SIZE AT MATURITY AND FECUNDITY OF ROCK CRABS, *CANCER IRRORATUS*, FROM THE BAY OF FUNDY AND SOUTHWESTERN NOVA SCOTIA

A. CAMPBELL[1] AND M. D. EAGLES[2]

ABSTRACT

Rock crabs, *Cancer irroratus*, were collected from lobster traps, trawls, and by divers in the Bay of Fundy and southwestern Nova Scotia, 1980-81. Estimates of maturity were similar using gonad examination, measurements of chela height, and abdominal width/carapace width ratios. The carapace width (CW) at which 50% of male and female rock crabs were mature was estimated to be 62 and 49 mm, whereas the onset of maturity was estimated to be 40 and 27 mm CW, respectively. Ovigerous females (range 41-100 mm CW) were heavier than nonovigerous females and males of the same carapace width, and carried from 47,130 to 567,690 eggs per female. Rock crabs in the Bay of Fundy and southwestern Nova Scotia appear to mature at a larger size than rock crabs from more southern waters.

The rock crab, *Cancer irroratus* Say, 1817, (Decapoda: Brachyura), is common along the Atlantic coast of North America from Labrador to South Carolina (Rathbun 1930; Squires 1966; Nations 1975). In Canadian waters, *C. irroratus* is generally found near the coast (depth <20 m) and is abundant in the southern Gulf of St. Lawrence (Caddy and Chandler 1976; Stasko 1976; Campbell 1979). At present, *C. irroratus* is underutilized due to high processing costs and limited market demand. Consequently, rock crabs are fished primarily as an incidental bycatch in the lobster fishery and, except in certain areas, are generally discarded or occasionally used as bait in lobster traps. Bigford (1979) summarized the numerous studies on the biology and ecology of *C. irroratus*. Little information exists on the reproductive biology of *C. irroratus* in its northern range, especially the Bay of Fundy and southwestern Nova Scotia (Krouse 1972, 1976, 1980; Scarratt and Lowe 1972; Elner and Stasko 1978; Elner and Elner 1980).

Size at maturity and fecundity are important parameters in determining reproductive potential and for managing a crab fishery. Crabs can be considered mature when males can mate successfully (Hartnoll 1969) and females are capable of extruding eggs. Although egg-bearing by female crabs is an obvious indication of functional maturity, depending on the season and other factors, a proportion of mature females may be found without external eggs at any given period. Estimation of maturity in these nonovigerous females and males can be determined by internal examination of the gonads (physiological maturity) and/or measurement of external morphological secondary sexual characteristics (functional maturity). This paper reports on the physiological and functional maturity, fecundity, and weight relations of different size-groups of *C. irroratus* males and females collected from the Bay of Fundy and southwestern Nova Scotia waters (Fig. 1).

METHODS

Male and nonovigerous female *C. irroratus* were collected near Alma, Beaver Harbor, and Grand Manan, New Brunswick, and at Scots Bay, Delap Cove, and Port Maitland, Nova Scotia, by lobster fishermen who used conventional lobster traps during March-July 1980 (Fig. 1). Additional samples were collected by divers on the southwestern shore of McNutt Island near Shelburne, Nova Scotia, during July 1981. Ovigerous *C. irroratus* were caught in lobster traps near Alma and on the eastern side of Passamaquoddy Bay, using bottom trawls during January-June 1980 and December 1980-February 1981.

The rock crabs were frozen individually in plastic bags within 6 h of capture and stored at ca −20°C. Prior to examination, the rock crabs were thawed at room temperature. We recorded the carapace width (CW, widest distance between the tips of the anterolateral spines of the carapace), the height of the

[1] Invertebrates and Marine Plants Division, Department of Fisheries and Oceans, Biological Station, St. Andrews, N.B. E0G 2X0, Canada.

[2] Invertebrates and Marine Plants Division, Department of Fisheries and Oceans, Biological Station, St. Andrews, N.B.; present address: P.O. Box 226, St. Andrews, N.B. E0G 2X0, Canada.

Manuscript accepted October 1982.
FISHERY BULLETIN: VOL. 81, NO. 2, 1983.

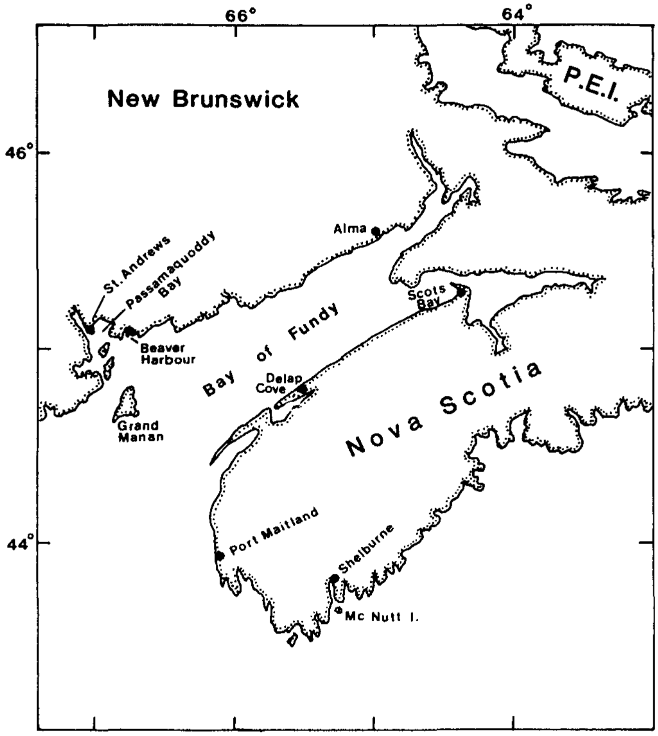

FIGURE 1.—Location of areas sampled for rock crabs in the Bay of Fundy and southwestern Nova Scotia.

left chela (Fig. 2), width of the sixth abdominal segment (see figure 4 in Bigford 1979) to the nearest 0.1 mm, whole body wet weight to the nearest 0.01 g, sex, and gonad stage (Table 1) for each crab. Eggs only were removed from ovigerous females and preserved in 5% Formalin[3] for 24 h then dried to a constant weight at 70°C for 48 h. The total number of eggs was calculated from the weight of the total egg mass divided by the average weight of an egg estimated from the known number (counted under dissecting microscope) and weight of three subsamples of about 500-1,000 eggs.

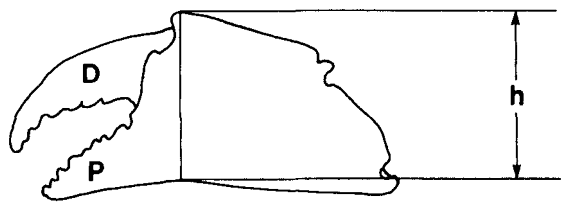

FIGURE 2.—Diagram of a male rock crab left chela indicating the chela height (h) measurement taken; D = dactyl; P = propus.

Gonad stages (Table 1) were based on a modified version of Haefner (1976) who indicated six stages of

[3]Reference to trade name does not imply endorsement by the National Marine Fisheries Service, NOAA.

TABLE 1.—Stages in gonad development of rock crab, *Cancer irroratus* (modified from Haefner 1976).

Stage of development	Male	Female
1. Undeveloped	Gonads not detectable without microscope.	
2. Slight	Vasa deferentia evident. Testes small or not apparent. Colorless. 0-8 small, developing spermatophores per 0.1 mm².	Ovaries threadlike. Colorless to white. No oocytes.
3. Moderate	Testes and vasa deferentia of approximately equal weight or vasa deferentia slightly heavier. Gonads quarter to half volume of hepatopancreas. White. 8-35 well-developed spermatophores per 0.1 mm².	Ovary half volume of hepatopancreas. White to light orange. Oocyte diameter 0.1-0.5 mm.
4. Developed	Gonads half volume of hepatopancreas. Vasa deferentia more than 3 times heavier than testes. White. >30 well-developed spermatophores per 0.1 mm².	Ovary volume approximately equal to that of hepatopancreas. Light orange to orange. Oocyte diameter 0.2-0.5 mm.
5. Well developed	Gonads dominant organ. White. >100 well-developed spermatophores per 0.1 mm².	Ovary larger than hepatopancreas. Orange to red. Oocyte diameter 0.2-0.5 mm.

gonadal development. Modifications to Haefner's classification include combining Haefner's first and second stages into a single immature stage and microscope measurements of oocytes, and examination for spermatophores. The diameters of three oocytes per ovary to the nearest 0.01 mm under a compound microscope were measured. Female *C. irroratus* were considered to be physiologically mature when ovaries were developed to greater than or equal to stage 3 since all ovigerous females had stage-3 ovaries. Male *C. irroratus* were estimated to be physiologically mature as judged by the size of the gonads and the presence of spermatophores (number per 0.1 mm^2 determined with a micrometer and microscope) in the vas deferentia (Table 1). About 10% of the vas deferentia of each gonad stage was subsampled and examined for the presence of spermatophores under 400× magnification. All males with gonad stage ≥3 had well-developed spermatophores. Stage-2 gonads were considered immature because of the low numbers of small developing spermatophores.

The proportion of physiologically mature crabs in each sex was calculated by dividing the number of mature gonad stages by the total number of gonads examined for each 5 mm CW class. The relationship between CW (X) in millimeters and proportion mature (Y) for both female and male *C. irroratus* was approximated by the logistic function:

$$Y = \frac{a}{1 + e^{b+cX}}$$

where a, the asymptote of the curve, and b and c, empirical constants, were estimated by nonlinear least squares approximation from the CW and proportion mature data using Marquardt's algorithm (Conway et al. 1970; Marquardt 1963).

Indices of functional maturity using morphometric criteria for male and female rock crabs were obtained by the following two methods: The first was to find 50% sexual maturity from the intersection of a pair of linear regressions that had the best fit (Somerton 1980a, b) to CW-chela height data; the second by dividing the abdominal width by CW for each individual crab and averaging the ratios for each 5 mm CW group.

The power curve of the linear form $\log_{10} Y = a + b \log_{10} X$ was used to approximate the relationship between CW(X) and total weight in grams (Y), and the number of eggs per female (Y), using the least squares method. Analysis of covariance was used to compare the slopes and elevations of all the regression equations (Snedecor and Cochran 1967).

RESULTS AND DISCUSSION

There were no significant differences using analysis of covariance ($P>0.05$) in size at maturity, CW-weight, or CW-fecundity relationships between rock crabs of the same sex from each sample area; therefore, the data were combined to present each relationship for one general Bay of Fundy-southwestern Nova Scotia area. Table 2 indicates that the CW-weight (g) relationship had a high correlation coefficient (r) for male, nonovigerous, and ovigerous *C. irroratus*. Although there were no significant differences between the slopes ($P>0.05$), there were differences in elevations ($P<0.001$) of the CW-weight regressions over similar CW ranges, between ovigerous females and males and between ovigerous and nonovigerous females (Table 2). Differences in elevation between male and nonovigerous females were probably not biologically significant at $P<0.05$ (Table 2). Krouse (1972) and Scarratt and Lowe (1972) also did not find a difference between males and nonovigerous females in the CW-weight relationship. We, as did Scarratt and Lowe (1972), found that ovigerous females were heavier than nonovigerous females carrying 2.2-45.2 g (wet weight) of eggs for a 41.1-100.2 mm CW range.

The CW-proportion mature relationship estimated from gonad development was described well by the logistic curve (Fig. 3). The CW at which 50% of males and females were mature was estimated at 61.7 and 48.6 mm, respectively. The smallest male found with mature gonads (stage 3) was 34.2 mm CW and the largest male with immature gonads (stage 2) was 95.1

TABLE 2.—Regression constants for the carapace width (Y) and weight (X in grams) relationship ($\log_{10} Y = a + b \log_{10} X$) for male, nonovigerous, and ovigerous rock crabs, *Cancer irroratus*. r = correlation coefficient.

Sex	Regression constants			Number	Carapace width (mm)	
	a	b	r		Min	Max
Male	−3.9422*o	3.0519	0.9948	476	15.6	137.8
Nonovigerous female	−3.9435*+	3.0667	0.9938	235	19.0	107.1
Ovigerous female	−3.7085o+	2.9921	0.9835	73	41.1	100.2

[1]Elevations followed by same symbol were significantly different: * at $P<0.05$; o and + at $P<0.001$, but there were no significant differences ($P>0.05$) between all three slopes (b) using analysis of covariance.

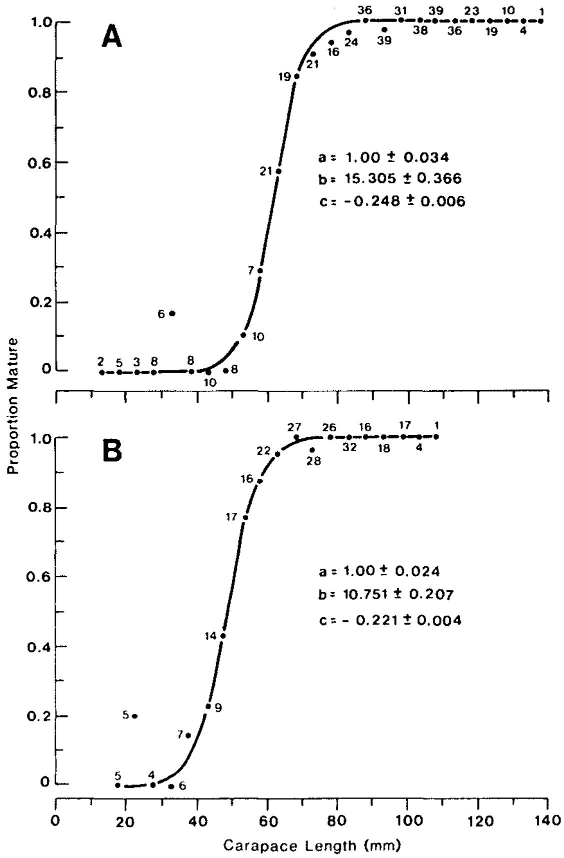

FIGURE 3.—Relationship between proportion mature based on gonad development and carapace width (CW) for (A) male and (B) female rock crabs from the Bay of Fundy and southwestern Nova Scotia. Values next to dots are numbers of crabs examined at every 5 mm CW class. a = asymptote, b and c = empirical constants followed by the 95% nonlinear confidence intervals for the logistic curve (see text for formula).

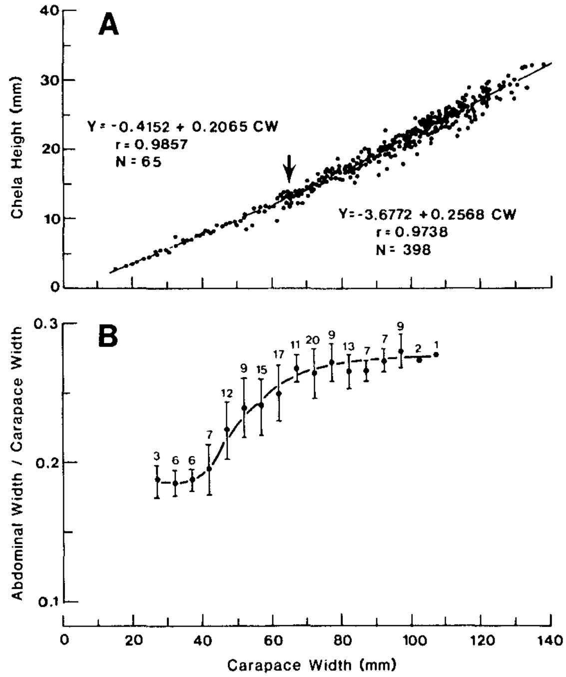

FIGURE 4.—Maturity estimation using rock crab morphometric data in relation to carapace width (CW) for (A) male chela height (Y) (arrow indicates inflection point of two regression lines or 50% maturity; r = correlation coefficient; N = number of individuals), and (B) female abdomen width/carapace width ratio (dots are means, vertical lines are ±1 standard deviations, numbers above each dot are the number of individuals measured for each 5 mm CW group).

mm CW. Most males in the 34.2-134.0 mm CW range had stage-3 gonads and in the 61.9-137.8 mm CW range had fully developed stage-5 gonads. The smallest female with mature ovaries (stage 3) was 20.2 mm CW and the largest female with immature ovaries (stage 2) was 72.2 mm CW. Many females had stage-3 ovaries in the 39.4-99.6 mm CW range, and many females had fully developed stage-5 gonads in the 44.7-105 mm CW range.

Size at 50% maturity for male rock crabs, estimated as the inflection point in the CW-chela height data, was 64.9 mm CW (Fig. 4A), which was similar (61.7 mm CW) to the estimate obtained by the gonadal inspection technique (Fig. 3A). Since only one regression line, using the best fit method (Somerton 1980a), could be obtained for the female CW-chela height data (not shown in this paper), this relationship could not be used to estimate sexual maturity in female rock crabs. The abdomen width/CW ratio was linear for males (not shown in this paper), but curvilinear for females (Fig. 4B), indicating that broadening of the abdomen is a female secondary sexual characteristic. The inflection and asymptote showing onset and 100% sexual maturity, respectively, occurred at about 37 and 77 mm CW (Fig. 4B) which is similar to that derived by gonadal inspection (Fig. 3B). Abdominal width and chela length (not height) have been used to estimate onset of sexual maturity of rock crabs by Shotton (1973) and Terretta (1973). The abdominal width/CW ratio has not been previously used for rock crabs, although commonly used for lobsters in estimating sexual maturity (Templeman 1935; Aiken and Waddy 1980). The results suggest that external morphological secondary sexual characteristics generally coincide with physiological maturity in *C. irroratus* females and males.

The presence of external eggs on females is an obvious indicator of functional maturity. The smallest ovigerous female was 41.1 mm CW, whereas most ovigerous females caught were ≥65 mm CW (Fig. 5), which generally agrees with the maturity curves based on gonad development (Fig. 3B) and abdominal width/CW ratio (Fig. 4B). There were no ovigerous females in our samples between 48 and 65 mm CW; perhaps this scarcity could be attributed to sample bias owing to gear selectivity and/or spatial and temporal effects on the sizes of ovigerous females collected.

Haefner (1976) showed an increase in development of gonads in relation to CW increase for *C. irroratus* males and females captured in the mid-Atlantic Bight. In general, the present data suggest that *C. irroratus* matures at a smaller size in southern than in northern waters of eastern North America. Along the Virginia coastline, the presence of eggs on females, morphological measurements, and observations on gonads of male and female *C. irroratus* indicated individuals are mature by about 30 mm CW (Shotton 1973; Terretta 1973). Reilly (1975) found ovigerous females as small as 14 mm CW, with many ovigerous crabs collected in the 14-25 mm CW range from Rhode Island waters. In northern populations along the Maine coast, Krouse (1972) suggested that females mature at 55-62 mm CW, based on the presence of ovigerous females, although most females were ovigerous in the 70-99 mm CW range. Scarratt and Lowe (1972) examined the gonads of *C. irroratus* from Northumberland Strait and found the smallest female with mature gonads to be 60 mm CW, but the smallest female with external eggs was 65 mm CW, whereas some males had developing gonads at a 50-100 mm CW range and there were a few with ripe gonads ≥69 mm CW. The results of this study on *C. irroratus* in the Bay of Fundy and southwestern Nova Scotia generally agree with those of Krouse (1972) and Scarratt and Lowe (1972) in that most ovigerous females were ≥65 mm CW (Fig. 5).

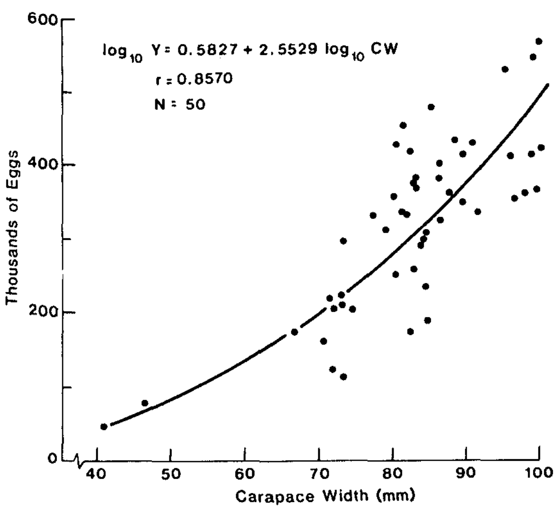

FIGURE 5.—Relationship between total number of eggs (Y) carried externally and carapace width (CW) of ovigerous female rock crabs from the Bay of Fundy and southwestern Nova Scotia; r = correlation coefficient, N = number of individuals.

The CW-fecundity relationship was described well ($r = 0.857$) by a power curve (Fig. 5). There were no significant differences ($P>0.05$) in CW-fecundity relation between newly extruded eggs (orange-red color) and well-developed eggs (pale gray-brown) and between specimens collected in 1980 and 1981, using analysis of covariance; thus the data were combined. The smallest ovigerous female (41.1 mm CW) collected had the lowest number (47,130) of eggs. A 99.8 mm CW female had the largest number (567, 690) of eggs. The only other published estimates of fecundity for *C. irroratus* are from Rhode Island (Reilly and Saila 1978). There were no significant differences ($P>0.05$) between the fecundity of *C. irroratus* females in the same size range (37-88 mm CW) from Rhode Island and this study. However, larger ovigerous rock crabs (90-100 mm CW) producing a greater number of eggs (320,000-567,690) per female (Fig. 5) were observed from Bay of Fundy and southwestern Nova Scotia relative to those reported from the Rhode Island area (Reilly 1975; Reilly and Saila 1978).

Interarea variations between *C. irroratus* of size at first maturity and fecundity may be caused by a number of factors such as differences in photo-period, temperature, and food availability. Temperatures are generally cooler in northern waters, such as in the Bay of Fundy, compared with southern waters, such as off Rhode Island (Colton and Stoddard 1972). Warmer temperatures probably lead to maturity at a smaller size in *C. irroratus* compared with colder waters (Kurata 1962). Although *C. irroratus* from the Bay of Fundy may produce more eggs at larger sizes (90-100 mm CW) than female crabs off Rhode Island, we hypothesized that the reproductive potential of this species is greater in warmer southern waters where more individuals mature at smaller sizes, thereby reducing the population generation time, than those rock crabs in colder northern waters. The integration of growth, size at maturity, and fecundity information to compare the reproductive potential of *C. irroratus* from these two areas requires further study.

ACKNOWLEDGMENTS

We thank S. Bellis, R. Chandler, D. Duggan, D. Graham, S. Hamet, and H. A. Leslie for technical assistance; F. Cunningham for graphics; R. W. Elner and D. J. Scarratt for reviewing earlier versions of this paper.

LITERATURE CITED

AIKEN, D. E., AND S. L. WADDY.
1980. Reproductive biology. *In* J. S. Cobb and B. F. Phillips (editors), Biology and management of lobsters, Vol. 1, p. 215-276. Acad. Press, N.Y.

BIGFORD, T. E.
1979. Synopsis of biological data on the rock crab, *Cancer irroratus* Say. U.S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 426, 26 p.

CADDY, J. F., AND R. A. CHANDLER.
1976. Historical statistics of landings of inshore species in the Maritime Provinces 1947-'73. Fish. Mar. Serv. Tech. Rep. 639, 240 p.

CAMPBELL, A.
1979. Invertebrates and marine plants commercial landings in the Passamaquoddy region and Bay of Fundy, 1973-78. Fish. Mar. Serv. Tech. Rep. 901:19-26.

COLTON, J. B., JR., AND R. R. STODDARD.
1972. Average monthly sea water temperatures, Nova Scotia to Long Island, 1940-1959. Ser. Atlas Mar. Environ., Am. Geogr. Soc. Folio 22.

CONWAY, G. R., N. R. GLASS, AND J. C. WILCOX.
1970. Fitting nonlinear models to biological data by Marquardt's algorithm. Ecology 51:503-507.

ELNER, R. W., AND J. K. ELNER.
1980. Observations on a simultaneous mating embrace between a male and two female rock crabs, *Cancer irroratus* (Decapoda, Brachyura). Crustaceana 38:96-98.

ELNER, R. W., AND A. B. STASKO.
1978. Mating behavior of the rock crab, *Cancer irroratus*. J. Fish. Res. Board Can. 35:1385-1388.

HAEFNER, P. A., JR.
1976. Distribution, reproduction and moulting of the rock crab, *Cancer irroratus Say*, 1917, in the mid-Atlantic Bight. J. Nat. Hist. 10:377-397.

HARTNOLL, R. G.
1969. Mating in the Brachyura. Crustaceana 16:161-181.

KROUSE, J. S.
1972. Some life history aspects of the rock crab, *Cancer irroratus*, in the Gulf of Maine. J. Fish. Res. Board Can. 29: 1479-1482.
1976. Size composition and growth of young rock crab, *Cancer irroratus*, on a rocky beach in Maine. Fish. Bull., U.S. 74:949-954.
1980. Distribution and catch composition of Jonah crab, *Cancer borealis*, and rock crab, *Cancer irroratus*, near Boothbay Harbor, Maine. Fish. Bull., U.S. 77:685-693.

KURATA, H.
1962. Studies on the age and growth of Crustacea. Bull. Hokkaido Reg. Fish. Res. Lab. 24:1-115.

MARQUARDT, D. W.
1963. An algorithm for least-squares estimation of non-linear parameters. J. Soc. Ind. Appl. Math. 11:431-441.

NATIONS, J. D.
1975. The genus *Cancer* (Crustacea: Brachyura): Systematics, biogeography and fossil record. Nat. Hist. Mus. Los Ang. Cty., Sci. Bull. 23:1-104.

RATHBUN, M. J.
1930. The cancroid crabs of America of the families Euryalidae, Portunidae, Atelecyclidae, Cancridae and Xanthidae. U.S. Natl. Mus. Bull. 152:1-609.

REILLY, P. N.
1975. The biology and ecology of juvenile and adult rock crabs, *Cancer irroratus* Say, in southern New England waters. M.S. Thesis, Univ. Rhode Island, Kingston, 146 p.

REILLY, P. N., AND S. B. SAILA.
1978. Biology and ecology of the rock crab, *Cancer irroratus* Say, 1817, in southern New England waters (Decapoda, Brachyura). Crustaceana 34:121-140.

SCARRATT, D. J., AND R. LOWE.
1972. Biology of rock crab (*Cancer irroratus*) in Northumberland Strait. J. Fish. Res. Board Can. 29:161-166.

SHOTTON, L. R.
1973. Biology of the rock crab, *Cancer irroratus* Say, in the coastal waters of Virginia. M.A. Thesis, Univ. Virginia, Charlottesville, 72 p.

SNEDECOR, G. W., AND W. G. COCHRAN.
1967. Statistical methods. 6th ed. Iowa State Univ. Press, Ames, 593 p.

SOMERTON, D. A.
1980a. Fitting straight lines to Hiatt growth diagrams: a re-evaluation. J. Cons. Int. Explor. Mer 39:15-19.
1980b. A computer technique for estimating the size of sexual maturity in crabs. Can. J. Fish. Aquat. Sci. 37:1488-1494.

SQUIRES, H. J.
1966. Distribution of decapod Crustacea in the northwest Atlantic. Ser. Atlas Mar. Environ., Am. Geogr. Soc., Folio 12.

STASKO, A. B.
1976. Northumberland Strait program: lobster and rock crab abundance in relation to environmental factors. Int. Counc. Explor. Sea C.M. 1976/K:25, 13 p.

TEMPLEMAN, W.
1935. Local differences in the body proportions of the lobster, *Homarus americanus*. J. Biol. Board Can. 1:213-226.

TERRETTA, R. T.
1973. Relative growth, reproduction and distribution of the rock crab, *Cancer irroratus*, in Chesapeake Bay during the winter. M.A. Thesis, College of William and Mary, Williamsburg, Va., 104 p.