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PROCESSED REPORT

# PRELIMINARY STUDY OF THE BIOLOGICAL CONSIDERATIONS REGARDING MANAGEMENT OF THE EASTERN BERING SEA KING CRAB STOCKS BY SIZE, SEX, AND SEASON (3 S)

BY

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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# Preliminary Study of the Biological Considerations Regarding Management of the Eastern Bering Sea King Crab Stocks by Size, Sex and Season (3 S)

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This report must be considered provisional in that the material presented is not necessarily exhaustive nor has it been reviewed by others, within and without NMFS, who have an interest in or a responsibility for the eastern Bering Sea king crab resource.

In our view the 3 S management system raises four obvious questions -- two of which are biological, another essentially economic but associated with a technical question, and the fourth, political. We have addressed ourselves to the biological questions but have briefly commented on the others mostly because the total NMFS responsibility for eastern Bering Sea king crab goes beyond pure biological and management considerations. In fact, although we have responded in very recent months to questions relevant to management, NWFC is not directly involved in the management of the U.S. fishery on this resource.

A fundamental consideration in applying the 3 S strategy to the management of the eastern Bering Sea crab fishery is the selection of a minimum legal size such that stock productivity is not adversely affected. Ideally, such a system would include: (1) Maintenance of the standing stock of mature females at a level which is maximal but does not depress their growth, survival, and fecundity due to density related factors. (2) Selection of the minimum retention size in the catch such that the spawning stock contains the number and size of mature males adequate to copulate all or most of the mature females (this assumes a relationship between number of spawners and recruitment).

To gain some insight into these questions, we examined the population estimates of mature (over 90 mm carapace length) eastern Bering Sea king crab by 5 mm size classes from the 1972 and 1973 NMFS trawl surveys (Tables 1 and 2 and Figures 1 and 2).

## Size Classes and Sex Ratios of Mature Crabs - 1972, 1973

Maximum size of females in the 1972 and 1973 trawl surveys was 165-169 mm and 155-159 mm, respectively. About 98% of the mature female population as estimated from the 1972 survey and about 95% of the mature female population in the 1973 survey were below 135 mm in carapace length which is equivalent to the current minimum size limit for the eastern Bering Sea crab fishery of 159 mm (6-1/4)" carapace width.

In the 1972 survey males exceeded females in numbers in all size classes larger than 100 mm. Males outnumbered females in size classes above 119 mm in the 1973 survey, however, in the two size classes between 95 mm and 104 mm (which contained the largest number of mature females) there were more than two females to each male.

For the mature population in carapace length size classes smaller than 135 mm (159 mm carapace width), the 1973 survey indicates that there were about 1.5 females per male. If male king crab can locate and service four females (there is some evidence that such is the case), then even with the removal of all males over 135 mm (carapace length), a sufficient number of mature males would be left on the grounds to service all mature females. If, however, the males are required to be as big or bigger than the females for successful copulation (a requirement which is inferred from observations of crab populations in the Gulf of Alaska but not a demonstrated requirement either in the Gulf or Bering Sea) then as shown later, some adjustment of fishing effort is necessary if optimum equilibrium yields are to be achieved.

Retaining the 135 mm (carapace length) minimum size, the data indicate that even if all legal size males were harvested, 19 million mature males or 77% of the mature male population in 1972 and 50.6 million males or 82% of the mature male population on the grounds in 1973 would have been protected from exploitation.

There is some evidence that skip molt crab are more successful in mating than recently molted crab. Sampling of U.S. commercial catches in recent years indicates that the percentage of new shell crabs in legal size animals has increased over that in the early years of the fishery. If true, this has implications concerning changes in growth rates in recent years and may also impact upon success in reproduction. The possible effects of the latter have not been evaluated here mostly because of the lack of time.

If we assume, however, that polygamy in the species compensates for the loss in effective fertilization attributable to recently molted mature males, from the 1972 and 1973 trawl surveys, it appears that a substantial quantity of spawners with acceptable sex ratio will remain even if all males over the current legal size are harvested. This would appear to be true even if the small number (and percentages) of females over 135 mm (carapace length) were also harvested unless increments to population growth due to the greater fecundity of larger females exceeds decrements to the population which might result from the slow growth and high mortality in this population and depression of growth in the male population which might be directly attributable to competition imposed by allowing larger females to remain on the grounds.

The preceding conclusion regarding the adequacy of the breeding population, even if all males over 135 mm (carapace length) were harvested, was strictly in terms of number of potential spawners and adequate sex ratios. This conclusion, which is largely intuitive, only assures us that the breeding population would maintain the potential for high productivity. It says nothing about the level of yield which might be expected for different ages of entry into the fishery and assumes that the quality of spawners has no bearing on stock productivity.

Optimum minimum size at entry as estimated from yield models

In his development of a yield-per-recruitment model for eastern Bering Sea king crab, Joe Greenough developed yield isopleths which predicted equilibrium yields (based on data from the 1954-61 period) for various ages at entry to the fishery and for various levels of effort expressed in units of tan and tan days. Greenough suggested that over reasonable levels of fishing effort, maximum yield could be achieved by adjusting the harvest so that the bulk of crabs would be in the 136-167 mm length range with the average falling in the 150-155 mm range.

Jim Balsiger extended upon Greenough's work utilizing more recent data in a simulation model which expressed effort in pot lifts rather than in tan-units (the latter gear having been entirely phased out of the Bering Sea fishery). Balsiger's yield isopleths indicated that the optimal age of entry to the fishery is between 45 and 52 months, which corresponds to a length of entry of about 136 mm. This carapace length is equivalent to the 159 mm carapace width size limit currently in force for this fishery. Essentially because of its relevance to further discussion of Balsiger's simulation model, we will talk around 136 mm, the size he specified as optimal and the lower range of sizes at entry specified by Joe Greenough.

From observations of the stock response to rather heavy fishing in the Gulf of Alaska and knowledge of mating behavior of king crab, it has been hypothesized that success in copulation requires that the males be as large as or larger than the females. Although not rigorously demonstrated to be a fact for the Gulf of Alaska king crab, and certainly not for Bering Sea king crab, Balsiger included this requirement as an element in his simulation model. Simulating the eastern Bering Sea king crab stock under exploitation for 40 years, the predicted equilibrium yield under the requirement of males larger than or equal to the size of females results in maximum sustainable yields with size at entry of 135 mm with effort (in terms of 186.9 x 1,000 pot lifts) about at the level generated in 1972. Holding to this minimum size, Balsiger's model forecasts a decline in yield which occurs due to the removal of a number of adequate size mature males to a level below that necessary to completely satisfy the reproductive potentiality of the females. For the same reason, below certain size classes of entry and certain intensities of fishing, the yield is predicted to decline and in some cases either stabilize at low levels, or fail to stabilize and go to extinction. Naturally the fishery would terminate before these extreme circumstances came to pass.

The results of the simulation modelling differ from the response of the population in terms of yield derived from his yield isopleths in that in the latter, although the optimum size of entry was the same, realistic increases in effort above that average effort exerted between 1966 and 1971 would result in a continued increase in yield. The increase in yield, however, would not be cost effective because Balsiger's yield isopleths indicate that a seven-fold increase in effort would increase the total yield per recruit by less than 5%.

General Comments

A few additional general comments. From the first two tables and figures presented it can be seen that the standing stock of legal size male crab in 1972 was about 5.7 million and in 1973 about 10.9 million. The catch in 1972 was about 4 million crab or roughly 70% of the total estimated legal sized male population as estimated for that year. In 1973, the commercial catch of about 5 million crab was about 46% of the standing stock of male crab over 135 mm in carapace length. The general increase in the population estimate in all categories (size classes, males and females and proportion of females) was beyond that which could be explained by recruitment alone. Modifications were made in the sampling trawl in 1973 which improved its bottom-tending qualities which undoubtedly increased the coefficient of catchability over that of the 1972 (and previous years) sampling gear. This would infer that the population estimates derived from surveys in most years prior to 1973 were underestimated. This would, of course, affect the level of the estimates of sustainable yield derived by both Greenough and Balsiger. With data at hand, however, we cannot evaluate the extent of bias which might have occurred in pre-1973 surveys. From the exploiter's point of view, it would be tempting to interpret this as evidence that past surveys underestimated the exploitable population by more than 100%. From a management point of view, however, we cannot be so quick to make such a direct interpretation since we are cognizant of the contagious (clustered) distribution of crab, sampling variation, and our general reluctance to severely depart from past population estimates on the strength of the results of the 1973 survey alone.

There is some concern about possible handling mortalities to undersized males and females caught in commercial pots and returned to the sea. We know of no information on this subject, however, it may be a significant source of mortality to some life history groups or during certain seasons. This possible source of mortality should be evaluated with or without the imposition of a non-quota 3 S management system.

The preceding discussion completely begs the question of how many females are necessary to optimize yield from the eastern Bering Sea stock. From a practical standpoint if the density of females fell below a postulated optimum nothing could be done to increase the number of females other than to reduce the mortality imposed upon them by such factors as bottom-fish trawling or derelict pots if these are demonstrated to be significant sources of mortality. Density of females in excess of that considered to be optimal could, of course, be reduced by allowing some harvest of females. In the absence of knowledge concerning the optimum number of females, we are not suggesting harvesting females. We do suggest, however, that it would be appropriate to investigate the consequences of harvesting some females in the total evaluation of 3 S management.

Also, regarding above question, "How many mature females are required to maximize yields?" and the assumption of a stock-recruitment relationship in eastern Bering Sea king crab we have one further comment.

Consider that each mature female crab molts annually and produces from 200,000 to 400,000 eggs per molt. The female of this species has obviously adapted to diverting energy to high egg production at the expense of growth. In the long-term evolutionary time scale, the average environmental stresses must have been such that this relatively high fecundity was necessary to perpetuate the species. Given these relatively high potentialities for production, for a given number of females, survival to recruitment can vary considerably depending upon the severity of environmental stresses. The impacts on yield from environmental variations probably override factors such as number of females or sex ratios. Since we have no real handle on the relationship of environment to production nor the capacity to forecast environment even if we have such historically established relationships, it would seem like good conservation to err on the conservative side by maintaining the spawning stock at maximum levels to cushion the shock, so to speak, against the more adverse environmental circumstances encountered by the population.

Similarly, there are reasons for conservative decisions regarding sizes at entry to the fishery and fishing pressures applied to the stock. Losses to long-term yield as a consequence of error in setting size at entry above the optimum would be attributable to a saturated environmental niche in which natural mortality exceeded growth and the full potential of the population to produce biomass in excess of that needed to sustain itself would be less than maximal. In other words, part of the potential fishery harvest would be lost to natural mortality. Losses to long-term yield resulting from setting size at entry below the optimum would be primarily attributable to harvesting crab below the age at which the net production resulting from an excess of growth over mortality has achieved a maximum. Natural mortality as estimated from 1966-68 tagging experiments is indicated to be quite low in the 132-152 mm average carapace length size classes. The remedial action in the first case, of course, would be to reduce the size limit which would result in an immediate increase in harvest in the successive year(s). The remedial action required if size at entry were set too low would be to increase the size at entry. The consequences of this action would be a reduction in harvest, and a lag period before animals of the new legal size accumulate in numbers which may be aggravated by the possible adverse consequences to reproductive potential due to harvesting under the old legal size. In the extreme, if the fishery had been cropping virtually all of the annual recruitment, an upward adjustment of minimum size by an increment equal to a year's average growth would result in a zero harvest for one year.

Summarizing our thoughts on the biological aspects of Mr. Jensen's question relating to 3 S:

1. From results of the 1972 and 1973 NMFS Bering Sea crab trawl surveys there is no evidence that the numbers of mature king crab or their sex ratio would be adversely affected if all male crab larger than 135 mm carapace length (which is equivalent to the current legal size of 159 mm carapace width) were harvested.

2. If we assume that the size of mature males relative to the size of mature females has no bearing on reproductive success, Dr. Balsiger's model using recent rates of growth estimates that the minimum size at entry to the fishery should be about 136 mm, which is about the current minimum legal size. According to his model (under the above assumption), although expended between 1966 and 1971, a seven-fold increase beyond this level would be required to increase yield by 5%.

3. If we assume that copulation success requires that males be larger than females, then according to Balsiger's simulation model, maximum yield is obtained with the current legal size and the effort generated in 1972. Under this assumption, for size of entry at 136 mm carapace length yield decreases at higher levels of effort due to the "excessive" loss of males greater than 136 mm to the fishery.

4. There is a need to evaluate the possible handling mortalities to undersized male and female crab caught in commercial pots and returned to the sea.

5. Considering our current state of knowledge, or more specifically our lack of knowledge concerning environmental impacts upon survival it seems prudent to maintain potential productivity at near maximum levels by protecting all females crabs.

6. We have not discussed seasonal closures because they are undoubtedly tied to areal considerations and we have not had time to examine the data for meaningful comment or recommendations. As a general guideline, however, the fishery should be prohibited during times and in areas where molting is prevalent or where females or undersized and juvenile crab predominate.

7. Recognizing that the ADFG has had the actual experience in managing the crab fishery we defer to them discussion of the foreseeable problems associated with 3 S management.

The Okhotsk Sea crab fishery has shown cyclic declines of considerable magnitude in abundance and average size as a result of very intensive and virtually unregulated pulse fishing over several decades. It is encouraging to note that even these high intensities of exploitation produced no irreversible changes in the stock and with relaxation of effort, the stock returned to high levels of abundance and larger average weights. It seems unlikely, therefore, that the Bering Sea stock would ever be threatened by biological extinction and our concern over the stock relates to "economic extinction." Accordingly, it is unavoidable that any biological recommendations for manipulating the fishery to achieve desired results is integrally tied to economic and political considerations.

Economic Considerations

Adoption of the 3 S strategy will mean, of course, that the fishery will be sustained essentially by incoming recruits. The welfare of the fishery then will be subject to the variations of fluctuating year classes. There will then arise a need for reliable forecasts of recruitment, without which the industry will be faced with possible economic chaos of unpredictable "boom or bust." Departure from the quota system which tends to dampen the oscillations of allowable catch (due to the "cushion" of availability of several year classes), it seems that some serious consideration should be given to limiting effort so that capitalization and effort is not keyed to the bumper years.

Another nagging thought. We are aware that the unusually cold winters of 1971 and 1972 in the Bering Sea are suspected to have severely reduced the ocean survival of western Alaska salmon stocks and there is some evidence of unfavorable impact on other Bering Sea fishes such as pollock. It is not inconceivable that the nauplii and zoea of crab might also have suffered heavy mortality as a result of the very late spring following those cold winters. If so, the effects will not be manifest until those year classes appear in the 1976 or 1977 surveys and as recruited crab in 1978 and later. Perhaps as a safety factor one might opt to save some of the earlier year classes for harvest during years when there is reason to suspect weak incoming year classes.

International Implications

The impact on international negotiations of going from quota to non-quota management is a question that may completely resolve itself if the U.S. can successfully phase out Soviet and Japanese participation in the eastern Bering Sea king crab fishery. In fact, the USSR is no longer involved in that fishery (although it still has a token quota) and the Japanese harvest of king crabs has been reduced by bilateral agreement to such a low level that Japanese quota have been based, first, on the contention that because of their status as "creatures of the continental shelf" they belong to the U.S. and, second, that the U.S. fishery has the capacity to fully harvest the allowable catch. As long as the U.S. can demonstrate that its fishery is fully utilizing the resource, whether by quota or some other reasonable management system, the rationale for decreasing Japanese participation in the fishery remains valid.

Figure 1.-- Population estimates of mature Bering Sea king crab by size class-1972

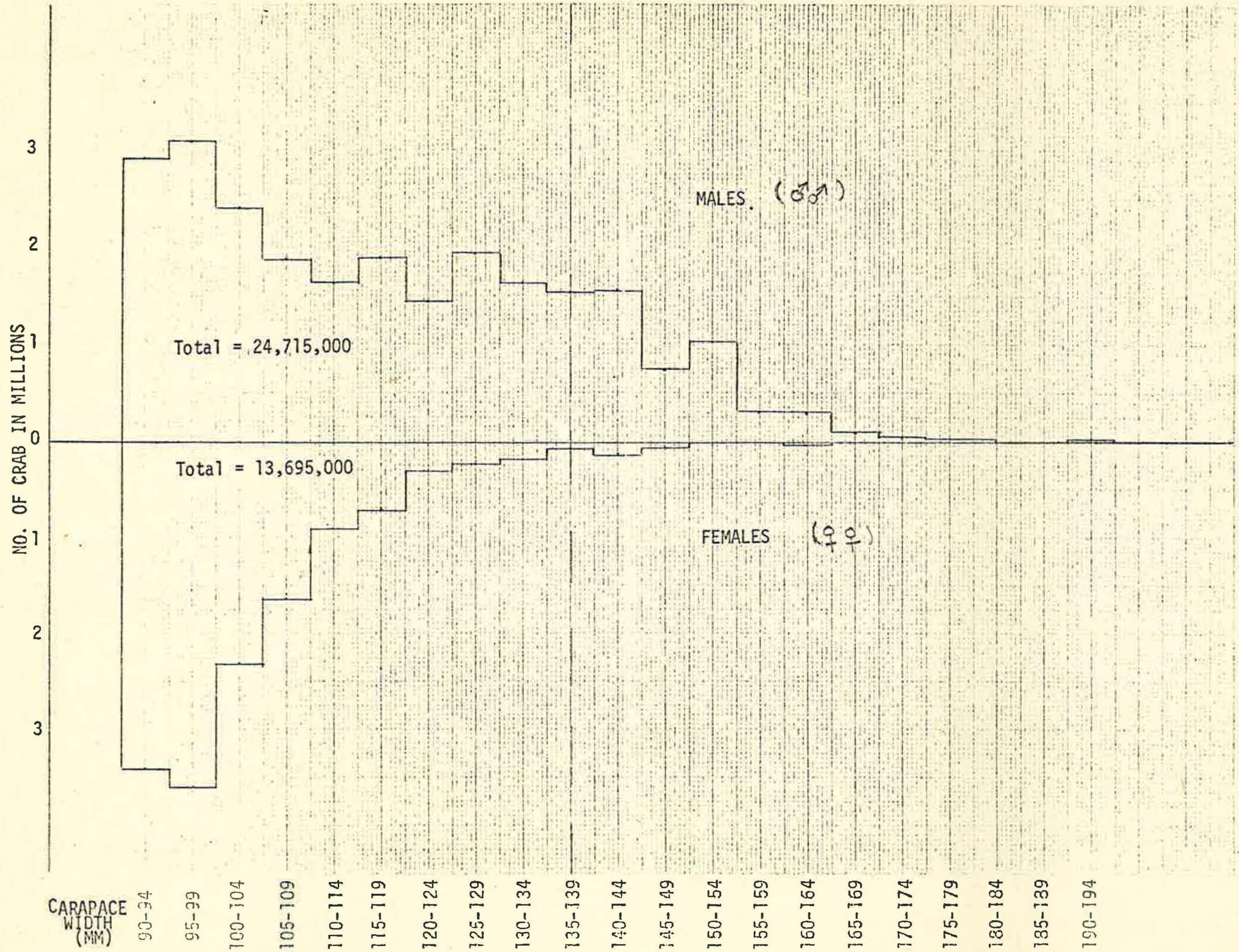

Figure 2.--Population estimates of mature Bering Sea king crab by size class-1973

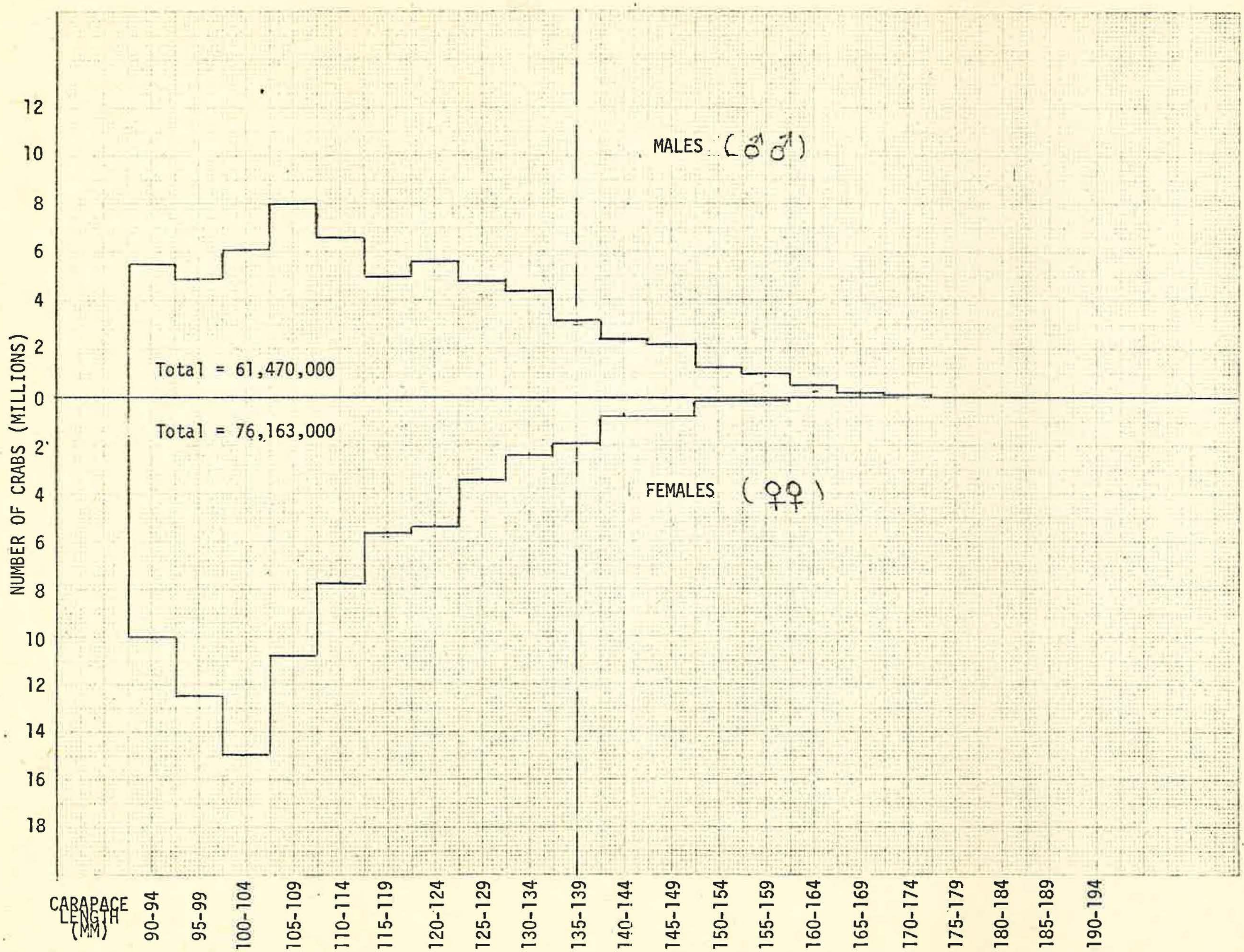

Figure 3.--Cumulative number of mature king crab in 5 mm size classes-1972

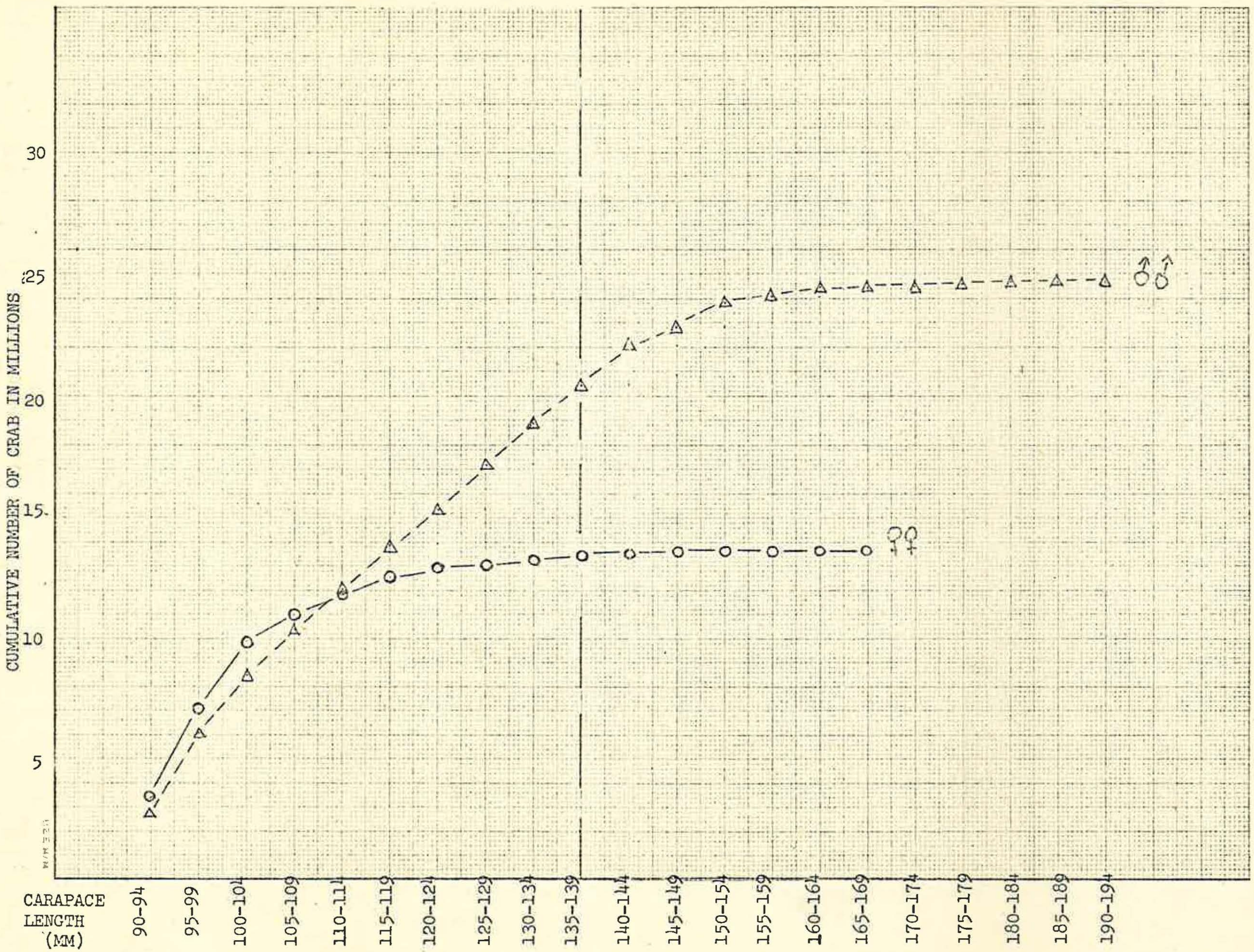

Figure 4.--Cumulative No. of mature king crab in 5 mm size classes-1973

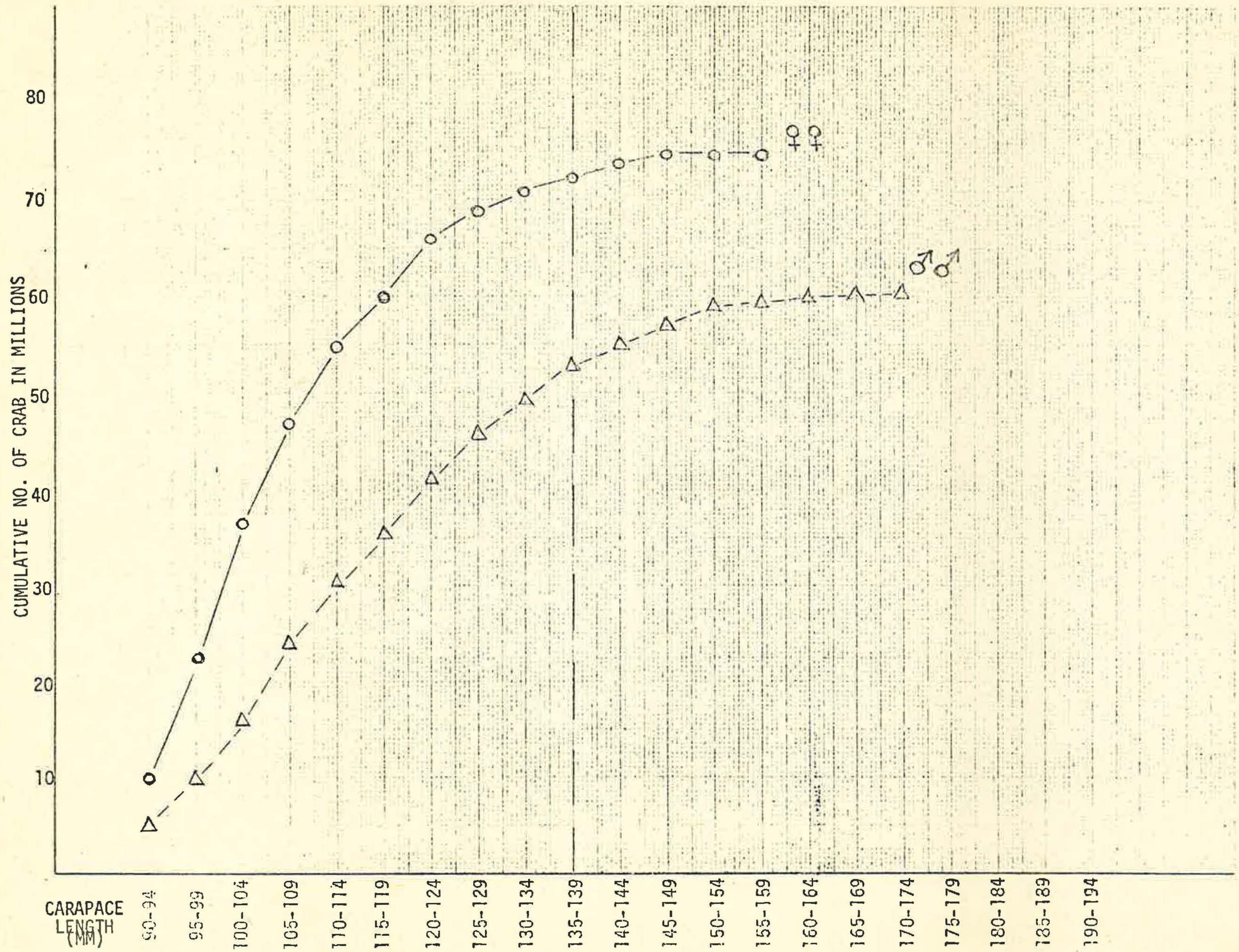

Figure 5.--Cumulative percentage of mature male and female king crab in 5 mm size classes-1972

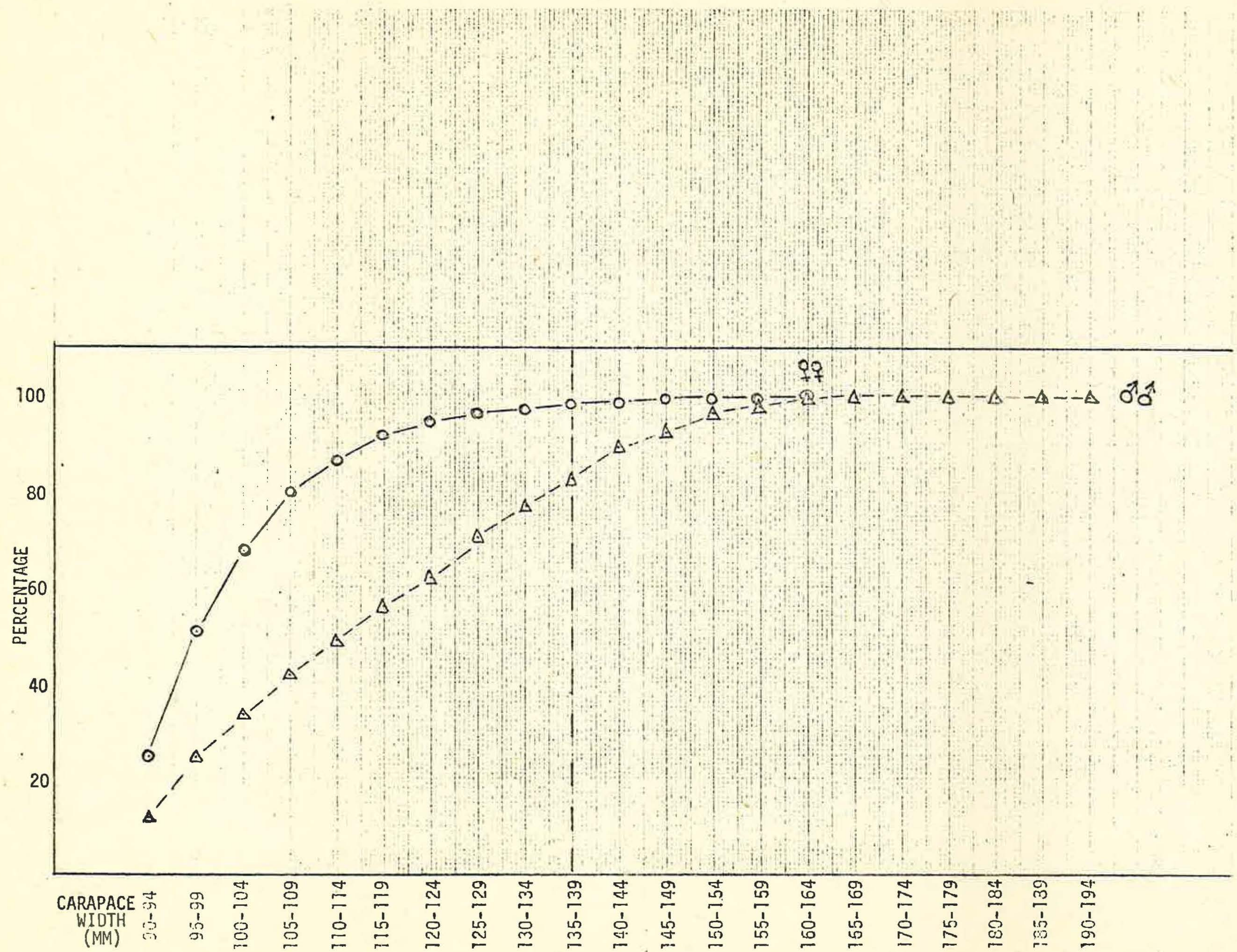

Figure 6.--Cumulative percentage of mature male and female king crab in 5 mm size classes-1973

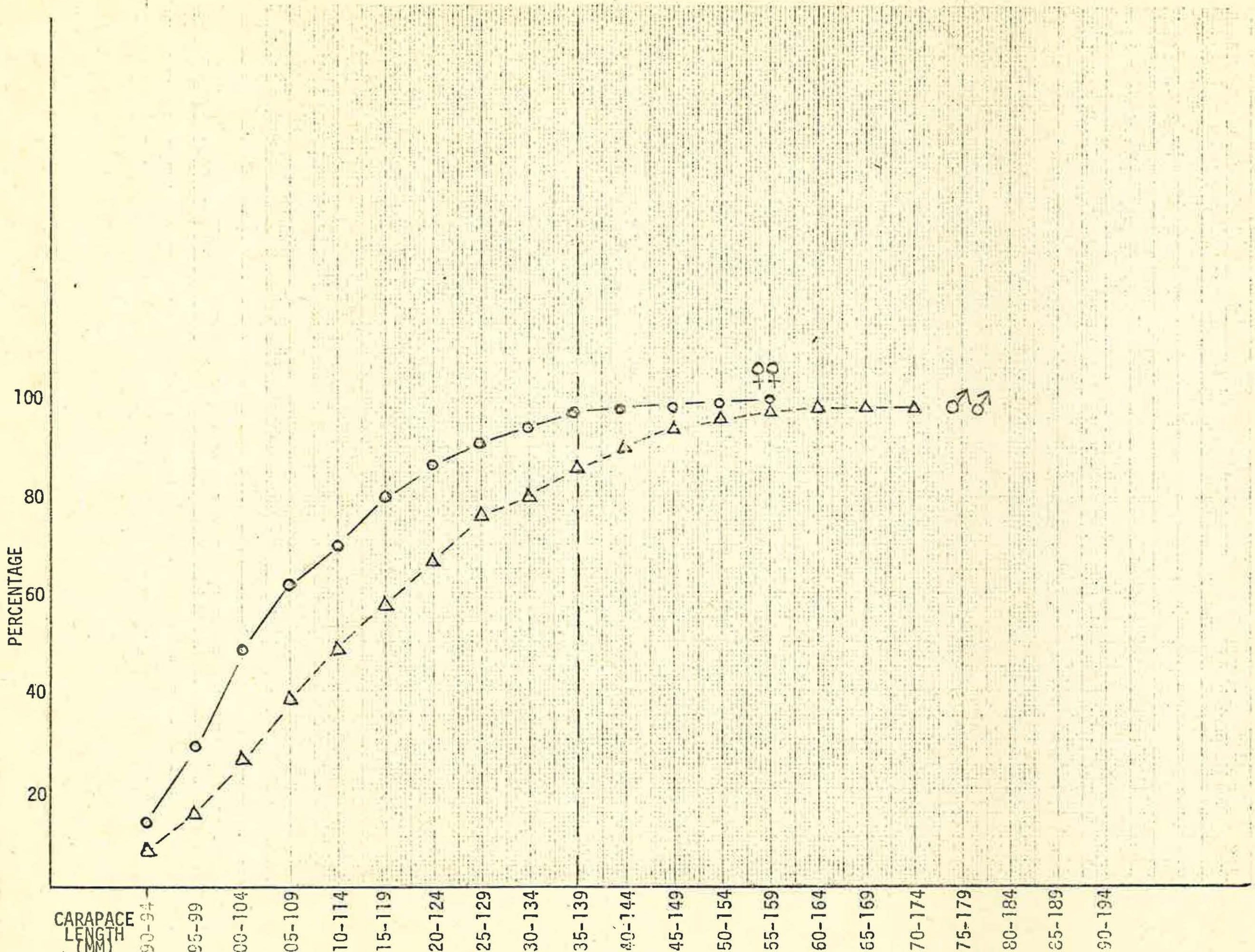

Table 1. Population Estimates (in 1000's) of Sexually Mature E. Bering Sea King Crab - 1972

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Carapace Length | No. | | Cumulative No. | | Percentage | | Cumulative % | | Sex Ratio No. M / No. F | Cumulative Sex Ratio M/F |
| | M | F | M | F | M | F | M | F | | |
| 90 - 94 | 2,963 | 3,404 | 2,963 | 3,404 | 11.99 | 24.86 | 11.99 | 24.86 | 0.87 | 0.87 |
| 95 - 99 | 3,157 | 3,624 | 6,120 | 7,028 | 12.77 | 26.46 | 24.76 | 51.32 | 0.87 | 0.87 |
| 100 - 104 | 2,400 | 2,318 | 8,520 | 9,346 | 9.71 | 16.93 | 34.47 | 68.25 | 1.04 | 0.91 |
| 105 - 109 | 1,881 | 1,622 | 10,401 | 10,968 | 7.61 | 11.84 | 42.08 | 80.09 | 1.16 | 0.95 |
| 110 - 114 | 1,656 | 894 | 12,057 | 11,862 | 6.70 | 6.53 | 48.78 | 86.62 | 1.85 | 1.02 |
| 115 - 119 | 1,888 | 736 | 13,945 | 12,598 | 7.64 | 5.37 | 56.42 | 91.99 | 2.56 | 1.11 |
| 120 - 124 | 1,445 | 321 | 15,390 | 12,919 | 5.85 | 2.34 | 62.27 | 94.33 | 4.50 | 1.19 |
| 125 - 129 | 1,951 | 264 | 17,341 | 13,183 | 7.89 | 1.93 | 70.16 | 96.26 | 7.39 | 1.32 |
| 130 - 134 | 1,644 | 206 | 18,985 | 13,389 | 6.65 | 1.50 | 76.81 | 97.76 | 7.98 | 1.42 |
| 135 - 139 | 1,529 | 81 | 20,514 | 13,470 | 6.19 | 0.59 | 83.00 | 98.35 | 18.88 | 1.52 |
| 140 - 144 | 1,546 | 137 | 22,060 | 13,607 | 6.26 | 1.00 | 89.26 | 99.35 | 11.28 | 1.62 |
| 145 - 149 | 775 | 64 | 22,835 | 13,671 | 3.14 | 0.47 | 92.40 | 99.82 | 12.11 | 1.67 |
| 150 - 154 | 1,035 | 0 | 23,870 | 13,671 | 4.19 | 0.00 | 96.59 | 99.82 | | 1.75 |
| 155 - 159 | 308 | 0 | 24,178 | 13,671 | 1.25 | 0.00 | 97.84 | 99.82 | | 1.77 |
| 160 - 164 | 306 | 24 | 24,484 | 13,695 | 1.24 | 0.18 | 99.08 | 100.00 | 12.75 | 1.79 |
| 165 - 169 | 100 | 0 | 24,584 | 13,695 | 0.40 | 0.00 | 99.48 | | | 1.80 |
| 170 - 174 | 51 | 0 | 24,635 | 0 | 0.21 | 0.00 | 99.69 | | | |
| 175 - 179 | 26 | 0 | 24,661 | 0 | 0.11 | 0.00 | 99.80 | | | |
| 180 - 184 | 26 | 0 | 24,687 | 0 | 0.11 | 0.00 | 99.91 | | | |
| 185 - 189 | 0 | 0 | 24,687 | 0 | 0.00 | 0.00 | 99.91 | | | |
| 190 - 194 | 28 | 0 | 24,715 | 0 | 0.11 | 0.00 | 100.02 | | | |
| Total | 24,715 | 13,695 | | | | | | | | |

M = Male
F = Female

Table 2. Population Estimates (in 1000's) of Sexually Mature E. Bering Sea King Crab - 1973

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Carapace Length | No. | | Cumulative No. | | Percentage | | Cumulative % | | Sex Ratio No. M / No. F | Cumulative Sex Ratio M/F |
| | M | F | M | F | M | F | M | F | | |
| 90 - 94 | 5,490 | 10,067 | 5,490 | 10,067 | 8.93 | 13.22 | 8.93 | 13.22 | 0.54 | 0.54 |
| 95 - 99 | 4,959 | 12,518 | 10,449 | 22,585 | 8.07 | 16.44 | 17.00 | 29.66 | 0.40 | 0.46 |
| 100 - 104 | 6,206 | 14,970 | 16,655 | 37,555 | 10.10 | 19.66 | 27.10 | 49.32 | 0.41 | 0.44 |
| 105 - 109 | 8,050 | 10,565 | 24,705 | 48,120 | 13.10 | 13.87 | 40.20 | 63.19 | 0.76 | 0.51 |
| 110 - 114 | 6,606 | 7,760 | 31,311 | 55,880 | 10.75 | 10.19 | 50.95 | 73.38 | 0.85 | 0.56 |
| 115 - 119 | 5,107 | 5,600 | 36,418 | 61,480 | 8.31 | 7.35 | 59.26 | 80.73 | 0.91 | 0.59 |
| 120 - 124 | 5,603 | 5,294 | 42,021 | 66,774 | 9.11 | 6.95 | 68.37 | 87.68 | 1.05 | 0.63 |
| 125 - 129 | 4,393 | 3,379 | 46,414 | 70,153 | 7.15 | 4.44 | 75.52 | 92.12 | 1.30 | 0.66 |
| 130 - 134 | 4,180 | 2,350 | 50,594 | 72,503 | 6.81 | 3.08 | 82.33 | 95.2 | 1.78 | 0.70 |
| 135 - 139 | 3,125 | 1,870 | 53,719 | 74,373 | 5.09 | 2.46 | 87.42 | 97.66 | 1.67 | 0.72 |
| 140 - 144 | 2,400 | 790 | 56,119 | 75,163 | 3.90 | 1.04 | 91.32 | 98.70 | 3.04 | 0.75 |
| 145 - 149 | 2,260 | 735 | 58,379 | 75,898 | 3.68 | 0.96 | 95.00 | 99.66 | 3.07 | 0.77 |
| 150 - 154 | 1,327 | 113 | 59,706 | 76,011 | 2.16 | 0.15 | 97.16 | 99.81 | 11.74 | 0.78 |
| 155 - 159 | 906 | 152 | 60,612 | 76,163 | 1.48 | 0.20 | 98.64 | 100.01 | 5.97 | 0.80 |
| 160 - 164 | 533 | 0 | 61,145 | 0 | 0.87 | 0 | 99.51 | | | |
| 165 - 169 | 202 | 0 | 61,347 | 0 | 0.33 | 0 | 99.84 | | | |
| 170 - 174 | 112 | 0 | 61,459 | 0 | 0.18 | 0 | 100.02 | | | |
| Total | 61,459 | 76,163 | | | | | | | | |

M = Male
F = Female

Table 3.--Estimates of M and q from the multiple regression model.

| Size Class Midpoint | 1954-1961 tagging years: M (annual rate) | 1954-1961 tagging years: q (based on 1,000's of tans) | 1966-1968 tagging years: M (annual rate) | 1966-1968 tagging years: q (based on 1,000's of pot lifts) |
|---|---|---|---|---|
| 82 | .62095 | | .06133 | |
| 87 | .50979 | | .00130 | |
| 92 | .68725 | | .10161 | |
| 97 | .51938 | | .15244 | |
| 102 | .36996 | | .11946 | |
| 107 | .39720 | | .11436 | |
| 113 | .62963 | | .12010 | |
| 117 | .48306 | | .11371 | |
| 122 | .53120 | | .08002 | .00009 |
| 127 | .14904 | | .07593 | .00024 |
| 132 | .13684 | .00021 | .07341 | .00115 |
| 137 | .05112 | .00039 | .08972 | .00230 |
| 142 | .23556 | .00062 | .12211 | .00501 |
| 147 | .24240 | .00146 | .16634 | .00526 |
| 152 | .28441 | .00306 | .29710 | .00766 |
| 157 | .57321 | .00361 | .66201 | .01231 |
| 162 | .93483 | .00385 | .75006 | .01060 |
| 167 | .62712 | .00461 | .80646 | .01692 |
| 172 | 1.61291 | .00696 | | |
| 177 | 2.00213 | .01334 | | |

Table 4.--Yield of crab in Millions of Pounds for Different Minimum Legal Sizes and Levels of Effort.

EFFORT MULTIPLIERS (REFERRED TO 1972 LEVEL OF EFFORT)

| Min. Size (length in mm) | 0.5 | 1.0 (1972) | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 |
|---|---|---|---|---|---|---|---|---|
| 110 | 13.45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 115 | 14.99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120 | 16.53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 125 | 18.74 | 16.31 | 0 | 0 | 0 | 0 | 0 | 0 |
| 130 | 21.16 | 21.60 | 17.19 | 11.66 | 0 | 0 | 0 | 0 |
| 135 | 23.59 | 25.35 | 22.27 | 15.65 | 4.63 | 0 | 0 | 0 |
| 140 | 23.37 | 24.47 | 23.59 | 16.09 | 6.39 | 0 | 0 | 0 |
| 145 | 22.05 | 23.37 | 23.81 | 16.31 | 7.50 | 0 | 0 | 0 |
| 150 | 14.99 | 20.06 | 22.49 | 19.18 | 16.31 | 6.61 | 1.10 | 0 |
| 155 | 6.83 | 12.57 | 13.01 | 13.67 | 14.33 | 14.77 | 7.50 | 0 |
| 160 | 1.98 | 5.29 | 6.83 | 8.16 | 10.36 | 11.68 | 11.68 | 8.82 |
| 165 | 0.44 | 1.76 | 2.86 | 4.19 | 7.28 | 9.26 | 9.70 | 9.92 |

Assumptions:

Mortality of ♂♂ = ♀♀

Growth ♀♀ as computed from earlier years' data.

If

$G_{♀♀ T} < G_{♀♀ (calc.)}$ then yield will increase in right hand columns.