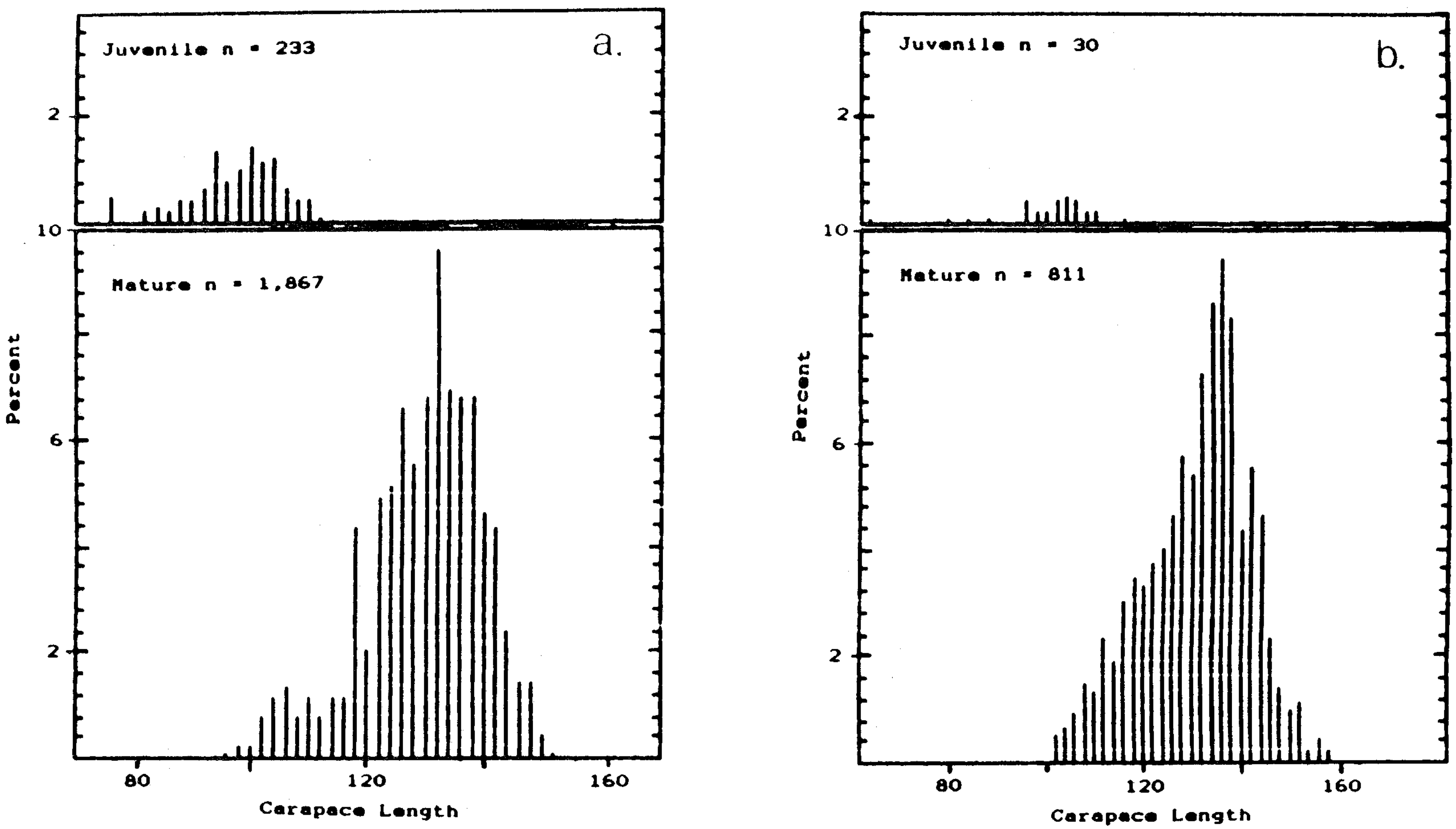

Figure 7. Female king crab carapace length frequency in 2-mm increments, Southern District index survey, (a) 1984 and (b) 1985.

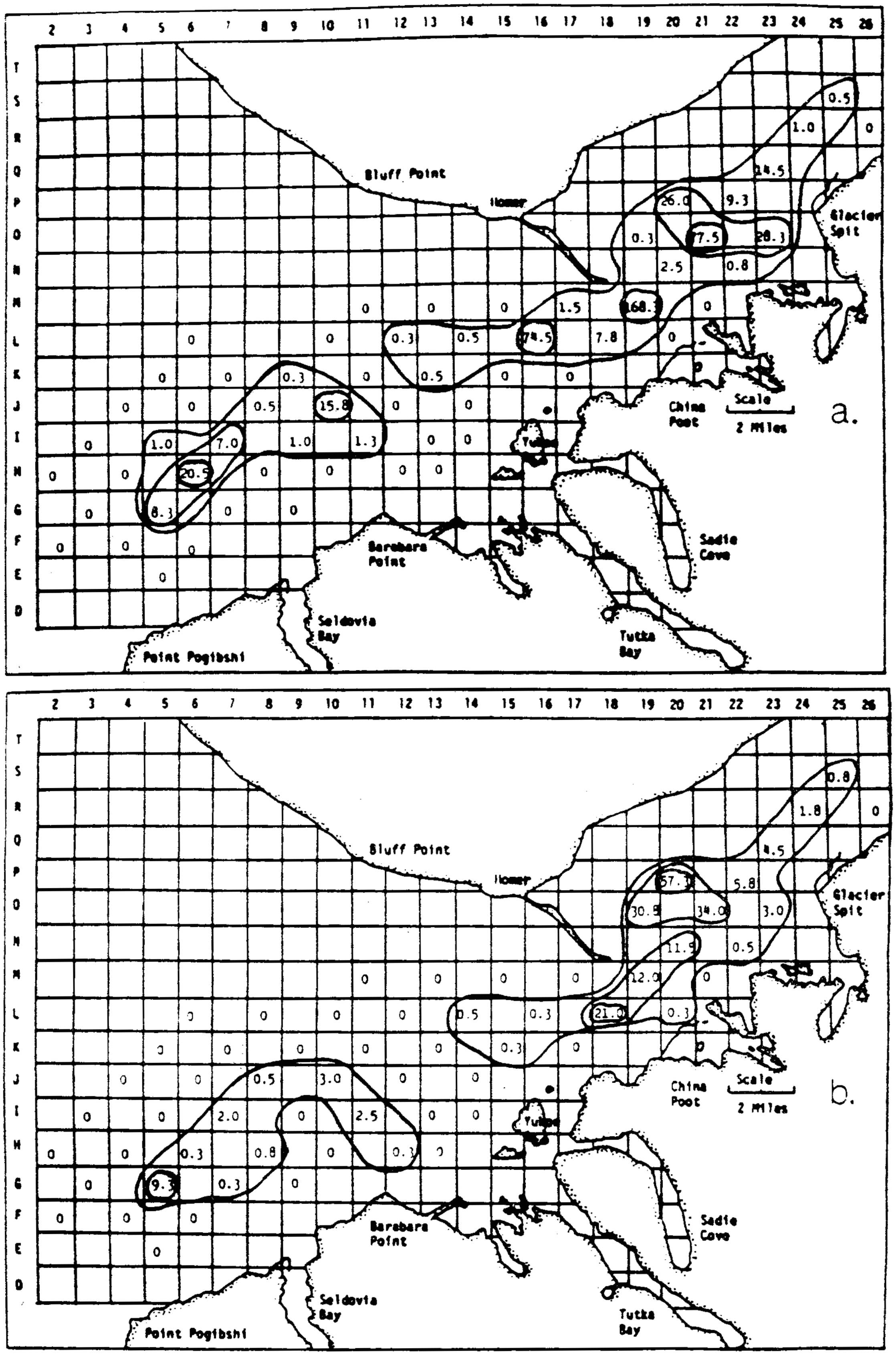

Figure 8. Average catch per pot of mature female king crab captured during index fishing in the Southern District, over (a) 9-26 July 1984 and (b) 8-18 July 1985.

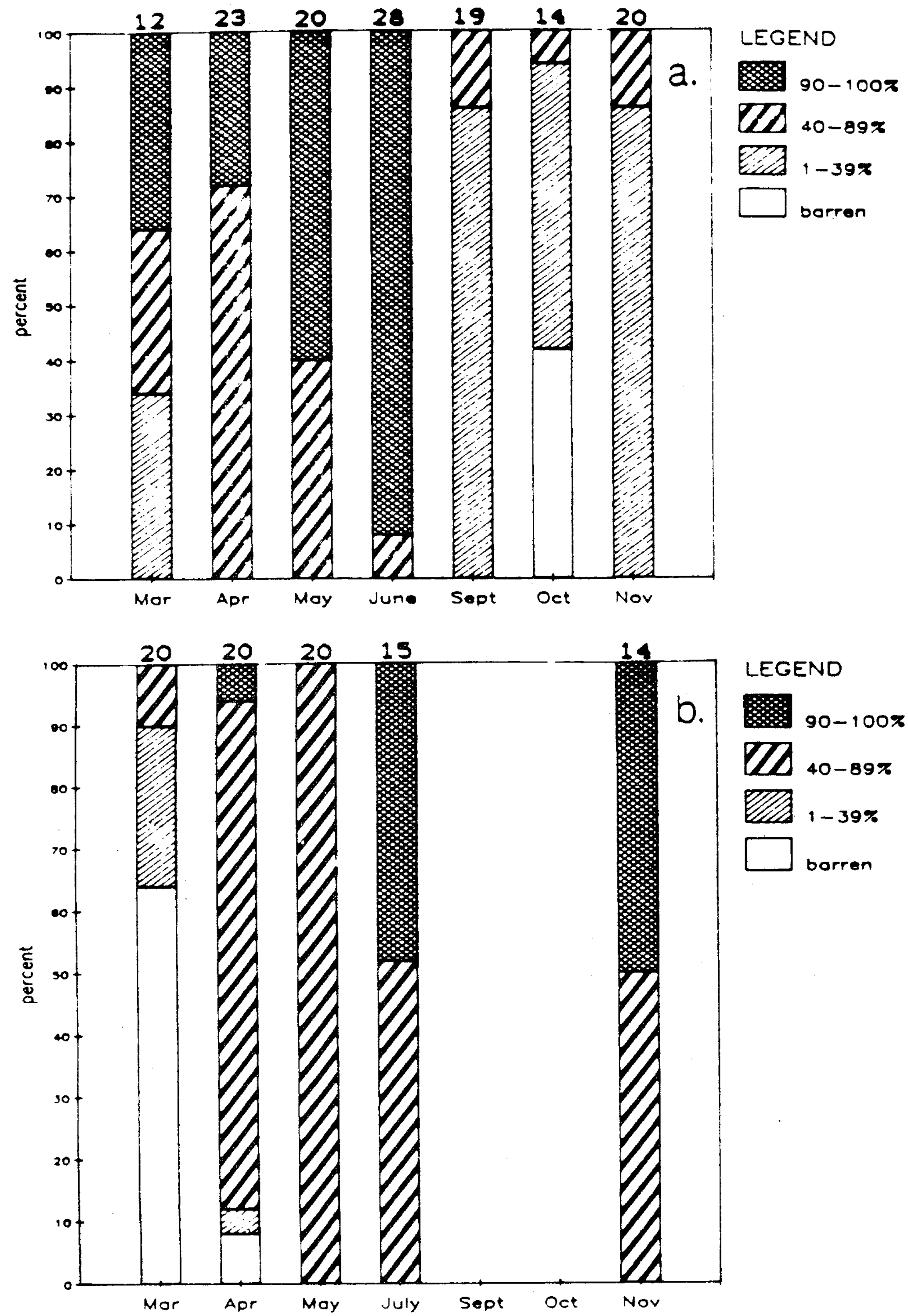

Figure 9. Percent ovigerity observed in female king crab sampled four km northeast of Homer spit at periodic intervals in (a) 1984 and (b) 1985. Sample size is given above each bar.

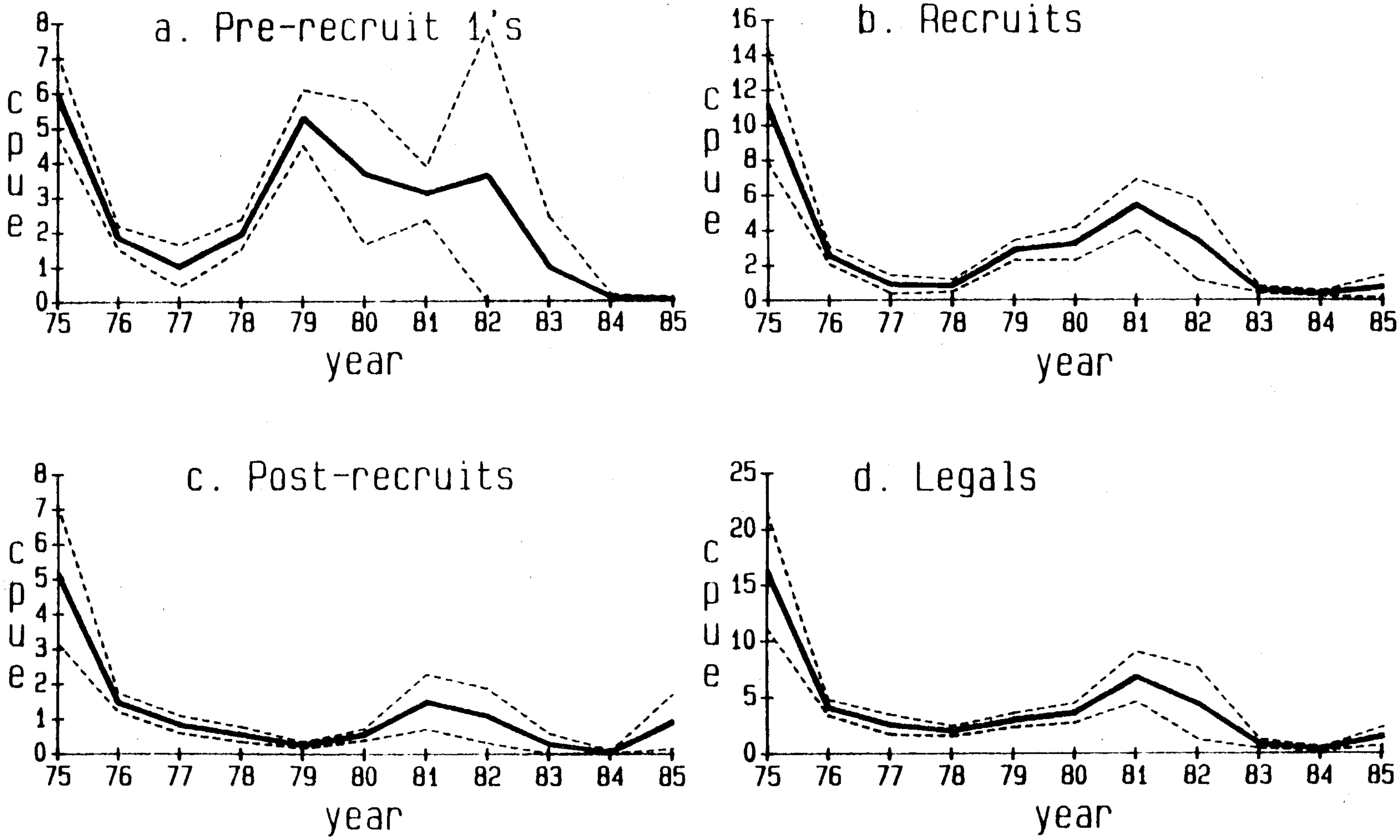

Figure 10. Mean stratified survey catch per pot and approximate 95% confidence interval (two standard errors) for male (a) prerecruit-1, (b) recruit, (c) postrecruit and (d) legal king crab, 1975-1985, Kamishak District.

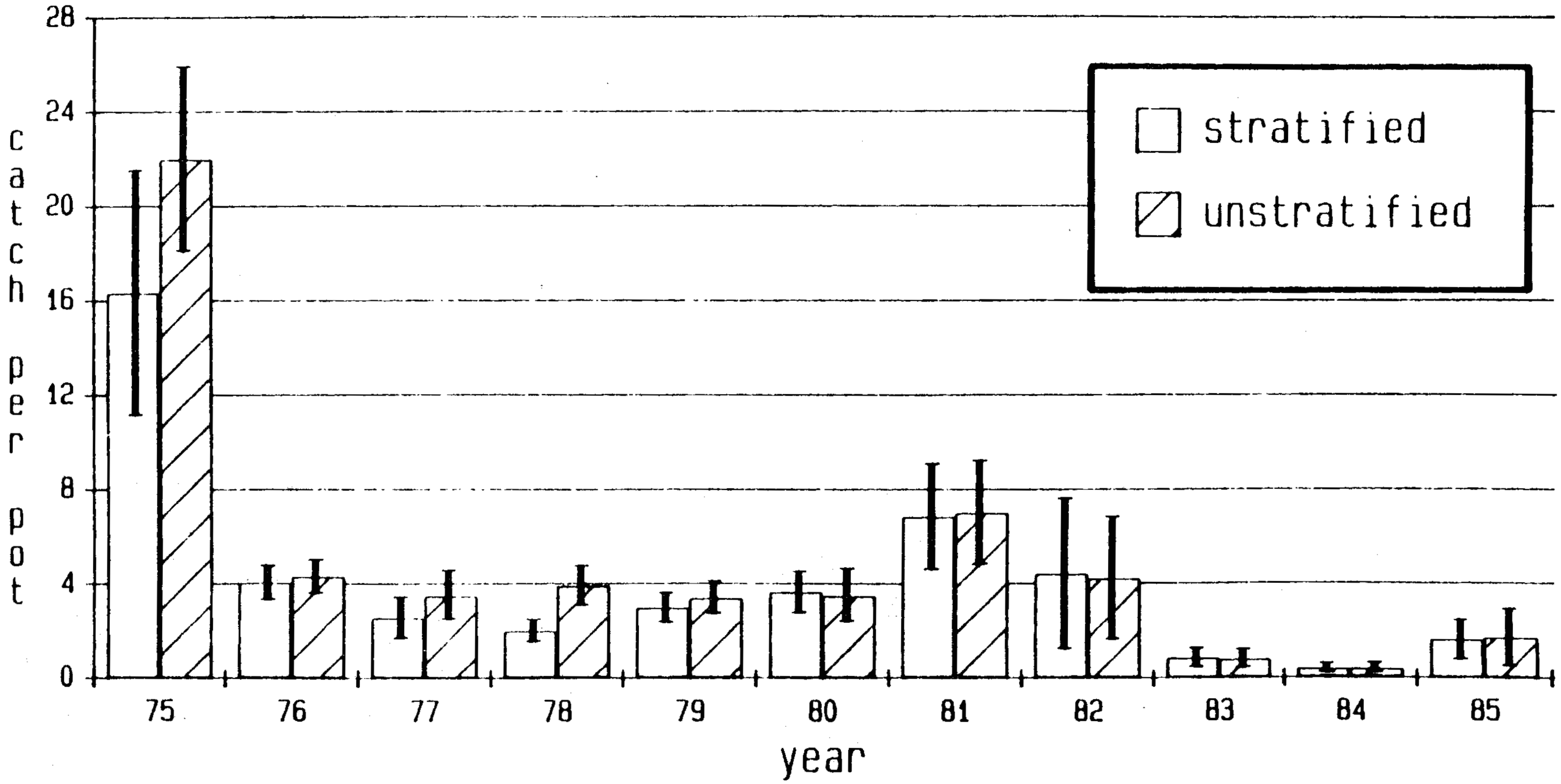

Figure 11. Comparisons between stratified and unstratified mean catch per pot and two standard errors (vertical bar) of legal male king crab in the Kamishak District by year.

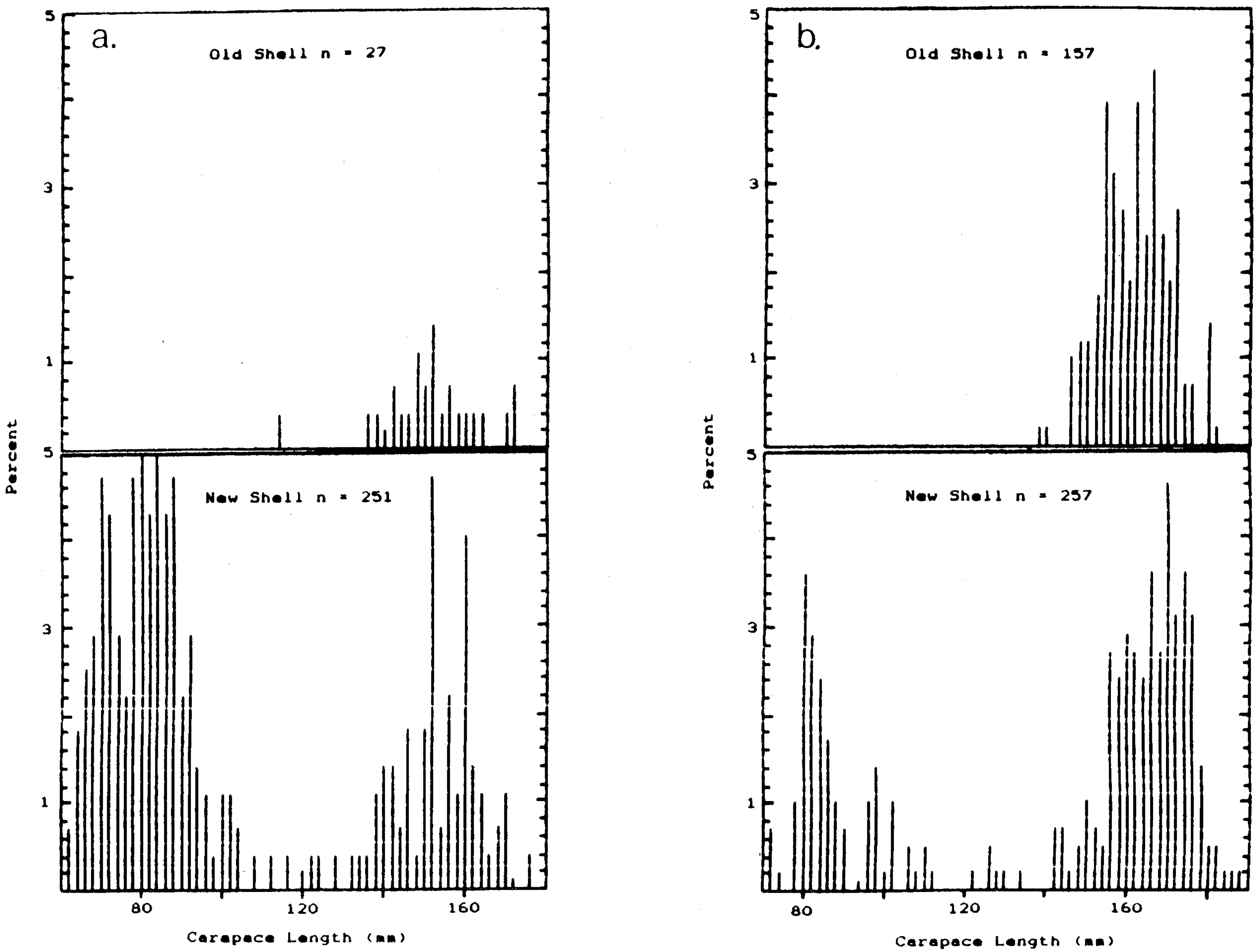

Figure 12. Male king crab carapace length frequency in 2-mm increments, Kamishak District index survey, (a) 1984 and (b) 1985.

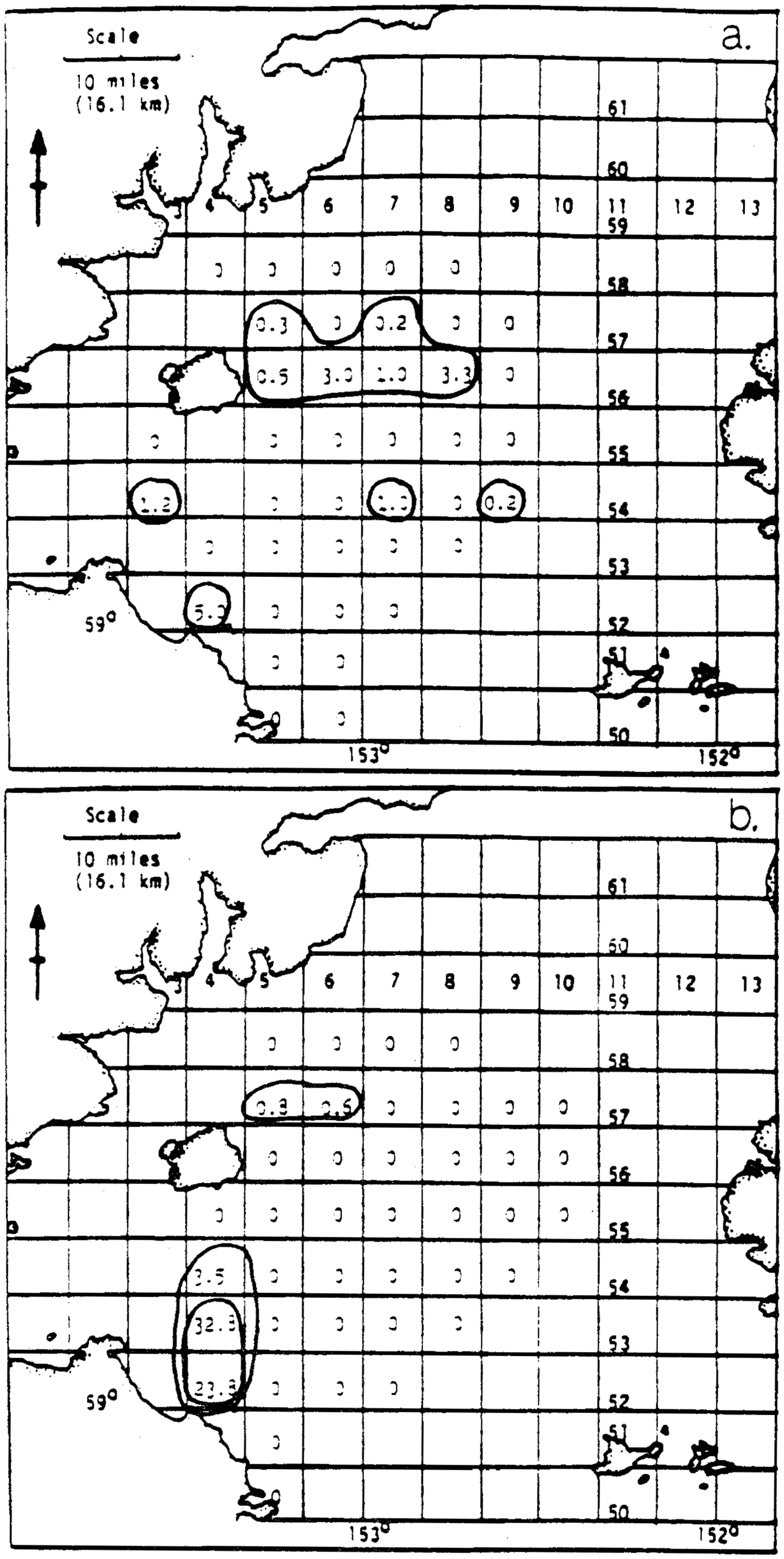

Figure 13. Average catch per pot of legal-sized male king crab captured during index fishing in the Kamishak District, over (a) 22 June - 2 July 1984 and (b) 17-27 June 1985.

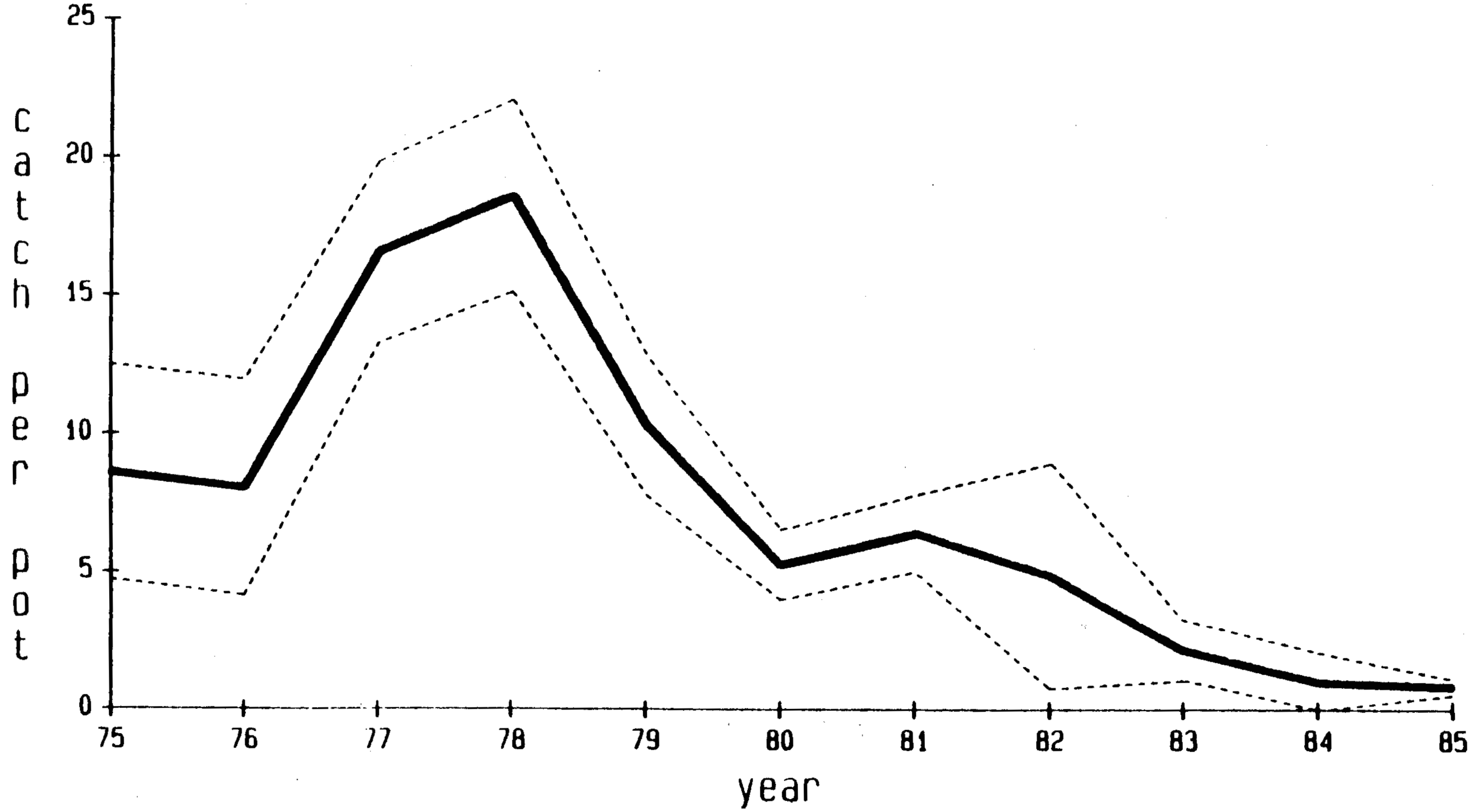

Figure 14. Mean stratified survey catch per pot and approximate 95% confidence interval (two standard errors) for mature female king crab, 1975-1985, Kamishak District.

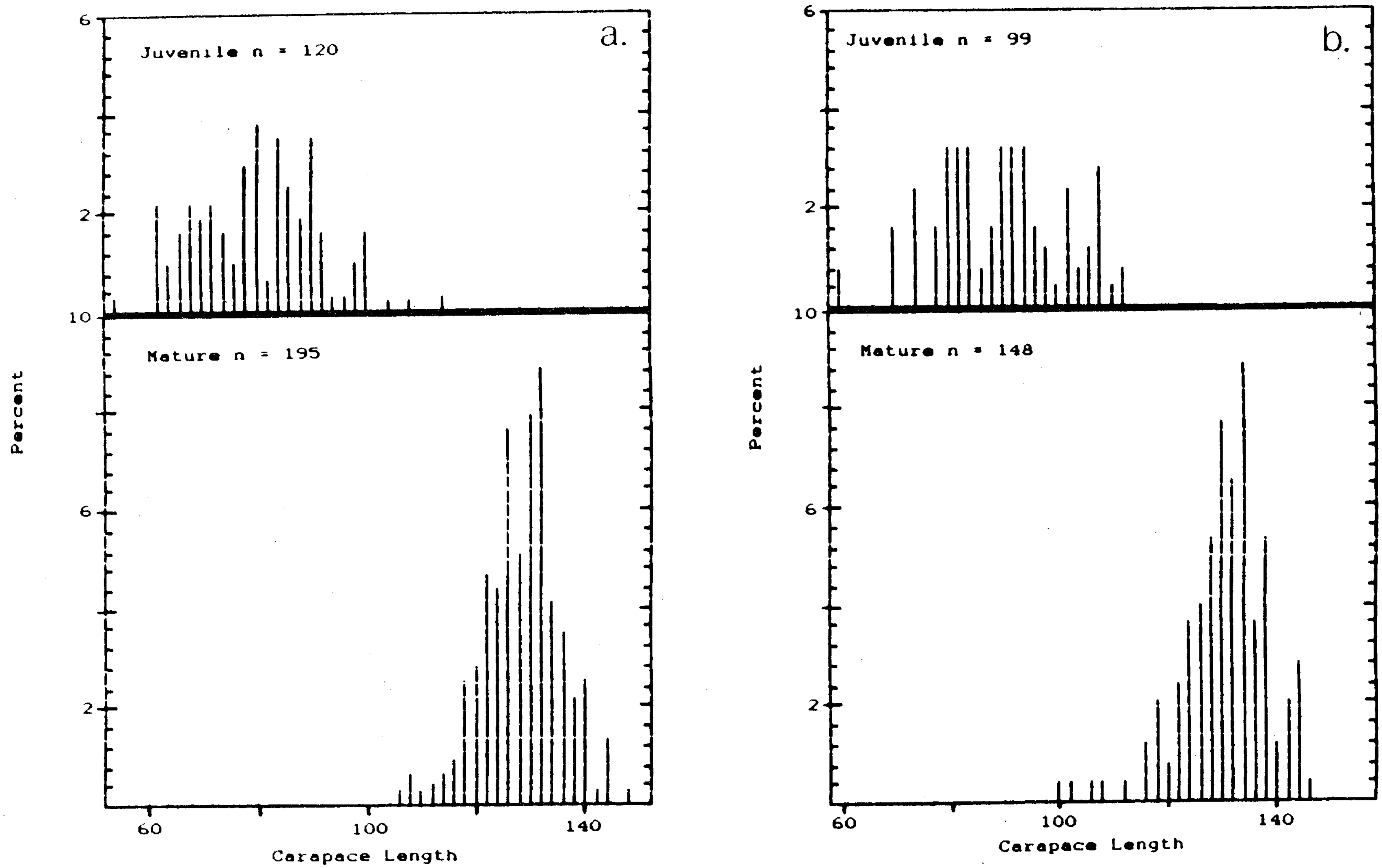

Figure 15. Female king crab carapace length frequency in 2-mm increments, Kamishak District index survey, (a) 1984 and (b) 1985.

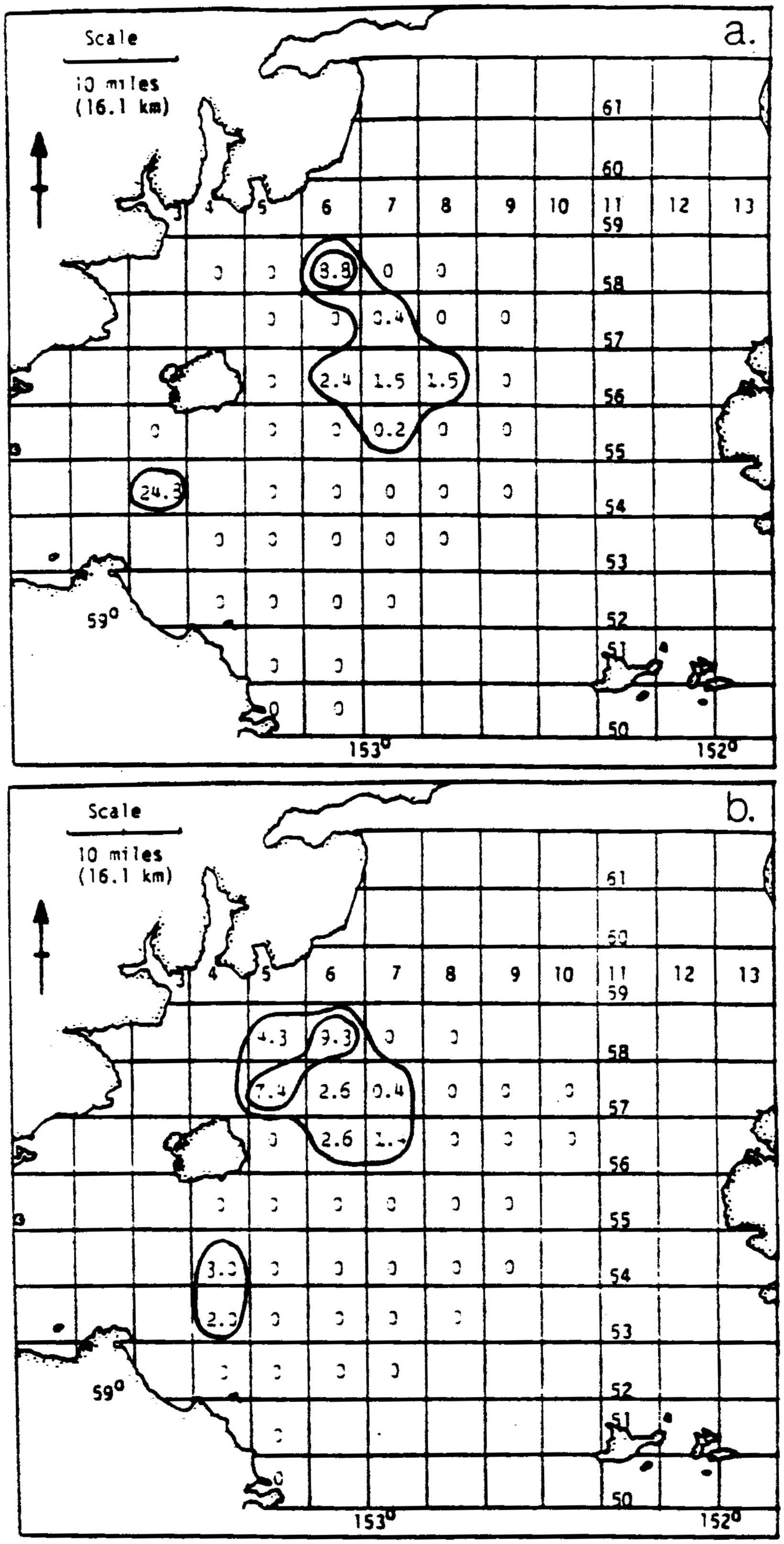

Figure 16. Average catch per pot of mature female king crab captured during index fishing in the Kamishak District over (a) 22 June - 2 July 1984 and (b) 17-27 June 1985.

APPENDICES

APPENDIX A. Notation used in calculations.

y = number of crab

j = pot

i = station

h = stratum

m = number of pots

n = number of stations

$\bar{y}$ = mean catch per pot within a station

$\bar{\bar{y}}$ = mean catch per pot within a stratum

$\bar{y}_{stsy}$ = mean catch per pot within a district

s_{1h}^2 = variance among station means

s_{2h}^2 = variance among pots within stations

N = total number of stations surveyed in the district

W_h = stratum weight (n_h / N)

z = size class (i.e 127-144 mm)

y_z = number of crab in size class z

Y = total number of crab captured

$\hat{p}_z$ = estimated proportion of males in a given size class z

$\hat{q}_z = 1 - \hat{p}_z$

F = fecundity (number of eggs)

x = carapace length in mm (i.e. 110 mm)

v = ovigerity category (i.e. 90-100%)

b_v = mean percent for ovigerity category v (i.e. v = 90-100%; b = 95%, which is the mean of v = 90 - 100%)

APPENDIX B. Male king crab tag release data.

Tag recovery data has been used in the management of the king crab fishery in lower Cook Inlet since 1974. Tags returned by the fleet are used to calculate Petersen estimates of absolute population size (Ricker 1975). Closure of the king crab fisheries since 1982 has prevented calculation of the Petersen estimate of abundance. However, legal males are still tagged and released during the survey.

In 1984, all legal-sized king crab captured were tagged with hog ring spaghetti tags clamped through the isthmus; in 1985, spaghetti tags were sewn through the isthmus with needles dipped in betadine. Tagged crab were relased where captured.

During the 1984 and 1985 Southern District surveys, 414 and 273 legal males, respectively, were tagged and released at their point of capture. During the 1984 and 1985 Kamishak District surveys, 72 and 314 legal males, respectively, were tagged and released at their point of capture.

Incidental tag returns were too few in number to be used in the calculation of Petersen population estimates.

APPENDIX C. Parasitic infestations of king crab eggs.

Since 1982, biologists in Cook Inlet have been interested in the fecundity of female king crab as it relates to population abundance. It is theorized that declines in percent egg clutch fullness in females was a factor in the decline of male king crab abundance in Cook Inlet, and other state waters. Accordingly, a contract was initiated with researchers at the University of California to provide assistance in analyzing egg samples for viability and the presence of egg predators.

In 1984 and 1985, samples of king crab eggs were collected from one location (Station P20) in Kachemak bay to monitor the prevalence of parasitic infestation and egg mortality through time. The fourth pleopod was clipped from the first 14-28 females captured, preserved in 5% formalin, and shipped to Dan Wickham at the University of California for analysis. During the 1985 survey, king crab eggs were taken systematically (every 50th mature female) to determine the incidence of parasitic egg infestations in the sampled population in July.

An apparent seasonal cycle of egg infestation by a nemertean worm predator exists (Wickham et al. 1985). Worm density per 100 eggs was .002 - .01 in samples taken during March and April 1984, and increased to 30-100 by September. Likewise, by November 1985, worm density in samples had increased to 60-100 (A. Kuris. University of California, Santa Barbara, pers. comm., 1986). Prevalence of worms in eggs masses was 10-20% in March and April 1984, and increased to 100% by June.

Egg mortality closely followed the rise in worm density through the late summer and fall months. The percentage of dead eggs was less than 1% in samples taken in March and April 1984, but by June egg mortality ranged from 1% to 50%. Likewise, in July 1985 the percentage of dead eggs in samples was high (A. Kuris, University of California, Santa Barbara, pers. comm.,1986).

Systematic sampling indicated that females throughout the Kachemak Bay area were affected. Variance in nemertean density was greater through time than through space (D. Wickham. University of California, Bodega Bay Laboratory, pers. comm., 1986).

Observations of ovigerity (Figure 11) in females sampled for laboratory analysis of egg viability were biased in that visual examination did not provide information on the number of dead eggs in the clutch. For example, in June 1984 nearly all females sampled were estimated at 90-100% ovigerity. Later laboratory analysis revealed that dead eggs comprised up to 50% of some samples. This indicates that ovigerity estimates made shortly after egg extrusion must be corrected for egg mortality to calculate fecundity. It is not likely that this correction factor is constant between years.