

Effect of Elevated Temperature on the Metabolic Activity of the Coral Reef Asteroid *Acanthaster planci* (L.)¹

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ABSTRACT: Standard rate of oxygen uptake in the coral reef asteroid *Acanthaster planci* (L.) was determined for the temperature range of 25° to 33° C and a metabolic rate-temperature (M-T) curve was drawn. *Acanthaster planci* is a metabolic conformer. The rate of oxygen uptake increased with increase of temperature to 31° C. The rate decreased at 33° C, which is slightly above the ambient temperature for the laboratory-reared *Acanthaster planci* tested. The decrease indicates a disturbance in the metabolic activity due to the elevated temperature. The incipient thermal death point for the asteroid was estimated to be near 33° C, at which temperature the animals did not maintain a normal behavior in feeding and resting cycles. Increasing modification in thermal conditions by human activity would pose a hazard to the maintenance of coral reef communities if *Acanthaster planci* represents metabolic conformer invertebrates with narrow tolerance to elevated temperature.

ALTHOUGH much research has been done on the effects of elevated temperature on temperate marine animals (see reviews by Kinne 1970, McWhinnie 1967, Vernberg and Vernberg 1970), knowledge of thermal stress on coral reef animals is limited. Mayer (1914) conducted thermal experiments on reef-building corals and other invertebrates in Samoa. Cary (1931) studied the effects of temperature on the Samoan Alcyonaria. Edmondson (1928, 1946) recorded behavior of both adults and larvae of Hawaiian corals under conditions of thermal stress. The above papers indicate that many coral reef invertebrates have narrow upper tolerance range of temperature for their survival and well-being. Thermal environments of coral reefs are subjected to increasing modifications by human activities, mostly by discharges of heated effluent from power generating plants. Since temperature has a direct effect on the metabolism, it is important to know how thermal conditions modify the metabolic activity and behavior of coral reef animals.

Acanthaster planci (L.), a coral-predator asteroid, is an excellent laboratory animal. It is easily maintained under laboratory conditions and can readily be subjected to experimentation under well-defined nutritive and behavioral conditions. Furthermore, it is a widely distributed and relatively common reef asteroid with populations recorded from the Red Sea and throughout the entire tropical Indo-Pacific region including Hawaii (see review by Vine 1972). Thus, it may well represent an important test animal for experimentation on the effects of altered thermal conditions on tropical reef organisms. This report considers the effect of water temperature on the "standard metabolic activity" of the starfish, measured in the laboratory as the rate of oxygen uptake when the test animals are at rest.

MATERIALS AND METHODS

Three laboratory-grown *Acanthaster* about 15 months old and from the same batch of fertilized eggs were used for the present experiment. They were about 120 mm in total diameter at the beginning of this series of observations and each individual specimen was weighed throughout the experimental period from 19 November to 9 December 1972 (Fig. 1). The

¹ This study was supported in part by an Environmental Protection Agency grant to R. S. Jones, and by a Government of Guam *Acanthaster* research appropriation. Contribution no. 48, University of Guam Marine Laboratory. Manuscript received 21 September 1973.

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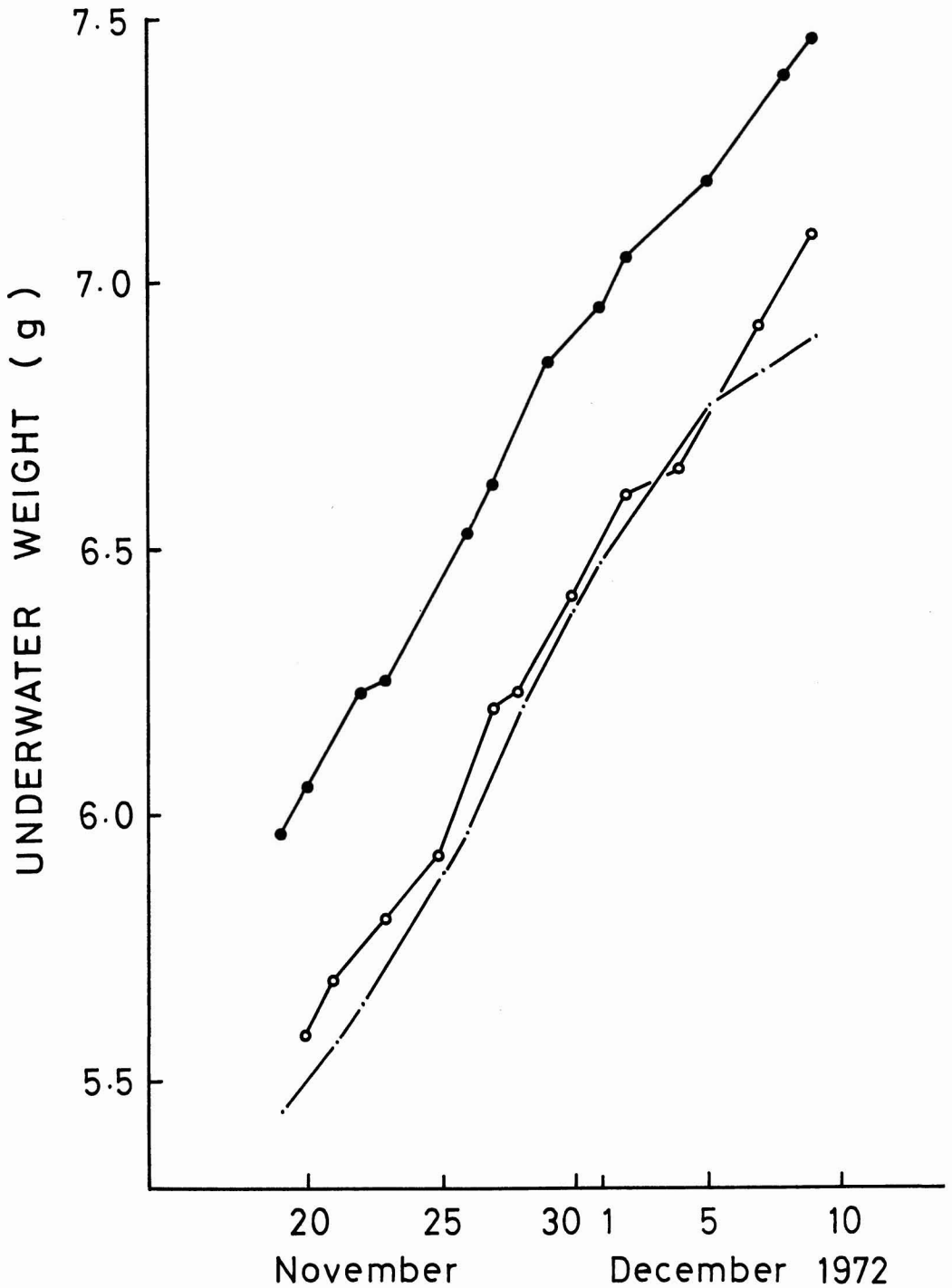


FIG. 1. Growth of *Acanthaster planci* during the experiment, from 19 November to 9 December 1972. Underwater weight, measured in seawater of about 1.024 in specific gravity, for the three experimental animals is plotted on ordinate.

animals were weighed in seawater by means of a specific-gravity type balance (Ohaus Dial-O-Gram Balance). Wet weight of asteroids determined in the air is highly variable due to permeability of the body to fluids, whereas weight in seawater gives more consistent results. The underwater weight of *Acanthaster* is approximately one-half its dry weight.

Each experimental animal was kept individually in a 40-liter rectangular plastic holding aquarium with a sand-filter bed on the bottom. Seawater in the aquarium was circulated by an air lift. The chlorinity of seawater in the aquaria was maintained at 19.1 ± 0.1 ‰ by adding distilled water to compensate for evaporation. Chlorinity was determined by silver nitrate titration. Water temperature of each aquarium was controlled by an immersion heater connected to a bimetal thermostat and was kept within $\pm 0.5^\circ$ C fluctuation at most.

Each animal was kept in a holding aquarium, the temperature of which was maintained at the next experimental level, for at least 12 hours prior to transfer into the respiration chamber.

The three young *Acanthaster* were fed exclusively *Acropora* spp. during the experimental period, as this genus of coral is consistently grazed by the asteroid in the laboratory. The asteroid showed cyclic feeding activities, feeding on coral at night and remaining quiescent in the day. The animals showed locomotive activities when disturbed during weighing and transfer from holding aquaria to respiration chambers. They became quiescent again within an hour inside the chamber and remained so during the observation period for up to 7 hours each day. It was possible to take advantage of their cyclic activities to determine the at-rest condition of experimental animals for measurement of standard metabolism in the growing young. The need to use well-fed animals was indicated by preliminary research that showed a marked reduction in rate of oxygen uptake in starved animals.

Rate of oxygen uptake was determined for the temperature range of 25° to 33° C at intervals of 2 degrees. Prior to the experiment, the experimental animals were raised through most of their coral-eating juvenile life in outdoor

aquaria, where their thermal environment fluctuated between 25° and 31° C.

Two respiration chambers were placed inside an aquarium of otherwise the same setting as the holding aquaria. Each consisted of 4.5-liter polycarbonate cylinder (ca. 16 cm in diameter \times 23 cm in height) and a Plexiglas cover fastened on top of the cylinder by means of rubber tubing. Three holes were drilled through the cover. One was drilled in the center to accommodate the glass shaft of an agitating plastic propeller (5 cm in diameter) that was connected to a 100-rpm motor. Two other holes were located near the edge of the lid for tubing through which seawater could be circulated through the chamber at the rate of about 1 liter per minute by a vibrating pump. The circulation of seawater through the respiration chamber was maintained from the time each starfish was placed inside the chamber until the end of each run except during the periods of uptake determination. The animals were thus conditioned in the chamber with circulating and agitated seawater. Temperature of the aquarium with the two respiration chambers was controlled at each experimental level within $\pm 0.05^\circ$ C by means of vigorous water circulation from two air lifts and a mercury thermostat.

Each determination of the rate of oxygen uptake was made by stopping circulation for 30 minutes and then sampling. Seawater samples were taken into 50-ml Winkler bottles through the outgoing circulation tube after it had been disconnected from the pump. The reduction in oxygen concentration inside the respiration chamber was computed as the rate of oxygen consumed in ml per hour per gram underwater weight of *Acanthaster*. Three replicate samples were titrated at the beginning and at the end of each determination period; the Winkler method was used. The means from the three determinations gave results with a relative error of less than 0.5 percent. Blank tests indicated a negligible rate of oxygen uptake in chambers without starfish. The bias due to sources of oxygen uptake other than the starfish was less than that due to titration error.

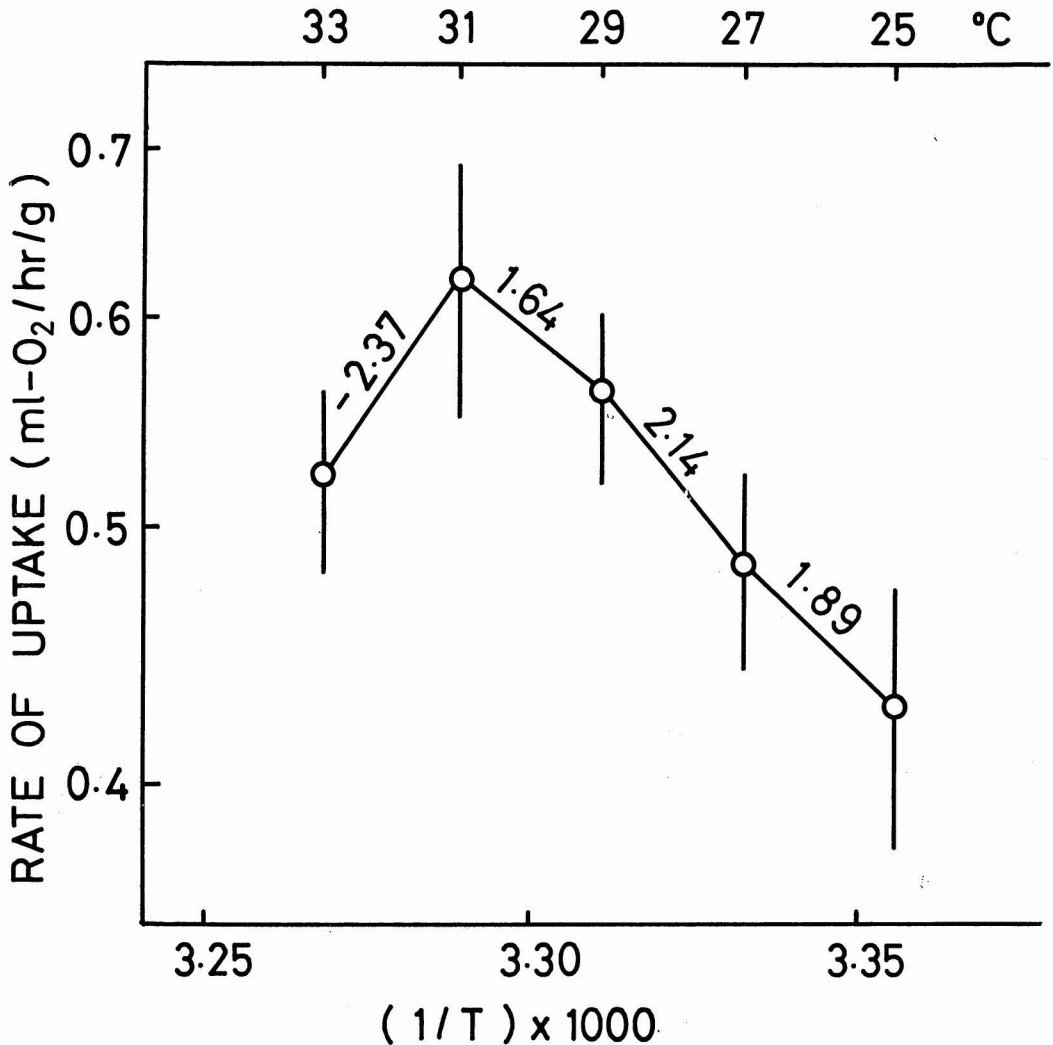


FIG. 2. Metabolic rate and temperature (M-T) curve of *Acanthaster*. Arrhenius plot of the rate of oxygen uptake of *Acanthaster* against the water temperature. Ordinate indicates the logarithm of the rate as ml oxygen consumed per hour, per gram of underwater weight. Abscissa indicates the reciprocal of the water temperature in degrees absolute, with an indication of centigrade scale on the top which corresponds to absolute temperature. Mean rate of uptake and 1 S.D. to either side is shown. The figures on the slopes indicate Q_{10} value for each slope.

RESULTS AND DISCUSSIONS

Each of three *Acanthaster* was exposed to each of the experimental temperatures: 25°, 27°, 29°, 31°, and 33° C. Six replicates of rate of oxygen uptake for each combination of temperature and animal were determined. The mean oxygen uptake, expressed as ml oxygen consumed per hour per gram underwater weight, for three animals and each temperature

level is shown in Fig. 2. An Arrhenius plot is used with the logarithm (base: 10) of the rate of oxygen uptake on the ordinate versus the reciprocal of absolute temperature on the abscissa.

Questions may be raised regarding the validity of using an Arrhenius plot for analysis of metabolic rate and temperature relationships in these organisms. Living systems have complex metabolic networks involving many different chemical reactions that affect metabolic rate in

many different ways. On the other hand, the effect of temperature on the rate of chemical reactions, in general, gives a straight line slope on the Arrhenius plot that is characteristic of the particular reaction. (See Farrell and Rose 1967 about problems on this point.) If we can assume that metabolism and growth of organism is an overall chemical reaction (as a blackbox), we might at least understand changes in the level of chemical reactions through the deviation of the metabolic rate and temperature curve (M-T curve) from a straight line slope on the Arrhenius plot. However, it would be difficult to explain what particular process would be affected in relation to the environmental temperature.

The results showed steady increase of the standard metabolic rate, determined as the rate of oxygen uptake in a quiescent condition in *Acanthaster planci*, between 25° and 31° C and a sharp decrease from 31° to 33° C. The great majority of researchers on the effects of temperature express their results by analyzing the temperature coefficient: Q_{10} value, instead of μ value from the Arrhenius's equation. Indeed, the Q_{10} value indicates the slope of the M-T curve on the Arrhenius plot as a close approximation within the narrow range of temperature that allows normal biological processes. Therefore, the Q_{10} values for each temperature step are indicated on the curve in Fig. 2. The slope of the M-T curve of *Acanthaster* gave Q_{10} values of about two up to 31° C, which means that the extrapolated rate of increase would be twofold with a 10° increase in temperature. However, the value between 31° and 33° C shows a negative figure, indicating a decrease in rate with an increase in temperature. A similar trend in the M-T curve was observed in the growth of microorganisms (Q_{10} value turned negative) above the optimum temperature by Farrell and Rose (1967). On the other hand, various temperate littoral invertebrates showed little change in their standard rates of oxygen uptake over a wide range of temperature. However, their active rates showed a decrease above ambient temperature (Newell 1970) similar to the decrease for standard rates in *Acanthaster*.

There seemed to be no significant difference in the behavior of the animals at temperatures up to 31° C. At 33° C the starfish showed signs

of stress that interfered with their normal cyclic feeding activity. When they tried to feed on coral pieces, which were placed in the holding aquaria on the first or second night, stomach eversion was incomplete and the feeding process was shorter than that under normal conditions. Moreover, the starfish ceased feeding activity altogether after 2 full days at 33° C in the holding aquaria. At this time all the body surfaces were swollen and the ambulacral grooves that are usually half-closed when the starfish is in a quiescent condition at normal temperature were wide open. When the starfish were kept at a higher temperature (35° C), the body became extremely swollen and tube feet showed a restless expansion and contraction from the gaping ambulacral grooves. Therefore, standard metabolic rate with temperatures above 33° C could not be determined.

It is well known that the rate of oxygen uptake in asteroids is determined not only by temperature but also by a number of endogenous and environmental conditions such as the body size, activity of the animal, nutrition, salinity, pH, and concentration of dissolved oxygen (Farmanfarmaian 1966). An attempt was made to account for the above factors in the present study either by controlling them or by monitoring the range of fluctuation. Feeding and activity of the experimental animals were fairly constant except at 33° C when the animal stopped feeding. Body size increased considerably during the observation period (Fig. 1), but the weight increment during this period seemed to have little effect on the rate of oxygen uptake. Duplicate determinations at the same temperature on the same animal at different sizes produced nearly identical results. The weight increased about 25 to 30 percent but the increment of diameter was less than 20 percent during the period. Salinity of seawater in the experimental aquarium was controlled at 34.50 ± 0.10 ‰ (chlorinity 19.10 ± 0.05 ‰) and pH varied between 8.0 and 8.1, with a tendency toward inverse correlation with temperature. It is doubtful that either salinity or pH affected the results significantly.

Because the solubility of oxygen in seawater decreases with increase in water temperature, the level of dissolved oxygen in the experimental aquarium and respiration chambers varied

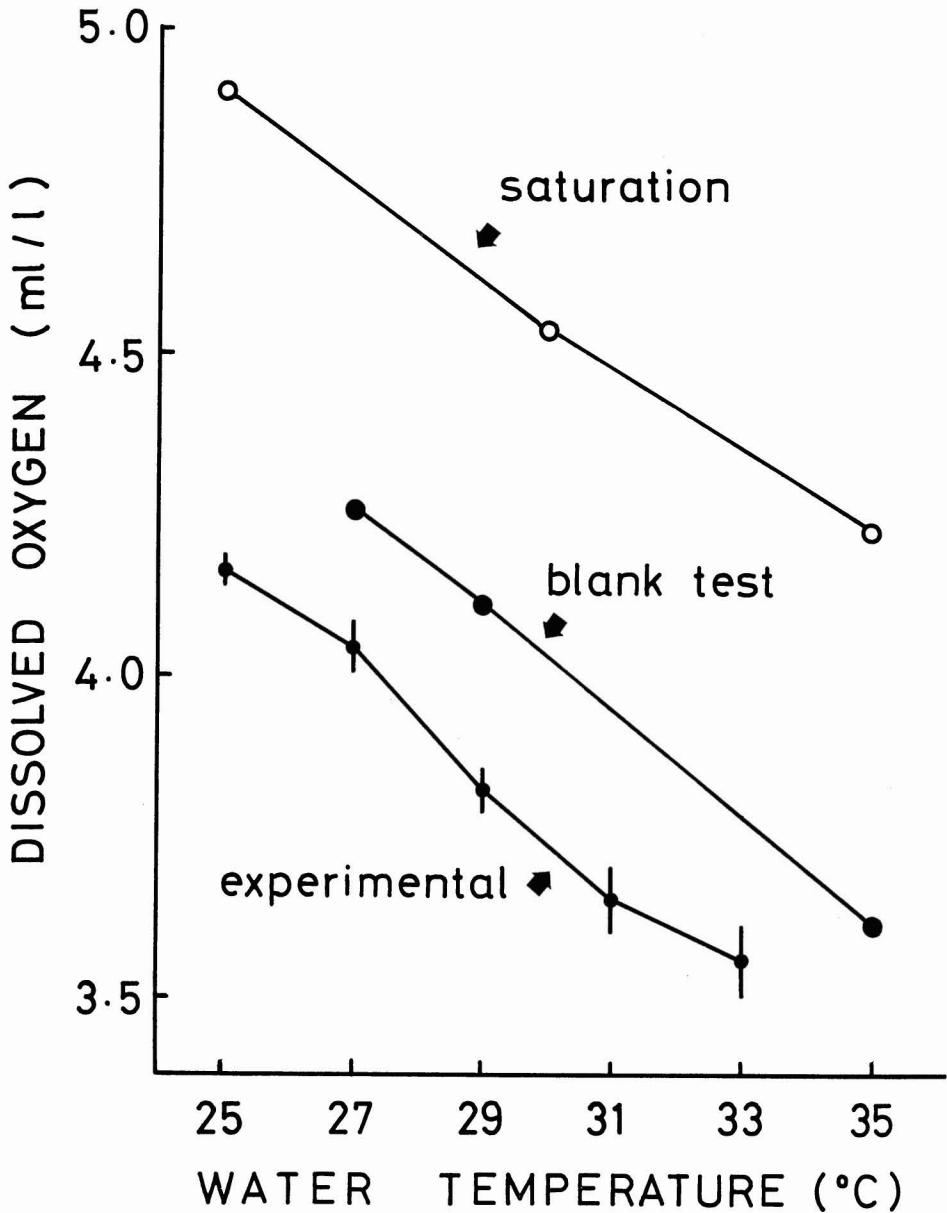


FIG. 3. Relationship of water temperature and concentration of dissolved oxygen inside the respiration chambers with animals (mean and 1 S.D. from initial determinations when the circulation of water stopped) and without animals (blank tests). A theoretical concentration of oxygen saturated in the seawater of 19.1‰ in chlorinity (after Green 1965) is also shown.

significantly with the changes in water temperature as a matter of course. The dissolved oxygen in the respiration chambers and that of theoretical concentration at full saturation are shown in Fig. 3. As the theoretical concentration decreased with increase of temperature, the oxygen

concentration in the respiration chambers decreased in a similar manner. The saturation level remained at about 90 percent in the chamber without the animal and about 80 to 85 percent with the animal. The reduction in the latter was due to the limited water circulation between the

aquarium and the chamber. *Acanthaster* would presumably be similar to other asteroids in that the rate of oxygen uptake is related to the concentration of oxygen (Farmanfarmaian 1966). The slope of M-T curve in Fig. 2 might be much steeper than that observed if the determination of oxygen uptake was carried out at a constant level of environmental oxygen concentration of each temperature.

The elevated temperature results in a reduced oxygen concentration. The increased requirement for oxygen in poikilothermic animals with accelerated metabolism at higher temperature is obviously not favored by this reduction of oxygen tension. The response of *Acanthaster* to high temperature in the form of swollen body and gaping ambulacral grooves might be an aid in the exchange of dissolved gases. The main respiratory surface of asteroids is believed to be the podia (tube feet), which are enclosed inside the ambulacral grooves (Farmanfarmaian 1966). However, the actual rate of oxygen uptake dropped at 33° C, compared with that at 31° C.

Thermal death in *Acanthaster planci* was observed in three field specimens and two laboratory-grown ones. Those starfish, ranging from 5 cm to 18 cm in total diameter, were kept in aquaria under the same culture conditions described in the present experiments. Water temperature was held between 33° and 34° C for these animals and their behavior and appearance were noted. There seemed no significant differences between the responses of the five animals. The general pattern of their thermal death was as follows:

1. Cease feeding within 1 or 2 days.
2. Dorsal spines depressed, body wall swollen, and ambulacral grooves wide open within 3 to 4 days.
3. Spines located near arm tips are shed from the body surface, locomotion ceases, and degeneration of whole body commences a day later.

The period required for the complete death of the animals was about 1 week at temperatures between 33° and 34° C.

CONCLUSION

Acanthaster planci represents a typical metabolic conformer in that its rate of oxygen uptake is controlled by environmental temperature and other factors. The range of temperature in which the starfish could behave normally and maintain normal metabolism seems to be limited to 31° C. At 33° C, the starfish showed abnormal behavior, ceased feeding, and its metabolic activity seemed to be disturbed as the slope of M-T curve turned negative. The asteroid has no specialized respiratory organ and is not organized to regulate a constant metabolic level over any range of temperature. These characteristics, which may be common among many invertebrates, will prove detrimental to their population maintenance if the thermal environment is modified above a certain level. Information on this point is very important in evaluating the effects of thermal discharge over coral reefs by the power plants which use seawater as a coolant.

The incipient thermal death point is near 33° C for *Acanthaster*, although this point might be shifted slightly beyond this range by acclimation. Water temperature around Guam fluctuates between 27° and 30° C outside the reef (oceanic water), but may be several degrees warmer inside the reef margin. Tide pools and small lagoons on the reef-flat often show large fluctuations in environmental conditions. The temperature range that may stress *Acanthaster* is found commonly in such areas when spring tides are low in the mid and late afternoon. *Acanthaster* is uncommon on the reef-flat and may avoid these areas because of stress including high temperature. There is, however, at least one conspicuous reef asteroid, *Linckia laevigata*, which does inhabit the reef-flat habitat avoided by *Acanthaster*. It would be interesting to make a comparative study of the relationship between metabolic activity and temperature for *Linckia*, since resistance to thermal stress in this species may be different from that of *Acanthaster*.

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