

To see the effect of sample size on the maximum age more clearly, we can approximate Equation (1) by

$$\frac{1}{Z} \sum_{i=1}^n \frac{1}{i} + t_c \cong \frac{1}{Z} \int_{1/2}^{n+1/2} \frac{dX}{X} + t_c = \frac{\ln(2n+1)}{Z} + t_c.$$

Hence $E(t_{\max}) \cong \frac{\ln(2n+1)}{Z} + t_c$ (2)

Holt (1965) presented similar findings as an asymptotic result.

The expected value of the maximum age is shown in the table for three values of Z and several values of n when t_c equals 0.

$$E(t_{\max}) = \frac{1}{Z} \sum_{i=1}^n \frac{1}{i} \text{ for } Z =$$

n	1.0	0.5	0.25
50	4.5	9.0	18.0
100	5.2	10.4	20.7
150	5.6	11.2	22.4
200	5.9	11.8	23.5
250	6.1	12.2	24.4
500	6.8	13.6	27.2
1,000	7.5	15.0	29.9

Increasing the sample size from 100 to 1,000 causes the expected value of the maximum age to increase by 43%. Increasing the sample size from 200 to 1,000 will cause a 27% increase.

If the mortality rate is higher for older fish, the maximum age will increase even more slowly with increasing sample size. For example, if the age structure is governed by the Gompertz equation, the maximum age in a sample tends to increase as the log of the log of the sample size (Beverton 1963).

Addendum

Dr. W. E. Ricker (pers. commun.) has suggested that a geometric mean (GM) regression would be more appropriate than the ordinary predictive (arithmetic mean, AM) regression for predicting values of $\log Z$ since both variables are naturally variable. The regression equation presented here can be converted to a GM line by dividing the slope (b) by the square root of the coefficient of determination ($|r|$) and passing the line through the point defined by the means of the log transformed values of Z and t_{\max} (Ricker 1973). The means are: for mollusks, mean ($\ln(Z)$) = -0.821 and mean ($\ln(t_{\max})$) = 2.465; for fish, -0.767 and 2.214; for cetaceans, -2.684 and 4.154; for all groups, -1.093 and 2.585.

GROWTH OF *GERYON QUINQUEDENS* (BRACHYURA: GERYONIDAE) JUVENILES IN THE LABORATORY¹

The deep-sea red crab, *Geryon quinquegens* Smith, is a large brachyuran of commercial interest inhabiting the upper continental slope in the western Atlantic Ocean from Nova Scotia to Argentina (Scelzo and Valentini 1974). Studies of the biology of the species have concerned distribution, abundance, and bathymetric limits (Wigley et al. 1975; Haefner 1978); the ovarian cycle of adult females (Haefner 1977); and development and behavior of larvae in the laboratory (Perkins 1973; Rosowski 1979; Sulkin and Van Heukelem 1980; Kelly et al. 1982). Studies of the rate of growth of the species have been limited to inferential analysis of size-frequency data, and it appears that 13-15 molts are required for the crab to grow from a carapace width of 20 mm to the maximum size of 150 mm (Haefner 1978).

In this note we report results of a study of the effects of temperature on the rate of growth of juvenile red crabs in the laboratory.

Methods

Groups of juvenile red crabs were reared for nearly 1 yr at one of four temperatures: 6°, 9°, 12°, and 15°C. Temperatures were chosen to approximate those of bottom water at depths ranging from 200 to 2,000 m in the western North Atlantic (Haefner 1978). Each group at 6°, 9°, and 12°C consisted of five individuals. The crabs in these groups were the progeny of one female and resulted from laboratory-reared larvae. The group at 15° consisted of 25 crabs. These crabs were the progeny of another female whose larvae were also laboratory-reared.

During the experiment, juvenile red crabs were held in darkness at ambient pressure at 35‰ salinity. Diet consisted of frozen brine shrimp (*Artemia salina*), chopped mussel (*Mytilus edulis*), and clam (*Mercenaria mercenaria*), and bits of muscle from adult red crabs. Juveniles used in the experiment were subjected to experimental conditions upon molting from the megalopa stage to crab stage 1.

Crabs in groups at 6°, 9°, and 12°C were maintained individually in glass bowls (10.5 cm diameter) with a shallow layer of sand and a small piece of plastic tubing in which the crabs generally took up residence. The bowls were kept in aerated aquaria containing 25 l of filtered seawater. Upon molting to crab stage 4,

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each juvenile was transferred to a separate aquarium containing 1.5 l of seawater.

Crabs in the group held at 15°C were maintained in clear plastic boxes measuring 27 × 15 × 5 cm. Each box consisted of 18 chambers (each 4.5 × 5 × 5 cm). Crabs were maintained in individual chambers for the duration of the study.

In all cases, survival and molting were checked daily, and the red crabs were transferred weekly to clean culture vessels with clean seawater. Carapace width was measured with calipers after each molt. Measurements were taken at the widest dimensions of the carapace.

Results and Discussion

Our data show a linear relationship between carapace width and time over at least the first five post-larval molts (Fig. 1). This differs from results of some

other studies of growth in crustaceans in which increase in carapace width was a logarithmic function of time (for review see Hewett 1974). However, Tagatz (1968) and Simpson (1961) have reported linear increases in carapace width in captive crustaceans.

We recognize that the growth rates determined in the present investigation may be biased by laboratory conditions (diet, substrate, and pressure differed from natural conditions) and, further, that the small sample size at 6°, 9°, and 12°C requires cautious interpretation of results. Nevertheless, we have shown that growth occurs very slowly at 6°C, a temperature characteristic of depths >500 m (Haefner 1978). Between 9° and 15°C, however, growth is five to six times more rapid than at 6°C. The relative independence of growth from temperature in the 9°-15°C range suggests that this is an optimal range for juvenile existence. These conclusions suggest that if

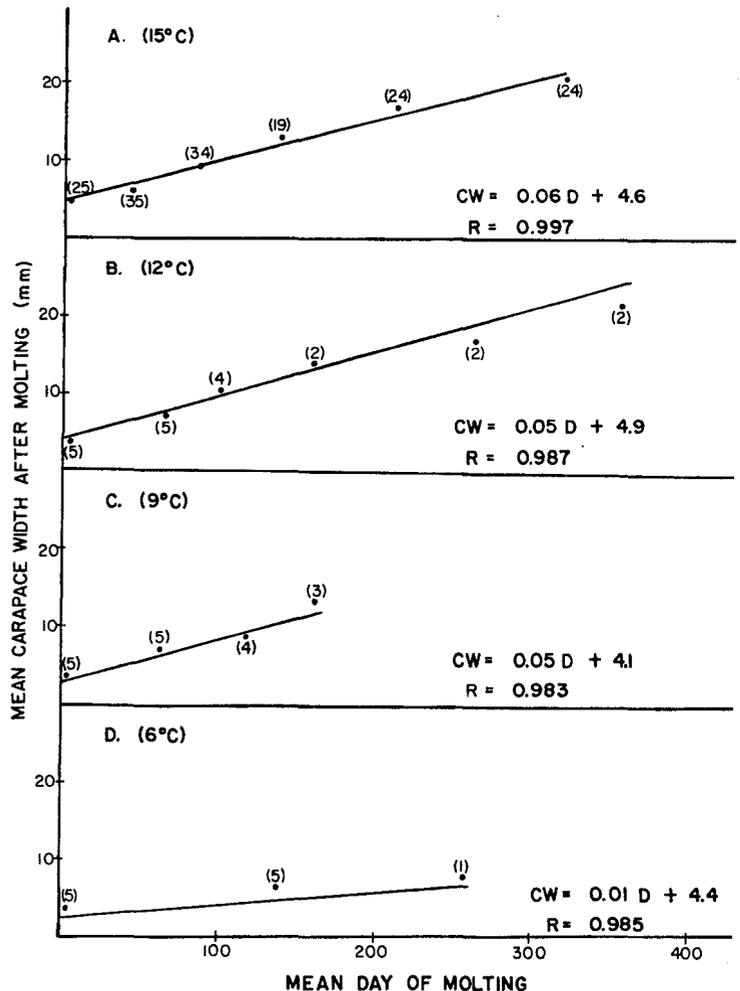


FIGURE 1.—Least-squares regression lines describing rate of increase in carapace width of juvenile red crabs, *Geryon quinquedens*. CW = carapace width; D = days postmetamorphosis. Numbers in parentheses adjacent to data points indicate number of crabs measured in calculating carapace width.

the settlement occurs at the base of the continental slope as suggested by Wigley et al. (1975) and Kelly et al. (1982), upslope migration to warmer water must occur quickly or else natural growth rates would be very slow.

Our growth equations predict that red crabs would enter the fishery (114 mm; Haefner 1978) in 5.3 yr at 15°C or in 6.0 yr at 9°-12°C. Maximum size of males is about 150 mm, and this would take 7.0 yr at 15°C, while females would require 6.5 yr to reach their maximum carapace width of 140 mm. However, there may be gender-related differences in growth rates, and our analysis does not take these into account (we were unable to determine gender in the juveniles). In any case, growth under natural conditions is probably somewhat greater than that in captivity (Winget et al. 1976), so our values represent maximum ages for crabs entering the fishery or reaching maximum size (Table 1). Crabs in our investigation reached a size of 20 mm in five postlarval molts at both 12° and 15°C. This, in combination with Haefner's (1978) results, suggests that the species undergoes 18-20 postlarval molts before reaching its apparent maximum size.

TABLE 1.—Predicted age (yr) of male red crabs, *Geryon quinquedens*, entering fishery or reaching apparent maximum size. Based on laboratory measurements of growth of juvenile crabs.

Temperature (°C)	Age	
	Enter fishery	Maximum size
9-12	6.0	8.4
15	5.3	7.0

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