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GROWTH OF THE ADULT MALE KING CRAB *PARALITHODES CAMTSCHATICA* (TILESIUS)

By DOUGLAS D. WEBER and TAKASHI MIYAHARA

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ABSTRACT

Estimates of the average growth rates of the eastern Bering Sea adult male king crab, *Paralithodes camtschatica*, are presented. Through examining the advancement of modal groups in size-frequency distributions collected in 5 successive years, the growth rate of the smaller adult male crabs is described. For the larger sizes the growth per molt observed in tagged individuals and the proportion of molting crabs observed in each year are combined in a theoretical model which represents the progression of a year class through time. The resulting growth curves calculated from the 1956, 1958, and 1959 data are strikingly similar and show that male crabs 80 mm. in carapace length will attain an average length of 168 mm. after 8 years of growth. Crabs growing at the rate depicted for 1957 would be 153 mm. in length at the end of an equal period.

GROWTH OF THE ADULT MALE KING CRAB *PARALITHODES CAMTSCHATICA* (TILESIUS)

By Douglas D. Weber and Takashi Miyahara
Fishery Research Biologists, BUREAU OF COMMERCIAL FISHERIES

A request for study of the southeastern Bering Sea king crab (*Paralithodes camtschatica* (Tilesius)) stock was made to the International North Pacific Fisheries Commission by the United States Government in February 1954 in accordance with Article III, Section 1, (c), (i) of the International Convention for the High Seas Fisheries of the North Pacific Ocean, for the purpose of ". . . determining need for joint conservation measures of the Contracting Parties conducting substantial exploitation of that stock." (The Contracting Parties in this instance are Japan and the United States.)

The Bureau of Commercial Fisheries Biological Laboratory in Seattle, Washington (then Pacific Salmon Investigations) was assigned this study for the United States. Investigations began in 1954, with emphasis on factors governing yield, e.g., growth recruitment, mortality, and abundance.

In compliance with part of the request, this report presents an estimate of growth of adult male king crabs of the eastern Bering Sea and describes methods employed. Although growth of all king crabs is being studied, that of adult males has been given priority, because the commercial fisheries are concentrated on them and need for their conservation must, therefore, be determined first.

The authors are indebted to many individuals who contributed toward this study. The Nippon Suisan Company, J. E. Shields Company, and Wakefield's Deep Sea Trawlers, Inc. cooperated in recovering tagged crabs; Seiwa Kawasaki, biologist of the Japan Fisheries Agency, recorded very complete tag recovery information, a major contribution; F. C. Cleaver and R. A. Fredin, advised and aided us throughout the study, and T. H. Butler, A. E. Peterson, and W. F. Thompson provided helpful comments concerning the treatment of data.

BACKGROUND INFORMATION

The king crab, being a decapod crustacean, has a typical rigid exoskeleton which prevents a change in carapace dimensions except at molting. Consequently the growth of an individual consists of a series of steps, the frequency of which decreases as the animal increases in age or size. An exception is the mature female king crab, which molts annually prior to egg extrusion, often without appreciable increase in carapace dimensions.

At molting the entire exoskeleton is cast along with the mouth and stomach parts, gills, tendons, and other structures of ectodermal origin. Since all hard parts of the body are lost, determination of growth must be achieved by means other than those applicable to animal forms which have permanent records of seasonal growth such as may be found on the scales of fish.

Several methods have been used to study growth of king crabs. Most of the studies were made by Japanese scientists and depend upon one or combinations of three basic types of data: Growth increment per molt and frequency of molt; size-frequency distributions from 1 year which show modes that are indicative of year classes; and size-frequency distribution data taken in successive years to observe the progression of weak or dominant year groups through the years.

Wang (1937) described growth rates for young crabs, as interpreted from an examination of modes in size-frequency distribution and for the older crabs by following the progression of modes in size-frequency data collected in 3 successive years. Marukawa (1933) studied live tank-reared crabs and observed growth per molt and frequency of molt in conjunction with size-

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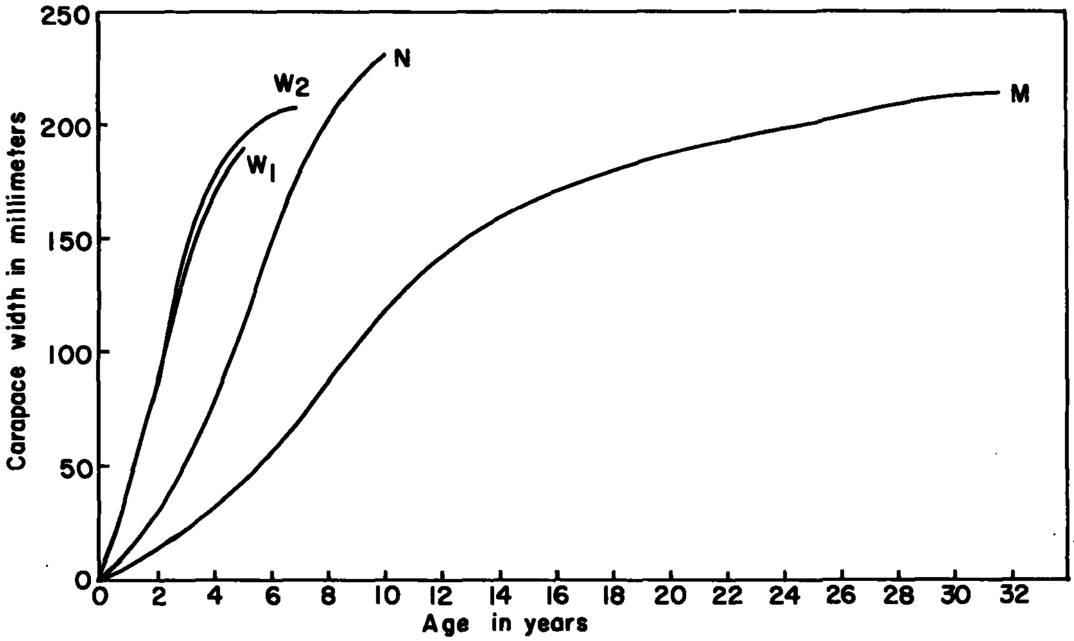

FIGURE 1.—King crab growth curves from published results. Curves W_1 and W_2 derived from Wang (1937) for crabs from Northern Hokkaido and Sakhalin, respectively; curve N derived from Nakazawa (1912); and curve M from Marukawa (1933).

frequency distributions. Nakazawa (1912) estimated growth of king crabs by combining data from his studies on king crab with published information on the frequency of molt and growth rate of *Homarus americanus* and *Cancer pagurus*. The growth curves described by the above investigators are presented in figure 1.[1]

Wide differences in growth rates are indicated, and though the difference may in part be due to geographic separation, it appears that there may be some errors in interpretation.

Wang (1937), graphically presents a size-frequency distribution which shows a mode at 45 mm., a second at 85 mm., and others centered at 115 mm., 135 mm., and 155 mm. From other size-frequency distribution data collected in 3 successive years, he observes weak and dominant groups progressing from 135 mm. to 160 or 165 mm. and then to 185 mm. Wang combines the two sets of data and interprets the first two modes in the size-frequency distribution to be indicative of sizes at ages 1 and 2, and then from the modal progression, the sizes at ages 3, 4, and 5, to be 135 mm., 165 mm., and 185 mm., respectively. Wang apparently does not interpret the increased frequency of 115-mm. crabs as representing a year class. Unfortunately, sufficient data are not presented to permit examination of his frequency distribution, and reasons are not given for excluding the 115-mm. group which is quite evident in the size-frequency distribution presented.

Wang's assignment of age 1 to the first mode in his sample (45 mm.) is not consistent with the findings of other researchers. Marukawa and Nakazawa both describe 1-year-old crabs to be of about 7 and 8 mm., respectively. Also, the Fisheries Agency of Japan (1958) reports that 3,084 juvenile crabs, ranging in size from 6 to 15 mm. in carapace length with a mean size of 9 mm. (carapace width, 8 mm.), were collected in the eastern Bering Sea in late May and early June of 1957. Since hatching in the eastern Bering Sea occurs in April and May and it is generally agreed that there is about a 10-week period of larval life be-

[1] Marukawa, Nakazawa, and Wang's results were presented in terms of carapace width, and are so shown in figure 1. However, most if not all king crab investigators are presently using carapace length measurements, since this dimension is more definite and the points of measurement are more resistant to flexing when measuring calipers are applied. The conversion from width to length for male king crabs may be made by the formula: carapace length=.14+0.925 (carapace width), for sizes less than 95 mm. in carapace width; and for sizes greater than 95 mm. the formula is: carapace length=1.84+0.744 (carapace width). These relations were calculated from length-width measurements of eastern Bering Sea king crabs.

fore the adult form occurs at 2 mm., it is unlikely that these 9 mm. crabs are of 0-age class, but are probably 1 year old.

Further, it is our belief that another year group between 8 mm. and 45 mm. is to be expected. In a study [2] of the growth of small crabs in Unalaska Bay, Alaska, we sampled at 4-month intervals from May 1958 through May 1959. By observing the progression of modes in these samples, we concluded that crabs sampled in May of 1958 were in their second year at a carapace width of 11 to 12 mm. and were in their third year at a carapace width of 37 mm. According to our data, a crab near the end of its third year of life would be approximately 45 mm. or larger. If geographic variation in growth is not great, it seems reasonable to expect that if crabs near Japan are about 8 mm. at age 1, then at age 2 they would be less than 37 mm., and 45-mm. crabs may be 3 years of age rather than 1-year-old as postulated by Wang. It would then appear that Wang's curve may be shifted 2 years to the right. Also the inclusion of another year group at 115 mm., as noted in Wang's size-frequency distribution, would tend to decrease the slope beyond 85 mm.

Marukawa (1933), in his comprehensive and informative paper on *Paralithodes*, presents a discussion on growth, including the curve shown in figure 1, in which males reach a maximum carapace width of 216 mm. in 31 years. A review of Marukawa's methods and results is presented by McKay and Weymouth (1935), who point out that the early modes in Marukawa's size-frequency data probably represent instars rather than year classes, and that later modes most likely indicate chance irregularities. We generally agree with the reviewers. Marukawa's size-frequency distributions of smaller crabs show modes at 7, 17, 25, 34, 42, and 53 mm., which he interprets as being year classes. As discussed in the previous paragraph, progression of modes in a series of size frequencies taken throughout a year indicates greater spacing between year classes than are shown in Marukawa's size distribution. Sato (1958), also points out that the 17, 34, and 42 mm. modes in Marukawa's frequency curve can be considered as instars. That modes in the larger sizes are due to chance irregularities is suspected, since our observations of growth increments resulting from one molt would span from 3 to 6 modes. Thus, if some of the early modes were considered instars rather than year classes, the lower portion of Marukawa's curve would be steeper and would shift the remainder of the curve to the left. Consideration of fewer age classes in the larger sizes would also steepen the curve, and it would approach maximum size more rapidly.

Nakazawa (1912) presented information that enabled construction of the curve shown in figure 1, but unfortunately he did not include the data upon which his annual growth increments were based. His curve, however, is intermediate between Wang's (1937), whose growth rate appears too rapid, and that of Marukawa's (1933) which appears too slow. Other investigator's results of growth studies have been examined but were not included, since sufficient data were not presented to enable constructing curves.

The reports examined and the curves presented in figure 1 show wide differences that, as stated earlier, seem to be mainly due to errors in interpretation, but may, in part, be due to actual differences in growth demonstrating the difficulties in estimating growth of king crabs.

The growth studies to be discussed in the remainder of this report pertain to the eastern Bering Sea king crab. Although sexual maturity appears to be attained from 85–95 mm., the term adult used in this report includes all crabs larger than 80 mm. in carapace length. Determination of growth for the smaller sizes is based on modal progressions in size-frequency distributions, since modes are fairly well defined and little is known of growth per molt and molting frequency in these sizes. In the larger sizes, year classes tend to overlap due to nonmolting crabs, and modes when evident are probably made up of various year classes. For this situation a method was developed which is dependent upon a composite of the amount of growth observed in tagged crabs and the proportions observed to molt in any particular year. The resulting growth curve for the larger sizes, therefore, takes into consideration both molting and nonmolting crabs.

[2] The results of this study are described briefly in a paper submitted to the International North Pacific Fisheries Commission for inclusion in the 1959 Annual Report.

SOURCES OF DATA

Each summer since 1955, a commercial fishing vessel has been chartered to otter trawl for samples at predesignated stations 20 miles apart. The stations sampled by year are represented in figure 2.

The gear used each year was similar to that described by Greenwood (1958). This trawl is commonly called a "400 eastern type."

At each station all crabs caught were measured to the nearest millimeter, shell conditions were noted, and males were tagged and released. Two measurements were taken. Length of carapace was measured from the posterior margin of the orbit of the right eye to the midpoint of the posterior margin of the carapace. Greatest width of the carapace between spines was also measured as a check on accuracy of length measurement since a definite relationship exists between length and width.

We recorded four shell conditions, soft, new, old, and very old, which are subjective classifications of the length of time since molt. The principal basis of classification are scratches and discolorations of the ventral basal segments of the appendages. A soft exoskeleton is indicative of a crab which has just molted, since after approximately 1 week the shell becomes firm and resists flexing. New-shell crabs have hard exoskeletons, the ventral surfaces of which are white and unscratched, and are presumed to have molted during the winter or spring immediately preceding the sampling period. Crabs with yellowish ventral exoskeletons and multiple darkly stained scratches are classified as old-shells and are judged not to have molted for one or more years. The very-old-shell condition is an extension of the old-shell and is characterized by an almost black ventral exoskeleton and dense growth of fouling organisms. The time since last molting is not well

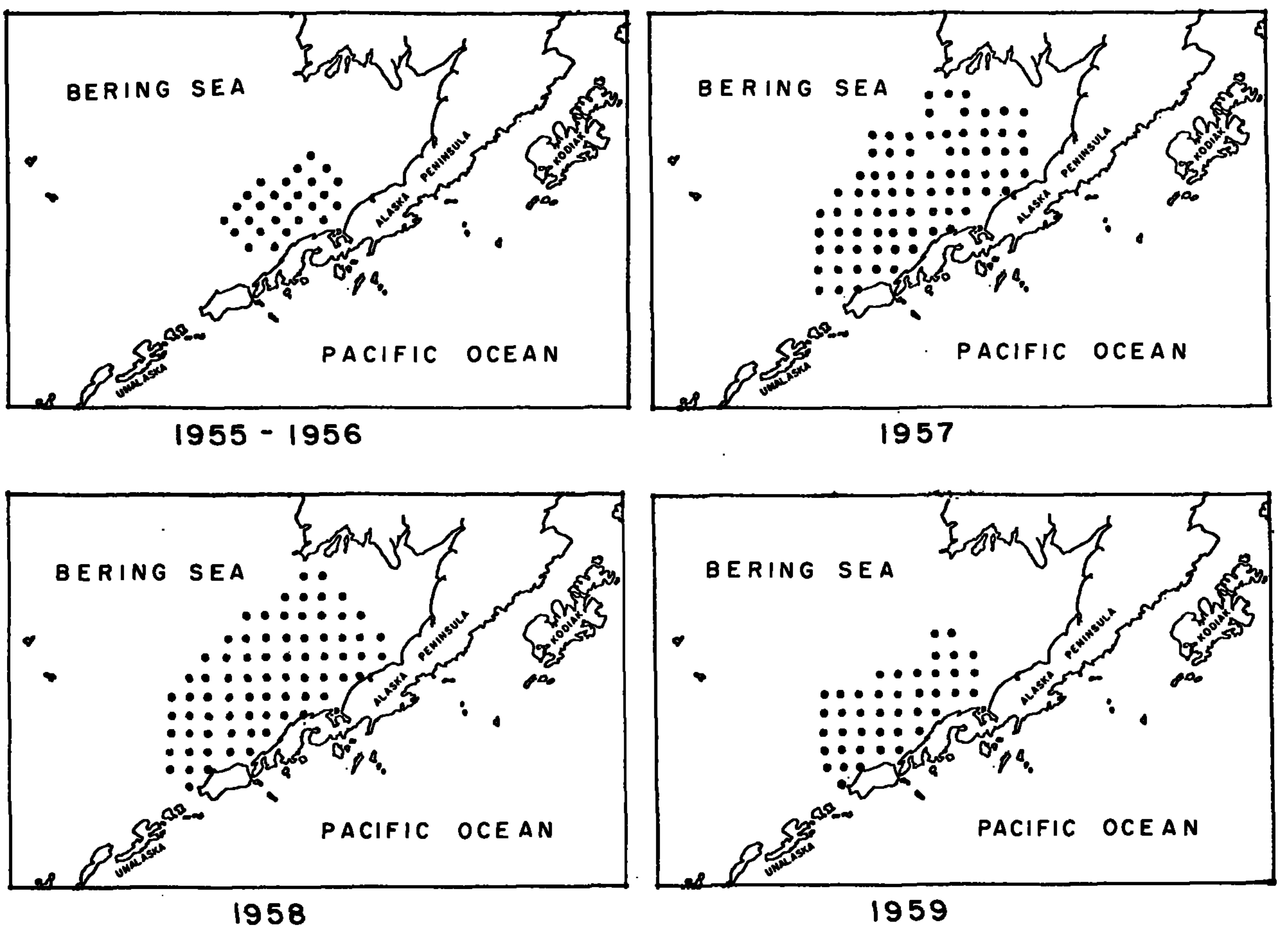

FIGURE 2.—King crab sampling stations for the years 1955 through 1959.

defined for the very-old-shell condition, but is believed to be noticeable in the second year after last molt. Individual fouling organisms which settle on the shell have not been considered as a measure of time since molting because the life cycle, such as time of setting and growth of these organisms in the Bering Sea is not known and would demand a separate study.

Shell conditions are the basis of determining molting frequency, and for the purpose of growth we are interested in those that molted in the current year and those that did not. In the remainder of this report soft and new-shell conditions are grouped as new-shell and refer to crabs that have molted in the current year, while old- and very-old-shell conditions are grouped as old-shell and refer to crabs which have not molted during the current year.

Since initiation of investigations in 1954, crabs have been tagged with either a Petersen disc-type tag on a leg or through the carapace, or with a spaghetti-type tag through the muscular isthmus between the posterior margin of the carapace and the abdominal region. Since Petersen disc-type tags are probably lost at molting, analysis of growth from tagged crab data has been restricted to recoveries of spaghetti-type tags which remain attached through molt.

Of 23,826 male crabs released with spaghetti-type tags in years 1955 through 1959, 1,103 have been recovered, of which 1,017 were returned with complete measurement data. Changes in sizes indicating growth were observed in 325 recoveries.

ADEQUACY OF DATA

Two population properties are assumed in this report. They are: (1) the growth of tagged individuals and the size frequency distribution samples are representative of the population, and (2) the same population is sampled each year. Support for these assumptions is provided from examination of our field observations which show: tagged crabs mix uniformly with the untagged crabs throughout the fishing area; repetitive sampling performed in 1956 and again in 1958 resulted in similar size-frequency distributions and percentages of shell conditions within each year; tagged crabs continue to be taken in successive years after release, and only in the Bering Sea. In addition, the sampling areas, particularly since 1957, are believed to include the major distribution of this population, since explorations by the United States Fish and Wildlife Service in 1949 (Ellson, Powell, and Hildebrand, 1950) and by the Japanese in 1957 (Fisheries Agency of Japan, 1958) revealed very few *Paralithodes camtschatica* in adjacent areas of the eastern Bering Sea.

In subsequent discussions, it will be evident that the 1957 data are anomolous with other years. The samples included fewer molters in the population, thus reducing the proportion of molting to nonmolting crabs. Examination of this feature shows that the 1957 data were collected later in the summer than in any of the other years. It is therefore possible that changes in distribution associated with this time period may affect the availability of new-shell crabs. That only new-shell crabs are affected is suspected by examination of all data which shows that the abundance of old-shell crabs appear relatively unchanged regardless of the time of sampling.

There is general agreement in published reports that male crabs larger than 110 mm. in carapace length, molt no more than once annually. From a study of shell conditions, Vinogradov (1945) established that the majority of the larger males molt once every 2 years. Also our records show that several tagged crabs were returned after 3 years with no evidence of molting.

The Fishery Market News (1942), Wallace, Pertuit, and Hvatum (1949) and discussions with fishermen indicate that the adult male king crab molting period and growth occur in late winter or early spring in the eastern Bering Sea. Our observations aboard chartered vessels show that soft-shell male crabs were caught only in May, and these have numbered one-tenth of 1 percent of the total number of males sampled. No male crabs in the molting or postmolting stages have been found in the summer and late fall surveys. Since growth takes place before our sampling periods, and there is no noticeable change in size-frequency distribution or shell-condition proportions during the sampling season, the crabs taken may be considered as representing an instantaneous sample.

The relation between time of molting and our period of sampling is an important part in differentiating, through the use of shell condition, the crabs that molted during the current year from those that did not molt. The crabs that molted in the winter and early spring have had their shells no more than 6 months at the time of summer sampling, whereas those not molting have had their shells not less than 1 year. Although shell condition is a subjective classification, the difference in discoloration and marking of the exoskeleton is distinct.

Confidence in the ability to distinguish between the current year molters and those that molted in the previous year may be shown by an examination of shell-condition classifications of tagged crabs, recorded at release and again at recovery. The bulk of the recoveries and the classifications, were made aboard the Japanese mothership by a biologist following, for the most part, our written description of the various shell conditions. Excluding all tagged crab recoveries showing changes in length measurements, and therefore indicative of having molted, there were 595 tag returns with shell-condition data available for study. Table 1 shows the shell conditions recorded at release and recovery of the crabs and their periods of freedom.

Of the 417 recoveries of new-shell releases, one recovered after a year of freedom was classified as new-shell, and by our criteria of shell conditions is considered in error. An additional six were classified as new-old, indicating some doubt. The six doubtful cases were recorded in 1956, and after the 1957 season the definitions of the shell conditions were made more explicit. Of the old-shell releases, two recoveries within the year of release were classified as new shells on recovery and are considered misclassified. The amount of error in classification appears to be no more than 1.5 percent and may be as low as 0.5 percent if the six doubtful cases are not included.

Table 1.—*Shell condition classification at recovery of nonmolting tagged crabs*

Shell condition at release	Shell condition at recovery	Periods of freedom			
		Within year	After 1 year	After 2 years	After 3 years
New-shell	New	[1] 25	1	0	0
	Old	0	306	76	3
Old-shell	New	2	0	0	----------
	Old	72	82	22	----------

[1] Six additional crabs were recovered but classified as new-old and are not included.

The amount of growth per molt is determined by an examination of the tagged crab measurement data that were taken at release and again at recovery. Preliminary analysis of the relation of width and length of tagged crabs indicated some measurement error. Therefore, width on length regression and a 99 percent confidence interval around this regression were calculated from a random sample of 744 crabs. All tag recoveries where measurements fell beyond the interval were not considered in the analysis. A few recoveries were also discarded due to illogical length to shell condition relations, for example, an increase in carapace length inconsistent with a logical change in shell condition.

In order to determine the range of measurement error, we examined 128 within-season tag recovery measurements (appendix table 2) reasoning that variations in measurements for this group must result from error or bias. Plotting the deviations of recovery from release measurements shows that 99 percent of the deviations lie between plus and minus 4.4 mm. This is shown graphically by the shaded histogram in figure 3.

All tagged crabs, that measured 5 mm. or more larger when recovered, and which had a corresponding increase in width, are considered to represent crabs that grew during their periods of freedom. The deviations of the lengths at recovery from the lengths at release for 325 male crabs depicting growth are shown by the unshaded histogram in figure 3. Considering the shell condition and the length of time at liberty, 15 crabs with length increments greater than 23 mm. were considered to have molted at least twice, and therefore are not used in the analysis.

GROWTH BY SIZE FREQUENCIES

Length measurements of all male king crabs taken during station pattern sampling each year since 1955 (Appendix table 1) were smoothed by a moving average of three; the resulting numbers at each millimeter of length were expressed as percentages of each year's total. Percentages were used to compensate for varying numbers between years. To emphasize the dominant size groups and their progressions, the percentage deviation of each year's size frequency distribution from the 1955 through 1959 mean distribution was calculated. The resulting yearly positive and negative deviations are plotted on figure 4. Examination

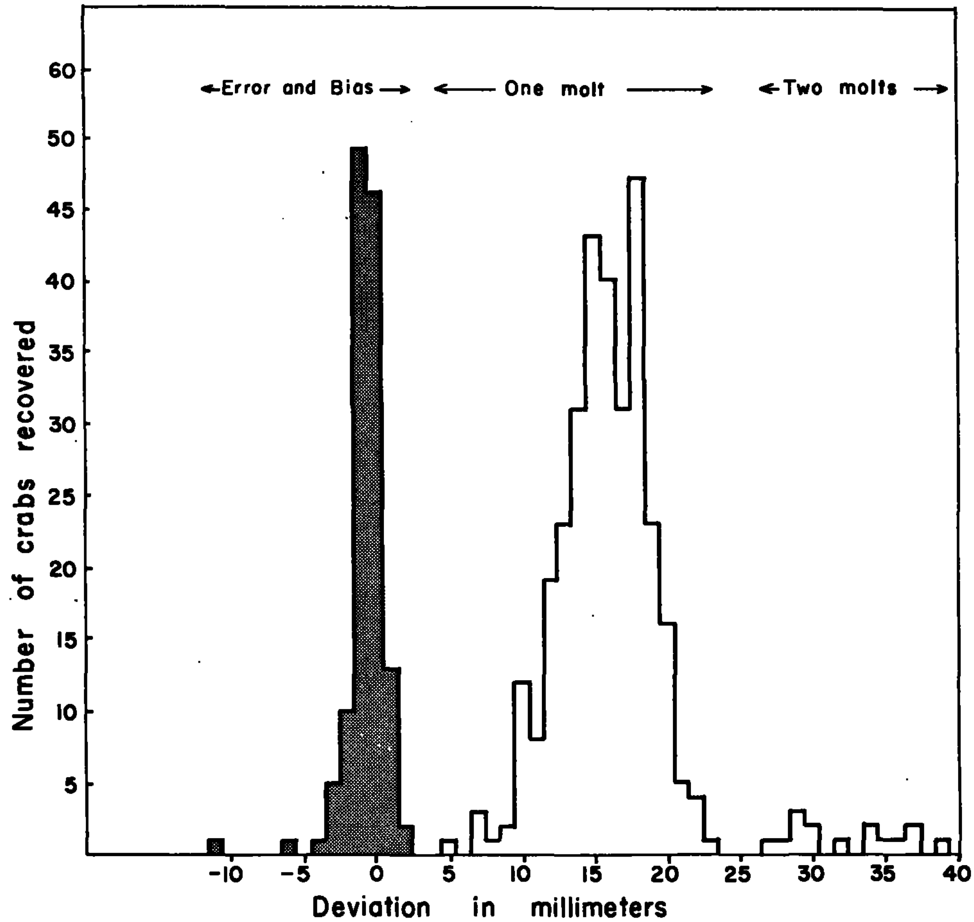

FIGURE 3.—Deviations of carapace length recovery measurements from release measurements. The shaded histogram represents 128 within-year tag recoveries. The unshaded histogram represents 325 tag recoveries showing growth.

of these deviations shows the presence and progression of at least two dominant size groups and one deficient size group. Since the juvenile crab studies have not progressed sufficiently to allow assignments of ages to the size groups represented, we have considered the size increase in relation to the time of entry into the sample of each dominant and weak group. These groups are designated for reference as A, B, and C.

TABLE 2.—*Range and mean size by year for size groups A, B, and C in figure 4*

Year	Size (mm.)					
	Group A		Group B		Group C	
	Range	Mean	Range	Mean	Range	Mean
1955	74-100	84.7				
1956	90-111	101.6	66-89	80.0		
1957	101-121	111.7	90-100	94.2	64-89	77.4
1958	122-141	131.7	101-121	111.3	84-100	92.3
1959	134-174	152.5	111-129	119.5	106-108	107.3

Dominant group A, shown first in the 1955 distribution, advances through the successive years to 1959 where it appears to include a rather wide range of sizes. Group B, which is characterized by a scarcity of crabs, is observed to progress from 1956 through 1959. Dominant size group C first became evident in 1957 and appears to be reduced after 2 years' progression. The reduction of group C is, in part, due to the method of using deviations from a mean, in which the strength of one size group, such as indicated by A in 1956 and 1957, may affect the plotted strength of another.

In order to present more clearly the progressions of these groups, the range and mean lengths were calculated, and are listed in table 2. In figure 5, the progressions of mean values of each group are plotted on years after first entry in the samples. Also included is the mean progression

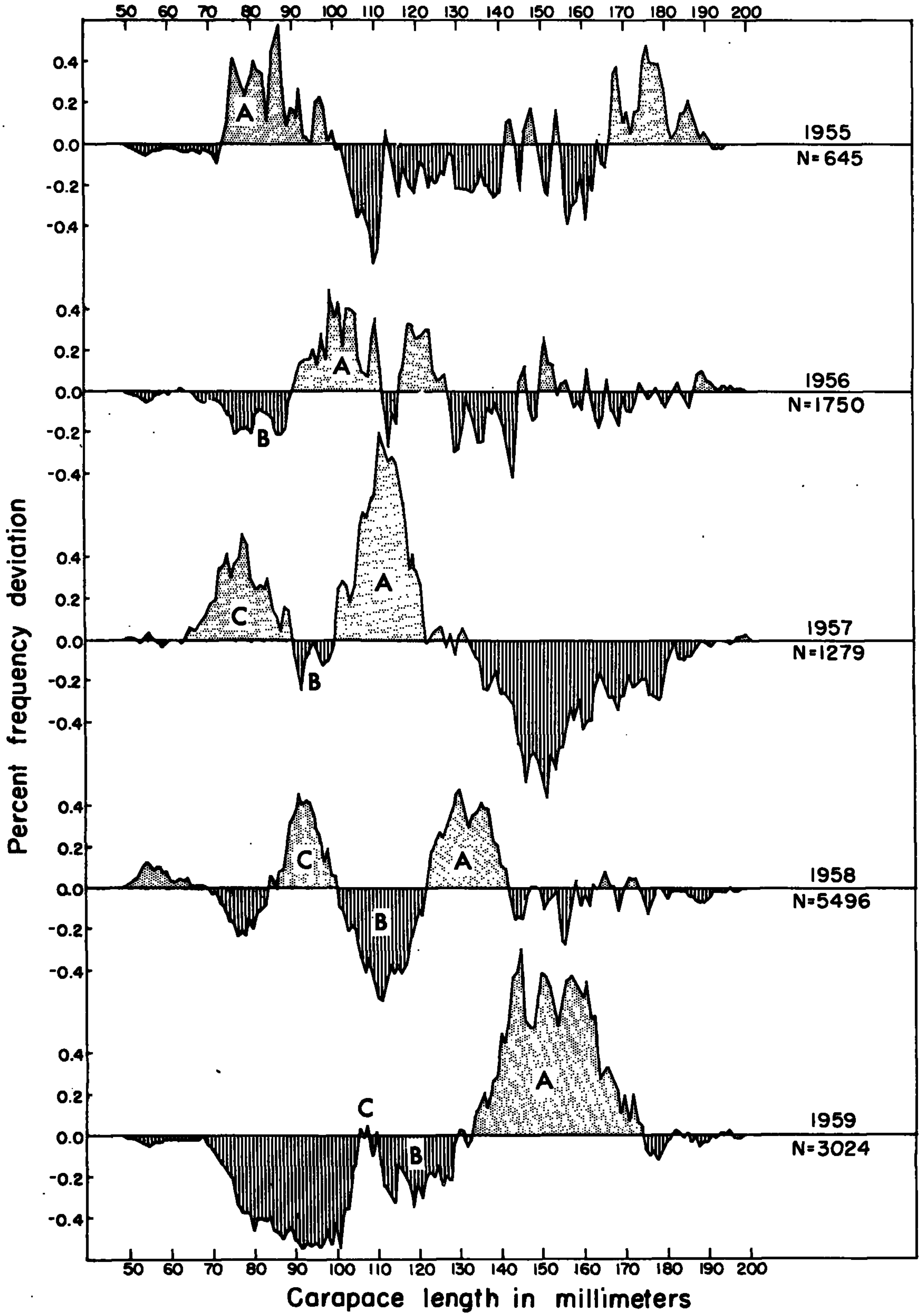

FIGURE 4.—Annual deviation from the 1955 through 1959 average size frequency expressed in percentage and smoothed.

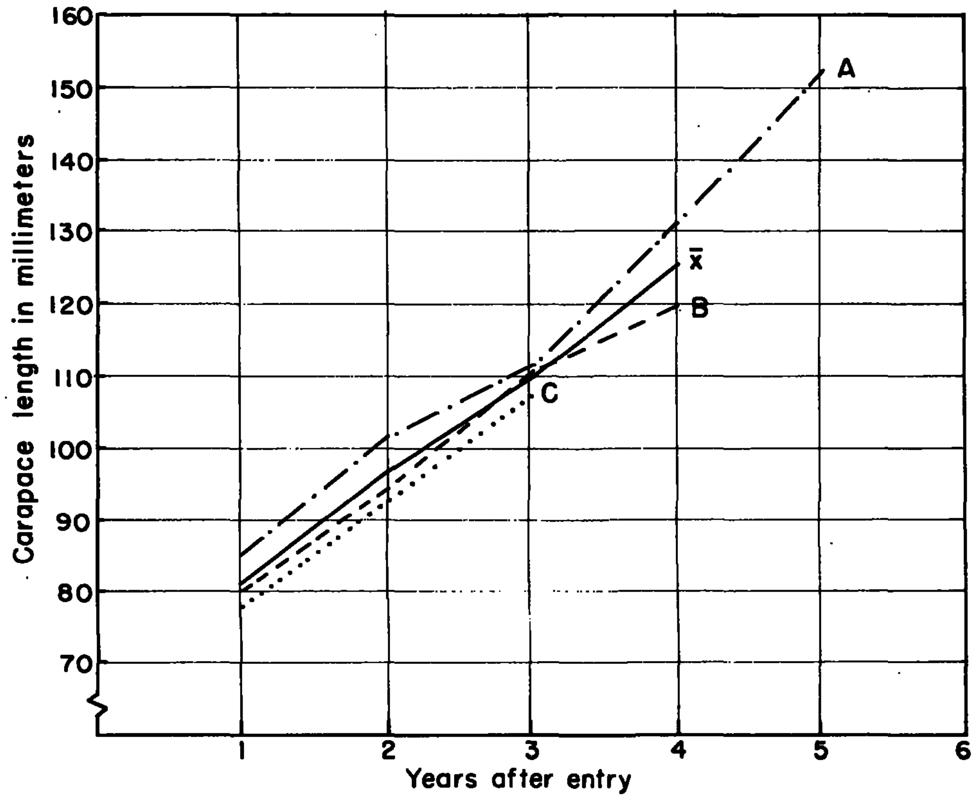

FIGURE 5.—Progressions of the mean values of size groups A, B, and C. x̄ denotes the progression of the mean of the size group means.

of these means which shows a relatively constant increase of approximately 15 mm. per year.

Although modes other than those discussed were evident, only the more prominent ones in the smaller sizes were considered. This selection was guided by the suspicion that due to the lesser frequency of molting in the larger sizes, an overlapping of year classes occurred, and the modes or means of individual classes became unidentifiable. To alleviate the problem of attempting to define annual growth in the large adult male king crabs by following the progressions of distinctively weak or dominant modes, another method was developed, which involves the determination of growth in length per molt and the proportions molting.

GROWTH INCREMENT PER MOLT

Three hundred and ten tagged and recaptured crabs representing growth from one molt (appendix table 3) range in size from 98 to 169 mm. before molting. The carapace length at release and the observed growth increments for these crabs are shown in figure 6.

The straight line shown in figure 6, fitted by the method of least squares, represents the regression of growth increment on size for the size range of our data. It is recognized that a second degree polynomial ($\hat{Y}=-62.989+1.1410X-0.0041X^2$) better fits the data, significantly reducing the mean square from 8.994 to 8.233. However, growth curves based on linear and curvilinear regressions were compared and it was found that the maximum difference at any one point between the curves did not exceed 2 mm. Since the use of a straight line regression simplifies subsequent discussions, and results are not appreciably affected, we have considered the growth increment for one molt as being represented by the straight line regression in figure 6. This line is expressed by the equation $\hat{Y}=13.14+0.018X$. The mean expected growth increment, $\hat{Y}$, varies from 15.1 mm. for a carapace length of 110 mm. to 16.0 mm. for carapace length 160 mm., a difference of only 0.9 mm. Thus the growth increment of crabs of these

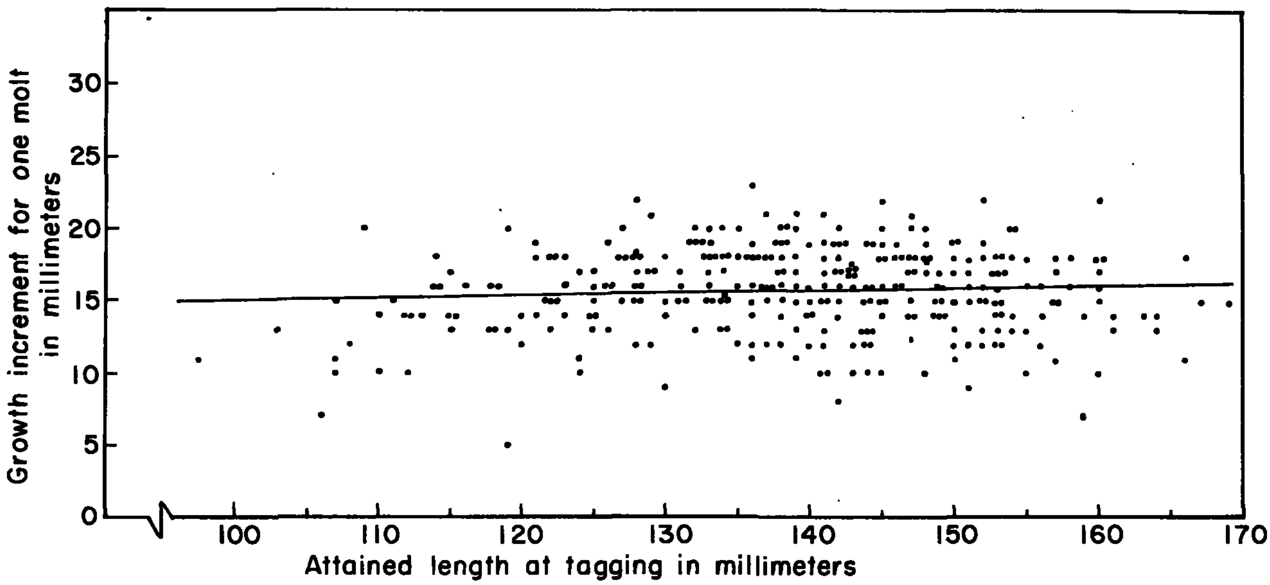

FIGURE 6.—Carapace length increment for one molt of 310 tagged crabs. The line represents the linear regression of growth increment on size as determined by the method of least squares.

sizes is essentially constant and for the purpose of this discussion we regard the growth increment per molt as being 16 mm. for all male crabs 110 mm. in carapace length and larger. Extrapolation of the regression line beyond 170 mm. may introduce error, but the results are not appreciably affected as only a small proportion of the crabs of these larger sizes molt.

AVERAGE ANNUAL GROWTH INCREMENT OF THE POPULATION

If all adult male crabs molted once annually, their growth would be described as an accumulation at the rate of 16 mm. per year. However, the small adults molt annually, but as they increase in size, molting occurs less frequently. Since we do not yet know the molting frequency of individual crabs, we cannot describe their growth rate. We can, however, determine the average annual growth of the population by adjusting the growth increase determined from tagged individuals by the proportions of molting crabs observed.

The numbers of non-molters (old-shell crabs) and molters (new-shell crabs) by size, observed in samples for the years 1956 through 1959, are shown in figure 7. Shell condition was not recorded in 1955.

Since all sizes of adult male crabs greater than 110 mm. in carapace length were shown to increase by approximately 16 mm. per molt, the new-shell distribution for each year was shifted 16 mm. to the left. This has the effect of returning the new-shells to their size prior to molting. We then smoothed both distributions by a moving average of 7 mm. and calculated the proportion of new-shell to old-shell crabs for each millimeter size class. The result of the transformation, using the 1958 data as an example, is shown in figure 8. By multiplying the proportions molting by 16 mm., the average annual growth increment of crabs greater than 110 mm. was calculated for each year's data and shown in figure 9.

AVERAGE GROWTH RATES

In any growth study it is highly desirable to define growth in terms such as the growth of individuals or of an age class. Until permanent records of growth are found in crabs, or tagged individuals are returned after prolonged periods of freedom, it is unlikely that the growth rate of individuals can be described. It appears possible, however, to estimate the average growth rate of a year class.

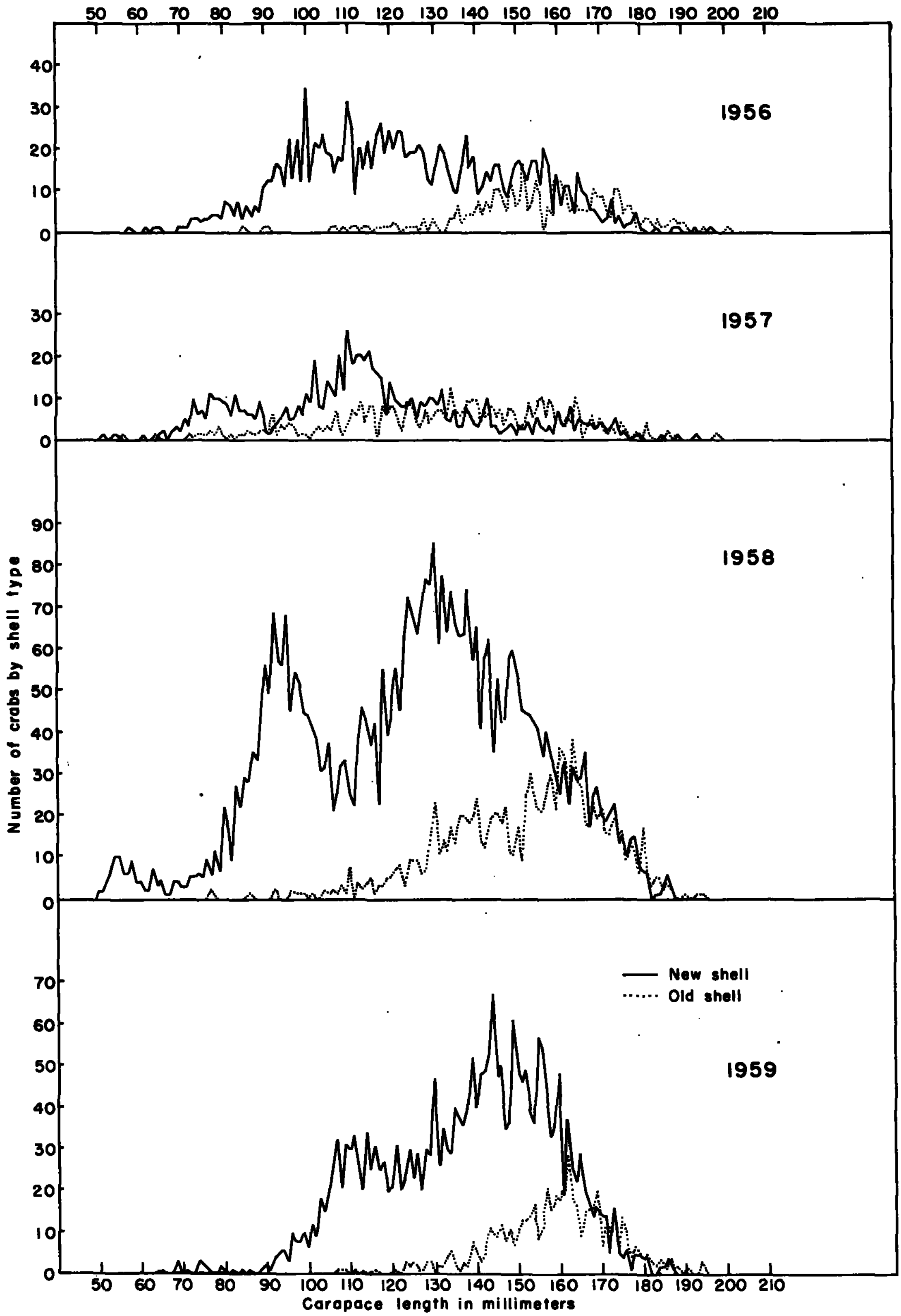

FIGURE 7.—Size-frequency distribution by shell condition for the years 1956 through 1959.

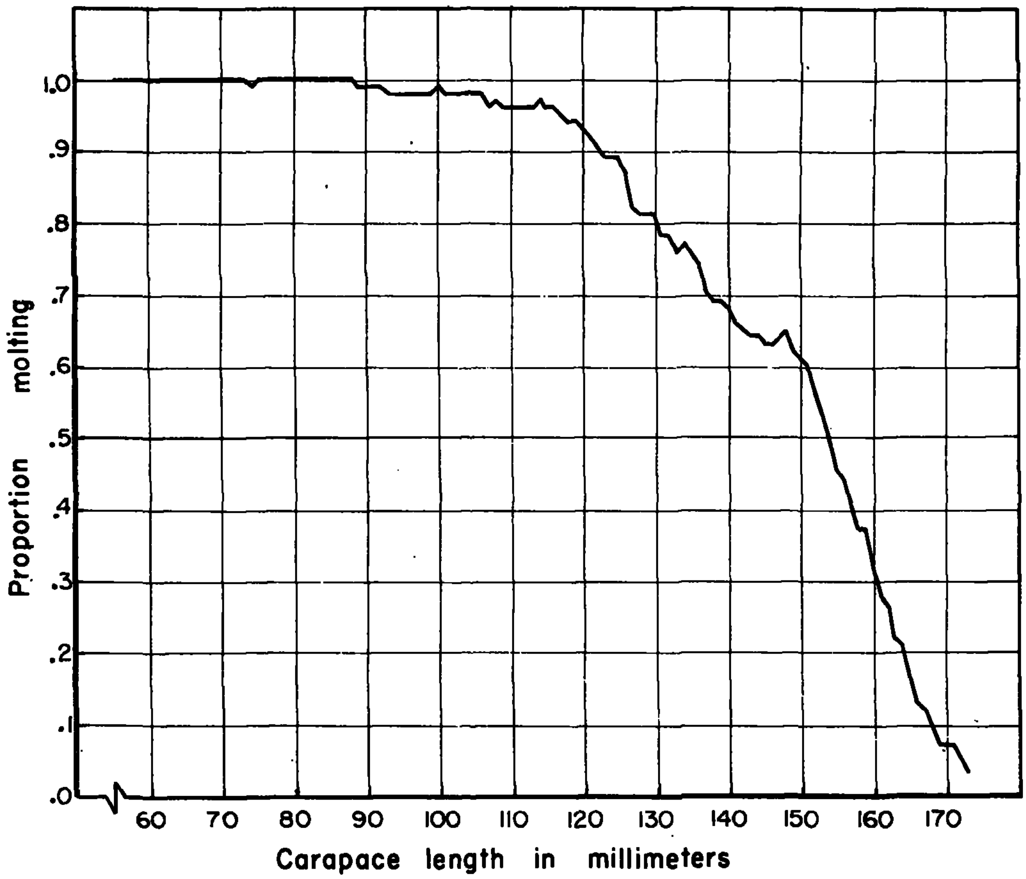

FIGURE 8.—Proportion of crabs molting, by size, as calculated from the 1958 sampling data.

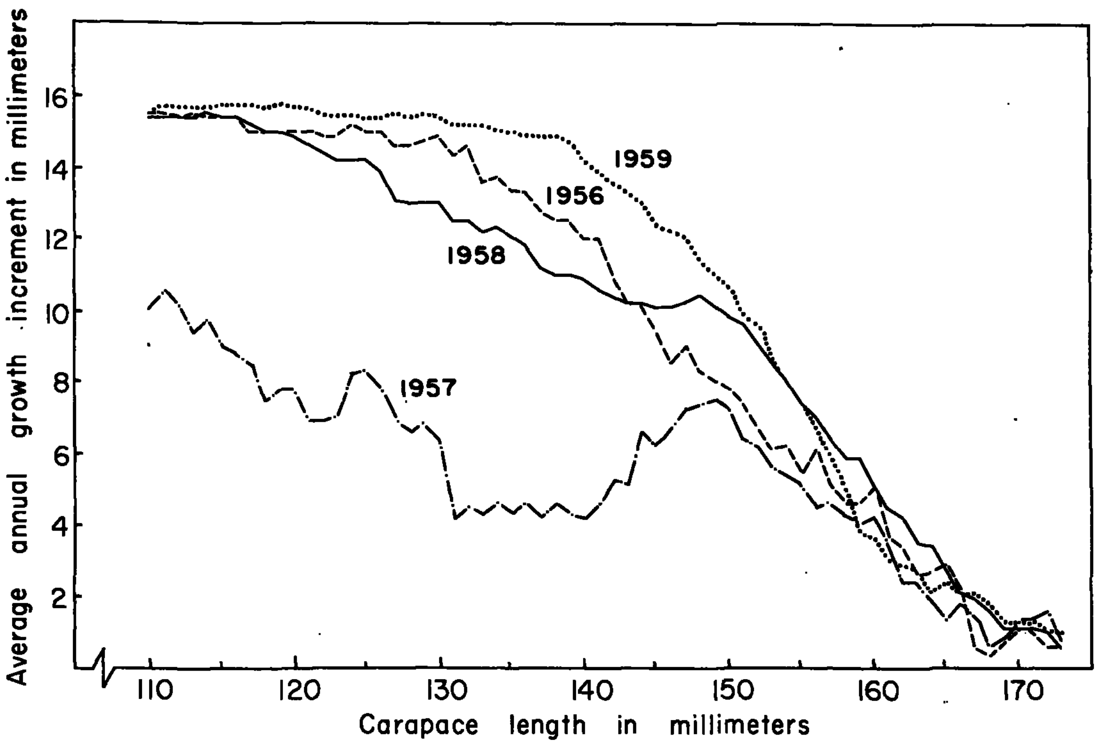

FIGURE 9.—Average annual growth increments for the years 1956–59.

The simplest method of estimating the average growth rate would appear to be a stepwise accumulation of the average annual growth increments. For example, using the 1958 data (fig. 9) and assuming that the growth increments represent growth potential in terms of length, crabs 110 mm. in length at some single age N would, on the average, increase in size by 15.4 mm., resulting at age $N+1$ in an average size of 125.4 mm. The average annual increment for 125.4 mm. crabs can then be added to determine the size at age $N+2$, etc. It can be seen that the average annual increment is the average amount of growth for all crabs of a size, and that the proportions used are made up of crabs that have, and those that have not, molted. The resulting relation of size with time by this accumulating process is, therefore, in terms of average size against average age.

To avoid the use of double averages, a method was developed to express the growth rate in terms of average size at a particular age. The method utilizes a model which we believe represents the growth of the eastern Bering Sea king crab stock, and depicts the advancement of a size group through 6 years.

We will examine a hypothetical group of 10,000 male crabs under the assumption that the attained sizes of several year classes in one year are representative of the growth of one year class from year to year. Basic inferences derived earlier in the report from tagging and from the sampling data for 1958 are utilized in a hypothetical model. These are: (1) when male king crabs 110 mm. and larger molt, the carapace length increases by 16 mm., and (2) the proportion molting by 16 mm. intervals (fig. 8) are: at 110 mm. carapace length, the proportion molting, P is 0.96; at 126 mm. $P=0.87$; at 142 mm. $P=0.65$; at 158 mm. $P=0.37$; and at 174 mm. $P=0.03$. Since there were no crabs larger than 195 mm. taken in 1958, we assume P at 190 mm. to be 0.02, allowing for a slight decrease in molting frequency.

The smallest size considered in the model is 110 mm., a size generally common to the progressions of modes described previously. Since most, if not all, crabs less than 110 mm. molt at least annually, and the modes in size frequency distributions of these sizes are quite definite, we assume that 110 mm. crabs in the model are all of one age class at N years of age. The sizes, numbers, and average size present in each of the successive years from age N to age $N+5$ are calculated and shown in table 3. At the end of the first year, since 96 percent of the 110-mm. crabs molt and 4 percent do not molt, the age group has been segregated into two size classes with an average length of 125.4 mm. The following year the crabs are of age $N+1$, and the 110-mm. crabs ($N=400$) and the 126 mm. crabs ($N=9{,}600$) are calculated to be distributed in varying numbers in three size classes consisting of 16 crabs remaining at 110 mm., 1,632 crabs at 126 mm., and the remaining 8,352 advancing to 142 mm. In this manner, at the end of the year of age $N+5$, five size classes are represented, the average length of the year class being 167.8 mm.

The 1956, 1957, and 1959 data are treated in the same manner, and the average lengths for each age for all years are tabulated in table 4. The growth curves based on the average sizes for each age are shown in figure 10. Both the table and the figure include an extension below 110 mm. to ages $N-1$ and $N-2$. The extension is the mean of the means of the progression of modes in the size frequency distribution discussed earlier.

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TABLE 3.—*A model representing the advancement of one size group of crabs following the growth trend as observed from the 1958 sampling data*

[Explanation of symbols: *N*, age in years; *P*, proportion molting; *q*, old shell]

Beginning of year					End of year							
Age in years *N*	Number of crabs	Carapace length in mm.	Proportion molting *P*	(1-P) *q*	Number of crabs by carapace length (mm.) and shell condition: 110	126	142	158	174	190	206	Average size in mm.
N	10,000	110	0.96	0.04	[1] 400	9,600						
Total					400	9,600						125.4
N+1	400	110	.96	.04	[1] 16	384						
	9,600	126	.87	.13		[1] 1,248	8,352					
Total					16	1,632	8,352					139.3
N+2	16	110	.96	.04	[1] 1	15						
	384	126	.87	.13		[1] 50	334					
	1,248	126	.87	.13		[1] 162	1,086					
	8,352	142	.65	.35			[1] 2,923	5,429				
Total					1	227	4,343	5,429				150.3
N+3	1	110	.96	.04		1						
	15	126	.87	.13		[1] 2	13					
	50	126	.87	.13		[1] 6	44					
	162	126	.87	.13		[1] 21	141					
	334	142	.65	.35			[1] 117	217				
	1,086	142	.65	.35			[1] 380	706				
	2,923	142	.65	.35			[1] 1,023	1,900				
	5,429	158	.37	.63				[1] 3,420	2,009			
Total					0	30	1,718	6,243	2,009			158.4
N+4	1	126	.87	.13			1					
	2	126	.87	.13			2					
	6	126	.87	.13		[1] 1	5					
	21	126	.87	.13		[1] 3	18					
	13	142	.65	.35			[1] 5	8				
	44	142	.65	.35			[1] 15	29				
	141	142	.65	.35			[1] 49	92				
	117	142	.65	.35			[1] 41	76				
	380	142	.65	.35			[1] 133	247				
	1,023	142	.65	.35			[1] 358	665				
	217	158	.37	.63				[1] 137	80			
	706	158	.37	.63				[1] 445	261			
	1,900	158	.37	.63				[1] 1,197	703			
	3,420	158	.37	.63				[1] 2,155	1,265			
	2,009	174	.03	.97					[1] 1,949	60		
Total					0	4	627	5,051	4,258	60		164.0
N+5	1	126	0.87	0.13			1					
	3	126	0.87	0.13			3					
	1	142	.65	.35				1				
	2	142	.65	.35			[1] 1	1				
	5	142	.65	.35			[1] 2	3				
	18	142	.65	.35			[1] 6	12				
	5	142	.65	.35			[1] 2	3				
	15	142	.65	.35			[1] 5	10				
	49	142	.65	.35			[1] 17	32				
	41	142	.65	.35			[1] 14	27				
	133	142	.65	.35			[1] 47	86				
	358	142	.65	.35			[1] 125	233				
	8	158	.37	.63				[1] 5	3			
	29	158	.37	.63				[1] 18	11			
	92	158	.37	.63				[1] 58	34			
	76	158	.37	.63				[1] 48	28			
	247	158	.37	.63				[1] 156	91			
	665	158	.37	.63				[1] 419	246			
	137	158	.37	.63				[1] 86	51			
	445	158	.37	.63				[1] 280	165			
	1,197	158	.37	.63				[1] 754	443			
	2,155	158	.37	.63				[1] 1,358	797			
	80	174	.03	.97					[1] 78	2		
	261	174	.03	.97					[1] 253	8		
	703	174	.03	.97					[1] 682	21		
	1,265	174	.03	.97					[1] 1,227	38		
	1,949	174	.03	.97					[1] 1,891	58		
	60	190	.02	.98						[1] 59	1	
Total					0	0	223	3,590	6,000	186	1	167.8

[1] Old shell.

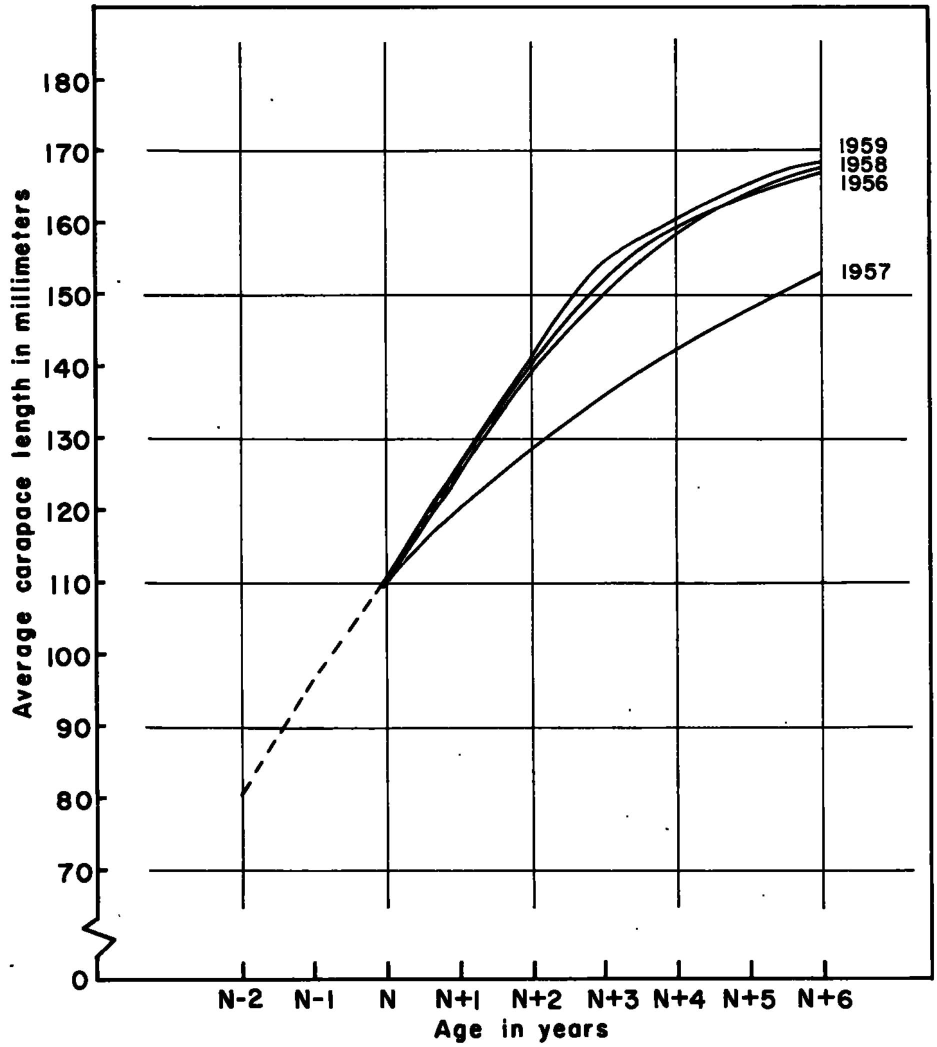

FIGURE 10.—Average growth curves of adult male king crabs for each of the years 1956 through 1959 as determined from population models (solid lines). The broken line extension represents the average progression of modes in the size frequency distributions. *N* represents an age in years at which crabs are 110 mm. in carapace length.

TABLE 4.—*Average size at each age of the southeastern Bering Sea population of adult male king crabs as determined from modal progression in size-frequency distribution and from growth per molt multiplied by the molting proportions in each size*

Age	Average sizes present by year			
	1956	1957	1958	1959
$N-2$	80.7	80.7	80.7	80.7
$N-1$	96.0	96.0	96.0	96.0
N	110.1	110.1	110.1	110.1
$N+1$	125.5	120.1	125.4	125.4
$N+2$	140.6	128.7	139.3	140.9
$N+3$	152.0	136.1	150.3	154.6
$N+4$	159.0	142.5	158.4	161.4
$N+5$	163.7	148.1	164.0	165.4
$N+6$	167.2	153.0	167.8	168.4

It would be unrealistic to extend the growth model beyond $N+6$, because very few crabs greater than 200 mm. in carapace length are taken in the eastern Bering Sea. In addition, from the curves presented, it appears that in most years the average length is approaching an asymptote, and any further increase in age will not greatly affect the average size of the year class.

DISCUSSION

The growth rates calculated from the 1956, 1958, and 1959 data show general agreement, but 1957 data suggests an appreciably lower rate. This is due primarily to the apparent lower proportion of molters in the 110- to 150-mm. carapace length range. In view of the discrepancy of the 1957 data, and because of the few years for which we have data, no attempt has been made to develop a single growth curve.

The model assumes that molting rate is a function of size. It might be questionable that crabs of any one size, which did not molt, will exhibit the same molting rate the following year. The molting proportion, P, used in the model are the proportions observed in the entire sample (population), and in the larger sizes undoubtedly includes several year classes with crabs of various shell conditions. The assumption that crabs of a common size, with varying time since the last molt, have equal molting rates is guided by the fact that the P's are averages of all molting rates that occur in the eastern Bering Sea; that is, the molting rates of new-shell and old-shell and, to a lesser degree, very-old-shell crabs make up P.

If molting rates of the various shell conditions differ widely, they must differ around P; that is, any large deviation of the molting rate of one shell type from P must be accompanied by a compensating deviation of one or both of the other. For example, if the molting rate of old-shell crabs is high, the molting rate of new-shell crabs would be low, and in any particular year of the age-class progression where old-shell crabs predominate, the average size would be greater than that indicated in the model. However, in the following year the increased number of new-shell crabs resulting from the high-molting rate of the old-shell crabs would be subject to the low molting rate of crabs having new shells. The result would be a lower average size of the year class for that year. The growth rate under such a condition would be step-like, and smoothing would result in a curve that would approximate that developed by considering P constant for size, as we have done.

Observed molting proportions may also be affected by other factors: (1) varying environmental conditions, (2) varying year class strength, (3) differential natural mortalities by shell conditions, and size. Our studies with respect to the above factors have not progressed sufficiently to measure their effect on molting proportions.

The model does not consider mortality. Although this may be unrealistic, mortality was not included since our measures of mortality rates are not yet definitive, and constant loss would not change the results.

There is no reason to expect appreciable differential natural mortality by size or age for the range of size and age being discussed here. It might be expected, however, that there would be a higher death rate of crabs that molt than those that do not. The effect of molting mortality is negated by the fact that molting proportions are based on numbers surviving; therefore, after the effect of molting mortality. Although there is some differential mortality due to fishing, since the fishery continually strives to catch the larger old-shell male crabs, this mortality is not evaluated in the model. The fishery operates concurrently with our sampling efforts, and at present there is no way to assess its effects. In addition, preliminary examination shows that the fishery, through 1959, takes a relatively small proportion of the king crab population as a whole.

For use in calculation of yield, it would be expedient to express our growth curves as mathematical functions. At present, however, the complexity of interdependence of growth, mortality, and recruitment precludes the mathematical formulation of a growth parameter which is suitable for analytical purposes. Either elimination or determination of the interaction of mortality and recruitment on our data must be resolved first; for prediction of yield under varying conditions requires that each parameter be independent or in terms of coefficients which represent the magnitude of their integrated effect. Also, the growth rate presented represents the average growth of the population by lengths and would, for the purpose of calculating yields, be more meaningful if presented in terms of weights. The king crab's live weight is, however, not very significant, since meat-weight is subject to wide variation for any one size, while body-weight remains essentially constant. Therefore, it seems more appropriate to discuss growth by weights and resulting yield in a study of productivity.

It would be desirable to compare the growth curves developed in this paper with those of Marukawa (1933), Nakazawa (1912), and Wang (1937), presented earlier. The Marukawa and Wang growth curves are based on size intervals between modes and progression of modes in size-frequency distributions which would tend to reflect the growth of only molting crabs. Nakazawa bases his curve on growth increment per molt and frequency of molt which he assumes occurs at least once a year. Thus, his curve would also reflect primarily the growth of only molting crabs. The curves developed in our paper, on the other hand, are weighted by the proportion of each size that does not molt and for the larger sizes particularly will show a slower growth rate. Therefore, the curves developed by the authors cited and those described in this report are not directly comparable.

Considering the rate of growth concerning juvenile crabs, as shown by the data of the above investigations and our observations in Unalaska Bay, we speculate that an 80-mm. crab ($N-2$) in the eastern Bering Sea may be about 4 years old. We hesitate, however, to place a precise estimate of size and corresponding age on our N values until the present juvenile crab studies are further advanced.

SUMMARY

During the 6 years (1954–59) the U.S. Fish and Wildlife Service has carried on a study of the southeastern Bering Sea king crab *Paralithodes camtschatica*. One phase of the investigations has been to estimate the rate of growth of the adult male king crab.

Estimating the growth rate required the use of three factors: (1) group progression in size-frequency distribution; (2) growth increment per molt; and (3) the proportion of each size molting in any given year.

Observations of size group advancement through 5 years of size-frequency distribution samples afforded an estimate of the growth rate for the smaller adult crabs. Results show that a size group of crabs averaging 81 mm. in carapace length attains a length of 126 mm. after three years—an annual growth increment of 15 mm.

Tagged crabs measured at release and again at recovery provided data indicating that the growth per molt is approximately 16 mm. for all crabs more than 110 mm. in length. The proportion molting for each size was calculated from observations on shell condition reported during each year of the station-pattern sampling program. By combining growth per molt and the proportion molting, the average annual growth increment of crabs greater than 110-mm. carapace length is calculated. The resulting curves for each year of sampling exhibited a rapidly decreasing average annual growth increment as the crabs increase in size.

The growth rate of crabs, greater than 110 mm. in length, was estimated by employing a model which represents the progression of a year class through time for each of the years 1956–59.

The growth rates as estimated from size-group progression and the model method were combined. The resulting growth curves calculated from the 1956, 1958, and 1959 data were quite similar, and showed that on the average, male crabs 80 mm. in carapace length will attain a length of 168 mm. after 8 years of growth. Crabs growing at the rate depicted for 1957 would be 153 mm. in length at the end of an equal period. The reduced growth rate for 1957 was due primarily to the lower frequency of molting recorded in the 110 to 150 mm. sizes.

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APPENDIX

The following tables of data on the king crab are those on which the figures and calculations in the text are based.

APPENDIX TABLE 1.—*Size frequency distribution and size frequency by shell conditions of male king crabs from sampling data taken in each of the years 1955–59*

Carapace length in mm.	1955 [1] total	1956			1957			1958			1959		
		Shell condition		Total	Shell condition		Total	Shell condition		Total	Shell condition		Total
		New	Old		New	Old		New	Old		New	Old	
50	-	-	-	-	-	-	-	2	-	2	-	-	-
51	-	-	-	-	1	-	1	2	-	2	-	-	-
52	-	-	-	-	-	-	-	4	-	4	-	-	-
53	-	-	-	-	-	-	-	6	-	6	-	-	-
54	-	-	-	-	1	-	1	10	-	10	-	-	-
55	-	-	-	-	1	-	1	10	-	10	-	-	-
56	-	-	-	-	-	1	1	6	-	6	-	-	-
57	-	-	-	-	-	-	-	6	-	6	-	-	-
58	-	1	-	1	-	-	-	9	-	9	-	-	-
59	-	-	-	-	-	-	-	4	-	4	-	-	-
60	-	-	-	-	-	-	-	4	-	4	-	-	-
61	-	-	-	-	1	-	1	2	-	2	-	-	-
62	-	1	-	1	-	-	-	2	-	2	-	-	-
63	-	-	-	-	-	-	-	7	-	7	-	-	-
64	-	1	-	1	-	1	1	3	-	3	1	-	1
65	-	1	-	1	1	-	1	4	-	4	1	-	1
66	-	-	-	-	2	-	2	1	-	1	-	-	-
67	-	-	-	-	-	-	-	1	-	1	-	-	-
68	-	-	-	-	2	-	2	4	-	4	1	-	1
69	-	-	-	-	3	-	3	4	-	4	3	-	3
70	1	1	-	1	2	-	2	3	-	3	-	-	-
71	-	1	-	1	5	-	5	3	-	3	1	-	1
72	-	1	-	1	3	1	4	5	-	5	-	-	-
73	1	3	-	3	10	-	10	5	-	5	1	-	1
74	2	3	-	3	6	1	7	6	-	6	3	-	3
75	3	2	-	2	7	1	[2] 9	5	-	5	2	-	2
76	5	3	-	3	5	1	6	9	-	9	1	-	1
77	7	3	-	3	11	2	13	6	2	8	-	-	-
78	2	4	-	4	10	1	11	11	-	11	-	-	-
79	4	4	-	4	8	3	11	7	-	7	2	-	2
80	6	3	-	3	9	1	10	22	-	22	-	-	-
81	5	7	-	7	8	-	8	17	-	17	-	-	-
82	5	6	-	6	6	1	7	9	-	9	1	-	1
83	5	4	-	4	11	-	11	27	-	27	-	-	-
84	5	7	-	7	7	1	8	22	-	22	1	-	1
85	3	3	1	4	7	1	8	29	-	29	-	-	-
86	10	6	-	6	6	2	8	28	1	29	1	-	1
87	6	4	-	4	6	1	7	35	-	35	-	-	-
88	5	6	-	6	5	1	6	33	-	33	-	-	-
89	3	5	-	5	9	2	11	44	-	44	1	-	1
90	3	10	1	11	4	2	6	56	-	56	2	-	2
91	8	12	1	13	1	1	2	49	-	49	1	-	1
92	3	12	-	12	3	6	9	68	2	70	4	-	4
93	7	16	-	[2] 17	4	1	5	57	-	57	5	-	5
94	4	15	-	15	6	3	9	56	-	56	6	-	6
95	3	11	-	[2] 12	8	2	10	68	-	68	3	-	3
96	7	22	-	22	5	4	9	45	2	47	10	-	10
97	9	13	-	13	5	3	8	54	1	55	8	-	8
98	4	22	-	22	8	1	9	51	1	52	8	-	8
99	5	12	-	12	6	1	7	45	1	46	10	-	10
100	7	34	-	34	11	1	12	44	-	44	7	-	7
101	4	12	-	12	9	-	9	42	1	43	12	-	12
102	5	21	-	21	19	2	21	38	-	38	9	-	9
103	6	20	-	20	8	3	11	31	-	31	18	-	18
104	3	23	-	23	7	2	9	31	2	33	15	-	15
105	3	19	-	19	14	3	17	37	1	38	21	-	21
106	4	18	1	19	12	2	14	21	2	23	27	-	27
107	3	14	1	15	15	7	22	26	1	27	32	1	33
108	5	18	-	[2] 19	20	3	23	32	3	35	21	1	22
109	3	17	1	18	12	1	13	33	1	34	31	1	[2] 33
110	4	31	-	31	26	4	30	25	7	32	30	-	30
111	2	24	1	25	18	7	25	22	-	22	33	1	34
112	6	9	1	10	20	6	26	35	4	39	26	-	26
113	10	20	-	[2] 21	20	9	29	46	2	48	20	1	21
114	8	15	1	16	19	4	23	43	3	46	34	-	34
115	5	21	1	22	21	8	29	37	5	42	25	1	26
116	6	15	-	15	17	8	25	42	1	43	31	1	32
117	5	23	1	24	16	1	17	23	3	26	25	-	25
118	9	26	1	[2] 28	15	8	23	55	3	58	27	-	27
119	3	19	1	20	6	7	13	39	5	44	20	-	20
120	5	24	1	[2] 26	14	8	22	43	5	[2] 49	21	1	22

[1] See footnotes at end of table.

APPENDIX TABLE 1.—*Size frequency distribution and size frequency by shell conditions of male king crabs from sampling data taken in each of the years 1955–59*—Continued

Carapace length in mm.	1955 [1] total	1956			1957			1958			1959		
		Shell condition		Total	Shell condition		Total	Shell condition		Total	Shell condition		Total
		New	Old		New	Old		New	Old		New	Old	
121	8	20	2	22	10	8	18	55	7	62	31	1	32
122	7	24	1	25	9	4	13	45	8	53	20		20
123	4	24		[2] 25	8	2	10	63	3	66	23	3	26
124	5	18	1	[2] 20	8	9	17	72	9	81	30	2	32
125	10	19	1	20	10	8	18	67	9	76	23	3	26
126	3	19	1	[2] 21	5	5	10	63	9	72	29	1	30
127	6	21		21	14	3	17	71	6	77	20	1	21
128	10	19	3	22	8	7	15	76	7	83	30	3	33
129	6	13		13	10	4	14	75	14	89	29	3	32
130	7	11	3	[2] 15	10	6	16	85	23	108	47		47
131	5	17	1	18	8	7	15	61	10	71	26	2	28
132	8	21		[2] 22	12	7	19	77	14	91	35	2	37
133	5	19		19	5	5	10	64	11	75	31	4	35
134	6	14	3	17	4	12	16	73	17	90	29	6	35
135	6	10	3	[2] 14	7	7	14	66	13	79	40	2	42
136	6	9	6	15	3	6	9	63	20	[2] 84	37	1	38
137	7	14	2	16	3	7	10	63	20	83	36	3	39
138	6	23	4	27	8	9	17	74	18	92	40	2	42
139	8	15	4	19	6	9	15	57	19	76	52	8	60
140	7	18	4	22	4	10	14	65	24	89	40	5	45
141	4	9	7	16	3	5	8	41	14	55	48	3	51
142	11	10	4	14	7	7	14	57	12	70	49	5	54
143	12	14	7	21	10	6	16	62	18	80	53	11	64
144	6	12	4	16	3	8	11	35	20	55	67	10	77
145	9	16	10	[2] 27	3	5	8	52	20	72	47	9	[2] 57
146	5	16	10	26	1	7	8	42	18	60	50	12	[2] 63
147	11	11	7	18	2	3	5	43	22	65	35	8	43
148	9	8	5	13	3	7	10	58	11	69	36	11	47
149	7	11	14	25	4	7	11	59	10	69	61	7	68
150	9	16	6	[2] 23	1	4	5	53	17	70	49	11	60
151	7	17	7	24	5	2	7	45	9	54	46	13	59
152	4	14	16	[2] 31	2	4	6	44	23	67	49	13	62
153	8	12	5	17	4	9	13	44	30	74	41	14	55
154	11	17	7	[2] 25	1	5	6	42	23	65	36	17	53
155	11	17	12	[2] 30	5	9	14	40	21	61	57	8	65
156	7	11	8	19	3	10	13	34	21	55	54	12	66
157	1	20		[2] 21	2	5	7	40	26	66	41	21	62
158	7	16	6	22	3	10	13	34	30	64	33	15	48
159	7	5	4	9	1	5	6	31	21	52	35	19	54
160	3	14	13	27	7	7	14	25	36	61	48	18	66
161	9	6	12	18	4	3	7	33	34	67	19	22	41
162	3	11	10	21	3	5	8	23	23	46	37	28	65
163	6	11	5	16	8	4	12	33	38	71	27	18	45
164	7	4	7	11	2	10	12	28	28	56	22	16	38
165	8	14	5	19	5	6	11	29	27	56	29	9	38
166	1	10	5	15	4		4	35	18	53	20	15	35
167	5	9	5	14	4	3	7	17	17	34	18	16	34
168	11	5	5	10	4	6	10	25	24	49	14	16	30
169	8	5	10	[2] 16	2	2	4	27	19	46	17	20	37
170	5	3	8	11	4	5	9	20	22	42	14	7	21
171	3	2	8	10	3	2	5	18	16	34	14	13	27
172	7	3	4	7	2	1	3	20	15	35	5	10	15
173	3	8	3	11	4	3	7	23	19	42	16	16	32
174	5	2	10	12	5	1	6	13	15	28	6	7	13
175	8	4	10	14	1	4	5	15	16	31	4	14	[2] 19
176	6	1	4	5	2	3	5	10	9	19	6	9	15
177	6	2	6	8	1		1	14	13	27	1	4	5
178	4	2	6	8				15	10	25	5	7	12
179	5	5	1	6	1	2	3	7	6	13	5	5	10
180	6	1	2	[2] 4	2		2	6	17	23	4	4	8
181	1		3	3		4	4	6	6	12	4	5	9
182			3			1	1		3	3		3	3
183	2		1	1				1	5	6		2	2
184	1	1	3	4				1	5	6	2	4	6
185	2		1	1	1	1	1	4	2	6	1	1	2
186	3		1	1		2	2	3	6	9	4	3	7
187	2		2	2				1	2	3	1	1	2
188		1	3	4		1	1					2	2
189	1	1	2	3	1	1	2						
190	1		2	2					1	1		2	2
191			1	1								1	1
192													
193		1		1	1		1		1	1			
194									1	1		3	3
195			1	1									
196													
197		1		1									
198						1	1						
199													
201			1	1									
Total	645	1,375	355	1,750	808	470	1,279	4,354	1,140	[3] 5,496	2,440	580	3,024

[1] Shell condition not recorded in 1955.
[2] One crab of unknown shell conditions.
[3] Eight additional crabs under 50 millimeters.

APPENDIX TABLE 2.—*One hundred twenty-eight within-year tag recoveries*

Year released	Release: Carapace length	Release: Carapace width	Recovery: Carapace length	Recovery: Carapace width	Deviation from release measurement at recovery: Carapace length
	mm.	*mm.*	*mm.*	*mm.*	*mm.*
1955	150	170	146	173	−4
1955	191	229	188	229	−3
1955	168	202	170	203	2
1955	145	160	142	161	−3
1955	168	200	157	182	−11
1955	145	170	143	170	−2
1955	128	146	128	143	0
1955	137	155	135	156	−2
1955	177	220	176	220	−1
1955	167	200	167	201	0
1955	118	131	118	132	0
1955	171	203	170	202	−1
1955	155	178	155	179	0
1955	157	186	156	188	−1
1955	160	187	160	187	0
1955	147	173	148	174	1
1955	156	184	155	183	−1
1955	175	208	173	209	−2
1955	163	199	163	200	0
1955	178	211	177	210	−1
1955	167	202	165	Unknown	−2
1955	173	204	173	206	0
1955	169	196	169	198	0
1955	138	160	138	158	0
1955	172	201	171	202	−1
1956	128	147	127	146	−1
1956	149	177	149	173	0
1956	120	139	119	139	−1
1956	149	175	148	175	−1
1956	161	188	160	186	−1
1956	142	169	143	169	1
1956	157	186	157	184	0
1956	147	171	147	170	0
1956	154	183	154	184	0
1956	175	210	176	208	1
1956	150	182	150	180	0
1956	138	161	139	160	1
1956	157	183	156	182	−1
1956	131	149	131	147	0
1956	172	204	171	204	−1
1956	138	163	137	162	−1
1956	159	183	156	185	−3
1956	160	188	157	192	−3
1956	155	177	154	178	−1
1956	166	189	166	190	0
1956	148	177	147	176	−1
1956	146	165	146	167	0
1956	166	198	167	196	1
1956	147	176	146	174	−1
1956	150	176	151	177	1
1956	147	180	147	181	0
1956	151	176	152	177	1
1956	153	181	153	182	0
1956	151	180	152	182	1
1956	160	189	159	190	−1
1956	145	168	145	170	0
1956	162	192	162	192	0
1956	162	184	160	180	−2
1956	150	178	150	175	0
1956	155	183	154	179	−1
1956	155	182	152	182	−3
1956	155	184	155	186	0
1958 [1]	132	155	132	156	0
1958	95	108	95	108	0
1958	162	188	161	193	−1

APPENDIX TABLE 2.—*One hundred twenty-eight within-year tag recoveries*—Continued

Year released	Release: Carapace length	Release: Carapace width	Recovery: Carapace length	Recovery: Carapace width	Deviation from release measurement at recovery: Carapace length
	mm.	*mm.*	*mm.*	*mm.*	*mm.*
1958	157	191	156	192	−1
1958	149	171	148	169	−1
1958	168	203	168	201	0
1958	172	204	171	207	−1
1958	158	191	159	193	1
1958	161	197	163	196	2
1958	164	185	162	190	−2
1958	144	170	143	173	−1
1958	164	193	163	198	−1
1958	157	185	157	189	0
1958	186	213	185	220	−1
1958	161	187	161	190	0
1958	158	184	157	187	−1
1958	170	206	170	210	0
1958	184	217	183	226	−1
1958	181	210	181	213	0
1958	176	209	176	210	0
1958	175	208	175	209	0
1958	173	205	173	212	0
1958	144	166	143	168	−1
1958	165	200	165	202	0
1958	172	202	170	205	−2
1958	158	183	158	185	0
1958	164	196	164	197	0
1958	180	208	179	213	−1
1958	140	168	140	171	0
1958	160	183	158	188	−2
1958	152	173	151	175	−1
1958	162	196	161	195	−1
1958	137	163	138	163	1
1958	175	202	175	212	0
1958	166	193	167	196	1
1958	164	193	163	196	−1
1959	175	202	175	208	0
1959	143	167	142	170	−1
1959	166	195	165	196	−1
1959	152	182	151	185	−1
1959	175	208	173	214	−2
1959	162	186	162	191	0
1959	145	167	145	171	0
1959	171	203	170	207	−1
1959	167	197	167	199	0
1959	144	164	143	164	−1
1959	151	171	150	174	−1
1959	163	192	162	197	−1
1959	162	192	161	194	−1
1959	147	174	146	178	−1
1959	157	179	156	182	−1
1959	171	202	171	206	0
1959	164	194	163	199	−1
1959	162	188	162	191	0
1959	166	193	167	195	1
1959	167	190	166	196	−1
1959	153	176	153	177	0
1959	148	169	147	173	−1
1959	194	223	193	226	−1
1959	171	202	169	205	−2
1959	167	200	166	202	−1
1959	161	192	160	193	−1
1959	154	182	154	182	0
1959	148	172	149	175	1
1959	168	198	167	201	−1
1959	168	194	162	191	−6

[1] Carapace measurements of the 1957 within-year recoveries were not recorded.

APPENDIX TABLE 3.—*Spaghetti-type tag recoveries showing growth*

Year	Release data: Carapace length	Release data: Carapace width	Shell condition	Year	Recovery data: Carapace length	Recovery data: Carapace width	Shell condition	Growth increment: Carapace length	Growth increment: Carapace width
	mm.	*mm.*			*mm.*	*mm.*		*mm.*	*mm.*
1955	159	187	Unknown	1956	166	192	Unknown	7	5
1955	148	173	do	1956	158	184	New	10	11
1955	131	144	do	1956	146	164	do	15	20
1955	147	169	do	1956	165	195	do	18	26
1955	109	124	do	1956	129	150	do	20	26
1955	136	156	New	1957	151	179	Old	15	23
1955	119	130	do	1957	139	156	do	20	26
1955	135	155	do	1957	149	176	do	14	25
1955	135	153	do	1957	153	176	do	18	23
1955	149	173	do	1957	166	201	do	17	28
1955	135	156	do	1957	153	181	do	18	25
1955	149	174	do	1957	163	195	do	14	21
1955	160	193	do	1957	176	217	do	16	24
1955	137	153	do	1957	153	174	do	16	21
1955	141	160	do	1957	151	179	New	10	19
1955	160	185	do	1957	170	210	Old	10	25
1955	148	170	do	1957	166	196	do	18	26
1955	120	133	do	1957	134	153	do	14	20
1955	141	160	do	1957	159	184	do	18	24
1955	133	158	do	1957	149	186	do	16	28
1955	153	173	do	1957	167	195	do	14	22
1955	134	149	do	1957	154	176	do	20	27
1955	143	169	do	1957	159	190	do	16	21
1955	138	159	do	1957	153	180	do	15	21
1955	128	149	do	1957	146	175	do	18	26
1955	126	144	do	1957	142	170	do	16	26
1955	127	143	do	1957	145	166	do	18	23
1955	141	152	do	1957	160	187	do	19	25
1955	144	161	Unknown	1958	157	180	do	13	19
1955	149	178	Old	1958	163	199	do	14	22
1955	152	178	Unknown	1958	164	194	do	12	16
1955	146	164	do	1958	164	191	do	18	27
1955	117	135	do	1958	147	174	New	30	[1] 39
1955	122	143	do	1958	151	181	Old	29	[1] 38
1955	142	163	do	1958	161	192	do	19	29
1955	138	157	do	1958	155	183	do	17	26
1955	155	176	do	1958	168	194	do	13	18
1955	139	165	do	1958	150	184	do	11	19
1955	142	161	do	1958	159	190	do	17	29
1955	149	179	do	1958	163	200	do	14	21
1955	146	171	do	1958	162	195	Very old	16	24
1955	134	158	do	1958	147	178	Old	13	20
1955	134	144	do	1958	171	196	New	37	[1] 52
1955	159	176	New	1958	173	202	Old	14	26
1955	143	161	Unknown	1959	162	192	Very old	19	31
1955	128	145	do	1959	163	195	Old	35	[1] 50
1955	144	166	do	1959	176	211	do	32	[1] 45
1955	125	139	do	1959	154	186	do	29	[1] 47
1955	123	138	do	1959	157	186	do	34	[1] 48
1955	111	129	do	1959	148	180	do	37	[1] 51
1955	161	186	do	1959	175	209	do	14	23
1955	153	175	do	1959	169	198	Very old	16	23
1955	136	152	do	1959	147	174	Old	11	22
1955	125	141	do	1959	153	181	do	28	40
1955	143	171	do	1959	160	197	Very old	17	26
1955	164	191	do	1959	177	211	do	13	20
1956	155	180	Old	1957	171	203	New	16	23
1956	145	170	New	1957	161	196	do	16	26
1956	122	138	do	1958	135	156	Old	13	18
1956	125	146	do	do	142	169	do	17	23
1956	150	175	Old	do	161	189	do	11	14
1956	130	153	do	do	139	164	do	9	11
1956	139	155	do	do	156	175	do	17	20
1956	153	174	do	do	170	193	do	17	19
1956	152	183	do	do	167	207	do	15	24
1956	148	177	do	do	166	202	do	18	25
1956	163	196	do	do	177	215	do	14	19
1956	147	176	do	do	161	194	do	14	18
1956	151	174	do	do	160	187	do	9	13
1956	149	175	do	do	164	189	do	15	14
1956	138	161	New	do	150	180	do	12	19
1956	132	151	do	do	151	177	do	19	26
1956	129	142	do	do	141	159	do	12	17
1956	125	147	do	do	139	167	do	14	20
1956	140	164	Old	do	155	183	do	15	19
1956	148	172	do	do	168	202	do	20	30
1956	164	195	New	do	178	217	do	14	22
1956	141	164	Old	do	154	186	do	13	22
1956	149	174	do	do	165	201	do	16	25
1956	137	155	do	do	152	178	do	15	23
1956	149	177	New	do	164	199	do	15	22
1956	122	139	do	do	137	158	do	15	19
1956	130	147	do	do	145	168	do	15	21
1956	148	176	Old	do	165	194	do	17	18

See footnote at end of table.

APPENDIX TABLE 3.—*Spaghetti-type tag recoveries, showing growth*—Continued

Year	Release data: Carapace length	Release data: Carapace width	Shell condition	Year	Recovery data: Carapace length	Recovery data: Carapace width	Shell condition	Growth increment: Carapace length	Growth increment: Carapace width
	mm.	*mm.*			*mm.*	*mm.*		*mm.*	*mm.*
1956	151	172	Old	do	163	190	Old	12	18
1956	124	141	do	do	134	157	do	10	13
1956	142	161	New	do	161	186	do	19	25
1956	118	137	do	1959	134	157	do	16	20
1956	145	164	do	1959	163	189	do	18	25
1956	143	167	do	1959	160	194	do	17	27
1956	118	131	do	1959	154	181	Very old	36	[1] 50
1956	155	181	do	1959	173	209	Old	18	28
1956	148	170	do	1959	167	192	do	19	22
1956	152	173	do	1959	170	197	do	18	24
1956	150	178	Very old	1959	162	193	do	12	15
1956	107	119	New	1959	136	156	New	29	[1] 37
1956	156	185	Old	1959	168	202	Very old	12	17
1956	166	196	do	1959	177	210	Old	11	14
1956	161	188	do	1959	174	204	Very old	13	16
1956	147	174	do	1959	161	196	do	14	22
1956	152	176	New	1959	174	205	Old	22	29
1956	141	166	do	1959	156	187	do	15	21
1956	157	181	do	1959	175	204	Very old	18	23
1956	144	164	do	1959	163	195	Old	19	31
1956	143	168	do	1959	160	186	do	17	18
1956	142	167	do	1959	150	181	do	8	14
1956	148	179	do	1959	166	208	do	18	29
1956	145	166	do	1959	164	193	do	19	27
1956	156	181	do	1959	170	199	do	14	18
1956	128	153	do	1959	146	177	do	18	24
1956	157	187	do	1959	172	203	do	15	16
1956	160	193	do	1959	178	220	do	18	27
1956	131	156	do	1959	148	182	do	17	26
1956	128	147	do	1959	150	176	do	22	29
1956	129	151	do	1959	150	181	do	21	30
1956	147	169	do	1959	168	196	do	21	27
1956	131	146	do	1959	146	165	do	15	19
1956	136	159	do	1959	152	182	do	16	23
1956	133	156	do	1959	153	187	do	20	31
1956	132	157	do	1959	152	187	do	20	30
1956	146	176	do	1959	153	185	do	7	9
1956	135	157	do	1959	155	181	do	20	24
1956	147	178	Old	1959	165	205	Very old	18	27
1956	138	164	New	1959	154	186	do	16	22
1956	133	155	do	1959	151	177	Old	18	22
1956	139	156	do	1959	154	175	do	15	21
1956	145	160	do	1959	167	192	do	22	32
1956	146	173	do	1959	166	202	do	20	29
1956	160	182	do	1959	182	212	do	22	30
1956	137	160	do	1959	153	183	do	16	23
1956	136	154	New	1959	159	180	Old	23	26
1956	154	176	do	1959	174	204	do	20	28
1956	154	179	do	1959	166	199	do	12	20
1956	153	178	do	1959	168	201	do	15	23
1956	153	173	do	1959	171	197	do	18	24
1956	141	169	Old	1959	151	183	Very old	10	14
1956	145	168	do	1959	155	181	Old	10	13
1956	140	160	New	1959	154	180	do	14	20
1956	143	161	Old	1959	153	176	Very old	10	15
1956	147	166	New	1959	167	195	Old	20	29
1956	146	173	do	1959	164	200	do	18	27
1956	154	179	do	1959	174	207	do	20	28
1956	134	156	do	1959	152	178	do	18	22
1957	128	145	Old	1958	140	163	New	12	18
1957	133	147	New	1958	148	171	do	15	24
1957	107	121	do	1958	117	137	do	10	16
1957	113	127	do	1958	127	151	do	14	24
1957	125	144	do	1958	139	162	do	14	18
1957	112	129	do	1958	126	151	do	14	22
1957	106	119	do	1958	113	126	do	7	7
1957	110	125	do	1958	120	140	do	10	15
1957	119	133	Old	1958	124	144	do	5	11
1957	114	127	New	1958	130	150	do	16	20
1957	128	147	do	1958	144	170	do	16	23
1957	126	142	do	1958	145	168	do	19	24
1957	107	117	do	1958	122	141	do	15	24
1957	118	134	do	1958	134	156	do	16	22
1957	116	134	do	1958	132	154	do	16	20
1957	112	123	do	1958	126	141	do	14	18
1957	121	136	Old	1959	135	155	Old	14	19
1957	127	142	do	1959	147	170	do	20	28
1957	153	182	Very old	1959	167	205	do	14	23
1957	122	142	Old	1959	137	167	do	15	25
1957	153	178	do	1959	166	200	Very old	13	22
1957	115	128	New	1959	128	150	New	13	22
1957	142	168	Old	1959	158	190	Very old	16	22
1957	140	156	do	1959	156	178	do	16	22
1957	138	159	do	1959	157	186	do	19	27

APPENDIX TABLE 3.—*Spaghetti-type tag recoveries, showing growth*—Continued

Year	Release data			Year	Recovery data			Growth increment	
	Carapace length	Carapace width	Shell condition		Carapace length	Carapace width	Shell condition	Carapace length	Carapace width
	mm.	*mm.*			*mm.*	*mm.*		*mm.*	*mm.*
1957	123	141	Old	1959	139	166	Old	16	25
1957	157	190	do	1959	174	215	do	17	25
1957	127	141	do	1959	145	164	do	18	23
1957	135	152	do	1959	147	170	do	12	18
1957	147	172	do	1959	164	196	do	17	24
1957	136	160	New	1959	148	175	do	12	15
1957	151	176	Very old	1959	168	201	Very old	17	25
1957	128	145	New	1959	145	167	Old	17	22
1957	128	148	Old	1959	143	171	do	15	23
1957	134	147	do	1959	149	170	do	15	23
1957	107	118	New	1959	118	134	do	11	16
1957	142	157	do	1959	160	186	Very old	18	29
1957	141	160	Very old	1959	158	184	Old	17	24
1957	138	160	Old	1959	157	188	do	19	28
1957	145	163	Very old	1959	163	191	Very old	18	28
1957	137	160	New	1959	153	182	do	16	22
1957	137	154	Very old	1959	155	182	Old	18	28
1957	158	185	Old	1959	174	211	Very old	16	26
1957	145	169	do	1959	161	193	Old	16	24
1957	103	115	do	1959	116	136	do	13	21
1957	138	154	Very old	1959	156	182	do	18	28
1957	160	184	do	1959	177	208	Very old	17	24
1957	141	160	do	1959	157	183	Old	16	23
1957	122	132	Old	1959	161	181	New	39	[1] 49
1957	125	140	do	1959	140	162	Old	15	22
1957	139	155	Very old	1959	160	188	do	21	33
1957	139	161	Old	1959	155	([2])	do	16	([2])
1957	130	145	do	1959	148	169	do	18	24
1957	146	167	do	1959	165	195	do	19	28
1957	137	156	do	1959	158	181	do	21	25
1957	134	151	do	1959	149	172	do	15	21
1957	109	122	New	1959	139	162	New	30	[1] 40
1957	132	153	Old	1959	151	179	Old	19	26
1957	122	137	do	1959	140	159	do	18	22
1957	131	157	do	1959	147	181	do	16	24
1957	144	167	do	1959	159	188	do	15	21
1957	98	109	New	1959	109	121	do	11	12
1957	142	168	Old	1959	162	192	do	20	24
1957	132	155	New	1959	151	184	do	19	29
1957	134	155	do	1959	149	179	do	15	24
1957	153	174	Old	1959	170	201	do	17	27
1957	133	153	New	1959	148	176	do	15	23
1957	136	157	do	1959	152	183	do	16	26
1957	142	156	Old	1959	159	181	do	17	25
1957	140	167	do	1959	159	193	do	19	26
1957	143	167	do	1959	160	192	do	17	25
1957	158	186	do	1959	176	213	do	18	27
1957	166	185	do	1959	184	225	do	18	40
1957	128	144	do	1959	144	167	do	16	23
1957	126	145	New	1959	142	168	do	16	23
1957	154	181	Old	1959	168	203	do	14	22
1957	142	167	New	1959	156	187	do	14	20
1957	153	180	Old	1959	171	207	do	18	27
1957	137	149	do	1959	149	171	do	12	22
1957	122	142	New	1959	137	165	New	15	23
1957	152	175	Old	1959	171	204	Old	19	29
1957	154	184	do	1959	167	206	do	13	22
1957	134	156	do	1959	147	177	do	13	21
1957	132	150	New	1959	145	169	do	13	19
1957	124	148	do	1959	135	164	do	11	16
1957	121	138	do	1959	140	163	do	19	25
1957	124	140	Old	1959	141	165	do	17	25
1957	151	172	do	1959	169	201	do	18	29
1957	121	139	New	1959	139	163	do	18	24
1957	127	141	do	1959	142	163	do	15	21
1957	141	157	Old	1959	162	188	do	21	31
1957	128	146	New	1959	143	165	do	15	19
1957	149	178	Old	1959	165	201	do	16	23
1957	167	187	Very old	1959	182	219	do	15	32
1957	138	156	Old	1959	158	186	do	20	30
1957	144	168	do	1959	154	182	do	10	14
1957	157	186	do	1959	172	209	do	15	23
1957	115	131	New	1959	149	176	New	34	[1] 45
1957	160	190	Very old	1959	175	216	Old	15	26
1957	155	183	Old	1959	165	201	do	10	18
1957	111	126	New	1959	126	147	do	15	21
1957	115	130	Old	1959	132	152	do	17	22
1957	140	164	do	1959	154	181	do	14	17
1957	115	128	New	1959	129	148	do	14	20
1957	156	182	do	1959	172	208	do	16	26
1957	143	164	Old	1959	155	182	do	12	18
1957	125	150	Old	1959	138	168	New	13	18
1957	110	127	New	1959	124	147	do	14	20
1957	118	140	do	1959	131	162	do	13	22
1957	145	163	Old	1959	160	182	do	15	19
1957	114	131	do	1959	132	153	do	18	22
1957	144	176	do	1959	159	196	do	15	20
1957	154	177	Very old	1959	172	205	do	18	28
1957	139	162	New	1959	159	193	do	20	31
1957	139	162	Old	1959	157	188	do	18	26
1957	152	179	Very old	1959	168	206	do	16	27
1957	108	128	New	1959	120	144	do	12	16
1957	126	142	Old	1959	139	161	do	13	19
1957	136	157	New	1959	155	186	do	19	28
1957	152	177	Very old	1959	167	200	do	15	23
1957	138	159	New	1959	157	188	do	19	29
1957	128	153	Old	1959	146	177	do	18	24
1957	144	168	Very old	1959	156	186	Old	12	18
1957	151	172	Old	1959	166	194	do	15	22
1957	123	142	New	1959	141	171	do	18	29
1957	120	137	do	1959	132	154	do	12	17
1957	115	127	do	1959	129	147	do	14	20
1957	129	149	Old	1959	146	175	do	17	26
1957	125	147	New	1959	141	168	do	16	21
1957	119	132	do	1959	132	149	do	13	17
1957	138	159	Very old	1959	155	185	do	17	26
1957	112	126	New	1959	122	140	New	10	14
1957	118	133	do	1959	131	152	Old	13	19
1957	134	152	Very old	1959	151	178	do	17	26
1957	122	135	New	1959	140	162	do	18	27
1957	135	154	do	1959	151	177	do	16	23
1957	133	151	Very old	1959	150	178	do	17	27
1957	133	149	do	1959	151	177	do	18	28
1957	104	113	Old	1959	131	149	New	27	[1] 36
1957	144	170	Very old	1959	157	192	Old	13	22
1957	150	174	do	1959	165	198	Very old	15	24
1957	138	154	do	1959	152	178	Old	14	24
1957	130	151	Old	1959	144	168	do	14	17
1957	133	159	Very old	1959	151	186	do	18	27
1957	137	150	do	1959	153	173	do	16	23
1957	134	158	do	1959	152	183	do	18	25
1957	150	177	do	1959	167	198	do	17	21
1957	114	128	Old	1959	130	148	do	16	20
1957	144	164	Very old	1959	161	190	do	17	26
1957	160	187	Old	1959	178	215	do	18	28
1957	140	163	do	1959	152	185	do	12	22
1957	139	166	Very old	1959	152	187	do	13	21
1957	152	171	Old	1959	165	193	do	13	22
1957	141	165	do	1959	156	188	do	15	23
1957	157	176	Very old	1959	168	198	do	11	22
1957	151	170	do	1959	167	195	do	16	25
1957	145	170	do	1959	160	193	Very old	15	23
1957	136	158	Old	1959	154	187	Old	18	29
1957	146	168	do	1959	162	194	do	16	26
1957	145	169	Very old	1959	159	189	do	14	20
1957	153	181	do	1959	168	202	do	15	21
1957	150	179	do	1959	169	198	do	19	19
1957	144	167	do	1959	157	189	do	13	22
1957	129	149	Old	1959	146	173	do	17	24
1957	147	172	Very old	1959	164	196	do	17	24
1957	147	166	Old	1959	162	189	do	15	23
1957	136	158	Very old	1959	154	187	do	18	29
1957	133	152	do	1959	152	178	do	19	26
1957	141	164	Old	1959	153	186	do	12	22
1957	138	160	New	1959	158	188	do	20	28
1957	142	163	Very old	1959	157	191	do	15	28
1957	169	202	do	1959	184	226	do	15	24
1957	142	160	do	1959	161	189	do	19	29
1957	143	166	do	1959	160	189	do	17	23
1957	153	176	do	1959	165	194	do	12	18
1957	153	176	do	1959	170	200	do	17	24
1957	123	138	New	1959	137	157	do	14	19
1957	137	157	do	1959	155	181	Very old	18	24
1957	144	169	Very old	1959	160	193	Old	16	24
1957	150	173	do	1959	163	194	do	13	21
1957	123	140	Old	1959	135	156	do	12	16
1958	137	159	New	1959	155	187	New	18	28

[1] Considered as two molts.
[2] Unknown.