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Some effects of temperature on the growth and metabolic rate of juvenile blue crabs, *Callinectes sapidus*, in the laboratory*

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Abstract

Juvenile blue crabs, *Callinectes sapidus* Rathbun, were grown in the laboratory at different temperatures, and metabolic-rate determinations were made. Growth is shown to be dependent upon temperature. Crabs kept at high temperatures (34° and 27 °C) grow faster than those kept at lower temperatures (13°, 15°, and 20 °C). Increase in size per molt is less at higher temperatures than at lower ones. Mortality is directly proportional to temperature between 13° and 34 °C and is very high during ecdysis at elevated temperatures. Metabolic rate increases with temperature, but various degrees of acclimation are seen after 4 weeks exposure. No acclimation of general activity to temperature was found. The findings are applied theoretically to crabs living in the region of heated discharge canals of electrical generators: the motile blue crab could extend its growing season without decreasing size at maturity by active selection of thermal surroundings.

Introduction

In the oceans, temperature is commonly a master physical factor controlling the lives and distributions of organisms. The effect is particularly pronounced in the shallow estuarine zones, where large temperature changes may occur diurnally, seasonally, and from day to day.

Latitudinal variations within a species in metabolism, growth, and activity responses to temperature (Florkin, 1960; Segal, 1967) and seasonal changes in the metabolic rates at a given temperature and within thermal tolerance limits (Bullock, 1955; Florkin, 1960) indicate that many estuarine animals have the ability to partially compensate for temperature changes. Although such alterations enable the organism to exist in a wide range of thermal surroundings, its life pattern (feeding, growth, reproduction, and death) is manipulated by the ambient temperature.

Recently, man has begun to significantly alter the thermal environments of specific estuarine zones by the discharge of heated water from electrical generators. With more and larger power facilities being built (including very large atomic reactors), the need for knowledge of the influence of elevated temperatures on estuarine organisms is more critical than ever before. The increased water temperatures can profoundly effect mortality rates, growth, and metabolism, as well as every other life process (Naylor, 1965).

Some marine animals grow more rapidly in warm water than in cooler water (Adams, 1969; Nauman and Cory, 1969). However, warmer water does not invariably result in accelerated growth (Brett, 1971), and frequently results in smaller size at completion of growth. Because, in some species, large final size is indicative of long, slow growth rather than rapid growth, marine and estuarine animals often attain their greatest dimensions in the cooler areas of their distributions (Kinne, 1963, 1967).

In *Callinectes sapidus*, the growth rate seems to be decelerated by cold water. Thus, the average time necessary to reach maturity is 13 to 18 months in Chesapeake Bay (Churchill, 1918; Van Engel, 1958) but less than a year in the St. Johns River, Florida, USA (Tagatz, 1968). It is possible that the number of post-larval molts is fixed (Van Engel, 1958). Molting in females ceases with attainment of maturity. Although males may molt after reaching maturity, the rate is slow and the size increment per molt small (Gray and Newcombe, 1938). There is no reason to believe that variation in maximum molt-number, if it occurs, is correlated to temperature. Therefore, it is assumed that the maximum size reached by blue crabs reflects the size increase per molt rather than the number of molts. While size increase per molt may be inversely proportional to environmental temperature and, thus, final size greatest at lower temperatures as in some fish (Kinne, 1963) no conclusive data have been compiled on this subject.

The following investigation was undertaken to determine the effects of temperature on (1) growth rate, (2) adult size, (3) mortality rate, (4) metabolic rate, (5) gross activity of juvenile *Callinectes sapidus*. The results are utilized to present hypotheses of possible effects of a heated discharge on blue crabs living within it.

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Materials and methods

In order to determine some effects of temperature on *Callinectes sapidus*, two types of experiment were utilized: growth under controlled laboratory conditions, and metabolic rate determinations.

The experimental animals were juvenile blue crabs (20 to 69 mm carapace width) of both sexes from the Cedar Key area, Florida, USA. Collections of crabs were made continuously from September, 1970 to June, 1971.

The impact of temperature on molting rate and size increase per molt was determined by growing juvenile blue crabs at controlled temperatures in aquaria and recording their growth. The experimental tanks were 27 gallon (103 l) aquaria divided by fiberglass screen partitions into 10 chambers. Temperatures within the tanks were maintained (± 0.5 C°) by thermostatically controlled aquarium heaters and a low-temperature water-bath. The temperatures employed were 34°, 27°, 20°, 15°, and 13 °C.

Salinity, as well as temperature, was controlled to determine any interrelationship between these two factors. The salinity was the same in all tanks at any single time, but was lowered twice during the course of the investigation by the addition of deionized water. The three salinities employed were 27, 21, and 15‰.

The floors of the tanks were covered with coquina (*Donax variabilis*) shell-fragments, which acted as pH buffers. The pH of all experimental water was approximately 7.9. The water was aerated and circulated by air stones placed in the empty chambers at the ends of each tank, and filtered through synthetic filter-floss and activated charcoal by a power filter. The water in each tank was completely replaced at 1½ month intervals.

All crabs were slowly acclimated before being placed in experimental tanks, to prevent thermal or salinity shock. Each tank housed 8 crabs. Individuals which died or were infected with *Sacculina* were recorded and replaced by others previously acclimated to the salinity and temperature of the test tank.

Experimental crabs were fed a mixed diet of grouper fillet and beef or pork liver. Small pieces of *Caulerpa*, lettuce, or *Sargassum* were kept in each chamber. The crabs were fed more than they would eat; fresh food was given to them each day.

Carapace width (distance between the tips of lateral spines) of the crabs was measured initially and 5 days after each molt. Dates of molts were recorded. Observations of activity, food consumption, and aggression were made throughout the 6 months of test growth.

The effect of temperature upon the standard metabolic rate of juvenile *Callinectes sapidus* was determined by measuring the change in oxygen concentration in a closed chamber:

(1) A juvenile intermolt crab (2 to 6 g weight) was placed in a 1 l Erlenmeyer flask filled with water from the tank in which the crab had been living. The crab had been living for at least 1 month at the temperature designated as the acclimation temperature.

(2) The flask was placed in a constant temperature water bath for 20 min. The chamber was then closed with a tight fitting, rubber stopper, through which had been placed 2 hypodermic needles each attached to a 50 ml disposable syringe.

(3) Thirty milliliters of seawater of the same temperature and salinity as inside the chamber were forced into the chamber through one syringe, causing a 30 ml sample to be pushed into the other syringe. Two samples were taken in this manner at time zero and two more were taken 1½ h later.

(4) The oxygen concentration of each sample was determined using the Winkler method of oxygen determination as outlined in Strickland and Parsons (1968).

In each test situation, 5 chambers were used: 1 control (no crab); 2 chambers with female crabs; 2 chambers with male crabs.

To determine the effect of the falling oxygen concentration on the metabolic rate during the experiments, samples were taken at ½ h intervals over 2 h using the procedure outlined above. Again, 2 males and 2 females were used. This test was made at both 20 °C (with crabs acclimated to 20 °C) and 34 °C (with crabs acclimated to 34 °C).

The salinity was 27‰ for all metabolism experiments. All tests were made between 10.00 and 14.00 hrs to negate any effects of a diurnal rhythm on the metabolic rate.

Results

The average percent growth per molt and average intermolt periods of juvenile *Callinectes sapidus* grown in the laboratory tanks are shown in Table 1. These are applied to a starting size of 22 mm to generate the growth rate of a theoretical average crab at 34°, 27°, 20°, 15° and 13 °C. The rates are shown graphically in Fig. 1. Average growth rate[1] increases with temperature from 13° to 34 °C. Thus, after 70 days of growth, an average 22 mm crab will grow to 56 mm, if kept at 34 °C; 48 mm, if kept at 27 °C; 40 mm, if kept at 20 °C; and only 38 mm, if kept at 15 °C.

As shown in Fig. 2, the molting rate (molts per unit time) increases rapidly with increasing temperature from 13° to 27 °C. The increase in molting rate with temperature increase continues between 27° and 34 °C, but is much less than between 13° and 27 °C. Thus, the average number of crab-days (number of

[1] All growth-rate differences cited (intermolt duration, percent growth per molt, and total growth-rate) are significant to the 95% confidence level (Student *t* test).

Table 1. *Callinectes sapidus*. *Average growth in laboratory*

Temperature (°C)	Number of crabs	Carapace width before molting (mm)	Average growth per molt (%)	Average intermolt period (days)
34°	8	20—26	13.31	7.4
	13	27—34	14.68	9.5
	17	35—42	19.95	11.1
	10	43—51	15.18	15.6
	6	52—60	23.35	18.6
27°	11	20—26	13.49	11.7
	11	27—34	16.43	14.0
	14	35—42	20.57	18.5
	8	43—51	25.56	23.7
	3	52—60	27.08	29.5
20°	5	20—26	39.54	17.3
	6	27—34	20.39	35.0
	7	35—42	19.66	36.7
	6	43—51	19.94	32.8
	4	52—60	26.54	40.7
15°	2	27—34	15.95	25.5
	8	35—42	23.93	56.4
	3	43—60	21.55	61.0

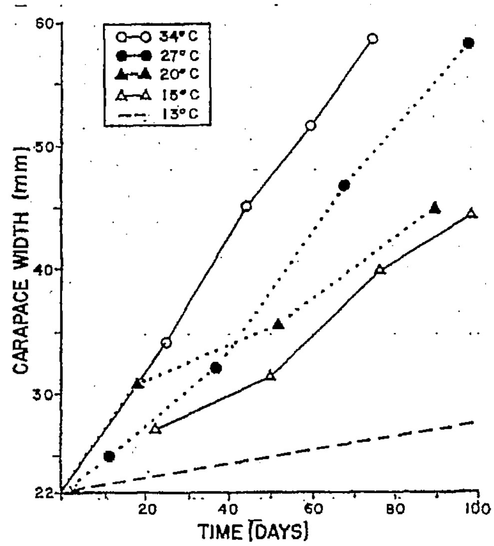

Fig. 1. *Callinectes sapidus*. Average growth-rate (increase in carapace width per unit time) of blue crabs grown at 34°, 27°, 20°, 15°, and 13 °C in the laboratory. Points were determined using the average starting size (22 mm) of experimental crabs 20 to 26 mm in carapace width and applying the post-exuvial percent width-increments and intermolt periods for each size range from Table 1. Lines connecting points indicate trends only, as increase in carapace width of blue crabs against time is, in reality, a stepwise progression

crabs × number of days) per molt at 34 °C is 27.7 and only increases to 30 at 27 °C, while at 20 °C, the average number of crab-days per molt is 57.6. Finally, below 13 °C, growth essentially ceases. In 524 crab-days, only two molts were recorded at 13 °C.

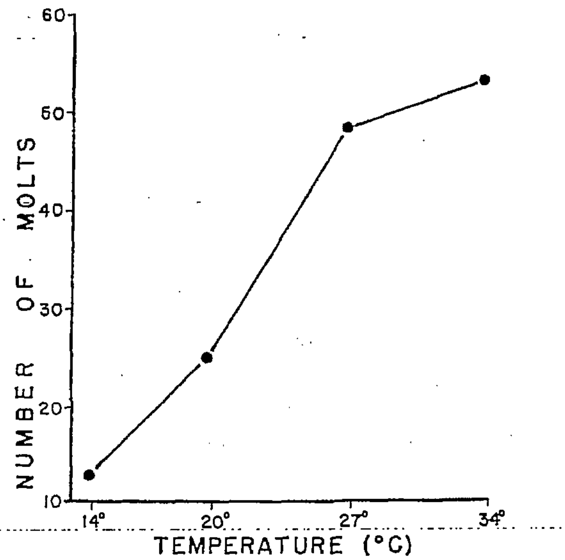

Fig. 2. *Callinectes sapidus*. Effect of temperature upon molting frequency. Each point represents total number of molts in 1440 crab-days (8 chambers with 1 crab each × 180 days) at temperature designated. Total number of molts from 13 °C experimental period and 15 °C period were pooled to give number of molts in 1440 crab-days. This is indicated as number of molts at 14 °C

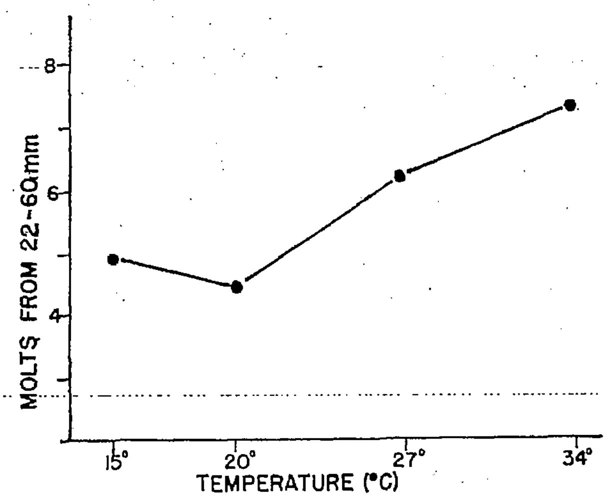

Fig. 3. *Callinectes sapidus*. Effect of temperature upon number of molts required for average blue crab grown in laboratory to increase in size from 22 to 60 mm carapace width. Based on post-exuvial percent width-increments shown in Table 1

The average post-exuvial percent width increments are shown in Table 1. Statistical analysis (Student t test) shows the average size-increases per molt at 20 °C to be greater than those at 27 °C (95% confidence). The difference between mean percent growth per molt at 27° and 34 °C, while continuing to show a decrease with temperature increase, is not

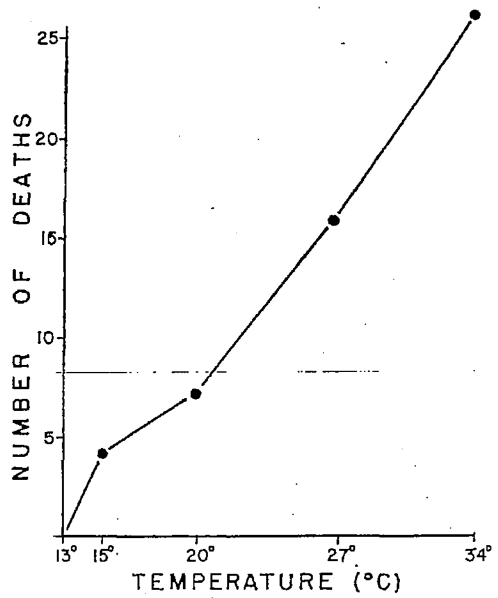

Fig. 4. *Callinectes sapidus*. Effect of temperature upon mortality rate in laboratory. Each point represents total number of crabs which died in 1440 crab-days (8 chambers with 1 crab each × 180 days) at temperature designated

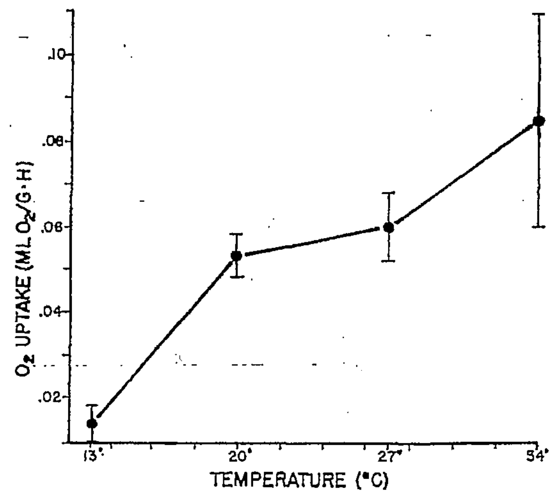

Fig. 5. *Callinectes sapidus*. Effect of temperature upon standard metabolic rate (O_2 used/g · h) of juveniles after more than 4 weeks acclimation to test temperature. Each point represents mean O_2 consumption/g of 4 crabs (2 males and 2 females) at temperature designated (values are shown in Table 2)

Table 2. *Callinectes sapidus*. *Rate of mortality of juveniles at various temperatures (total deaths and deaths during ecdysis). All data is based on 8 chambers each occupied by 1 crab at all times over 180 day period*

Temperature (°C)	Number of molts	Deaths during ecdysis	Mortality during ecdysis (%)	Total deaths in 1440 crab-days (8 chambers × 180 days)
34°	53	5	9.4	26
27°	48	4	9.2	16
20°	25	2	2.9	7
13°—15°	13	0	0	2

Table 3. *Callinectes sapidus*. *Standard metabolic rates of juveniles under various test-temperature/acclimation-temperature combinations*[a]

Test temperature (°C)	Acclimation temperature (°C)	O_2 (ml/l)	Metabolic rate (ml O_2/g · h)
34°	34°	2.9	0.1299 ± 0.0255
27°	27°	2.6	0.0600 ± 0.0084
20°	20°	3.5	0.0741 ± 0.0154
13°	13°	5.2	0.0128 ± 0.0051
34°	27°	2.3	0.1407 ± 0.0124
27°	20°	2.4	0.1321 ± 0.0109
27°	34°	2.7	0.0724 ± 0.0382
20°	27°	2.5	0.0565 ± 0.0144
13°	20°	3.4	0.0576 ± 0.0327

[a] All metabolism experiments are based on crabs weighing between 2 and 6 g. In preliminary studies, metabolic rates were determined for 18 crabs (12 females and 6 males) weighing 1.6 to 19 g. Tests were run at 12°, 20°, 23°, 27°, and 35 °C. Oxygen consumption/g · h did not vary greatly with weight in 2 to 6 g range.

significant at the 95% confidence level. Because the average percent growth per molt decreases with increasing temperature, particularly between 20° and 27 °C, the average number of molts required to reach a particular size must increase with temperature. The relationship of temperature to the average number of molts required to increase in carapace width from 22 to 60 mm (based on the post-exuvial percent width increments in Table 1) is shown in Fig. 3. Notice that, at 15° and 20 °C, 5 and 4.49 molts are necessary to grow from 22 to 60 mm, but at 27° and 34 °C, the number increases to 6.12 and 7.07, respectively.

Between 13° and 34 °C, mortality is directly proportional to temperature (Fig. 4). It is extremely high (1 death every 55.5 crab-days) at 34 °C, but drops to zero (no deaths in 524 crab-days) at 13 °C. Mortality during ecdysis is, likewise, temperature-dependent and is particularly high at 27 °C (9.2%) and 34 °C (9.4%) (Table 2).

The oxygen consumption of juvenile *Callinectes sapidus* acclimated to the test temperature is shown in Fig. 5. The standard metabolic rate increases with temperature. Between 20° and 27 °C the increase is only 15%. A much greater increase (40%) is seen between 27° and 34 °C, and the difference between the metabolic rates of crabs acclimated to 13° and 20 °C is over 300%.

The metabolic rates of crabs in thermal surroundings other than those to which they were acclimated showed marked increases when the test temperature was above the acclimation temperature, and decreases when it was below the acclimation temperature (Table 3). An increase in temperature over the acclimation temperature extended the metabolic rate above that of crabs acclimated to that temperature. Consequently, the O_2 consumption of crabs acclimated to 27 °C and tested at 34 °C (0.1407 ml O_2/g · h) was much higher than that of crabs acclimated to the 34 °C test temperature (0.0837 ml O_2/g · h). The O_2 consumption of crabs acclimated to 20 °C and tested

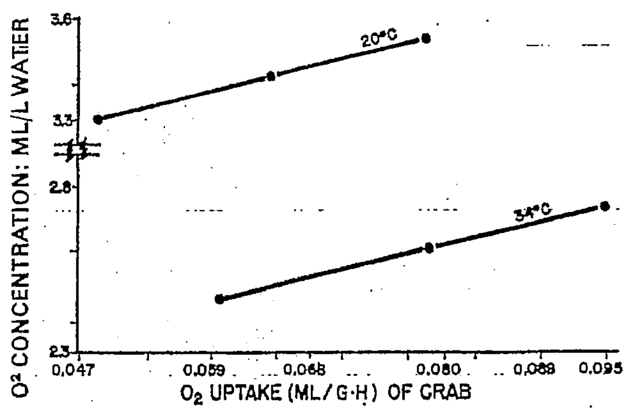

Fig. 6. *Callinectes sapidus*. Effect of small drops in O_2 consumption on metabolic rate (O_2 uptake/g · h) of juveniles as shown by lowering of O_2 consumption rate over time (2 h) by crabs in closed chambers at 20° and 34 °C. Each point indicated is mean of 4 crabs (2 male, 2 female) 2 to 6 g in weight. All animals had been acclimated to test temperature and beginning (high) O_2 concentration for at least 4 weeks

at 27 °C (0.1321 ml O_2/g · h) was likewise, much greater than that of crabs acclimated to 27 °C (0.0600 ml O_2/g · h). However, when the animals were exposed to temperatures below their acclimation temperatures, their metabolic rates did not immediately fall below the levels of crabs acclimated to the test temperature, except when crabs acclimated to 27 °C were tested at 20 °C. Thus, the O_2 consumption of crabs acclimated to 34 °C and tested at 27 °C (0.0724 ml O_2/g · h) was greater than that of crabs acclimated to 27 °C (0.0600 ml O_2/g · h). At very low temperatures (13 °C), acclimated crabs had a far lower rate of O_2 uptake (0.0128 ml O_2/g · h) than individuals acclimated to higher temperature (20 °C) (0.0576 ml O_2/g · h).

Oxygen concentration, as well as temperature, is a determining factor of metabolic rate (Fig. 6). Oxygen consumption by blue crabs is directly proportional to the oxygen concentration within the narrow range caused by decreasing oxygen in the closed metabolism chamber; the slope of the curve is independent of temperature between 20° and 34 °C. Therefore, the metabolic-rate determinations are not greatly altered by the use of a closed apparatus.

While no measurements were made of feeding and activity levels, the magnitude of the temperature effects on these variables allows simple observation to be sufficient. Food consumption is at a maximum at 34 °C, and is sharply reduced at lower temperatures: *Callinectes sapidus* adapted to 34 °C eat much more than do crabs adapted to 27 °C, which eat much more than do crabs adapted to 20 °C, and so on down to crabs adapted to 13 °C which eat essentially nothing. Activity, likewise, changes in proportion to temperature. Blue crabs acclimated to 34 °C are hyperactive, often scurrying from one chamber of their growth tank to another in order to avoid a net, and rapidly crawling out of the net when captured. Crabs living at 27 °C are active, but lack the extreme excitability of those at 34 °C. Aggression in blue crabs acclimated to 20 °C is greatly reduced. They will run from a net and attack it when cornered, but much more provocation is necessary to cause them to respond than is necessary with individuals living at the higher temperatures. Blue crabs living in cold water are extremely inactive and passive. Crabs acclimated to 15 °C react to a net only when prodded by it, casually pushing it away with their chela. Great effort is required to elicit any response from a crab living at 13 °C; the condition of the crab at this temperature is best described by the phrase "cold stupor". Thus, no acclimation to temperature in feeding or activity was observed.

Discussion

One of the most important factors influencing metabolic rate in poikilotherms is temperature. The rate of metabolism of *Callinectes sapidus* does not, however, passively follow the ambient temperature. It is evident that a degree of acclimation occurs within 4 weeks at all temperatures tested: the metabolic rate of crabs at other than acclimation temperature is not the same as that of crabs acclimated to the test temperature. When compared to the metabolic rates of crabs acclimated to other thermal conditions, the acclimated metabolic rate shows nearly complete or perfect compensation for temperature in the 20° to 27 °C range, incomplete compensation at 34 °C, and reverse compensation at 13 °C. Thus, between 20° and 27 °C, blue crabs are able to adjust their metabolic processes sufficiently to maintain an almost constant metabolic rate. At higher temperature, although an adjustment is made, the metabolic rate is well above that of the 20° to 27 °C level (Fig. 5). Conversely, at 13 °C, the metabolic rate of acclimated crabs is far lower than that of crabs acclimated to higher temperatures. This torpor may aid the blue crabs in coping with the cold winter months, when its reactions are slow and food may be scarce.

In *Pachygrapsus crassipes*, a marked correlation between molting frequency and water temperature was observed by HIATT (1948). In *Callinectes sapidus* this relationship is also found. However, the molting rate, while still increasing with temperature, does so much more slowly above 27 °C, and is, therefore, linear only from 15° to 27 °C (Fig. 2). The other growth factor, growth per molt, is significantly reduced above 20 °C. Consequently, while the average growth rate increases with temperature throughout the 13° to 34 °C range, the number of molts necessary to reach a particular size also increases with temperature (Figs. 1; 3). As the maximum size reached is assumed to reflect the size-increase per molt rather than the number of molts (see Introduction), blue crabs living in thermal surroundings of 27° to 34 °C are expected to grow more rapidly, but to cease growth when smaller, than those in cooler water. Whether or not the smaller size at maturity would, in any way, reduce reproductive capacity, has not been determined.

While increasing temperatures speed growth, falling temperatures impede it. *Callinectes sapidus*, which does not normally molt at 13 °C, and which has long intermolt periods at 15 °C, will undergo extended periods as juveniles in areas where winter temperatures reach these levels or below. The time necessary to reach maturity is increased without a corresponding increase in size at maturity over crabs grown at 20 °C.

The mortality rate of the blue crab is temperature dependent. The duration of exposure, as well as the magnitude, of the temperature is important. Below the 48 h median tolerance limit of about 39 °C TAGATZ, 1969; CIRC. FISH WILDL. SERV. WASH., 1970; personal observations), high death rates immediately attributable to the thermal regime drop significantly, but, an accelerated death rate over a much longer period, as compared to that of blue crabs living at lower temperatures is observed (Fig. 4). Mortality at ecdysis is particularly pronounced at 27° and 34 °C. In crustaceans in general, molting is accompanied by a large increase in O_2 consumption. The molting metabolism of *Pachygrapsus crassipes* is twice the normal rate (ROBERTS, 1957). So great an increase occurs that, if the active phase of exuviation is extended, death usually results from asphyxiation, since the respiratory surfaces do not function properly during the molt (PASSANO, 1960). A juvenile blue crab acclimated to 20 °C, which was allowed to molt in an experimental chamber at 20 °C, consumed 0.1127 ml $O_2/g \cdot h$ (compare with values in Table 3). Thus, the high mortality associated with molting at high temperature may be due, in part, to rises of an already high metabolic rate in an environment of limited O_2. (Increased temperature reduces the O_2-carrying capacity of water).

The effect of a heated effluent upon the blue-crab population of an area depends upon the natural thermal regime, the increase in temperature caused by the heated discharge, the availability of satisfactory nearby habitats outside the thermal plume, the food supply, and the action taken by the crabs themselves. In the region of Crystal River, Florida, where salt marshes near a large fossil-fuel electrical-generator effluent canal may reach 35° to 40 °C in the summer months, the effect upon the blue-crab juveniles depends upon their willingness to move. Crabs which remain in the adjacent estuarine zone throughout the year would grow rapidly but attain smaller size at maturity. In addition, blue-crab kills would be expected to occur during those periods of the summer when the temperatures approach or exceed 39 °C. Further, in the 27° to 34 °C range, an increased rate of mortality over that at lower temperatures is expected, although the upper 48 h thermal tolerance level is much higher (39 °C). However, the blue crab is highly motile and has been shown to migrate to less extreme temperatures seasonally (CHURCHILL, 1918; NUGENT, 1970). In the Crystal River area, alternative habitats unaffected by the heated effluent are available nearby. Many blue crabs may migrate into the warm thermal plume in the winter, and leave as the temperature rises in the spring. Assuming that sufficient food is available, 12 month growth would be possible rather than the 8 or 9 month growth period of the non-affected areas, where the water temperature is below 15 °C for 3 or 4 months during the winter. The size increase per molt at 20 °C is approximately equal to that at 15 °C; thus, the size at maturity of a crab seeking the mid 20 °C environment would be unaffected. Likewise, mortality at 20 °C is little higher than at 15 °C. If the juvenile blue crabs entered the effluent area as the temperature dropped below 20 °C in the fall, as expected, and left as it rose toward 27 °C in the spring, the period necessary to reach maturity would be shortened, while maximal size at maturity and low mortality rate were maintained. Population growth would be possible until food supply became limiting or other control mechanisms (parasitic infestation, predation, density-dependent reproductive suppression) arrested it. As *Sacculina* parasitism is already high in the area, and many other organisms seek the heated area in winter depleting the food supply to some degree and preying upon juvenile blue crabs, no significant population rise is expected, even though the juvenile period is shortened.

Callinectes sapidus farms, using heated effluent-water in the winter and cooler offshore water brought in by the intake canal in the summer (allowing the temperature to fluctuate between 20 °C and the middle 20°'s to encourage feeding and molting), could grow blue crabs from first instar to market size in 7 to 8 months rather than the normal 10 to 11 months expected along the coasts of northern Florida. However, satisfactory methods for raising blue-crab larvae on a large scale would need to be developed. (COSTLOW and BOOKHOUT (1959) have successfully grown blue crabs from egg to first crab stage in the laboratory, but their methods are too tedious to be used on a large scale).

Summary

1. In the blue crab *Callinectes sapidus* RATHBUN, growth rate increases with increasing temperature from 13° to 34 °C but, between 27° and 34 °C, the increase is much less than at lower temperatures.

2. Size increase per molt is less at 27° and 34 °C than at 20° and 15 °C. The number of molts necessary to reach a given size increases with temperature from 20° to 34 °C. As final size is determined by size increase per molt rather than number of molts, crabs living at high temperatures should be smaller when growth ceases than those living at lower temperatures.

3. At 13 °C, blue crabs show almost no growth.

4. Between 13° and 34 °C, mortality is directly proportional to temperature, being particularly high during ecdysis at elevated temperatures.

5. Standard metabolic rate increases with temperature (13° to 34 °C).

6. Partial metabolic acclimation to temperature occurs at 34 °C, nearly perfect acclimation between 20° and 27 °C, and reverse acclimation at 13 °C after 4 weeks exposure.

7. Food consumption decreases with decreasing temperature from 34° to 13 °C.

8. No acclimation of activity to temperature was found. Activity increases with increasing temperature from 13° to 34 °C.

9. The blue crab could extend its growing season in the area of a heated effluent along the northern Florida coast, without decreasing size at maturity, by active selection of thermal surroundings. Failure to leave the heated areas in the spring and summer would result in reduced size at maturity and high mortality.

10. Blue-crab farms in conjunction with power plants near the northern limit of the subtropical region, using heated effluent-water in the winter and intake water in the summer, could grow *C. sapidus* from first instar to market size in 7 to 8 months.

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