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Relative Growth, Reproduction and Distribution of the Rock Crab, Cancer irroratus, in Chesapeake Bay during the Winter

Roy Tim Terretta
College of William and Mary - Virginia Institute of Marine Science

RELATIVE GROWTH, REPRODUCTION AND DISTRIBUTION OF THE ROCK CRAB, *CANCER IRRORATUS*, IN CHESAPEAKE BAY DURING THE WINTER

A Thesis

Presented to

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The College of William and Mary in Virginia

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

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by

Roy Tim Terretta

1973

APPROVAL SHEET

This thesis is submitted in partial fulfillment of

the requirements for the degree of

Master of Arts

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Approved, March 1973

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ABSTRACT

Rock crabs, *Cancer irroratus*, were collected in Chesapeake Bay from commercial blue crab dredge boats between 1 December 1970 and 28 April 1971 to study distribution and abundance, migratory patterns, size distributions and growth, size at sexual maturity, season of molting and reproductive biology.

Rock crabs were found as far up the bay as 37°25' N. Abundance, which ranged from 0 to 1200 crabs/dredge-hour, decreased with distance from the mouth of the bay, suggesting that salinity is primarily responsible for rock crab distribution in the bay. Falling water temperature probably controls initial immigration into the bay in the fall, and rising temperature initiates emigration in early spring.

The 3176 crabs measured ranged from 27 mm to 94 mm in carapace width (females) and 18 to 138 mm (males). Mean widths for the 27 locations sampled ranged from 80 to 114 mm for males and 68 to 75 mm for females. Relative growth analyses showed a sexual dimorphism in shape of the carapace and in the carapace width-weight relationship but not in growth of the chelae. A pubertal molt as evidenced by a change in growth rate was not observed in males or females.

Peak molting activity occurred during the third week of December 1970 for females and the second week of January or about 3 weeks later for males. Post exuvial sclerotization takes 2 to 3 months. Mating takes place when females are soft or newly molted. Only newly molted and papershell females had "sperm plugs," a sign of recent mating. All of the 33 male crabs (49 to 113 mm in carapace width) and 28 of the 31 female crabs (59 to 89 mm in width) dissected were sexually mature. No evidence of previous spawning was observed.

A stalked barnacle, *Octolasmis lowei*, was the only "internal" symbiont observed, infesting the gills and branchial chambers of both male and female crabs. The density of *Octolasmis* in the branchial chamber increased as the season progressed, suggesting an estuarine origin.

RELATIVE GROWTH, REPRODUCTION AND DISTRIBUTION OF THE ROCK CRAB, *CANCER IRRORATUS*, IN CHESAPEAKE BAY DURING THE WINTER

INTRODUCTION

Cancer irroratus (Say, 1817), a brachyuran crab of the family Cancridae, is found only in the western Atlantic from Labrador to South Carolina (Rathbun, 1930; Rees, 1963; Williams, 1965; Wilder, 1966). Along the New England coast the rock crab is very abundant inshore in depths of 5 to 20 m and is frequently found in bays and in tide pools. Rock crabs are caught commercially as far south as New Jersey. In the Chesapeake Bight, *C. irroratus* is widespread over the continental shelf and very abundant inshore (Musick and McEachran, 1972). Rock crabs have been found in Chesapeake Bay as far up estuary as the mouth of the East River in Mobjack Bay (Cowles, 1930; Rathbun, 1930), but no records of abundance or general distribution are available. In the southern part of its range, *C. irroratus* is found in deeper waters, to 550 m. Williams (1965) reported the southern limit as South Carolina but then stated, without documentation, that ovigerous females are known to occur in March in Florida. This last statement is in obvious conflict with the first and may be in error.

Chesapeake Bay is well within the southern limit of the range of the rock crab. Large numbers of rock crabs are caught in the winter dredge fishery for blue crabs from the first of December to the end of March each year. At present, there is no market for Chesapeake Bay rock crabs and they are discarded overboard. In fact, dredgers avoid areas where rock crabs are plentiful because of the time required to separate them from blue crabs.

Despite the commercial importance of the rock crab in more northern waters, investigation of its biology has been almost totally lacking until recently. Perhaps this is because rock crabs are caught incidentally in other fisheries (e.g., in lobster pots, fish trawls, etc.), and are seldom actively sought for their own value.

The life history of C. irroratus is not very well known. Larvae are produced from early spring through summer (Connolly, 1923; Sandifer, 1972). Duration of juvenile life, growth rate and intermolt duration are unknown. Adult crabs appear to molt once per year, primarily in fall and winter (Turner, 1953, 1954; Jeffries, 1966; Telford, 1968; Scarratt and Lowe, 1972). In Northumberland Strait, New Brunswick, sexual maturity occurs by the time crabs are 60 mm to 70 mm in width (Scarratt and Lowe, 1972); mating takes place after the female has molted and is soft (Chidester, 1911). Adult males are usually larger and more numerous than females (Turner, 1953, 1954; Scarratt and Lowe, 1972).

Distribution relative to environmental factors has been examined in Northumberland Strait, New Brunswick (Scarratt and Lowe, 1972), Narragansett Bay, Rhode Island (Jeffries, 1966) and Chesapeake Bight, the offshore waters of Virginia

(Musick and McEachran, 1972). Jeffries (1966) also postulated an offshore migration in winter to deeper and warmer ocean waters, whereas Turner (1954) found no evidence for seasonal migration in Boston Harbor, Massachusetts.

The rock crab is an important food of fishes. Smith (1879) reported it from the stomachs of the striped bass, sea bass, tautog, kingfish, sea robin, goosefish, summer flounder, toadfish, dogfish, dusky shark, sand shark and common skate. Barans (1969) reported it from the stomaches of spotted hake, *Urophycis regius* in the Chesapeake Bight. Scarratt and Lowe (1972) found that the prey of rock crabs >25 mm consisted principally of polychaetes, mussels, starfish and sea urchins but they did not believe there was significant competition with lobsters for food or space.

The life history, size distributions, seasonal migrations, reproductive season and behavior, and ecology of *C. irroratus* remain largely unknown, especially in Virginia waters. The present report is based on a study of crabs in Chesapeake Bay, Virginia, designed to describe: 1) distribution and abundance; 2) migratory patterns; 3) size distribution and growth; 4) size at which crabs become sexually mature; 5) season of molting and mating; and 6) reproductive biology.

MATERIALS AND METHODS

Rock crabs were collected weekly during December 1970, less frequently until 9 March 1971, and between 22 and 28 April 1971 from commercial crab dredging boats (Fig. 1). The dredge boats, less than 10 m to over 20 m in length, are usually equipped with two dredges 1.8 m wide pulled by chain wound on power driven drums below decks. The dredges (Fig. 2), weighing about 90 kg each, have 15 cm teeth welded 8 cm apart on a crossbar which can be rotated to adjust the angle of the teeth as they dig into the substrate. The angle the teeth make with the bottom is made more acute on hard substrates and less acute on soft bottoms. The catch bag is about 65 cm deep. The top half of the bag is made of 15.5 cm stretch mesh, cotton or nylon 0.6 cm line. The bottom is made of metal rings 6.5 cm in diameter, clamped together with S-shaped hooks.

Dredging is limited by law to lower Chesapeake Bay and to the small bays on the ocean side of the eastern shore of Virginia (Van Engel, 1962; Virginia Marine Resources Commission, 1937). Concentrations of crabs in the lower part of the Chesapeake during the winter occur following the fall migrations of adult female blue crabs from the rivers and upper bay following mating. During the 1970-71 dredge

Figure 1. Chesapeake Bay blue crab dredge boat.


AUTOMATIC
AUTOMATIC

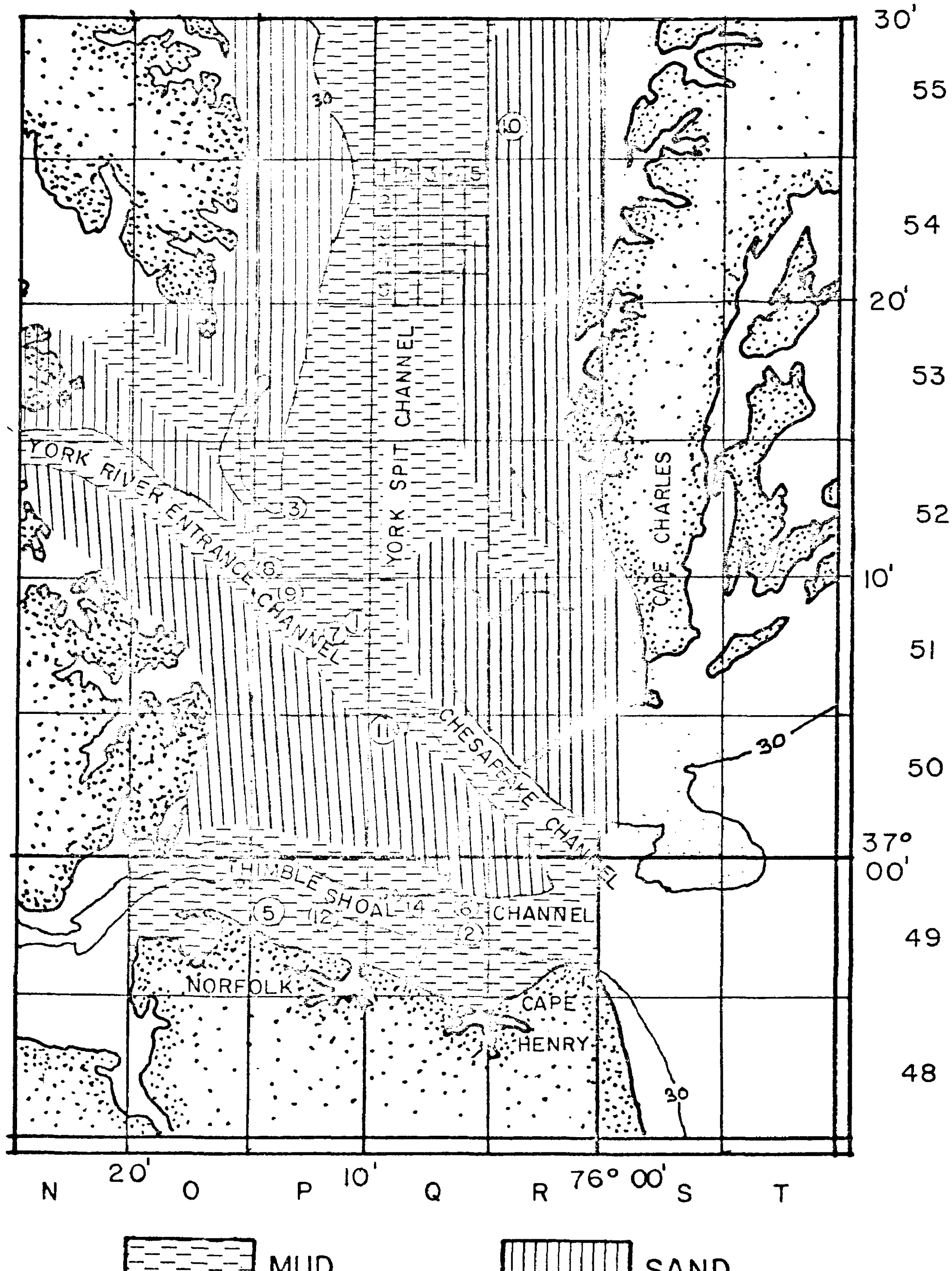
Figure 2. Chesapeake Bay blue crab dredge.

season almost all dredging occurred below 37°N, with concentrations of activity at the following areas (Fig. 3): 1) South of Thimble Shoal Channel from Willoughby Bank to the Chesapeake Bay Bridge Tunnel; 2) the area within a mile either side of York River Entrance Channel, including the channel; 3) the area within a mile either side of York Spit Channel (Baltimore Channel), including the channel; and 4) the area around and between Wolf Trap lighthouse and the "Old Cell," an abandoned naval ship degaussing station.

Dredge boats usually work the area within a radius of one mile of where they begin each day. If the catch is very poor they may move to a more productive location.

Sample locations were determined by triangulation or proximity to navigational aids. In the laboratory, locations were plotted on the VIMS grid, an alphanumeric system of designating areas of 5' latitude by 5' longitude. Letters are along the horizontal axis and numbers are along the vertical axis. In order to separate locations that may fall in the same grid, and to further pinpoint a location, each area was segmented into 25 smaller areas by horizontal and vertical lines delineating one minute of latitude and longitude respectively. A two digit coding system was used with rows numbered 1 through 5 from left to right and columns numbers 1 through 5 from top to bottom. The horizontal component was always read first followed by the vertical component. If more than one of these smaller rectangles was entered during a sampling day, the first

Figure 3. Chart of Chesapeake Bay with Winter Dredge Fishery sample locations, VIMS grid, and bottom types.



30'
55
54
20'
53
52
10'
51
50
37°
00'
49
48
N
20'
O
P
10'
Q
R
76° 00'
S
T
YORK RIVER ENTRANCE CHANNEL
YORK SPIT CHANNEL
CHESAPEAKE CHANNEL
THIMBLE SHOAL CHANNEL
CAPE CHARLES
NORFOLK
CAPE HENRY
30
MUD
SAND

pair of digits was followed by as many pairs as were required to adequately describe the location worked on a particular day (Fig. 3, Table 1).

Upon arrival at a sampling location at the beginning of the day, surface and bottom water samples for laboratory analysis of salinity and dissolved oxygen were taken with a Kemmerer bottle. Temperature was measured with a stem thermometer. Bottom sediment types were established by interviewing dredge boat captains. By examining the catch and by observing the way the dredges work, the vessel captains can determine hard sand, mixed mud and sand, and muddy bottoms.

Although both dredges were towed simultaneously from opposite sides of the boat, usually only the starboard dredge was observed. Dredges are towed at approximately 3 knots for an average of 15 minutes per haul and are lifted alternately. When possible, dredging time, rock crab catch, and blue crab catch were recorded for each haul. When catches were unusually large, numbers of rock crabs and blue crabs were measured by the bushel, 20-gal garbage can, or standard 100-lb crab barrel. The average number of crabs held in each of these containers was determined so that an estimate of catch per dredge-hour could be made. The time at which dredging began and stopped was recorded. The Virginia Marine Resources Commission sets limits on the number of barrels of blue crabs that may be caught per boat per day (25 barrels for 1970-71) primarily to maintain

TABLE 1

SUMMARY OF CATCH AND ENVIRONMENTAL DATA

Winter Dredge Fishery

Sample #	Date	Area	Temp. (°C)	Salin. (‰)	D.O. (mg/l)	Depth (m)	Bottom Type	Km From Bay Mouth	Abundance in Crabs/Dredge Hr.	Ratio Blue Crabs to Rock Crabs
1	1 Dec 70	P51	--	21.00	--	11.0	Mixed to Mud	24.14	135	4.0:1
2	1 Dec 70	Q49	11.4	24.71	8.8	11.0	Sandy	9.17	1050	0.7:1
3	8 Dec 70	P52	--	20.25	--	9.4	Mud	31.38	30	24:1
4	8 Dec 70	P49-Q49	7.9	24.35	8.8	10.1	Mud	11.91	90	8:1
5	15 Dec 70	P49	7.5	23.53	9.9	6.5	Mud	20.28	500	1.5:1
5a	15 Dec 70	P51	--	--	--	10.1	Mud	30.09	0	7500:0
6	21 Dec 70	Q49	8.2	23.49	9.8	10.4	Mixed	10.46	1200	
7	30 Dec 70	P51	--	20.9	--	10.5	Mixed	23.66	100	3:1
7a	30 Dec 70	P51	--	20.7	--	9.8	Mud	27.36	160	1.4:1
8	12 Jan 71	P52	4.6	26.93	--	10.9	Mud	30.25	66	2.5:1
9	10 Feb 71	P51	--	--	--	10.0	Mud	27.52		
10	16 Feb 71	R55	1.8	20.95	11.7	15.2	Mud	52.30	6	24:1
10a	23 Feb 71	P51	5.6	20.39	11.3	6.5	Sand	27.68	1-2	166:1
11	2 Mar 71	Q50	5.5	19.23	10.6	9.4	Sand	18.99	273	0.4:1
12	9 Mar 71	P49	5.2	19.83	10.5	7.0	Mud & Shell	16.09	57	2:1

TABLE 1. (Continued)

April Survey

Sample #	Date	Area	Temp. (°C)	Salin. (‰)	D.O. (mg/l)	Depth (m)	Bottom Type	Km From Bay Mouth	Abundance in Crabs/Dredge Hr.	Ratio Blue Crabs to Rock Crabs
149	22 Apr 71	Q53	10.9	23.10	9.20	12.2	Mud	32.19	7.5	--
166	22 Apr 71	Q52	11.6	23.41	--	10.7	Mixed	26.55	7	--
181	22 Apr 71	P51	11.8	23.76	9.3	10.7	Mixed	24.14	2	--
190	26 Apr 71	S50	11.9	30.61	9.2	9.1	Sand	--	12	--
195	26 Apr 71	U50	11.8	30.67	9.9	13.7	Sand	--	6	--
207	27 Apr 71	P45	13.1	19.05	6.9	9.1	Sand	18.19	14	--
220	27 Apr 71	Q49	12.8	21.49	5.9	8.6	Mud	8.85	26	--
220a	27 Apr 71	Q49	12.8	21.49	5.9	9.1	Sand	8.05	64	--
239	27 Apr 71	R50	12.5	26.29	3.9	18.3	Sand	9.17	664	--
242	27 Apr 71	R50	13.0	25.44	8.1	8.3	Sand	12.07	164	--
245	28 Apr 71	S49	11.0	30.72	4.7	19.8	Sand		6	--
249	28 Apr 71	S49	10.5	30.50	4.7	15.2	Sand	3.54	43	--
255	28 Apr 71	R50	11.8	30.04	9.2	13.7	Sand	9.33	140	--
258	28 Apr 71	S50	11.5	30.25	5.7	13.7	Shell Sand	10.30	4	--
261	28 Apr 71	Q51	13.0	27.46	8.6	13.7	Sand	17.54	30	--

market support when crabs are abundant. Dredging operations ceased either when the limit of 25 barrels of blue crabs was caught or at sundown, whichever occurred first.

Random samples of rock crabs were brought back to the laboratory at VIMS, Gloucester Point, Virginia, in plastic 20-gal garbage cans which were placed in a cold room overnight at 3.5 C. Crabs were measured with a clear plexiglass L-shaped measuring device with a clear metric ruler fastened to the top (Fig. 4). The dimension was measured by butting the crab against the base of the "L" and then reading perpendicularly through the rule. All measurements were made to the nearest millimeter.

Measurements taken from the crabs were: 1) carapace length, measured along the median line from the tip of the rostrum to the posterior margin; 2) carapace width measured at the widest point between the outermost anterolateral spines; and 3) length of the propodus of the larger chela, measured along the lower margin from the articulation with the carpus to its distal tip (Fig. 5). Weights of crabs with no missing limbs were determined using an Ohaus Scale Corporation triple beam balance. Sex was also noted.

Approximate stage in the intermolt cycle was determined for each crab measured. A number was assigned to each of five intermolt stage categories: 1) Hard: epimeral suture in subhepatic region of carapace does not break when firmly pressed, dorsal carapace extremely hard, no limb bud

Figure 4. Device used to measure rock crabs.

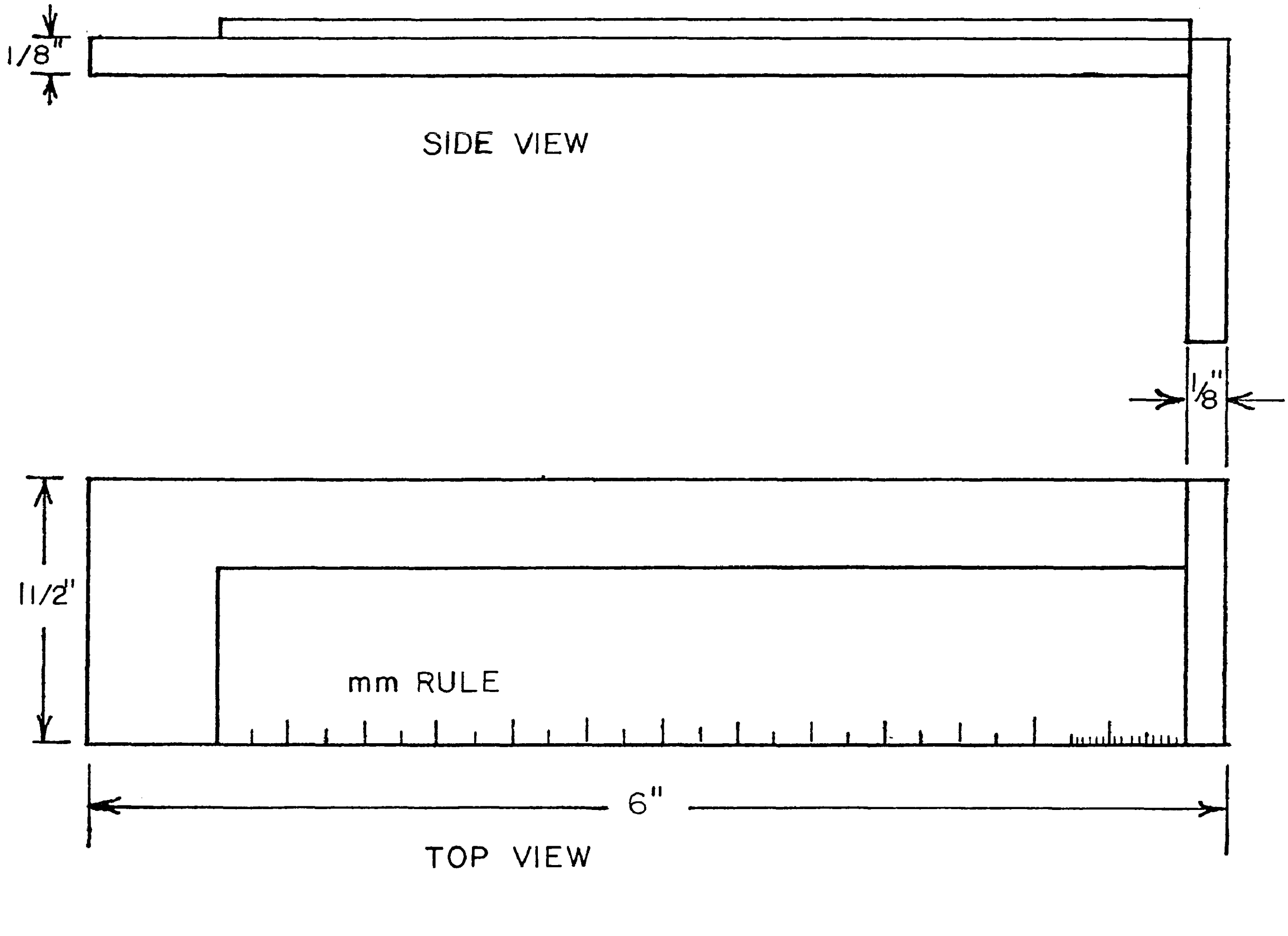
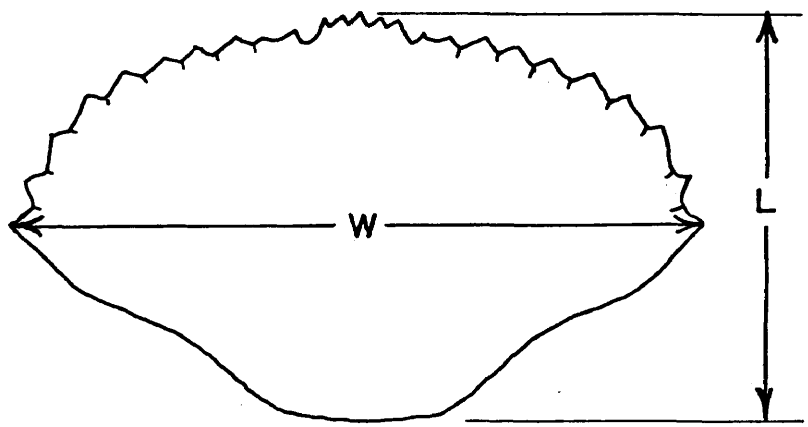
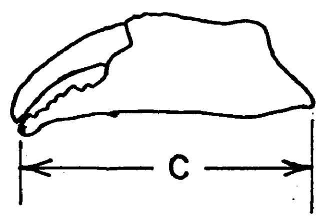

1/8"
SIDE VIEW
1/8"
11/2"
mm RULE
6"
TOP VIEW

Figure 5. Diagram of rock crab carapace and chela showing dimensions measured.





W = CARAPACE WIDTH

L = CARAPACE LENGTH

C = LENGTH OF CHELAR PROPODITE

formation where there are missing limbs (Stage C_4 to D_1) (Passano, 1960); 2) Peeler: epimeral suture in subhepatic region breaks cleanly when pressed, limb buds formed, hypodermis separates easily from exoskeleton when dactyl of fifth pereiopod is broken off (Stage D_2); 3) Buster or about to molt: ecdysial epimeral sutures open (Stage D_4); 4) Soft or newly molted: old exoskeleton already cast (Stage A); 5) Papershell: exoskeleton beginning to harden, dorsal carapace easily depressed (Stage B).

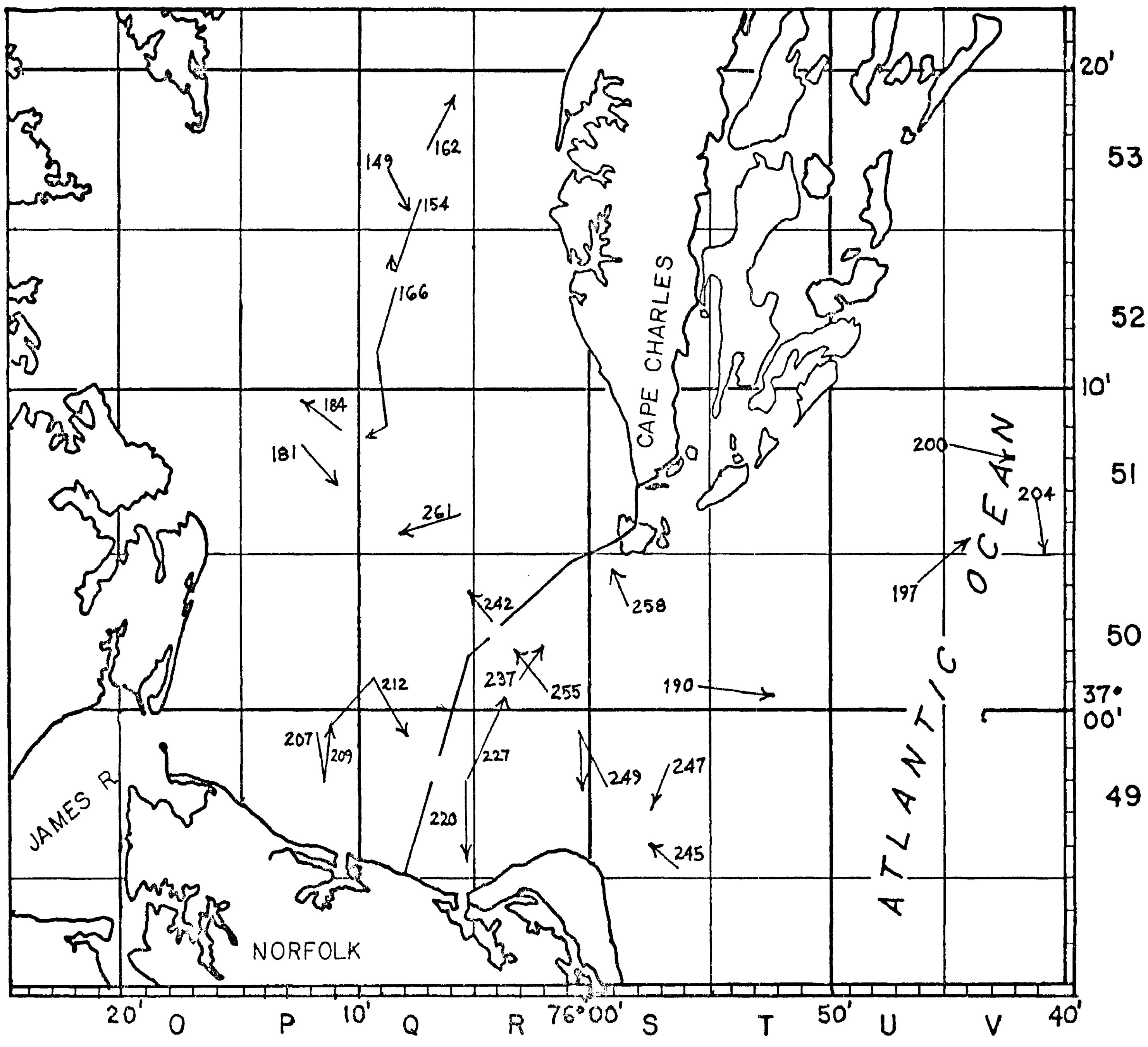
Crabs were examined for presence of external fouling organisms. Pleopods of female crabs were examined for evidence of previous spawning. The vulvae, or female reproductive openings on the 6th thoracic sterna were examined for presence of sperm plugs, a sign of recent mating. The reproductive potential of ovigerous females was determined. Mating behavior of a pair of rock crabs was observed in the laboratory.

A random sample of about 25 male crabs and all female crabs was preserved from each large sample for examination of the reproductive systems. Male gonads were measured and examined for presence of mature sexual products. Female gonads were observed for color, size, presence and diameter of oocytes. Shape, size and color of spermathecae were recorded as well as presence of sperm or spermatophores. The gills and gill chambers of both sexes were examined for parasites or commensals.

Carapace width-frequency distributions were assembled for each location. Since very few females were captured at any one location they were combined into one group for statistical analyses. Computations were made with IBM 1130 and 360 computers with a Hewlett-Packard programmable calculator.

During the dredge fishery season sampling was limited to areas where blue crabs were most abundant; thus, most of the lower bay was not sampled for rock crabs. In order to sample broad areas of the bay over a shorter period of time, the dredge boat East Hampton was chartered 22, 26, 27, and 28 April 1971. By this time the dredging season was over and water temperatures were warming rapidly. The survey was to also show if rock crabs were leaving or had left the bay. Accordingly, six transects were run, four across the bay and two in nearshore ocean waters (Fig. 6). Collection numbers where hydrographic data were taken are included on the figure. Hauls from both starboard and port dredges were examined. The starboard dredge was lined with 2.54 cm stretch mesh netting to note any differences in size distribution of crabs caught. Numbers, width, and sex of crabs were recorded.

Figure 6. April Survey sample locations; arrows denote path of dredging; collection numbers indicate where hydrographic data were recorded.



CAPE CHARLES
ATLANTIC OCEAN
JAMES R
NORFOLK
162
149
154
166
184
181
261
242
258
237
255
212
207
209
227
220
249
247
245
190
200
204
197
20'
10'
37°
00'
53
52
51
50
49
20'
O
P
10'
Q
R
76°00'
S
T
50'
U
V
40'

RESULTS

Abundance and Distribution

Interviews with crab dredgers reveal that rock crabs have occurred in Chesapeake Bay for at least the past 50 years; have been more numerous during the last five winters; have penetrated farther up bay each winter for the last five winters, and are occasionally found as far north as Tangier Island about 60 nautical miles from the bay mouth (Latitude 37°50'N); do not usually appear in large numbers until January; are more abundant on sand rather than mud substrates; are very abundant along the deep channels of lower Chesapeake Bay (Thimble Shoals Channel and Chesapeake Channel, Fig. 3); and are considered a nuisance to sort from the catch. Therefore, watermen avoid areas where the ratio of rock crabs to blue crabs is high.

Rock crabs are also abundant in Virginia's nearshore ocean waters, moving inshore during the winter as inshore temperatures fall within their preferred temperature ranges. A fish trawler working at night within a half mile of the beach near Rudee Inlet in December 1968 caught an estimated 910 kg of rock crabs in a one hour tow. On Virginia's Eastern Shore, rock crabs enter oceanside blue crab pots in late fall and early spring, a nuisance to crab potters as the rock crabs are presently discarded.

December 1970 to March 1971 Survey

During the 1970-71 dredging season 15 locations were sampled. Rock crabs were found mostly near deep channel areas in the lower bay. Abundance varied from 0 to 1200 rock crabs per dredge-hour (Table 1) averaging 262 crabs per dredge-hour during the winter and 79 crabs per dredge-hour during the April survey.

The results do not demonstrate conclusively what parameters limit rock crab distribution in the bay. Of the environmental parameters measured (temperature, salinity, dissolved oxygen, depth and bottom type) only temperature showed a significant correlation with rock crab abundance ($r = 0.756$) (Table 2). This is probably an artifact of sampling because sampling was not random over the entire dredge season. Early in the season when temperatures were warmer (Fig. 7), sampling was concentrated near the mouth of the bay where rock crab catches are usually large; whereas, later in the season when temperatures were cooler, sampling was concentrated farther up-bay where rock crabs are less abundant. The difference in bottom temperature between the bay mouth and a station 80 miles up-bay was found to be 10 or less December through March (Seitz, 1971). Thus, the temperature gradient over the area where rock crabs are found (i.e., 60 miles or less from the bay mouth) is less

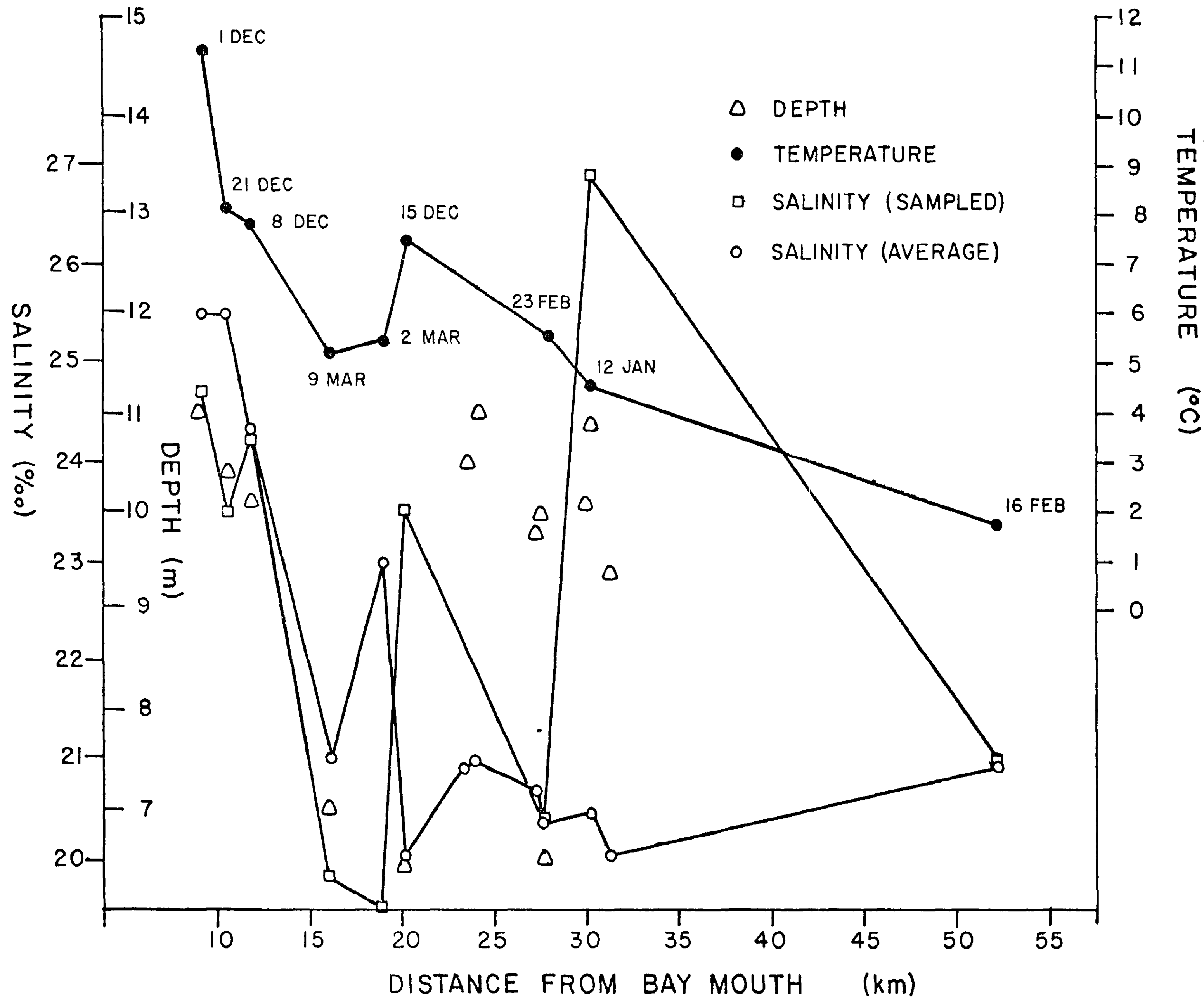
TABLE 2

RELATION OF ABUNDANCE OF ROCK CRABS TO ENVIRONMENTAL PARAMETERS.

Winter Dredge Fishery: Abundance (y) On

X:	Temperature	Salinity	Avg. Salinity	D.O.	Depth	Bottom Type	Distance
r	0.756	0.320	0.763	-0.563	0.029	-0.378	-0.615
N	9	9	13	8	13	13	14
Significant	Yes @ 5%	No	Yes @ 1%	No	No	No	Yes @ 5%
			April Survey				
r	0.211	0.159	0.287	-0.466	0.573	-0.310	-0.329
N	12	12	12	11	12	12	12
Significant	No	No	No	No	No	No	No

Figure 7. Relation of environmental parameters to distance up estuary from the mouth of Chesapeake Bay.


DEPTH
TEMPERATURE
SALINITY (SAMPLED)
SALINITY (AVERAGE)
1 DEC
21 DEC
8 DEC
15 DEC
9 MAR
2 MAR
23 FEB
12 JAN
16 FEB
SALINITY (‰)
DEPTH (m)
TEMPERATURE (°C)
DISTANCE FROM BAY MOUTH (km)

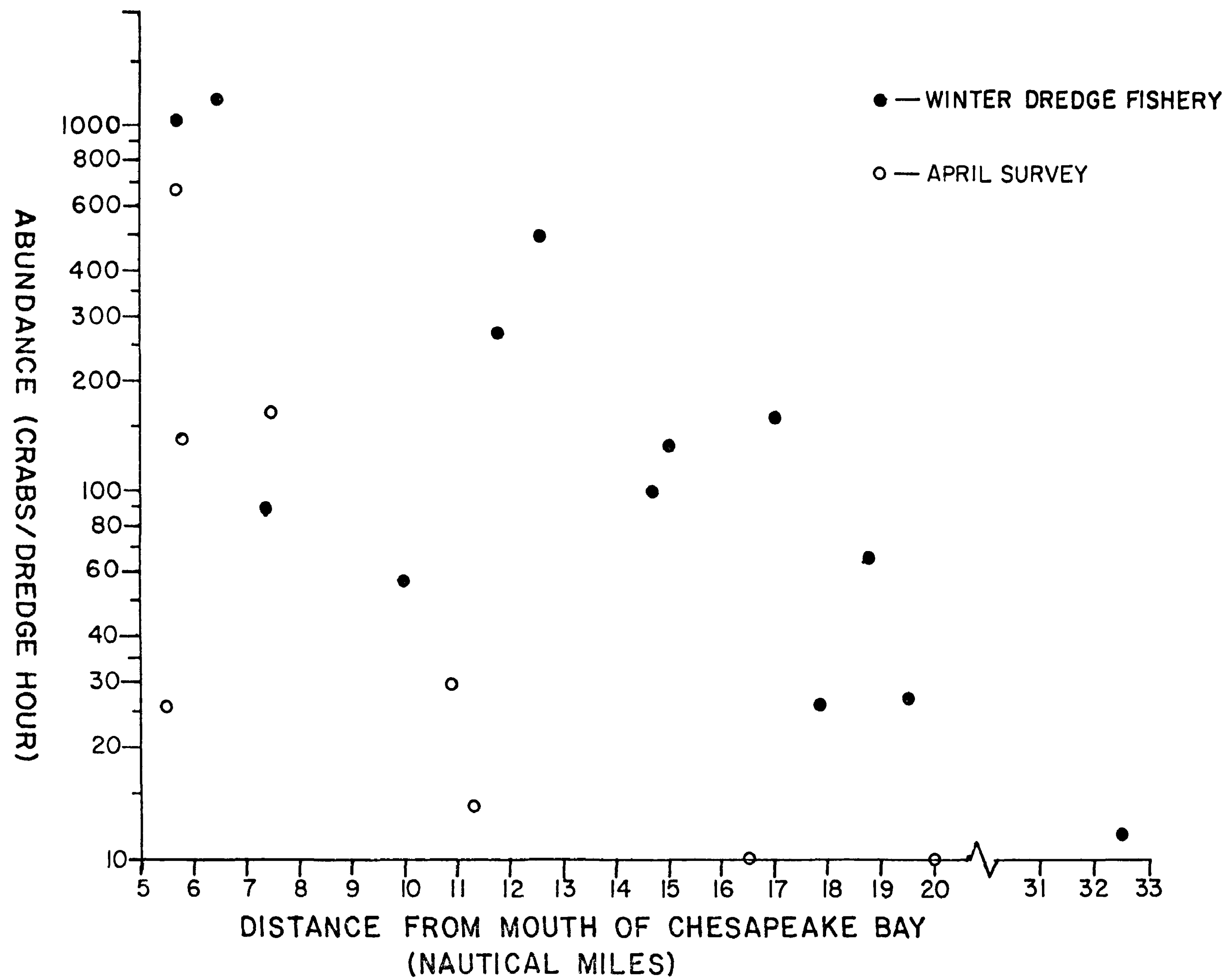
than 10. Consequently, it is very doubtful that rock crabs would respond to a temperature gradient this small.

Distance from the mouth of the bay showed a significant negative correlation with abundance (r = -0.615) (Table 2, Fig. 8), and is coincident with the salinity gradient. Figure 7 shows the relationship of some environmental parameters to distance from the mouth of the bay. Because salinity samples were taken only once per sampling day, a salinity datum does not always reflect the usual or average salinity for a given location. When average salinity values (Stroup & Lynn, 1963) at each location (Fig. 9a,b) are correlated with abundance a significant correlation coefficient is obtained (r = 0.763) (Table 2) suggesting that salinity is the primary factor limiting rock crab distribution in the bay during the winter.

Crabs were taken on all bottom types. Correlation analyses showed no association between abundance and bottom type or depth (Table 2). Variation in dissolved oxygen was slight because water in the bay in winter is usually near saturation due to wind mixing and low temperatures. No relation was found between dissolved oxygen and abundance (Table 2).

Blue crabs outnumbered rock crabs with two exceptions, samples 2 and 11 (Table 1). Ratios of blue crabs to rock crabs ranged from 0.4:1 to 7,500:0. The wide range of this ratio is primarily due to the distribution and abundance of rock crabs rather than blue crabs because the latter were

Figure 8. Distribution of rock crabs with distance up estuary from the mouth of Chesapeake Bay.

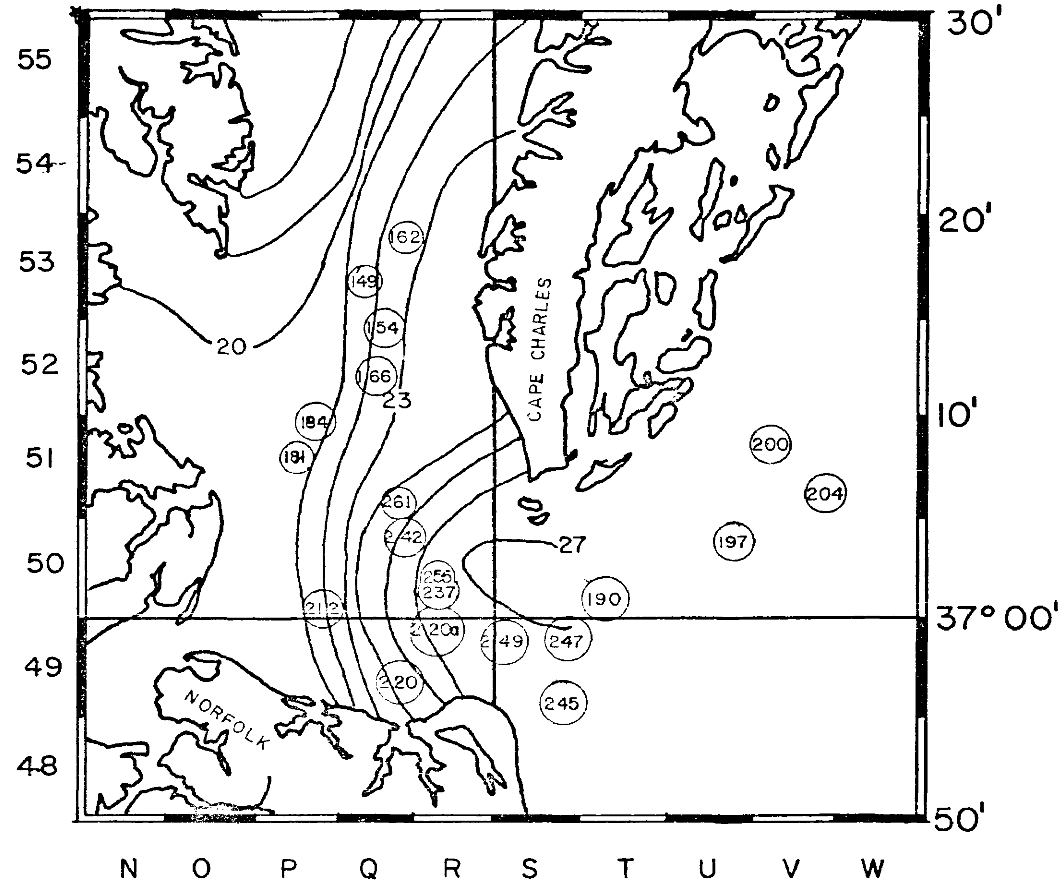


ABUNDANCE (CRABS/DREDGE HOUR)
1000
800
600
400
300
200
100
80
60
40
30
20
10
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
31
32
33
DISTANCE FROM MOUTH OF CHESAPEAKE BAY
(NAUTICAL MILES)
— WINTER DREDGE FISHERY
— APRIL SURVEY

Figure 9a. April Survey locations plotted on chart of Chesapeake Bay showing average salinity isohals.

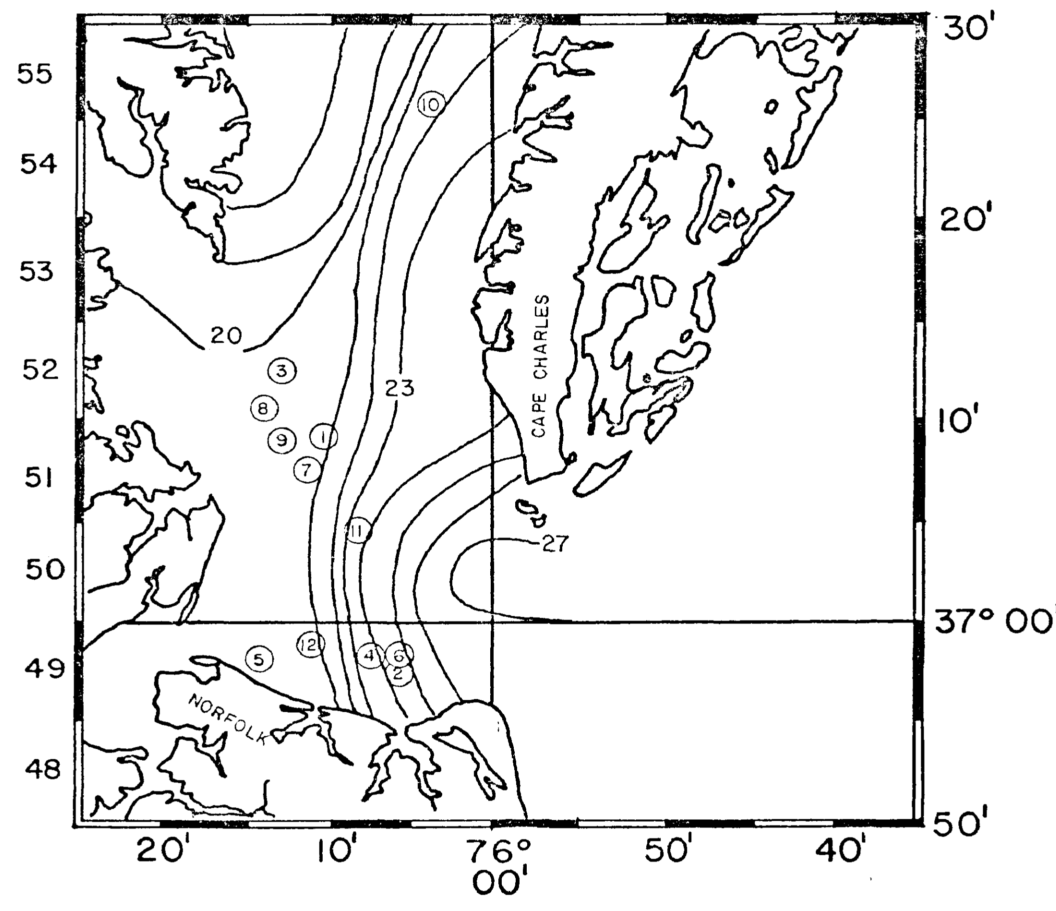
b. Winter Dredge Fishery locations plotted on chart of Chesapeake Bay showing average salinity isohals.

A.



55
54
53
52
51
50
49
48
30'
20'
10'
37° 00'
50'
CAPE CHARLES
NORFOLK
20
23
27
162
149
154
166
184
181
261
242
237
190
200
204
197
247
245
N O P Q R S T U V W

B.



55
54
53
52
51
50
49
48
30'
20'
10'
37° 00'
50'
CAPE CHARLES
NORFOLK
20
23
27
10
3
8
9
1
7
11
12
5
4
6
2
20'
10'
76° 00'
50'
40'

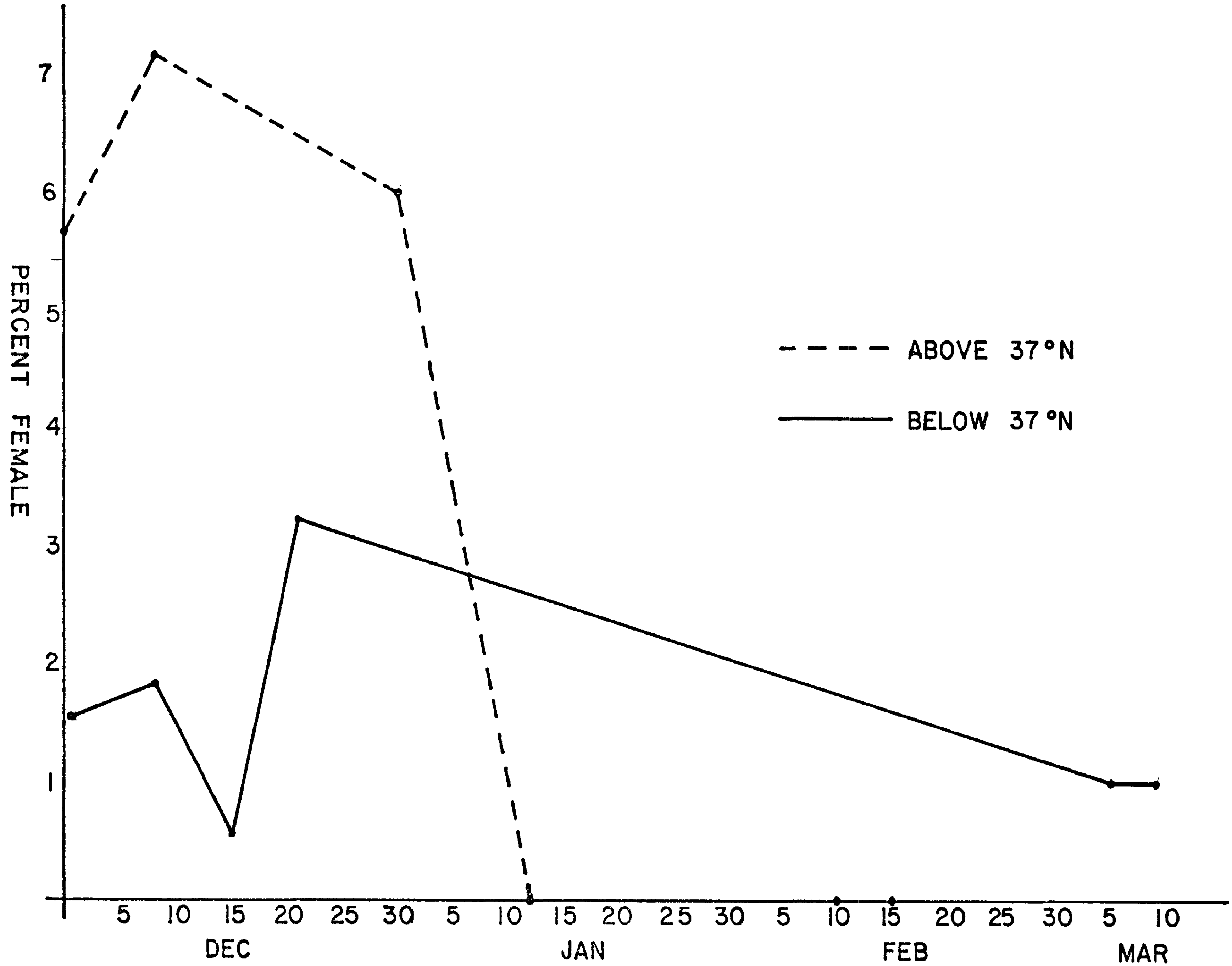
ubiquitous in most locations sampled, especially at the beginning of the dredge season; indeed, this is why dredge boats were working in these areas.

The percentage of female rock crabs during the winter months was quite low at all locations sampled (Fig. 10) and appeared to decline after December. There seem to be more female crabs north of 37°N, probably because salinities are higher in Chesapeake Channel than in Thimble Shoals Channel.

April 1971 Survey

During the April survey (22-28 April 1971) rock crabs were still found mostly in the deep channels of the bay. However, their number had declined considerably. This survey included several ocean stations near the bay mouth (Fig. 6) but at none of these stations were rock crabs very abundant (6 to 12 crabs/dredge-hour) (Table 1). The greatest density of rock crabs was found in Chesapeake Channel just southeast of the Chesapeake Bay Bridge Tunnel (140 to 664 crabs/dredge-hour). Only data obtained within the bay were used in the linear correlation analysis so that results could be compared to the dredge fishery data. None of the correlation coefficients is significant, including that obtained from average salinity values (Fig. 9b), probably because of the small sample sizes. In small samples the estimate, r, is not very reliable (Snedecor, 1956). Trends are the same as in the winter dredge fishery results.

Figure 10. Percentages of females in rock crab catches north and south of 37°N.


PERCENT FEMALE
7
6
5
4
3
2
1
5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30 5 10
DEC
JAN
FEB
MAR
ABOVE 37°N
BELOW 37°N

So few blue crabs were caught during the April survey that no blue crab to rock crab ratios were computed.

During the April survey female rock crabs were caught only outside of the bridge tunnel at stations 190 (Fig. 6) (5.9% of the catch), 249 (6.7%), and 255 (1%). Of the 9 females caught, 3 were ovigerous; 2 at station 249, and one at station 255.

Mean Carapace Widths and Frequency Distributions

Mean carapace widths, ranges and interval estimates ($\bar{x} \pm t_{.05}s_{\bar{x}}$) of male rock crabs for samples collected during the winter dredge fishery and during the April survey are presented in Figures 11 and 12 respectively. Analysis of variance and Tukey's w' procedure for comparison of means with unequal sample size (Steele and Torrie, 1960) were computed for the winter dredge fishery (WDF) carapace width data (Table 3) and the April survey data (Table 4).

For the WDF data, no significant mean differences were found among any locations south of 37°N. Rock crabs at all locations south of 37°N exhibit smaller mean carapace widths than at any stations above 37°N. There is, however, no significant difference between the largest mean width for crabs at lower bay stations and the two smallest values for crabs at higher bay locations (Table 3). North of 37°N, mean widths for January and February are significantly greater than those in December and March. Mean widths for

Figure 11. The means, interval estimates and ranges of the carapace widths of rock crabs taken during the Winter Dredge Fishery, December 1970 through March 1971. Numbers represent sample sizes; vertical lines represent ranges in width; horizontal lines represent mean widths; rectangles represent the confidence interval ($\bar{x} \pm t_{.05}s_{\bar{x}}$).

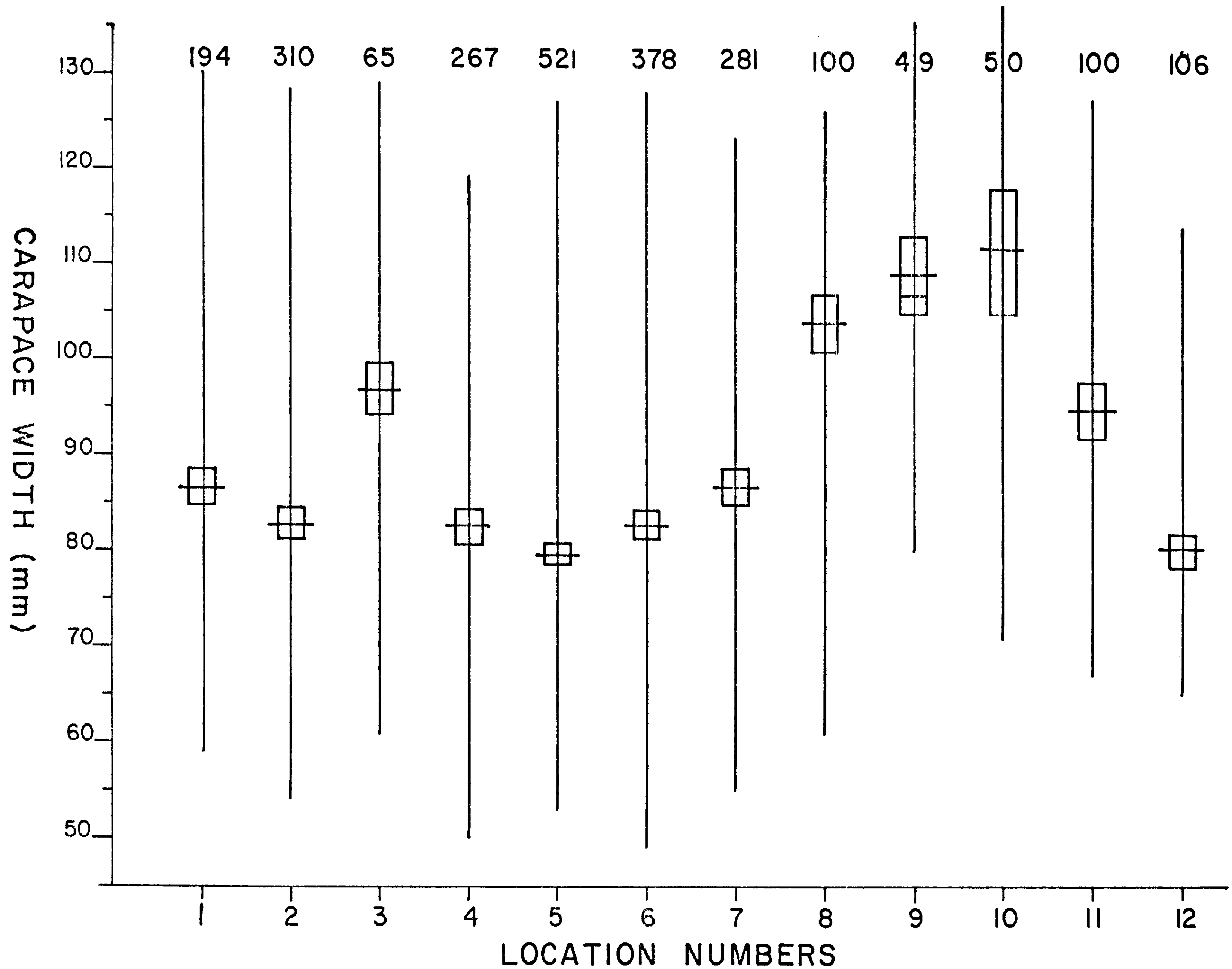

194
310
65
267
521
378
281
100
49
50
100
106
130
120
110
100
90
80
70
60
50
CARAPACE WIDTH (mm)
1
2
3
4
5
6
7
8
9
10
11
12
LOCATION NUMBERS

Figure 12. The means, interval estimates and ranges of the carapace widths of rock crabs taken during the April Survey, 1971. Numbers represent sample sizes; vertical lines represent ranges in width; horizontal lines represent mean widths; rectangles represent the confidence interval ($\bar{x} \pm t_{.05}s_{\bar{x}}$).

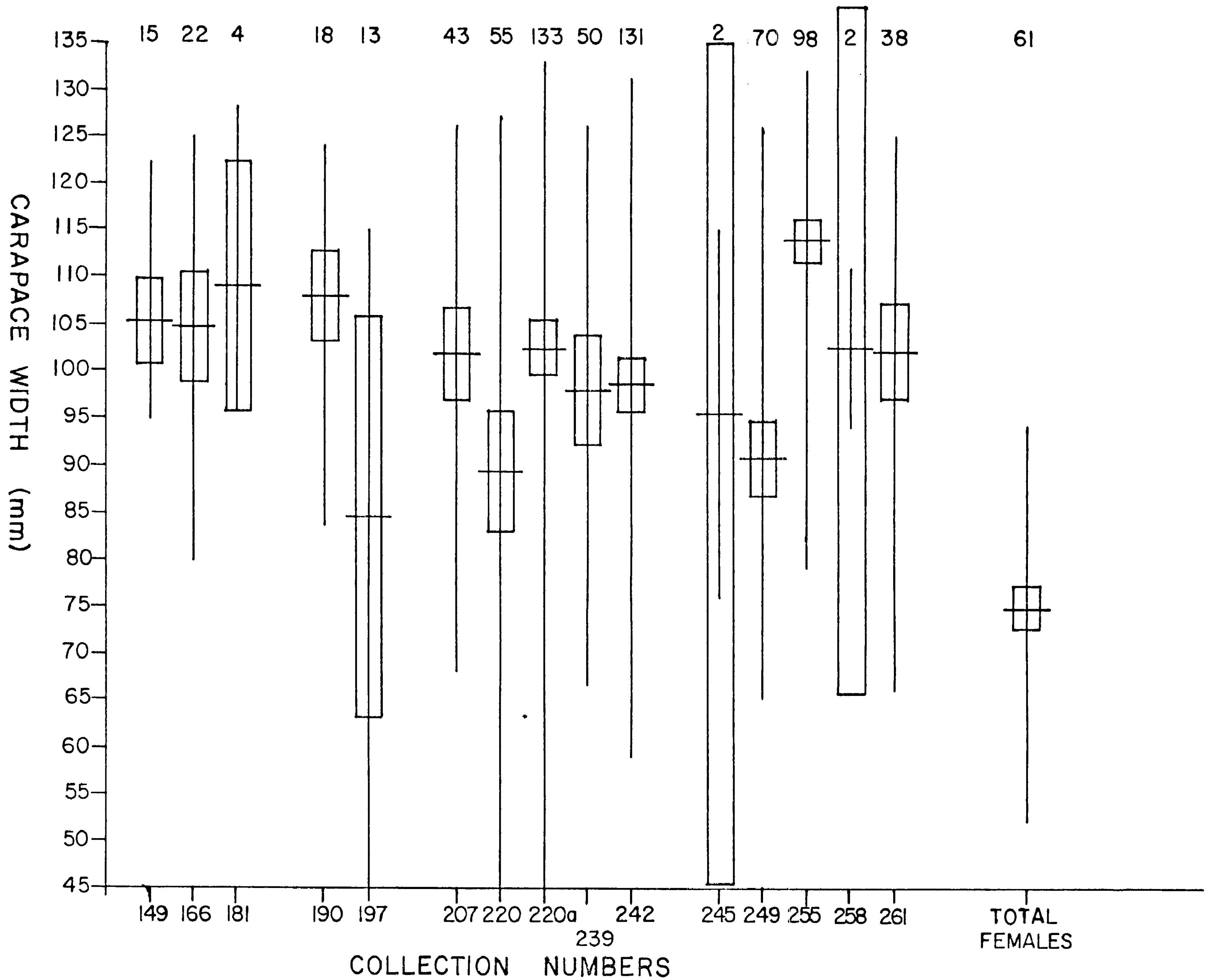

15 22 4 18 13 43 55 133 50 131 2 70 98 2 38 61
135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45
CARAPACE WIDTH (mm)
149 166 181 190 197 207 220 220a 239 242 245 249 255 258 261
TOTAL FEMALES
COLLECTION NUMBERS

TABLE 3

TUKEY's w' PROCEDURE FOR GROUPS WITH UNEQUAL SAMPLE SIZES

Winter Dredge Fishery Data

Location	Date	Location in Bay	$\bar{x}$	N
5	15 Dec 70	Down	79.68	521
12	9 Mar 71	Down	80.1851	106
4	8 Dec 70	Down	82.53	267
6	21 Dec 70	Down	82.81	378
2	1 Dec 70	Down	82.9097	310
1	1 Dec 70	Up	86.67	194
7	30 Dec 70	Up	86.69	281
11	2 Mar 71	Up	94.71	100
3	8 Dec 70	Up	96.95	65
8	12 Jan 71	Up	103.85	100
9	10 Feb 71	Up	108.92	49
10	16 Feb 71	Up	111.62	50

All Up Bay Stations are North of Latitude 37°N.

Bar Indicates No Significant Differences Between Means At 5% Level.

ANALYSIS OF VARIANCE

Source	SS	d	Mean Square	F-ratio
Between Groups	140066.37	11	12733.30	62.396**
Within Groups	491610.56	2409	204.07	
Total	631676.94	2420		

TABLE 4

TUKEY's w' PROCEDURE FOR GROUPS WITH UNEQUAL SAMPLE SIZES

April Survey Data

Location	Date	$\bar{x}$	N
S.I.S.	26 April 71	84.6	13
#220	27 April 71	89.4	55
#249	28 April 71	90.9	70
#239	27 April 71	98.0	50
#242	27 April 71	98.7	131
#207	27 April 71	101.8	43
#261	28 April 71	102.3	38
#220a	27 April 71	102.5	133
#166	22 April 71	104.7	22
#149	22 April 71	105.2	15
#190	26 April 71	107.9	18
#181	22 April 71	109.0	4
#255	28 April 71	114.0	98

Not Included in Multiple Mean Test

#245	28 April 71	95.5	2
#258	28 April 71	102.5	2

ANALYSIS OF VARIANCE

Source	SS	df	Mean Square	F-ratio
Between Groups	37928	12	3160.7	10.987**
Within Groups	194753	677	287.7	
Total	232682	689		

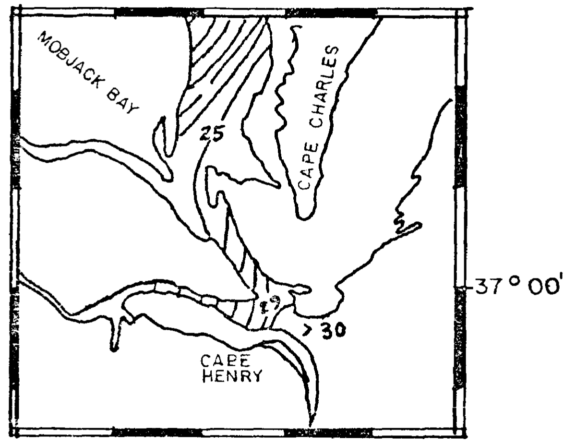
March are smaller than those in January and February both north and south of 37°N.

Mean carapace width correlates somewhat with depth (r^2, the coefficient of determination = 0.369; i.e., 36.9% of the variability in mean width can be attributed to variation in depth). The largest mean widths are associated with greatest depth ($y = 59.1 + 3.2\ x$, where y = carapace width and x = depth in meters). This relationship may reflect salinity preferences because in the Chesapeake Bay estuary an increase in depth usually results in a marked increase in salinity, especially near channels (Fig. 13) (Stroup and Lynn, 1963).

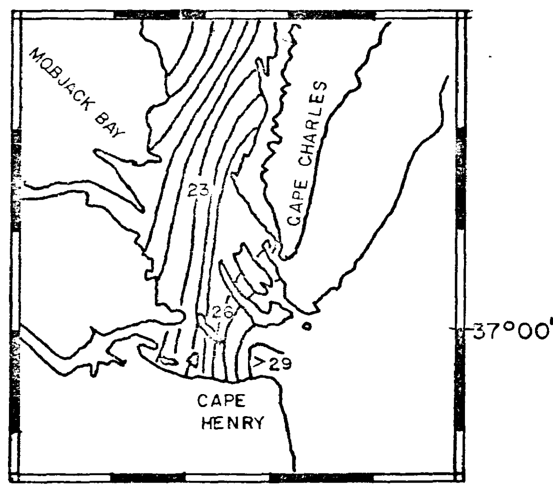
During 22-28 April 1971, it was found that crabs were larger toward the northern limits of distribution in the bay. Mean carapace widths decreased (although not significantly) from the head of York Spit Channel to the mouth of the bay following Chesapeake Channel. It was also found that crabs dredged over hard, sandy bottoms just north of Thimble Shoals Channel (Sample No. 220a) were significantly larger ($\bar{x} = 102.5 \pm 2.9$ mm) than those dredged from muddy substrates south of Thimble Shoals Channel (Sample No. 220) ($\bar{x} = 89.4 \pm 6.3$ mm) where the water was also shallower (Table 4).

One unusually large mean width (114.0 ± 2.2 mm) was obtained 28 April 1971 from the more northern side of Chesapeake Channel near the bridge tunnel. It is significantly larger than the mean widths obtained the previous day

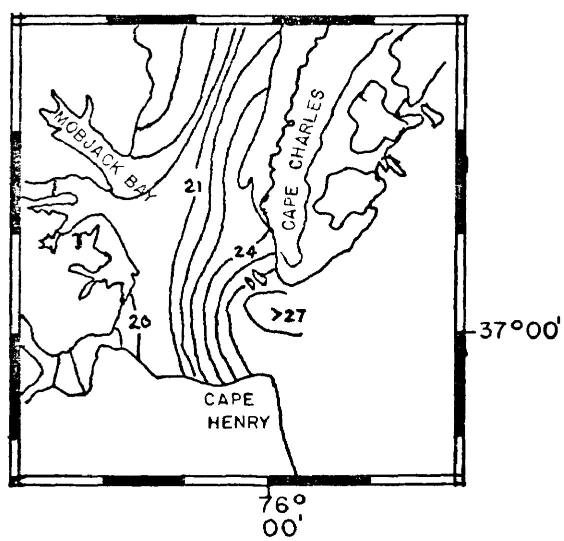
Figure 13. Charts of Chesapeake Bay with isohals at 10 feet, 20 feet, and 30 feet, showing the increase of salinity with depth.



30 ft SALINITY (‰)



20 ft SALINITY (‰)



10 ft SALINITY (‰)

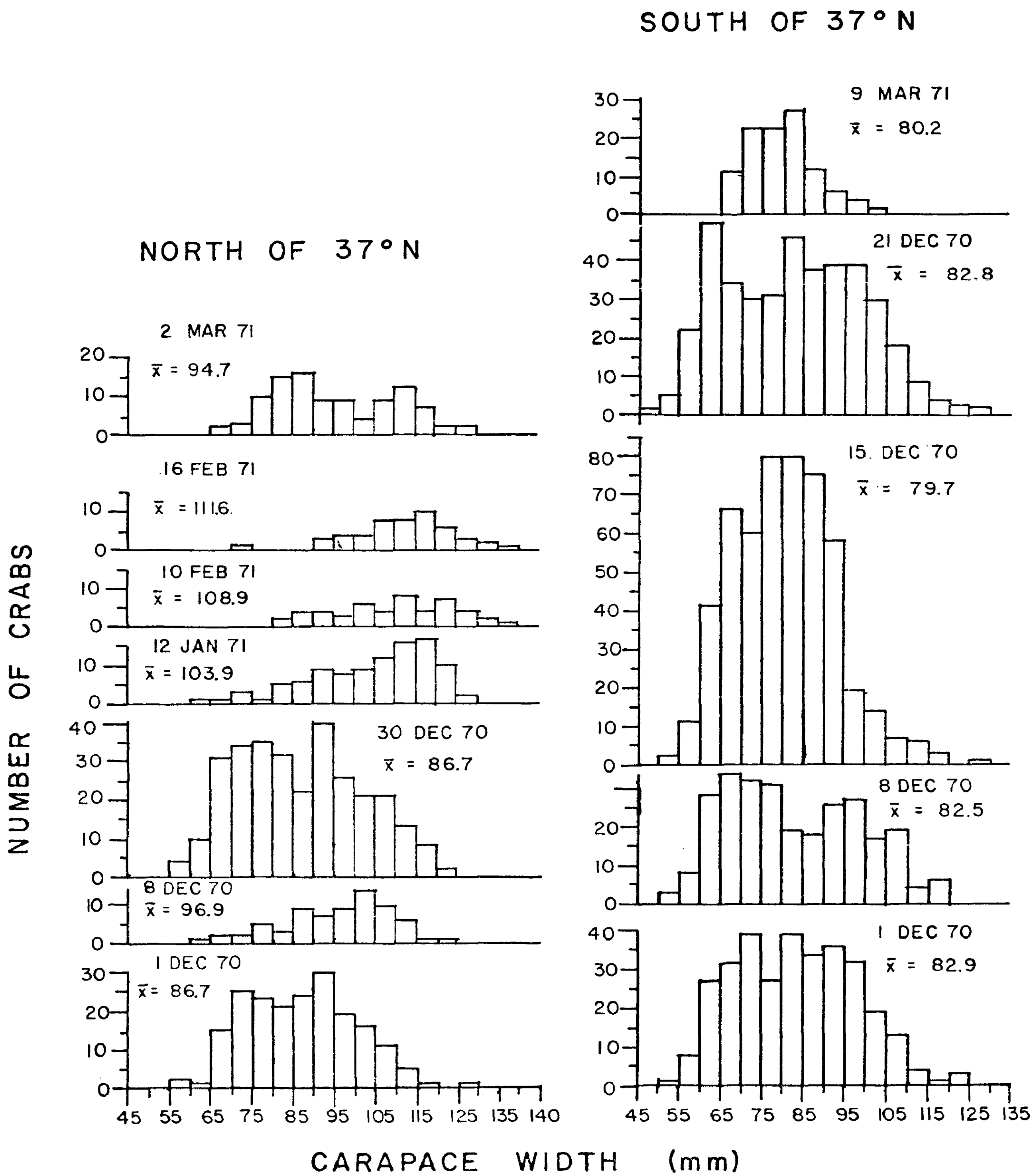
from approximately the same location (98.0 ± 5.7 mm and 98.6 ± 2.9 mm). The salinity for 27 April was around 25‰, and for 28 April it was 30‰.

Nine female rock crab carapace widths ranged from 25 mm to 89 mm with a mean of 67.3 mm, a smaller value than the mean width for all females captured during the winter dredge fishery ($\bar{x}$ = 74.9 ± 2.4 mm).

During the April cruises, there was no apparent correlation of mean carapace width with depth. Mean carapace widths were distributed randomly over the entire range of depths (r^2 = 0.056).

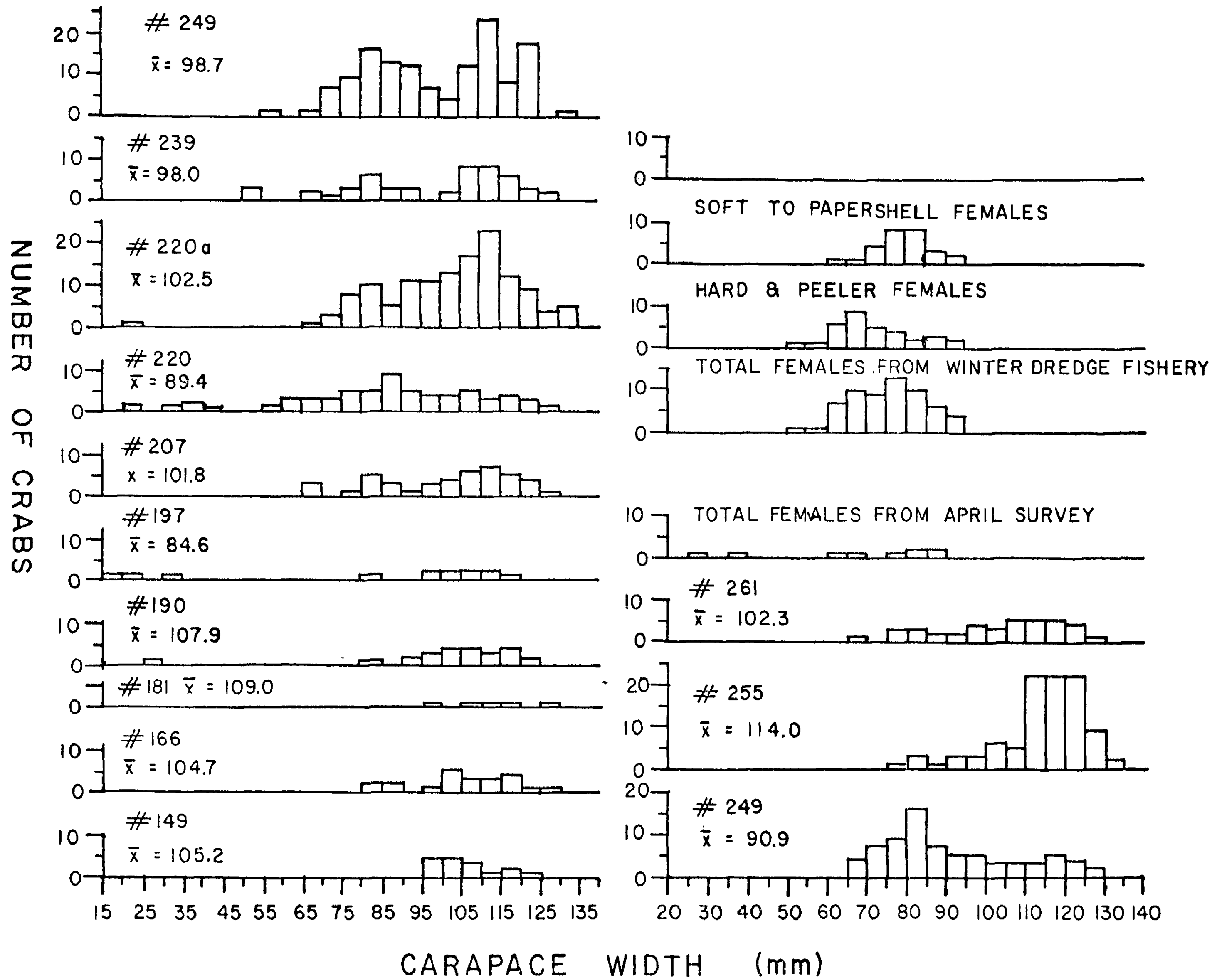
Carapace width-frequency distributions by 5 mm intervals for male rock crabs caught during the winter dredge fishery at locations north and south of 37°N (Fig. 14) and for crabs caught during 22-28 April and for all female crabs from all locations (because of the small number of females captured) (Fig. 15) are normally distributed in most samples with bimodality observable in some. The distributions are truncated at the smaller end of the scale due either to nonavailability to the dredge or to the absence of small crabs in the bay at the times sampled. North of 37°N the modal and mean carapace widths increase markedly, the mean progressively, after 30 December 1970. The 2 March 1971 sample shows an equally marked decrease. South of 37°N there is no significant change during December. Unfortunately, no samples were taken in this area during January or February. The

Figure 14. Carapace width-frequency distributions by 5 mm class intervals for rock crabs taken during the Winter Dredge Fishery.



SOUTH OF 37° N
NORTH OF 37° N
9 MAR 71
x̄ = 80.2
21 DEC 70
x̄ = 82.8
15. DEC 70
x̄ = 79.7
8 DEC 70
x̄ = 82.5
1 DEC 70
x̄ = 82.9
2 MAR 71
x̄ = 94.7
16 FEB 71
x̄ = 111.6
10 FEB 71
x̄ = 108.9
12 JAN 71
x̄ = 103.9
30 DEC 70
x̄ = 86.7
8 DEC 70
x̄ = 96.9
1 DEC 70
x̄ = 86.7
NUMBER OF CRABS
45 55 65 75 85 95 105 115 125 135 140
45 55 65 75 85 95 105 115 125 135
CARAPACE WIDTH (mm)

Figure 15. Carapace width-frequency distributions by 5 mm class intervals for rock crabs taken during the April Survey.



NUMBER OF CRABS
249
x̄ = 98.7
239
x̄ = 98.0
220a
x̄ = 102.5
220
x̄ = 89.4
# 207
x = 101.8
# 197
x̄ = 84.6
190
x̄ = 107.9
181 x̄ = 109.0
166
x̄ = 104.7
149
x̄ = 105.2
SOFT TO PAPERSHELL FEMALES
HARD & PEELER FEMALES
TOTAL FEMALES FROM WINTER DREDGE FISHERY
TOTAL FEMALES FROM APRIL SURVEY
261
x̄ = 102.3
255
x̄ = 114.0
249
x̄ = 90.9
CARAPACE WIDTH (mm)

9 March sample is not significantly different from the December samples; neither was the March sample from above 37°N.

Samples taken during the April survey have modal and mean carapace width values similar to those north of 37°N. Samples #220 and #249, both taken south of 37°N, have modal values of 87 mm and 82 mm respectively and mean values of 89.4 mm and 90.9 mm respectively. These values are similar to those obtained during the WDF for locations south of 37°N. Another point worth noting is the fact that the maximum sizes of crabs increased only slightly during the WDF; the April survey data also show little or no increase over maxima obtained during the winter.

Carapace width-frequency distributions for females are also presented in Figure 15. The females are first presented as a total group and then separated into hard through peeler molt stages and soft to papershell molt stages. Modal width value for hard and peeler stage females was 67 mm; for soft to papershell females, 80 mm. This represents an average increase in absolute size of 13 mm, or a 19% increase in size.

Relative Growth

The results of regression analysis for body measurements made on rock crabs are summarized in Table 5. There was a linear relationship between carapace width and both carapace length and chela length for male and female rock

TABLE 5

REGRESSION ANALYSIS OF ROCK CRAB MORPHOMETRIC DATA

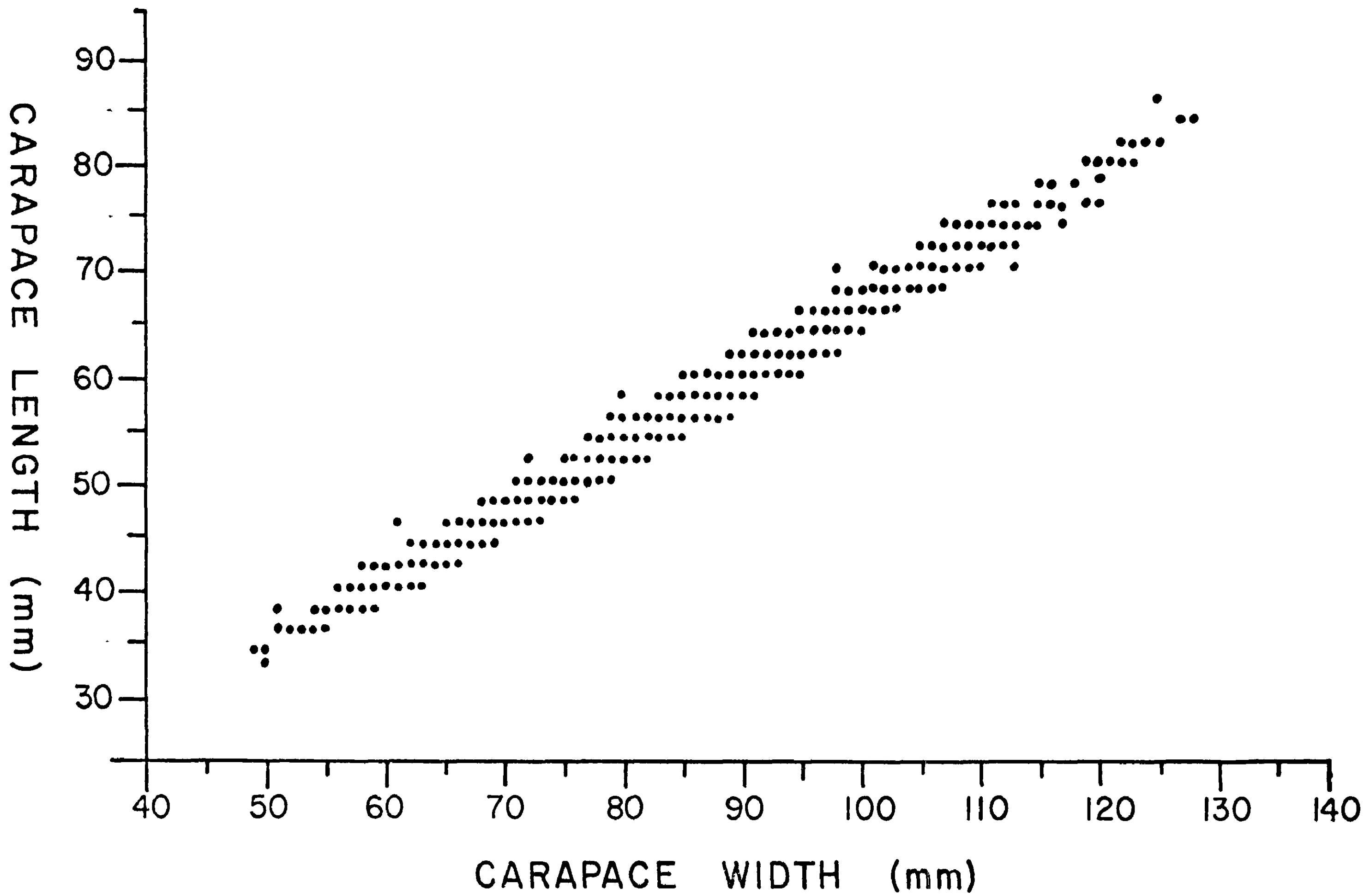
Relationship Examined	Sex	N	$\bar{x}$ Width (mm)	$\bar{y}$ Other Part	Regression Equation	r
Carapace Width - Carapace Length	Male	2013	83.4	55.3	$y = 1.324 + 0.647\ x$	.992
	Female	59	74.8	51.3	$y = -2.249 + 0.715\ x$	.987
Carapace Width - Chela Length	Male	499	87.7	41.1	$y = -6.011 + 0.536\ x$	.930
	Female	46	74.9	33.9	$y = 0.369 + 0.447\ x$	.946
Carapace Width - Log Weight	Male	467	90.0	2.0	$\log y = 0.658 + 0.014\ x$	.972
	Female	29	72.7	1.7	$\log y = 0.576 + 0.015\ x$	.961
Log Carapace Width Log Weight	Male	466	1.9	2.0	$\log y = -3.872 + 3.017\ x$	.981
	Female	31	1.8	1.7	$\log y = -3.1379 + 2.6125\ x$	.958
	Male (Molt Stage 3-5)	49	2.0	2.1	$\log y = -3.048 + 2.574\ x$	.942

crabs (Figs. 16-19). The relationship between carapace width and weight was curvilinear (Figs. 20, 21); therefore, the data were rectified by logarithmic transformation of both total weight and carapace width (Figs. 22, 23) and log-log regression was performed.

Because of the vast differences in ranges and numbers between males and females only those males ≤93 mm carapace width (corresponding approximately to the maximum carapace width for females) were used for covariance analysis. Carapace widths at the lower end of male and female ranges were approximately the same. Results of covariance analysis are summarized in Table 6. For carapace length on carapace width regression, the slope and intercept values for males under 94 mm in width remained close to those values for their entire range. Covariance analysis revealed a significant difference in slope between male and female crabs. For crabs of the same width, females have greater carapace length, a tendency which increases with width over the range tested.

Covariance analysis of length of the propodus of the chela relative to carapace width showed no significant sexual differences in regression coefficients or adjusted means. Variances for males and females were significantly different; it is felt that measurement-transcription error or the preponderance of large males caused the difference in variance. The regression equation for males ≤93 mm in width was slightly different from the regression equation

Figure 16. Carapace length plotted against carapace width for male rock crabs.



CARAPACE LENGTH (mm)
90
80
70
60
50
40
30
40
50
60
70
80
90
100
110
120
130
140
CARAPACE WIDTH (mm)

Figure 17. Carapace length plotted against carapace width for female rock crabs.

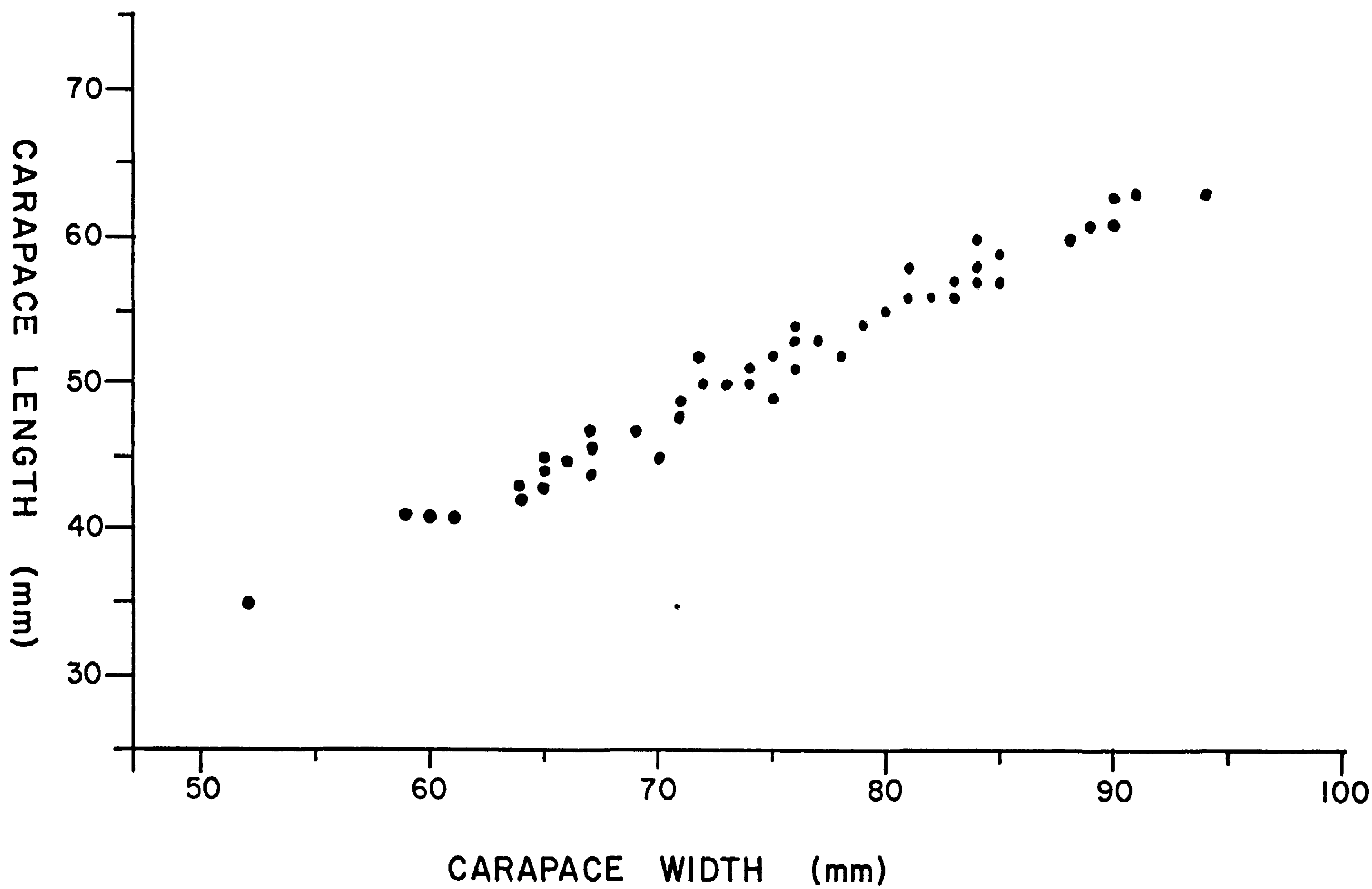

CARAPACE LENGTH (mm)
70
60
50
40
30
50
60
70
80
90
100
CARAPACE WIDTH (mm)

Figure 18. Length of the propodite of the larger chela plotted against carapace width for male rock crabs.

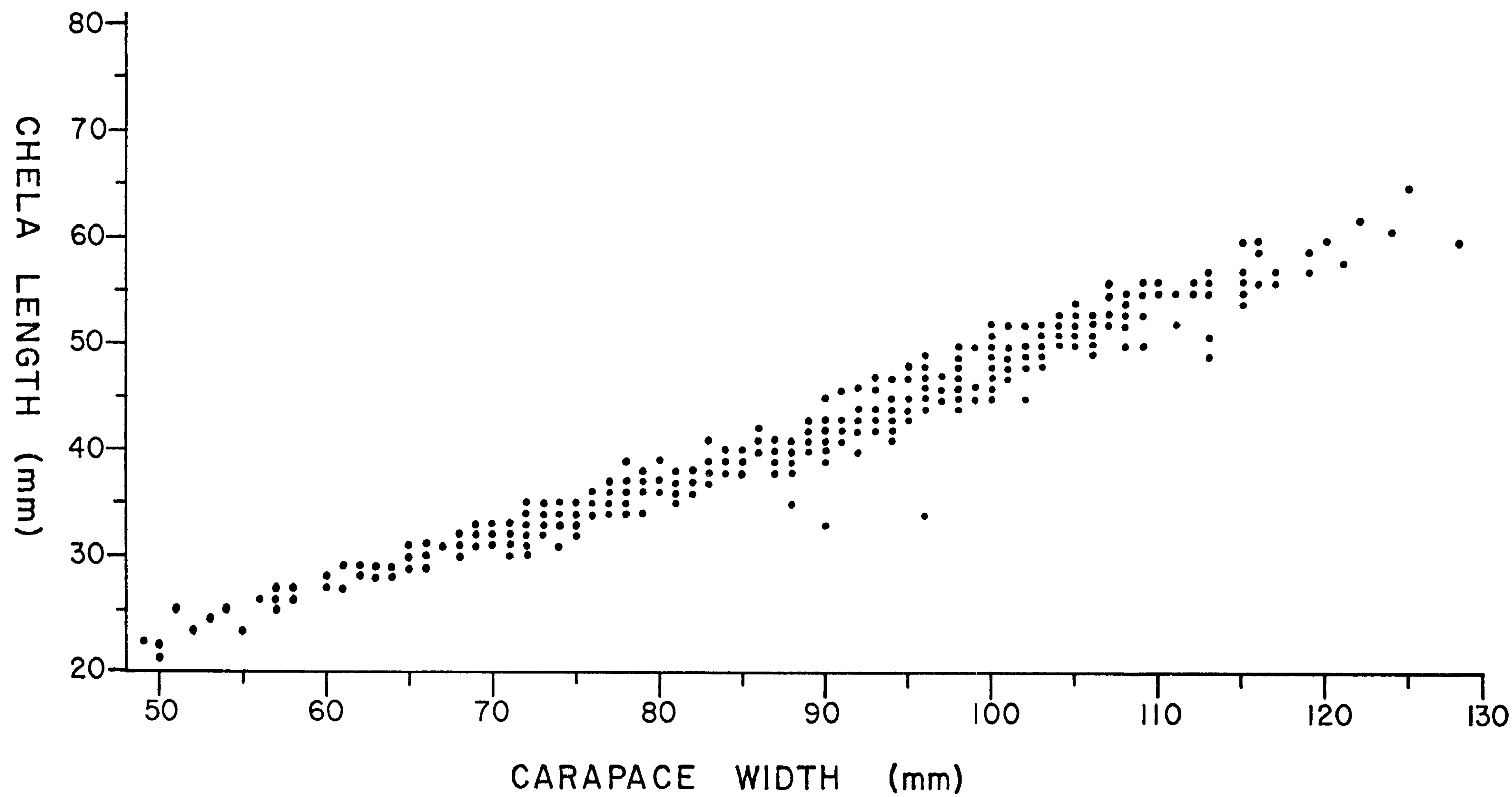

CHELA LENGTH (mm)
80
70
60
50
40
30
20
50
60
70
80
90
100
110
120
130
CARAPACE WIDTH (mm)

Figure 19. Length of the propodite of the larger chela plotted against carapace width for female rock crabs.

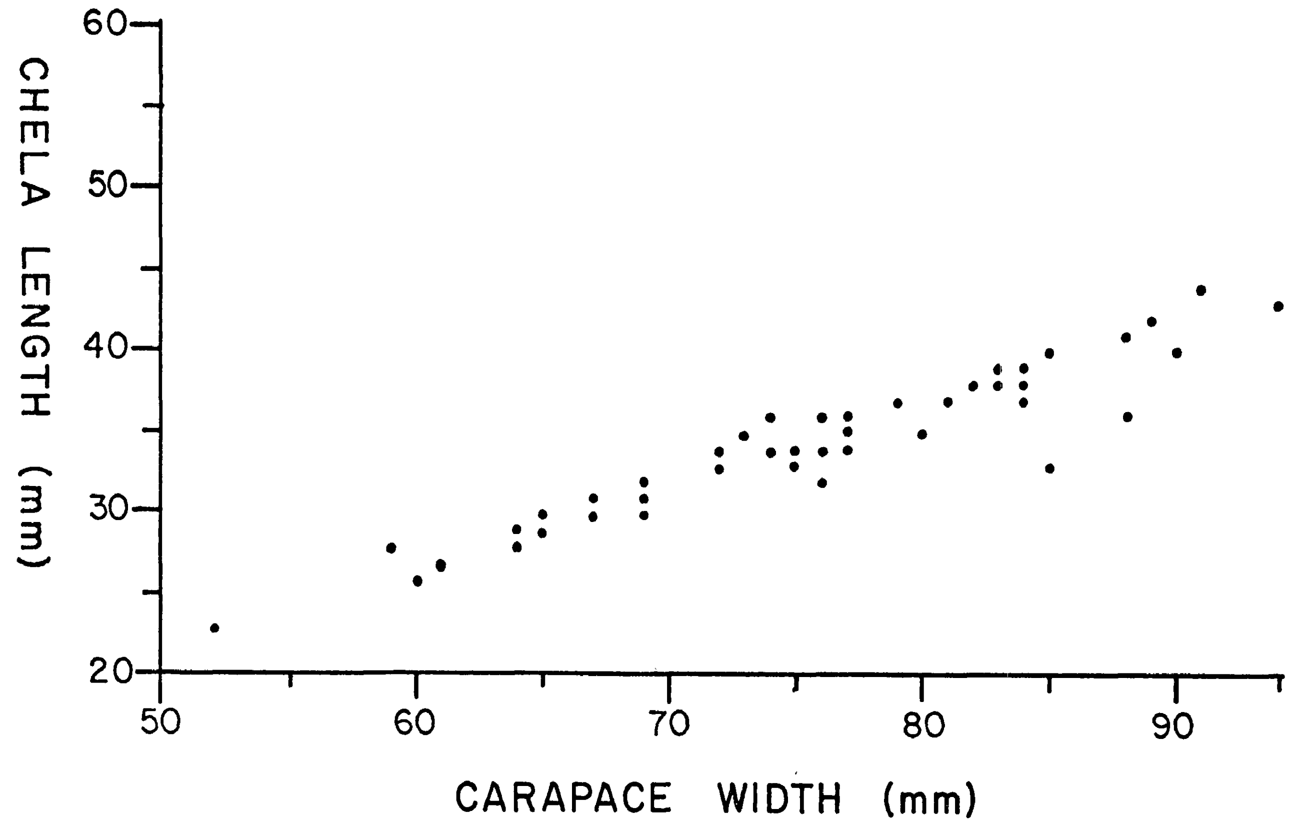

CHELA LENGTH (mm)
60
50
40
30
20
50
60
70
80
90
CARAPACE WIDTH (mm)

Figure 20. Total weight plotted against carapace width for male rock crabs. Plot of antilog of log-log regression for all male crabs and male crabs in molt stages 4 (newly molted) and 5 (papershell).

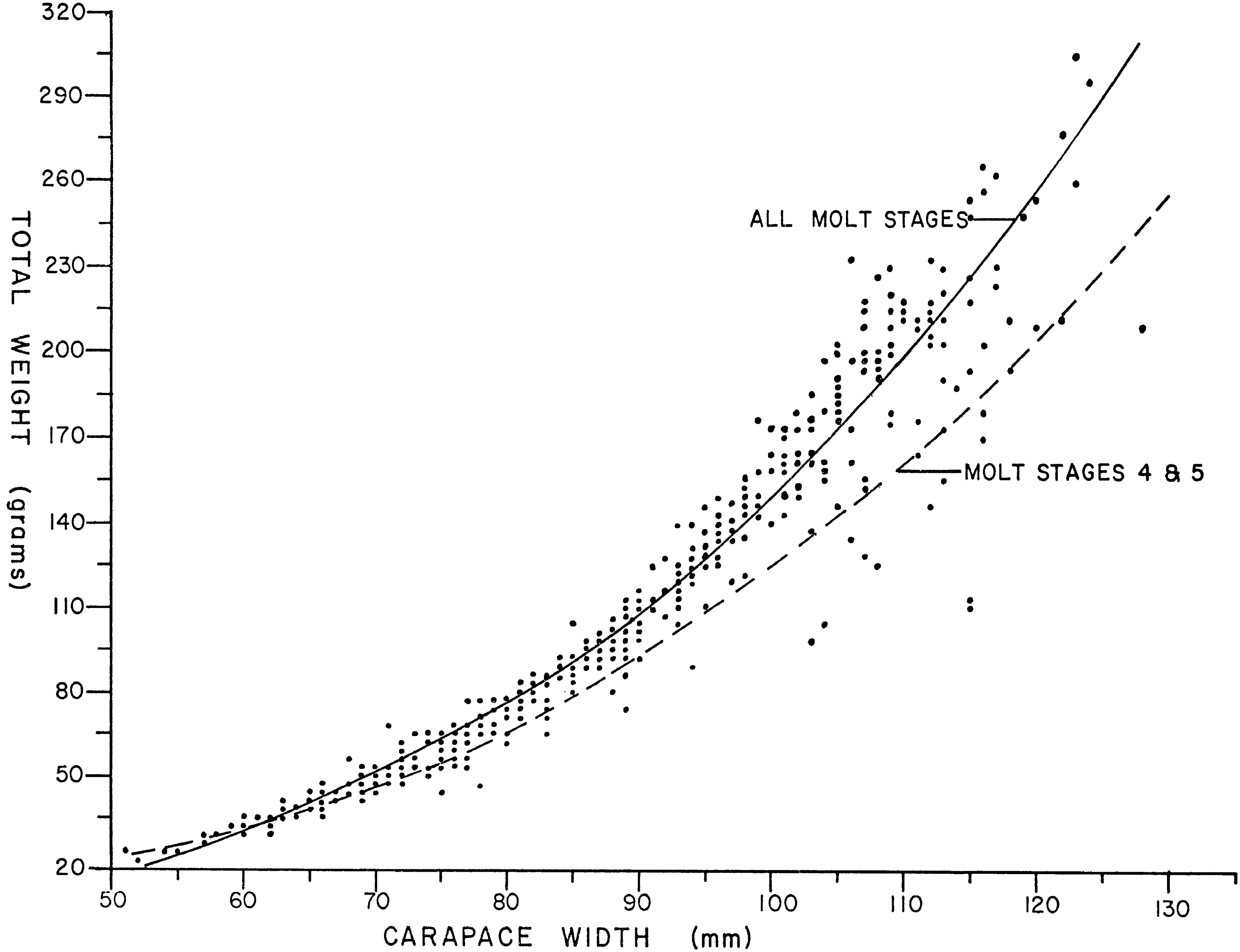

TOTAL WEIGHT (grams)
320
290
260
230
200
170
140
110
80
50
20
CARAPACE WIDTH (mm)
50
60
70
80
90
100
110
120
130
ALL MOLT STAGES
MOLT STAGES 4 & 5

Figure 21. Total weight plotted against carapace width for female rock crabs.

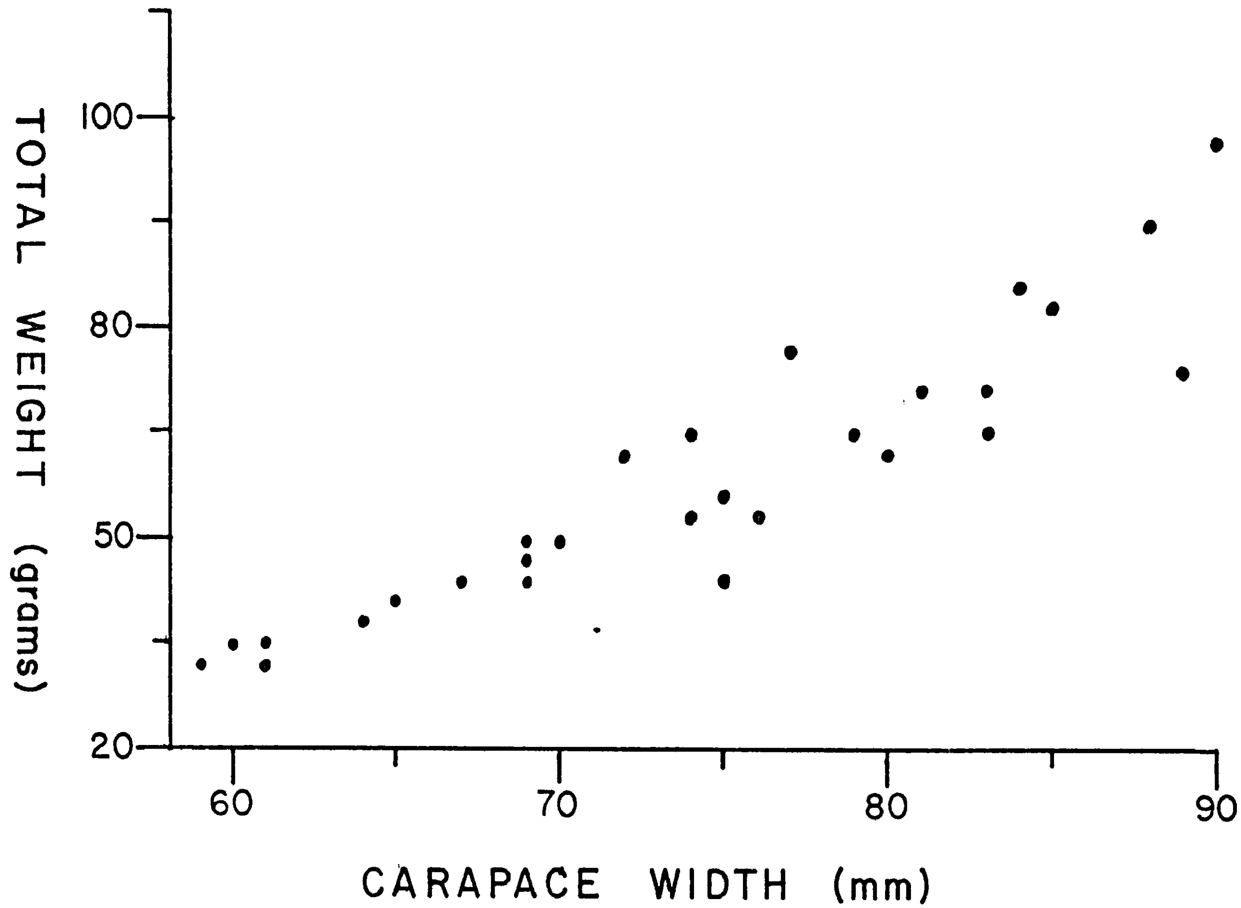

TOTAL WEIGHT (grams)
100
80
50
20
60
70
80
90
CARAPACE WIDTH (mm)

Figure 22. Log of weight plotted on log of width for male rock crabs.

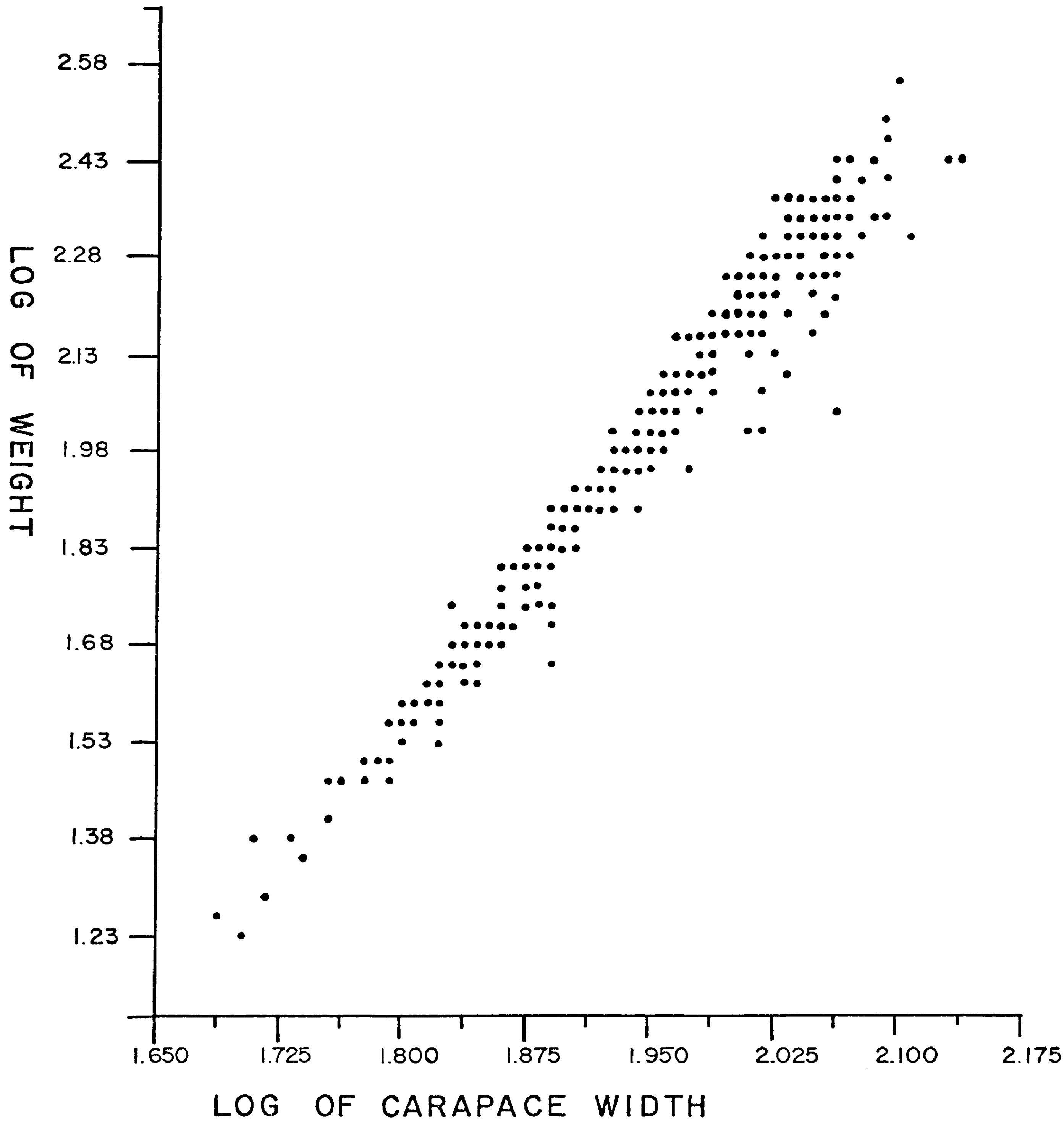
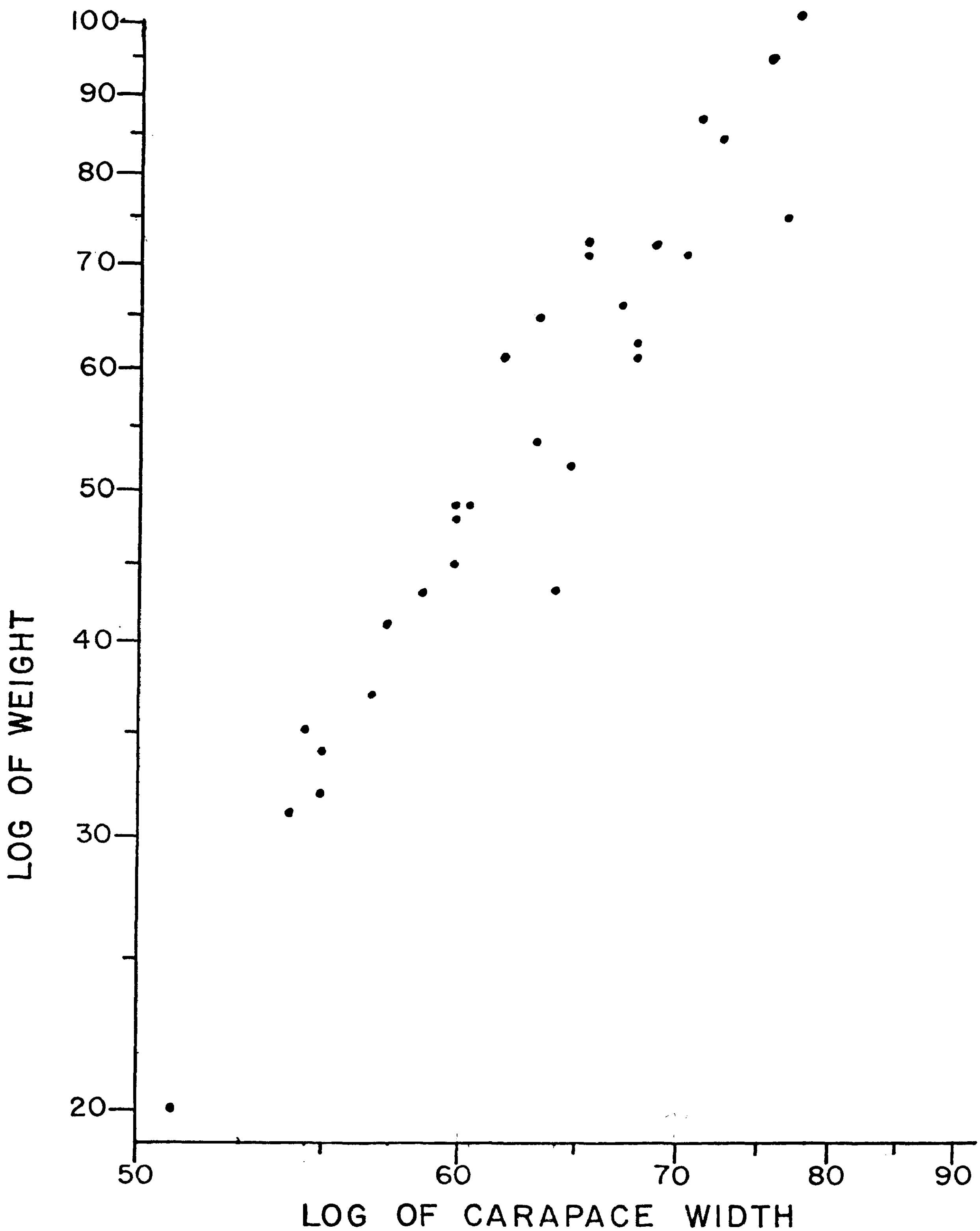

LOG OF WEIGHT
2.58
2.43
2.28
2.13
1.98
1.83
1.68
1.53
1.38
1.23
1.650
1.725
1.800
1.875
1.950
2.025
2.100
2.175
LOG OF CARAPACE WIDTH

Figure 23. Log of weight plotted on log of width for female rock crabs.



100
90
80
70
60
50
40
30
20
LOG OF WEIGHT
50
60
70
80
90
LOG OF CARAPACE WIDTH

TABLE 6

COVARIANCE ANALYSIS OF ROCK CRAB MORPHOMETRIC DATA FOR MALE ROCK CRABS ≤ 93 mm AND ALL FEMALE ROCK CRABS.

Relationship Examined	Sex	# Individuals	$\bar{x}$	$\bar{y}$	Regression Equation $y = a + b x$	r	F Var. 1,2	F Rog. Coef.	F Adj. Mean
Carapace Width - Carapace Length	M	1481	76.50	50.82	$y = 1.4432 + 0.6454 x$	0.985	1.111	19.012**	101.756**
	F	59	74.83	51.27	$y = -2.2499 + 0.7152 x$	0.987			
Carapace Width - Chela Length	M	307	77.55	35.38	$y = 0.0255 + 0.4559 x$	0.835	4.156**	0.002	0.210
	F	47	75.21	34.11	$y = 0.3631 + 0.4582 x$	0.948			
					$\log y = \log a + b \log x$				
Log Carapace Width Log Weight	M	242	1.8807	1.7991	$\log y = -3.8548 + 3.0063 x$	0.981	2.068**	11.972**	5.813*
♂ ≤ 90 mm Width	F	31	1.8599	1.7213	$\log y = -3.179 + 2.6125 x$	0.958			

for the entire range of males. The slope value is smaller for the reduced range, 0.4559 as compared to 0.536 for the entire range. The new equation does fit the data for the reduced range better than the equation for the entire range, suggesting either a slight curve or a change in rate of growth of the male chela around 90 mm carapace width.

A significant sexual difference was found in the log carapace width-log weight relationship. The analysis was run using males $\leq$90 mm carapace width. For this range, the male and female variances and the slopes were significantly different. For crabs of the same carapace width, males weigh more than females.

As the scatter diagram for the male carapace width-weight relation (Fig. 20) shows, there are many outliers above 93 mm carapace width. These are most likely due to difference in molt stages of the crabs; papershell crabs are lighter than hard crabs of the same carapace width due to the watery nature of their flesh and the reduced calcification of the shell. Arithmetic regression lines, calculated from log-log equations for all male crabs and for males in molt stages 4 and 5 (soft and papershell), were plotted on the scatter diagram (Fig. 20). The curve for male crabs in molt stages 4 and 5 falls within the outliers showing that these points do represent the lighter soft and papershell crabs.

Season of Molting

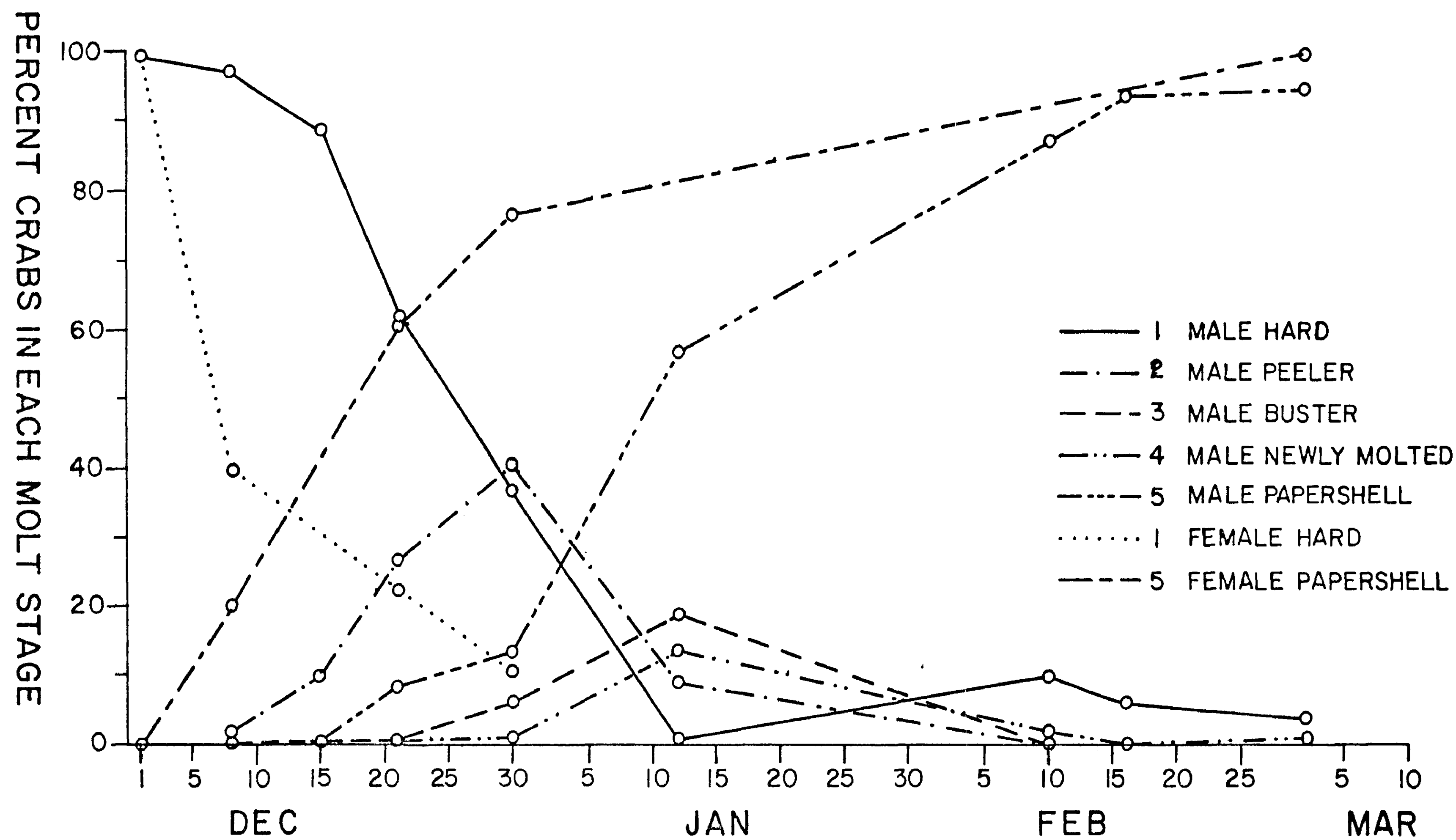
Molting of male rock crabs occurred in Chesapeake Bay from the middle of December to the end of February, with a peak around the second week in January. The percentage of male rock crabs in each molt stage during the winter months is given in Table 7 and is graphically presented in Figure 24. At the beginning of the dredge fishery season, all of the male crabs obtained were in the hard "C" stage. By the end of the first week 3% were peeler crabs (Stage D_2). The percentage of hard crabs continued to decline steadily to ~ 1% on 12 January 1971, then increased to 10% on 10 February, after which it decreased to 4% by 2 March. The percentage of crabs in the peeler stage increased rapidly to about 41% on 30 December 1970 and then decreased just as rapidly to less than 10% by 12 January 1971. By 10 February 1971, no peeler crabs were observed in the samples. Crabs that were in buster and newly molted stages (D_4 and A) were not found in the samples until 21 December 1970 when they were both less than 1%. Percentage of crabs in the buster stage rose to 6.5% by 30 December and peaked at 19% on 12 January 1971. By 10 February and subsequently, no crabs in the buster stage were observed in the samples. Newly molted crabs comprised 2% of the sample on 30 December and peaked at 14% on 12 January. One newly molted crab (~ 2%) was found 10 February, and another single individual on 2 March. It can be seen from the graph that the percentage of buster and newly molted stage crabs

TABLE 7

PERCENT OF MALE ROCK CRABS IN EACH MOLT STAGE DURING THE WINTER DREDGE FISHERY.

Sample #	Area	Date	C Hard #	C Hard %	D_2 Peeler #	D_2 Peeler %	D_4 Buster #	D_4 Buster %	A Newly Molted #	A Newly Molted %	B Papershell #	B Papershell %	Total	No Data
1	P51	1 Dec 70	185	100									185	9
2	Q49	1 Dec 70	48	100									148	167
3	P52	8 Dec 70	66	97.05	2	2.95							68	2
4	Q49	8 Dec 70	255	98.83	3	1.17							258	14
5	P49	15 Dec 70	217	89.30	25	10.28					1	0.42	243	281
6	Q49	21 Dec 70	68	62.96	29	26.85	1	0.92	1	0.92	9	8.35	108	294
7	P51	30 Dec 70	40	37.03	44	40.74	7	6.48	2	1.85	15	13.90	108	191
8	P52	12 Jan 71	1	1.00	9	9.00	19	19.00	14	14.00	57	57.00	100	0
9	P51	10 Feb 71	5	10.20					1	2.05	43	87.75	49	0
10	R55	16 Feb 71	3	6.00							47	94.00	50	0
11	Q50	2 Mar 71	4	4.00					1	1.00	95	95.00	100	0

Figure 24. Percent of male crabs in each molt stage during the Winter Dredge Fishery, 1 December 1970 to 2 March 1971.


PERCENT CRABS IN EACH MOLT STAGE
100
80
60
40
20
0
1
5
10
15
20
25
30
5
10
15
20
25
30
5
10
15
20
25
5
10
DEC
JAN
FEB
MAR
1 MALE HARD
2 MALE PEELER
3 MALE BUSTER
4 MALE NEWLY MOLTED
5 MALE PAPERSHELL
1 FEMALE HARD
5 FEMALE PAPERSHELL

closely parallel one another.

The percentage of crabs in the buster and newly molted stages is low because of the relatively short period of time the crabs are in this stage (i.e., crabs become papershells (Stage B) within a few hours after molting). Papershell crabs began to appear on 15 December (< 1%). The percentage of papershell crabs increased steadily through 16 February to 94%. By 2 March it had increased slightly to 95%, probably the maximum expected since some individuals were by this time becoming hard crabs and some may not molt.

The peak of female rock crab molting activity occurred around the third week of December (Fig. 24, Table 8). On the first day of sampling all of the females captured were hard. This percentage dropped rapidly to 40% by 8 December and then decreased less rapidly but at a constant rate through 30 December. Very few female peeler stage crabs were detected, perhaps because that stage was more difficult to distinguish in females or because so few females were caught. Four individuals (40%) were in this stage on 8 December. One crab (5.6%) was in this stage 30 December. The only female buster (7.7%) was observed during the season on 21 December. One newly molted female (7.7%) was also captured on this date, as well as one (5.6%) on 30 December. The curve for female papershells during the period from 8 December to 21 December parallels that for males during 30 December to 12 January, but occurs

TABLE 8

PERCENT OF ♀ ROCK CRABS IN EACH MOLT STAGE
DURING THE WINTER DREDGE FISHERY.

Date	Molt Stage										Total
	Hard C		Peeler D_2		Buster D_4		Newly Molted A		Papershell B		
	#	%	#	%	#	%	#	%	#	%	
1 Dec 70	15	100									15
8 Dec 70	4	40	4	40	0		0		2	20	10
15 Dec 70	3	100	0		0		0		0		3
21 Dec 70	3	23	0		1	7.7	1	7.7	8	61.6	13
30 Dec 70	2	11.1	1	5.6			1	5.6	14	77.7	18
2 Mar 71	0		0		0		0		1	100	1

a little over three weeks earlier. By 30 December, about 77% of the females were papershells, whereas only about 14% of the males were in this molt stage.

Thus, it appears that the peak of molting in male rock crabs occurs when the most busters and newly molted crabs are found and the number of papershells is increasing most rapidly. For the 1970-71 dredging season, this peak occurred around 12 January 1971. The peak of molting in female rock crabs, following the same criteria, must have occurred around 21 December 1970, or about three weeks before that of males.

Limb bud formation and development on crabs with missing limbs is another sign of approaching molt. If a crab autotomizes a limb far enough in advance of molting an initial outgrowing papilla (basal growth) will appear on the stump, after which growth may cease or continue at a reduced rate (growth plateau) (Bliss, 1960). Next, marking the beginning of the peeler stage or proecdysis (D_0), there is a short period of extremely rapid increase in size of the regenerating limb (premolt growth) terminating just before molt. This period of premolt growth occurs 12 to 25 days before molting in Gecarcinus lateralis. Rock crabs were not examined for limb buds until 8 December 1970. At that time about 7% of the crabs that were missing limbs had developed limb buds (Table 9). By 15 December, the figure had risen to 16.8%. The percentage declined to about 7.5% on 21 December, remained at 7.5% on 30 December,

TABLE 9

OCCURRENCE OF LIMB BUDS ON MALE ROCK CRABS WITH ONE OR MORE MISSING LIMBS.

Sample #	Area	Date	No Limbs Missing or No Data	Present		Absent		Total
				#	%	#	%	
1	P51	1 Dec 70	194	-		-		-
2	Q49	1 Dec 70	315	-		-		-
3	P52	8 Dec 70	0	5	7.1	65	92.9	70
4	Q49	8 Dec 70	14	18	7.0	240	93.0	258
5	P49	15 Dec 70	423	17	16.8	84	83.2	101
6	Q49	21 Dec 70	294	8	7.4	100	92.6	108
7	P51	30 Dec 70	194	8	7.6	97	92.4	105
8	P52	12 Jan 71	0	1	1.0	99	99.0	100
9	P51	10 Feb 71	0	0	0.0	49	100	49
10	R55	16 Feb 71	0	0	0.0	50	100	50
11	Q50	2 Mar 71	100	-		-	-	-

but decreased to 1% by 12 January 1971. No crabs with limb buds were found during February, March or April.

Fouling organisms can often reveal a crab's molting history. Rock crabs showed no evidence of a terminal anecdysis; no crabs had large barnacles or other slow growing animals attached to them. Eighty-five percent of the male rock crabs sampled at the beginning of the dredging season had no fouling organisms (Table 10). However, by 21 December, this figure had fallen to 37%, indicating that crabs were being infested by an estuarine fouling organism. As crabs began and continued to molt the percentage of "clean" crabs began to rise and reached 98% by 16 February 1971 when 94% of the crabs sampled were papershells. The most common fouling organism was a bryozoan, Alcyonidium sp., which occurred on all external surfaces of infested crabs. Some crabs had only a few small patches on appendages or on the carapace. Others were so heavily encrusted with the bryozoan that the integument could not be seen. The bryozoan continued to grow and spread on crabs held in York River sea water (16-20‰) at VIMS, supporting the idea that the infestation has its source in the Chesapeake Bay estuary. At the beginning of the season the bryozoan was found on 13% of the crabs examined. By 21 December, 61% of the male crabs were affected. This level of infestation decreased to 2% by 16 February 1971.

Eight crabs had very small unidentified barnacles less than 3 mm in diameter located on the dorsal carapace. The

TABLE 10

OCCURRENCE OF FOULING ORGANISMS ON MALE ROCK CRABS.

Sample #	Area	Date	0 None #	0 None %	1 Bryozoan #	1 Bryozoan %	2 Barnacle #	2 Barnacle %	3 Crepidula #	3 Crepidula %	4 Hydroids #	4 Hydroids %	Total	No Data
1	P51	1 Dec 70	46	85.2	7	13.0			1	1.8			54	140
2	Q49	1 Dec 70	--											315
3	P52	8 Dec 70	36	52.9	32	47.1							68	2
4	Q49	8 Dec 70	88	66.2	41	30.8	4	3.0					133	139
5	P49	15 Dec 70	54	52.4	47	45.6	2	1.9					103	421
6	Q49	21 Dec 70	40	37.0	66	61.1	2	1.9					108	294
7	P51	30 Dec 70	55	52.4	50	47.6							105	194
8	P52	12 Jan 71	77	77.8	22	22.2							99	1
9	P51	10 Feb 71	44	89.8	5	10.2							49	0
10	R55	16 Feb 71	49	98.0	1	2.0							50	0
11	Q50	2 Mar 71	--		--								--	100

small size of the barnacle and the fact that they were taken from 8 December to 21 December suggests that the barnacles were also of estuarine origin. Only one crab was found with a small Crepidula sp. attached to the dorsal carapace. And, on 5 April 1971, about 8 km east of Cape Henry, one crab (a gravid female) was found with hydroids identified by Dr. Dale Calder of VIMS as Hydractinia echinata. The hydroids were very abundant on the dorsal anterolateral margin of the carapace.

Mating in the genus Cancer occurs when the female is in the newly molted or "soft" molt stage (Hartnoll, 1969). This suggests that mating of Cancer irroratus in Chesapeake Bay occurs primarily in December. During the period of study, the peak of mating activity occurred 15-30 December. All soft and papershell as opposed to none of the hard female crabs had sperm plugs, a sign of recent copulation. Only one instance of premating and copulatory behavior was observed in the laboratory. On 8 December, a "doubler" (male and female pair in premating embrace) was found in the holding tank (Fig. 25). The premolt female was 74 mm in carapace width, the male 118 mm in width. The female, with all pereiopods tightly flexed against her body, was carried with her sternum against that of the male who was in the superior position. The male clasped the female with his chelipeds only (Fig. 25). The pair remained in this position, which must have precluded feeding by either, through 10 December. On the morning of 11 December, the

Figure 25. Male and female rock crab in premating embrace.

pair were found copulating, male uppermost with the female in the "soft" condition. The female abdomen was fully extended resting against the posterior of the male. The male abdomen was slightly extended, allowing the intromittent organs to pass lateral to the abdomen so that the apical portion of the pleopods could insert into the paired vulvae of the female. The piston-like second pleopods were rhythmically pumping about every 30 seconds. The postmolt female had a carapace width of 90 mm, an increase of 16 mm or 22%. The sea water system failed the same afternoon and the pair died before further observations could be made.

Reproductive System

Thirty-three male and 31 female *Cancer irroratus* in various molt stages were dissected in order to examine the reproductive systems, to determine the state of gonad development and to look for macroscopic internal parasites. A summary of results is presented for males (Table 11) and females (Table 12).

Male

The testes were indistinct, possibly a result of poor preservation. Apparent testicular material was found lying beneath the hypodermis of the carapace and on the dorsal surface of the hepatopancreas. The testis has the gross appearance of a paddle or spatula and extends only about half-way toward the lateral margin of the carapace. The

TABLE 11

MALE ROCK CRAB REPRODUCTIVE SYSTEM.

Carapace Width	Molt Stage	External Fouling Organism	Parasites	Presence of Spermatophores	Size of Spermatophores	Dia. of PVD
113	5	Bry.	None	+		
53	1	Bacterial Lesions	None	+		
86	5	Bry.		+		
93	1	None	None	+		
70	1	None	None	+		
72	1	None	None	+		
78	1	Bry.	None	+		
83	2	Bry.	_Octolasmis_	+		
96	2	Bry.	_Octolasmis_	+		
113	1	Bry.	_Octolasmis_	+		
99	1	Bry.		+		
72	1	None	None	+		
76	2	None		+		

TABLE 11 (Continued)

Carapace Width	Molt Stage	External Fouling Organism	Parasites	Presence of Spermatophores	Size of Spermatophores	Dia. of PVD
125	1	Bry.	Octolasmis	+		
90	1	None	Octolasmis	+		
100	1		Octolasmis	+		
74	1	None		+		
54	1	None		+	.031	1.25 mm
59	2	Bry.	Octolasmis	+	.03-.04	1.125 mm
67	2	None	Octolasmis	+		1.4
70	1	None	None	+	.039 x .049	1.9
50	1	None	Octolasmis	+	.0416	1.125
83	1	Bacterial Lesions	Octolasmis	+		
70	2	Bry.	Octolasmis	+		1.875
72	2	None	Octolasmis	+		2.175
90	2	Bry.	Octolasmis	+		2.175
87	2	Bry.	None	+		1.95

TABLE 11 (Continued)

Carapace Width	Molt Stage	External Fouling Organism	Parasites	Presence of Spermatophores	Size of Spermatophores	Dia. of PVD
49	1	Bacterial Lesions	None	+	.039	0.9
80	2	Bry.	*Octolasmis*	+	.0429	1.35
61	1	Bry.	None	+		.75
64	2	None	*Octolasmis*	+		1.20
72	1	None	*Octolasmis*	+		1.50
70	1	Bry.	None	+		1.50

TABLE 12

FEMALE ROCK CRAB REPRODUCTIVE SYSTEM.

				Gonad					Spermathecae		
Carapace Width	Molt Stage	Fouling Organisms	Gill Parasites	Color	Posterior Horn Wide	Posterior Horn Thick	+ or - oocytes	Ova. Dia.	Presence of Sperm	Evidence of Previous Spawn	+ or - Sperm Plugs
78	5	None	None	Yellow					+	None	+
65	1	Bry.		White	1 mm	1 mm			+	None	-
89	1	Bry.		Beige	3.5	3	+			None	-
85	5	Bry.	None	White	2.5	1.5	+	.13 mm	+	None	+
80	5	None		Yellow	4		+	.21	+	None	+
71	2	None	None				+	.054	-	None	-
59	2	None	None				?	.054	-	None	-
65	2	None	None	Pink-Orange	2.5	1.5	+	.095	-	None	-
72	1	None	None	Pale Beige			+	.105		None	-
75	2	None	None	Pale Yellow	2.0	1.0	+	.08		None	-
69	2	None								None	-
65	1	None		Pale Beige	2.0	0.5	+	.108		None	-
79	5	None		Pale Orange	3.75		+	.178	+	None	-

TABLE 12 (Continued)

Carapace Width	Molt Stage	Fouling Organisms	Gill Parasites	Gonad: Color	Gonad: Posterior Horn Wide	Gonad: Posterior Horn Thick	Gonad: + or - oocytes	Gonad: Ova. Dia.	Spermathecae: Presence of Sperm	Spermathecae: Evidence of Previous Spawn	Spermathecae: + or - Sperm Plugs
76	2	None		Pink-Orange	4.5	2.0	New	.1836	+	None	+
76	5	None	None	Pale Orange-Brown	3.0		+	.1512	+	None	+
62	3	None	Octolasmis	Pale Orange-Pink	1.9		+	.1188	+	Old eggs .27 mm	-
82	2	Bry.	Octolasmis	Pale Orange	4.5		+	.3348	+	None	-
75	5	None	None		3.0	1.35	+	.1720	+	None	+
77	5	None	None		2.25		+	.091	+	None	+
75	2	None	Octolasmis	Pale Orange			+	.130	+	None	-
65	3	None	None	Pale Beige			+	.117	+	None	-
63	2	None	Octolasmis	Pale Beige	1.73		+	.1365	+	None	-
61	2	None	None	Yellow-Orange			+	.2330		None	-
75	4	None	None	Pale Beige	1.6		+	.1248	+	None	+

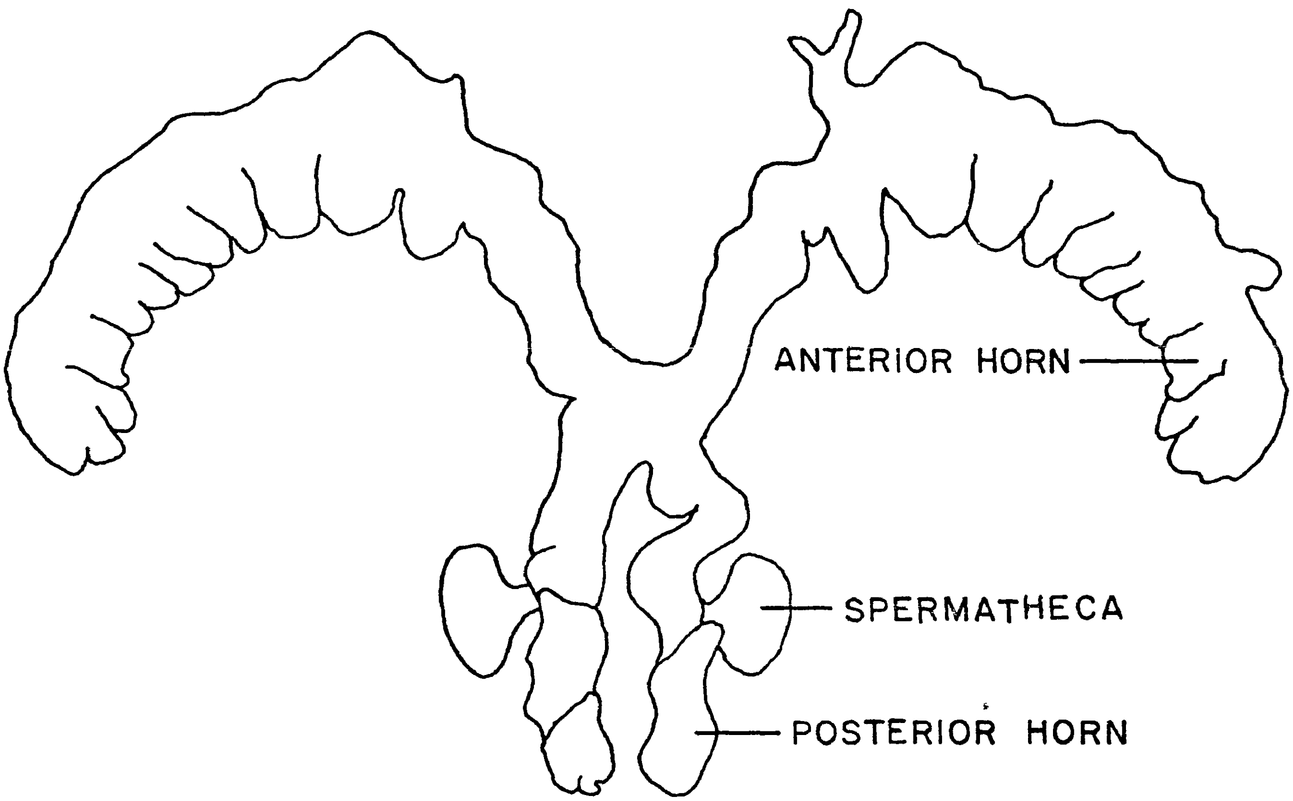
TABLE 12 (Continued)

Carapace Width	Molt Stage	Fouling Organisms	Gill Parasites	Gonad: Color	Gonad: Posterior Horn Wide	Gonad: Posterior Horn Thick	Gonad: + or - oocytes	Gonad: Ova. Dia.	Spermathecae: Presence of Sperm	Spermathecae: Evidence of Previous Spawn	Spermathecae: + or - Sperm Plugs
87	4	None	None	Pale Beige			+	.1248	+	Old eggs .4320	+
86	4	None	None	Pale Orange	2.015		+	.1404	+	None	+
85	5	None	None	Pale Beige	1.875		+	.1274	+	None	+
74	4	None	None	Cream	1.5		+	.1170	+	None	+
79	4	None	None	Pale Yellow	1.5		+	.135	+	None	+
88	1	Bryozoan	<u>Octolasmis</u>	Yellow	4.8		+	.2430	+	?	-
83	1	Hydroids	<u>Octolasmis</u>	Pale Yellow	2.63		+	.081 to .1350	+	?	-

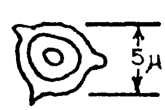
vasa deferentia originate at the mediad ends of the testes and extend posteriorly along each side of the digestive tract. Their anterior and median portions are white, convoluted, and more bulbous than the testes. Posteriorly the vasa deferentia become slender, straight, translucent tubes leading into the penes which exit the body through openings on the ventral surface of the coxopodite of the last pereiopod. The penis is cone-shaped with a basal diameter and height of about 2-3 mm. The tips of the penes rest against the grooved bases of the first abdominal pleopods, the functional intromittent organs. The intromittent organs receive the sexual products from the penes and act as tubes of transport in copulation, carrying these materials into the paired oviducts and seminal receptacles (spermathecae) of the adult female. The second pleopods are similar to the first but have shorter spines that insert into the posterior foramena of the first and force sexual products through the intromittent spines of the first pleopods. Spermatophores, found in the median vasa diferentia, are elliptical, with an average diameter of $\sim 40\ \mu$. The spermatozoa are nonmotile and appear as a central dark sphere with an outer disk-shaped clear margin with three wings or algae (Fig. 26b). Total diameter of a sperm is $\sim 5\ \mu$.

Figure 26a. Diagram of female reproductive system.

b. Diagram of rock crab spermatozoon.



1 1/2 X
OVARY



970 X
SPERM

Female

The paired ovaries of the female are bilobed. The anterior lobes or horns extend anterolaterally above the hepatopancreas to the extreme lateral margins of the carapace. The posterior horns pass to either side of the digestive tract. The two ovaries are joined by a commissure behind the pyloric foregut, forming a bridge over the midgut. Short ducts arising from the mid-ventrolateral portion of the posterior horns connect each ovary to one of the spheroidal, cream-colored spermathecae (Fig. 26a). Each spermatheca is continue into a short oviduct (vagina) which opens to the exterior by means of the vulva on the sternum of the sixth thoracic somite. The spermathecae contain only free spermatozoa which must remain alive in the spermathecae until fertilization takes place several months later at spawning. Immediately after copulation crystalline-like cylinders called "sperm plugs" form in each oviduct, completely blocking the vulvae and vaginae. This effectively prevents further copulation and also prevents the loss of any sperm. Female crabs found with sperm plugs always had greatly distended spermathecae.

The condition of the ova in the ovary depends upon the degree of maturity of the gonads. Immature ovaries are small and pale, and no evidence of eggs can be detected by the naked eye. The mature gonads, are much larger and fuller in appearance. They have a bright orange-red color, and separate eggs can be distinguished. The color is due to the presence of yolk granules which form the main part of the mature ovum. The smallest and largest ova observed were 54 μ and 334 μ respectively (Table 12). There was a tendency toward larger ova as the season progressed. Small immature ova are almost transparent so the nucleus and sometimes what appears to be a nucleolus could be seen. As ova increased in size and developed further they became translucent with yolk granules, finally becoming completely opaque.

Only two ovigerous female crabs were obtained during this study. The first, 88 mm wide, was captured on 3 February 1971 in Chesapeake Channel just northwest of the bridge tunnel. The sponge was bright orange and was probably newly deposited. Zoeae were not visible as the eggs were filled with yolk. Eggs from the sponge were 459 μ in diameter, whereas ova from the posterior horn of the ovary were 243 μ. The posterior horn itself was 4.8 mm wide. The spermathecae, measuring 9.6 mm x 6.6 mm, were still filled with sperm. The gonads did not appear to be shrunken or deflated as might be expected in a newly spawned crab, suggesting, along with partially full spermathecae, that a female crab has the ability to spawn more than once after a single copulation. By weighing the sponge mass and a small sample from it and then counting the eggs in the sample, the sponge was calculated to consist of $\sim$ 300,000 eggs. The second ovigerous crab, 83 mm wide, was captured on 5 April 1971 at A-05, a station located about five miles east of Cape Henry. The sponge was dark brown and the eggs were about to hatch. Some zoeae were expelled when the crab was placed in formalin. The ovary was pale and thin in appearance; the posterior horns were 2.6 mm wide. Average ovum diameter in the posterior horn was 135 μ. The average diameter of the eggs on the sponge was 486 μ. The sponge mass was calculated to consist of $\sim$ 250,000 eggs.

Eggs, when spawned, become attached to the endopodite setae of the abdominal appendages with each egg individually attached to a seta by a short stalk or funiculus.

Maturity

The criterion for determining sexual maturity in male crabs was the presence of spermatophores (small, oval-shaped, transparent packets containing sperm) in the median vas deferens. All males were mature by this criterion.

Sexual maturity in females is harder to determine as a mature female may have gonads in an immature or spent stage of development. In this study, the criterion for sexually mature females was the presence of sperm in the spermathecae. By this criterion all female crabs examined were sexually mature with the exception of three crabs (carapace widths 71 mm, 59 mm, and 65 mm) in which no spermathecae could be discerned. All three of these crabs were peelers; this means they had not yet molted and mated this season. Old egg cases or stalks on the setae of the abdominal pleopods, "old" eggs in the ovary, or (in some brachyuran species) nemertean worms in the gills are evidences of previous spawning. None of these evidences were observed with the exception of what appeared to be clumps of "old" eggs in the ovaries of two females. The first, with carapace width 62 mm, taken 21 December 1970, had "new" eggs 118.8 μ in diameter and "old" eggs 270 μ in diameter. The second female, 87 mm in width, captured 30 December 1970, had "new" eggs 124,8 μ in diameter and "old" eggs 432 μ in diameter, a diameter similar to the spawned eggs of the two ovigerous crabs captured.

Internal Macroparasites

Octolasmis loweii Darwin, a stalked or goosenecked barnacle, was the only macroscopic organism found in *Cancer irroratus* during the dissection study (Tables 11, 12). The barnacle was found almost anywhere in the branchial chamber but occurred primarily on the gills. Male rock crabs showed a higher incidence of infestation (48.5% for males vs. 19.4% for females) as well as a greater number of barnacles per crab. In crabs with light infestation (12 or less), the barnacles were located most often on the medial side of the posterior phyllobranchiate gills. In heavy infestations (12 to 100), *Octolasmis* was found on all surfaces of the 18 gills, branchial chambers and the gill cleaners or epipodites of the maxillipeds. Although the association is thought to be commensal, the sometimes dense occurrence of *Octolasmis* must be detrimental to the host as it most certainly reduces the respiratory current through the branchial chamber and also reduces the amount of oxygen available to the crab.

DISCUSSION

Abundance and Distribution

Cancer irroratus may enter or leave the Chesapeake Bay in a surprisingly short period of time. Jeffries (1966) determined the species' prodigious walking ability (thus its migratory potential) by forcing crabs to walk at 3.45 m/min (4.98 km/day) in a glass jug. In one experiment a crab paused only briefly during a 3 week test (104.58 km). Other species of *Cancer* are reported to migrate (Waldron, 1958; Humes, 1942; Pearson, 1911). Tagging studies in Oregon showed that *C. migister* migrates up to 30 km in 5 days (Waldron, 1958). Many crabs traveled 3.2 km per day for up to 10 days. Others traveled 1.1 km/day up to 50 km. Crabs released offshore traveled an average of 13.3 km in an average of 80 days from release to capture. Crabs released in bays moved an average of 6.7 km during the same time. The greatest distance moved was 130 km by two crabs in 152 days and 92 days. In England, the common crab, *C. pagurus*, may migrate as much as 45 km in 36 days (Humes, 1942).

Although temperature probably controls initial ingress and perhaps egress of *C. irroratus* in Chesapeake Bay, it probably does not control distribution in the bay. In winter temperatures in the lower bay stabilize and are quite uniform (Seitz, 1971). Jeffries (1966) experimentally found optimum walking temperatures for _C. irroratus_ to be 14 to 18 C. According to Rathbun (1930), the rock crab is most frequently collected where water temperatures are 14 to 21 C. Musick and McEachran (1972) found the rock crab most abundant in temperatures of 4 to 8 C in Chesapeake Bight. The 24 C isotherm corresponds closely to the southern limit of the genus _Cancer_ in the northern hemisphere (Mackay, 1943a). The genus is also unknown north or south of latitudes having annual mean surface water temperatures of less than 4 C.

The bottom temperature in Chesapeake Channel on 12 October 1970 was 21.1 C (VIMS Hydro-data Bank). On 11 November 1970 it was 15.1 C. Rock crabs may have entered Chesapeake Bay as early as the middle of October, the heretofore higher water temperatures having provided a thermal barrier.

However, during the April survey, 22 to 28 April 1971, when temperatures ranged from 10 to 13 C, large numbers of rock crabs were found only in Chesapeake Channel southeast of the Chesapeake Bay Bridge Tunnel (Fig. 6). This is interpreted as a vernal emigration although why the crabs should leave the estuary while the temperatures are well within their preferred range is not clear. Perhaps the crabs were acclimatized to the cooler temperatures of winter and moved out as water temperatures began to rise. Also other environmental factors (e.g., increasing photoperiod) may have caused an emigration.

The decrease in abundance of crabs with distance from the mouth of the bay and with decreasing salinity suggests that salinity is of primary importance in limiting rock crab distribution in Chesapeake Bay. In general, salinity varies inversely with distance up estuary from the bay mouth. The greater abundance of crabs on the northern and eastern sides of the lower Chesapeake Bay may result from the circulation of water. The major circulation of water in Chesapeake Bay exhibits characteristics of the partially mixed class of estuaries (Seitz, 1971). In such estuaries, a 2-layered flow exists, with the surface layer of lower salinity water flowing toward the ocean and the bottom layer of higher salinity water moving from the ocean toward the head of the estuary. Numerous factors govern the circulation and distributions of temperature and salinities in an estuary such as Chesapeake Bay. Multiple sources of fresh water along the western shore of the lower Chesapeake Bay, and the Coriolis force which exerts a lateral force on the water moving into and out of the bay, are thought to be the most important. Temperature and salinity distributions in cross sections of the bay indicate that fresher water in the upper layer is usually found concentrated on the southern or western shore while the saltier water in the lower layer is usually concentrated more toward the northern and eastern sides of the deep water channels (Seitz, 1971). Crabs may follow the denser, saltier water up the deep channels of the bay when cooling water temperatures fall within their preferred range.

There is no literature on salinity preference or tolerance of adult C. irroratus or any other Cancer species. Adult rock crabs have molted and been maintained at VIMS for several months in York River water at 17 to 21‰. Although they survived, this does not mean they would venture into salinities this low during a migration.

Other environmental factors (e.g., depth, bottom type, and dissolved oxygen) apparently have little effect on rock crab distribution or abundance in Chesapeake Bay. Recall, however, crab dredgers' reports that rock crabs are more numerous on hard substrates. Perhaps the data collected were not sufficient to show this trend. On the other hand, blue crabs are usually less numerous on hard substrates and rock crabs appear to be relatively more abundant in the catch.

In Chesapeake Bay C. irroratus showed no substrate preference. In Narragansett Bay, Rhode Island, C. irroratus prefers sandy substrates to rocky bottoms (Jeffries, 1966). In Chesapeake Bight, rock crabs are taken over all sediment types but the probability of capture is higher over sandy bottoms than over silt, clay or coarse canyon sediments (Musick and McEachran, 1972). Rathbun (1930) indicates that C. irroratus is found on all types of bottoms but is found more frequently on sandy bottoms. Wherever two or more species of Cancer coexist, they are usually segregated by substrate preferences (Jeffries, 1966; Waldron, 1958; Knudsen, 1964). Scarratt and Lowe (1972) working in Northumberland Strait, New Brunswick, where substrates were sand, boulders, or bedrock, found rock crabs to be most abundant on a boulder strewn substrate. However, the mean size of crabs on sand was significantly larger than on the other substrates. They suggest that since _C_. _borealis_ does not occur in Northumberland Strait, _C_. _irroratus_ occupies the rocky substrate (which may provide more protection than sand) that would be occupied by its congener if it were present. Since _C_. _irroratus_ occurs in Chesapeake Bay with no interspecific competition it may occupy niches usually filled by its congener _C_. _borealis_, or some other species. _C_. _irroratus_ receives little or no competition from the blue crab because in winter the blue crab is frequently in a torpid state buried in the substrate.

Although I found no relation between crab abundance and depth in Chesapeake Bay, Musick and McEachran (1972) found _C_. _irroratus_ in Chesapeake Bight to be more abundant in waters less than 19 m and greater than 110 m in depth during fall and winter 1967-1968.

Male rock crabs vastly outnumber females in Chesapeake Bay. The lowest male to female ratios occurred near the beginning of the winter dredge fishery (13:1 above 37°N; 30:1 below 37°N) and became higher as the season progressed. In April, male to female ratios ranged from 16:1 to 1:0 and females were found only outside of Chesapeake Bay Bridge Tunnel. In Northumberland Strait, New Brunswick, the male:female ratio for rock crabs was 1.31:1 in spring and 1.47:1 in fall (Scarratt and Lowe, 1972). The seasonal ratios were not significantly different from each other, but combined they were significantly different from 1:1.

It is likely that following copulation females from Chesapeake Bay return to higher salinity oceanic waters to spawn. Mating in Chesapeake Bay occurs primarily in the month of December. Musick and McEachran (1972) found that about 10% of the rock crabs caught in Chesapeake Bight during January and February were ovigerous; and ovigerous crabs were found only in waters < 30 m deep. Sastry (1970) found that larval survival in _C_. _irroratus_ to the first crab stage was highest in 30 to 35‰ salinity water at 15 C in the laboratory. Sandifer (1972) studied the occurrence of rock crab larvae in Chesapeake Bay and nearshore ocean waters. Larvae were found to be most abundant at salinities > 25‰ and at temperatures of 13 to 21 C. Larvae were taken from 5 miles offshore of Cape Henry (the outermost sampling station) to 10 miles up the bay; abundance was greatest 5 miles offshore and declined rapidly with distance up the bay. Thus, females may migrate to waters of higher salinity where environmental conditions for larval survival are most favorable.

Mean-Size and Frequency-Distribution

Crabs at stations north of 37°N appear to have greater mean widths. When looking at mean widths and width-frequency distributions simultaneously, it appears that some significant mean width differences are due to the presence or absence of a modal group at certain sample locations; that is, north of 37°N the mode representing smaller crabs is reduced or absent; south of 37°N the mode representing larger crabs is reduced or absent.

Mean widths of rock crabs taken during the April survey also increased up estuary. Perhaps as rock crabs become larger they also become more euryhaline. In the March 1971 samples there was a group of medium-size crabs (mode 80-85 mm) that appears to have migrated into the bay. This is especially evident in the 2 March sample above 37°N. The January and February samples showed few or no crabs in this range. In the 2 March sample there was a strong mode in this range which decreased the mean from about 107.7 to 94.7 mm. This mode could represent smaller crabs that had molted outside the bay and had, at their last molt, become physiologically able to osmoregulate in waters of lower salinity.

In the previous down bay sample (#6 on 21 December 1970) there was a large group of crabs in the 80-105 mm range. A strong mode also occurred in the 60-65 mm range. The majority of these crabs should have molted in the last week of December 1970 or the first few weeks of January 1971.

In the sample taken below 37°N on 9 March, the mode at 80-85 mm must represent those crabs that composed the 60-65 mm mode in December. Large crabs were all but absent from the 9 March sample and may have left this area. Their absence may have been due to intensive dredging during January and February. The area south of Thimble Shoals Channel, off Little Creek and Ocean View was very heavily dredged during the 1970-71 dredge fishery season. From 15 January 1971 on, most rock crabs were papershells (molt Stage B). It was observed on many occasions that paper-shell crabs culled overboard from the dredge boats floated on the surface of the water where they fell prey to seagulls. A significant portion of the available crabs were probably killed in this manner.

During the April cruises, few or no rock crabs were found south of Thimble Shoal Channel, where the 9 March sample was taken, although they were common north of the channel, opposite Little Creek. Smaller crabs represented by a mode at 80-85 mm were present primarily in samples taken east of the Chesapeake Bay Bridge Tunnel, making most of these samples bimodal, the higher mode occurring at 110-120 mm. During April female rock crabs were found only east of the Chesapeake Bay Bridge Tunnel in Chesapeake Channel. Of the nine females caught, three were gravid. A few very small crabs (15-40 mm) were caught but again only east of the bridge tunnel.

Polymodality in the width-frequency distribution may represent different year classes, or different instars of the same year class. Since only one well defined period of molting was recognized for C. irroratus in Chesapeake Bay and only one period is generally noted for this species in other areas on the northeastern coast (Jeffries, 1966; Turner, 1953; Telford, 1968; Scarratt and Lowe, 1972), it is believed that the rock crab, in the size range studied, molts only once per year. Therefore, the modes probably represent successive year classes which would also represent successive instars if the crabs molt once per year. Post-larval C. magister is reported to reach the 12th instar in two years after which it molts once per year to the 15th instar when it either dies or molts every other year (Butler, 1961).

Polymodality in the width-frequency distributions was also observed by Scarratt and Lowe (1972) for rock crabs in Northumberland, New Brunswick. In the spring they found modes at 32-34 mm, 38-42 mm, 80-85 mm and 110-115 mm. In the fall they found no prominent modes although crabs were most abundant from 15 to 45 mm. Turner (1954), plotting width-frequencies by 5 mm intervals for potted rock crabs in Boston Harbor, Massachusetts, found the distributions to be unimodal from May to November. The largest size group was 100-108 mm in May and June; which decreased to 90-95 mm in July and August and to 85-90 mm in November. In May, $\sim$ 80% of the crabs were > 95 mm in width; by August only

~ 20% were > 95 mm. Turner attributed part of the decline of large crabs to fishing mortality. Selectivity of the gear (modified lobster pots) may explain the absence of smaller sizes.

Relative Growth

There are two kinds of sexual differences. The first is the difference in primary sexual organs and in certain secondary sexual characters present in the earliest post-larval stages. Second, with the onset of sexual maturity, other secondary sexual characters change in one or the other sex producing differences; or differences present may be accentuated (Weymouth and MacKay, 1934).

Significant sexual differences were found in the relative growth of the carapace of *C. irroratus*. Females exhibit greater carapace length in proportion to carapace width. MacKay (1942) found no sexual differences in the carapace width-length relationship in *C. pagurus*. He did find a difference in slope between mature and immature crabs which occurred between 4 and 6 cm. Weymouth and MacKay (1934, 1936) found that in *C. magister* there are no significant sexual differences in relative growth of the carapace until a width of 10 cm is attained. At 10 cm, the size at which *C. magister* females reach sexual maturity, females begin to show greater carapace length in proportion to width. The change is very marked and occurs at the molt of puberty. No such molt of puberty was observed in female

C. irroratus over the range studied (50-94 mm). The carapace width-length regressions for male and female rock crabs converge at ~ 50 mm, the lower limit of the width range for both males and females.

The carapace width-length relationship for *C. irroratus* is negatively allometric over the range examined. In both males and females there is less growth in length than in width. The relationship is negatively allometric for *C. magister* (Weymouth and MacKay, 1934, 1936) and immature *C. pagurus*, but is isometric for mature *C. pagurus* (MacKay, 1942).

No significant sexual differences were found in regressions for length of the propodite of the larger chela on carapace width. Only measurements from male crabs < 100 mm in carapace width were used because no females were found larger than about 100 mm, a width which appears to be maximum for the sex (Scarratt and Lowe, 1972).

C. irroratus differs from some other species of *Cancer* in the negative allometry of the major chela propodite. *C. pagurus* and males of *C. magister* exhibit positive allometry (MacKay, 1943b; Weymouth and MacKay, 1936). Also the growth of the propodite of the major chela is sexually dimorphic in both *C. pagurus* and *C. magister*.

For *C. irroratus* in Chesapeake Bay, males weigh significantly more than females of the same width. However, Scarratt and Lowe (1972) reported that the regressions of weight against carapace width for male and female rock crabs are not significantly different. They did not state whether or not they used a reduced range of males but their ratio of males to females was 197 to 126. Their regressions were computed using natural logarithms, whereas common logarithms were used in this study; however, this should not affect the results. There may be a geographic difference in growth.

A pubertal molt apparently does not occur in the size range of *C. irroratus* studied because there is no change in rate of relative growth in the parts examined. This, along with data on the reproductive biology, suggests that all crabs in the samples examined were mature.

Molting and Mating

Winter molting and mating in *C. irroratus* is probably induced by decreasing photoperiod and allows spring spawning when environmental conditions are likely to be most favorable for larval survival. All the available biological evidence (molt stages observed while sampling, limb bud development and fouling organisms) shows that the rock crab molts in Chesapeake Bay during the months of December through February. Along the coastal New England states and in New Brunswick, Canada, *C. irroratus* is reported to molt between July and December--the farther north the earlier the season of molting (Turner, 1953; Telford, 1968; Scarratt and Lowe, 1972). In most instances, the temperature was falling as it was in Chesapeake Bay during December, January and February. In almost all other Cancridae, molting and mating occur after the summer solstice (Table 13) when photoperiod is decreasing.

Pontoporeia affinis, a boreo-arctic amphipod reproduces in winter as do many other marine animals living in high latitudes (Sergerstrale, 1970). Thorsen (1946) suggested winter mating is advantageous where environmental conditions are especially favorable for the new generation in early spring. Sergerstrale (1970) found that gonadal maturation in P. affinis was triggered by the decrease in photoperiod in late summer.

In the present study, C. irroratus females molted about three weeks before males. Similarly, Edwards (1966) reported that C. pagurus females molt about one month before males. This is probably an adaptation, in a species that molts but once per year, that allows hard (Stage C) males to inseminate females which can only mate when soft (Stage E). Decreasing photoperiod probably triggers proecdysis in rock crabs replete with organic reserves garnered over the summer and fall, in order that mating and vitellogenesis will have occurred before spawning in early spring.

Post-exuvial sclerotization proceeds very slowly in rock crabs which become papershells (Stage B) quite soon after ecdysis but remain in Stage B for many months. At the time of the April cruises (22-27 April) the carapaces of virtually all crabs were in an advanced papershell

TABLE 13

SEASONS OF MOLTING FOR THE GENUS CANCER.

Source	Species	Location	Season of Molting (Mating)
Magoon, 1970	*C. magister*	Washington	Oct.-Dec.
Knudsen, 1964	*C. magister*	Puget Sound, Washington	June-Aug.
Butler, 1960	*C. magister*	Queen Charlotte Is., B.C.	May-Sept.
Knudsen, 1964	*C. oregonensis*	Puget Sound, Washington	Apr.-June
" "	*C. gracilis*	" " "	June-Aug.
" "	*C. productus*	" " "	"
Edwards, 1966	*C. pagurus*	Great Britain	July-Aug.
Terretta, 1972	*C. irroratus*	Chesapeake Bay	Dec.-Feb.
Turner, 1953, 1954	*C. irroratus*	Massachusetts	July-Dec.
Telford, 1968	*C. irroratus*	Maine	Fall
Scarratt & Lowe, 1972	*C. irroratus*	New Brunswick, Canada	

condition; i.e., the dorsal carapace could be depressed without breaking by exerting moderate thumb pressure. During this time the flesh is particularly watery which prompted Turner (1953) to suggest a closed season in Massachusetts from December through April because of the low meat yield. C. pagurus requires 3 to 5 months for Stage B (Pearson, 1908). In Washington, C. magister has a closed season from September 15 to January 1 while it is in the papershell stage (Magoon, 1970). Slow shell deposition is probably common to all Cancridae and is probably a result of a low metabolic rate due to the low temperatures of the waters they inhabit. During this time, crabs are actively feeding and accumulating organic reserves.

It is unfortunate that only one act of mating was observed in C. irroratus. Scarcity of females and the difficulty of bringing back live specimens prevented further observations; also, by the time it was realized that December was the peak mating period, mating activity began to decline and females became even more scarce. Chidester (1911) reports the only account in the literature of mating in rock crabs. His description of mating, however, is ambiguous and incomplete. He also maintained that when, in two instances, soft females were removed from pairs in copulo and were replaced by hard females without sperm plugs, that the males succeeded in inserting the verges and actual copulation took place. He does not give the sizes of the crabs involved nor the physical conditions under which the experimental encounter took place. In the other observed Cancridae (C. gracilis, C. magister, C. oregonensis, C. pagurus, and C. productus) mating takes place immediately after female ecdysis (Cleaver, 1949; Butler, 1960; Knudsen, 1964; Edwards, 1966; Snow and Neilsen, 1966; Hartnoll, 1969). Mating behavior is basically similar in these five species. The male carries the premolt female beneath him for a period of 3-10 days. In C. magister, as observed in this report for C. irroratus, the female is carried with her sternum held against that of the male. But in the other four species, the female has her carapace against the male's sternum. There is some evidence that males are able to distinguish premolt females (Edwards, 1966; Snow and Neilsen, 1966). The male releases the female to permit her to molt, and in C. magister he does so in response to increased activity of the female, which molts in a protective cage formed by the male's walking legs and upraised body (Snow and Neilsen, 1966). In C. pagurus the male releases the female and assists her escape from the old integument (Edwards, 1966). After ecdysis, copulation occurs with the male uppermost. After copulation the male continues to carry the female in the premolt position until her integument has partially hardened (Hartnoll, 1969).

After copulation in the rock crab, the contents of the spermathecae form sperm plugs, which are hard rod-like crystalline bodies that extend into the vaginae and protrude from the vulvae. This phenomenon was first described in rock crabs by Chidester (1911). C. pagurus is the only other crab in the genus in which sperm plugs have been observed (Edwards, 1966). He observed that the plugs disappeared externally in three to eight weeks but that portions remained internally for over a year. Sperm plugs are easily visible in an impregnated soft rock crab female. Their presence is an obvious indication that copulation has occurred. Only one of 13 post-molt rock crab females examined had no sperm plugs although she did have sperm in the spermathecae. This evidence shows that rock crab mating in Chesapeake Bay occurred in December during the period of study. Copulation can occur only once because the presence of the plugs in the vaginae prevent reinsertion of the male intromittent organs. The sperm plug is generally believed to be produced by the male (Hartnoll, 1969). There are some indications that secretions by the female could be responsible for its hardening. The purpose of the sperm plug is unclear. It may serve to prevent the loss of sperm after copulation.

Sexual Maturity

A crab is generally regarded as becoming mature when it enters the intermolt during which it is first able to copulate successfully (Hartnoll, 1969). In males a general criterion of maturity is that the vasa deferentia contain large numbers of spermatozoa enclosed in spermatophores

(Pearson, 1908; Haley, 1969; Hartnoll, 1969). In addition, external morphological changes, affecting the chelae in particular, may coincide with maturity or the molt of puberty. In females maturity cannot be determined from the condition of the gonads. This is because oogenesis often occurs up to several months or even a year after mating, and at copulation the ovaries can still be immature. The pubertal molt is usually much more prominently developed in females than in males and can involve changes in the abdomen, pleopods and sternum (Hartnoll, 1969). Another valuable criterion for determining whether females are mature is the presence of sperm in the spermathecae (Haley, 1969). All male C. irroratus examined were mature by the above criterion of spermatophores in the vasa deferentia. The smallest male observed in this study was 49 mm in carapace width. With three exceptions, all female rock crabs examined had sperm in the spermathecae and were thus mature. Because females smaller than 59 mm were not caught and observed, it was not possible to determine whether the three females without sperm in the spermathecae had definite juvenile characteristics or if they merely had not been fertilized at the last ecdysis. There is some evidence that female rock crabs may become mature when very small. W. A. Van Engel (personal communication) has a gravid C. irroratus female only 28 mm wide and 19 mm long. The crab was captured in lower Chesapeake Bay on 15 January 1957, spawned on 5 February and molted 18 February. On

November 1970 a gravid female 39 mm in width and 25 mm in length was taken by the VIMS Crustaceology Department in lower Chesapeake Bay near Lynnhaven. In spring 1972, an ovigerous female 28 mm in width was taken in the Atlantic Ocean off Chincoteague, Virginia, by Lewis Shotton, a graduate student at VIMS. These incidents suggest a surprisingly early maturity for female rock crabs and by implication, male rock crabs also. Scarratt and Lowe (1972), on the other hand, suggest a much larger size for gonadal maturity. Their criteria indicate that crabs under 50 mm in width are immature. This may very well be true if the above examples are anomalous.

Examination of the gonads of female rock crabs indicated that vitellogenesis (yolk deposition) began in December. Reproductive and somatic growth processes tend to be antagonistic because they must compete for the same organic reserves (Adiyodi and Adiyodi, 1970). Thus, vitellogenesis probably does not begin until proecdysis is initiated and possibly not until ecdysis has taken place. Yolk deposition seems to occur quite slowly in post-molt females, probably as a result of reduced metabolic rate due to low temperatures and also because the crabs are slowly hardening and renewing organic reserves. Hard (1942) described development of the ovary in blue crabs by dividing growth and ovulation phases into five stages. Stage I describes the ovary after the terminal anecdysis and first and only copulation. Here the ovary is very small, white, thread-like, and contains only small immature eggs. In Stage II the ovary increases greatly in size, the anterior and posterior horns increase in length, and the ovaries become orange in color due to formation of yolk. It is believed that most of the female rock crab ovaries examined would correspond best with Hard's Stage II if indeed a comparison can be made. Blue crabs mate only once and spawn once or twice whereas Cancer mates and spawns once per year. There is evidence that some Cancer spp. may spawn twice after one mating (Knudsen, 1964). Hard's Stage IV (the condition of the ovary between the first and second ovulation) may more accurately describe the rock crab ovary in December. In Stage IV the ovary has usually decreased in size but the ovary is still filled with eggs, most of which are fully as large as those in a mature ovary (Stage III) but they lack the great quantity of yolk characteristic of the mature egg; the relatively small amount of yolk present is sufficient to give an orange color to the ovary. In *C. irroratus* ovaries, many eggs were found in all parts of the ovary but, especially during the first part of December, little or no yolk material was observed. The ovary was pale yellow or beige in all instances, possibly because of color loss in the preservative. The egg mass of a preserved gravid female changed from bright orange to pale yellow in the few months it was in 10% formaldehyde solution. After December only a few females were captured, thus making it impossible to follow ovarian development continuously.

In C. irroratus the spermatophores probably rupture when they leave the vasa deferentia during copulation. Only free spermatozoa were found in the spermathecae of female C. irroratus. This is also true of C. magister (Butler, 1960) and C. pagurus (Pearson, 1908).

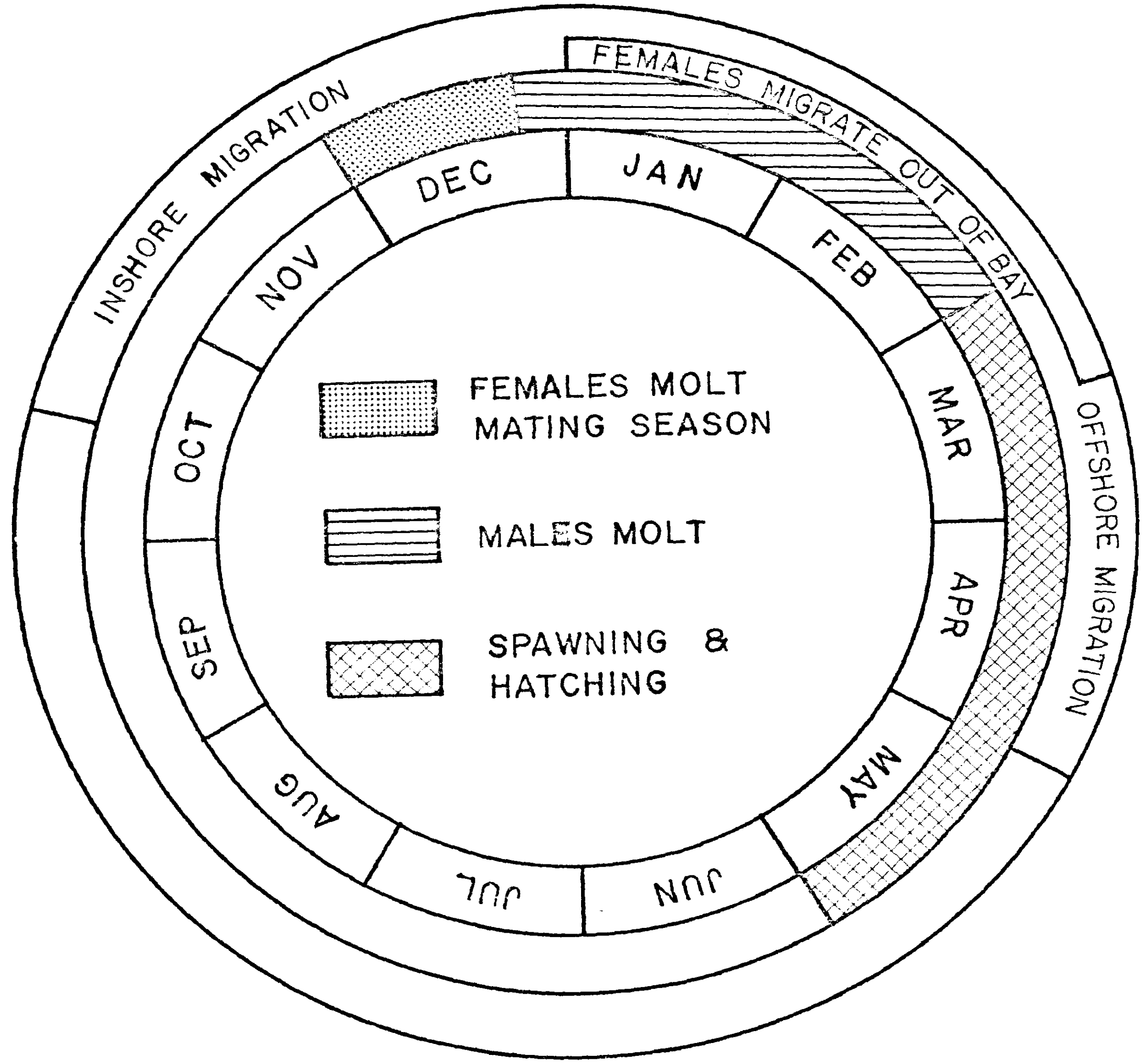
A suggested integrated summary of the life cycle of C. irroratus in Chesapeake Bay is presented in Figure 27. An inshore migration occurs around the middle of October when water temperature falls within the species' preferred range. The few females that enter the bay molt in December when mating also takes place. Males molt beginning in late December, peaking in mid-January with a gradual decline in molting activity which ceases around the end of February. Meanwhile, females migrate offshore to higher salinity waters to prepare for spawning in March, April and May. Males begin to migrate offshore in mid- to late March in response to rising temperature or lengthening photoperiod.

The Chesapeake Bay "population" is a peripheral group intruding from nearshore waters into the polyhaline zone. Most of the population remains outside the bay along the coast.

Parasites

Octolasmis lowei Darwin has not been previously reported on Cancer irroratus. It has been reported for: Callinectes sapidus, Callinectes ornatus, Libinia

Figure 27. Possible life cycle of rock crabs living in the Virginia Bight and migrating into Chesapeake Bay in the late fall and winter.



FEMALES MIGRATE OUT OF BAY
INSHORE MIGRATION
OFFSHORE MIGRATION
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
FEMALES MOLT
MATING SEASON
MALES MOLT
SPAWNING &
HATCHING

emarginata, *Menippe mercenaria*, *Panopeus herbstii*, *Calappa flammea*, and *Hepatus epheliticus* (Humes, 1941). *Octolasmis* is most commonly and abundantly found on *Callinectes sapidus*. At Grand Isle, Louisiana, 19% of male and 43% of female blue crabs carried *Octolasmis* (Coker, 1901). At Beaufort, North Carolina, 56% of male and 89% of female blue crabs were infested (Coker, 1901). Not only did the adult female blue crabs have a greater frequency of infestation, but the number of barnacles per female was noticeably greater than that per male (Humes, 1941; Coker, 1901).

The opposite was true for *C*. *irroratus* from the Chesapeake Bay in winter 1970-71; males had a higher frequency and density of infestation. This is probably because many of the female crabs examined had recently molted. The covering of the gills and lining of the branchial chamber, morphologically a part of the exoskeleton, are cast off at each molt; thus, the barnacles, attached to the external surface of the exoskeleton, are cast off at each molt. In blue crabs (as was found in rock crabs) *Octolasmis* was most often attached on the concave or mediad side of the gills, but occasionally was found on other parts of the gills, on the scaphognathite or on the branchial chamber walls (Humes, 1941). Adult female *Callinectes sapidus* which carried *Octolasmis* on their gills frequently had nemertean worms of the genus *Carcinonemertes* coiled up between the gill lamellae; however, no relationship was found between nemerteans and barnacles that would favor their occurrence together or inhibit the occurrence of one after the other has become established (Humes, 1941).

Although orientation of the barnacles was not examined in rock crabs, Dinamani (1964) found that the orientation of *Octolasmis stella*, infesting the spiny lobster *Puerulus sewelli*, showed a positive response to respiratory water currents of the branchial region of the lobster in having their cirral net facing the current. Blue crabs whose gills are heavily infested with *Octolasmis* are moribund and and exhibit high laboratory mortality although no organic connection between the barnacle and its host is found. When the cirripeds are present in large numbers much of the gill is occupied, gill lamellae are fastened together, the respiratory current is retarded and the barnacles have first chance at the water.

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