Some Temperature Studies on the Beetle, Popilius Disjunctus

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tion, but a few could be identified as *Katsuwonus pelamis* and *Thunnus atlanticus*. There were no indications that these fish had been taken from hooks or had suffered any crippling injuries which would have enabled the sharks to "run them down." Backus, *et al.* found similar stomach contents in white-tips from other captures.

An explanation of at least one method of capture of such active swimmers was apparent after observations from the *Oregon* on Cruise 62, north of the Virgin Islands in September 1959. Late one afternoon, about 2 miles off the 100 fathom curve, a strong tide-rip paralleled the shelf contour for several miles, and along the rip were continuous schools of tuna feeding on numerous but scattered small Spanish sardines, *Sardinella anchovia.* Several passes through the schools with trolling lines resulted in the capture of 9 blackfin tuna, ranging from 3 to 16 pounds. The tuna schools were very dense and the feeding behavior of the tuna was typical—fast darting rushes at the surface with frequent leaps clear of the water. It is difficult to describe the frenzied cut and slash of small schooling tuna working bait fish.

Mixed with the tuna were many white-tip sharks, ranging from about 3 to 6 feet in length. Each shark was swimming slowly in a rather erratic, sinuous course with its snout protruding from the water, its mouth wide open at just about the surface level. At one point, the sharks were so numerous that they were spaced not over 10 feet apart in an area some 50 feet wide by 300 feet long. No attempt was made by the sharks to chase after or snap at the hundreds of tuna in the same area. It was an inescapable conclusion, however, that the white-tips were merely waiting and ready for those moments when tunas would accidently swim or leap right into their mouths. The identical behavior of so many sharks, observed over a 30 minute interval, would indicate this to be a well-established feeding pattern. Only with the first hand observations, at close quarters, can one give complete credence to the likelihood that oceanic sharks obtain a segment of their food in the manner described.

There might seem to be the possibility that the white-tips were trying to scoop up the small *Sardinella;* however, the low schooling density of this species at the time appeared to make this quite profitless.

One somewhat similar example was cited by Springer (1957), where small blackfins were seen to leap into the mouth of a whale shark, which was "pumping" smaller fishes.

Another feeding observation was made in August, 1957, on *Oregon* Cruise 46 in the western Caribbean, at a position along the 500 fathom curve due north of Cape Gracias a Dios, Honduras. Sea conditions were rough with precipitous waves, but the wind had died off and the water visibility was quite good. Late in the afternoon a flock of about 20 red-footed boobies and white-bellied boobies were observed diving. We approached the area and saw that they were working on a tight, dense ball of small threadfins, *Polydactylus* sp. The ball was about 6 feet in diameter and, when first sighted, was within a foot of the surface. A few of the boobies were sitting on the water and reaching down to take big gulps of the threadfins. Lying alongside the school was a large white-tip (estimated 7 to 8 feet in length), which was biting off mouthfuls of fish, much in the manner of a person eating an apple. Apparently the school of threadfins was completely indifferent to the predation in progress and displayed no evasive action whatever. We attempted to drift the *Oregon* up to the school to dip-net a sample, but the violent roll of the vessel and the turbulence caused by the bilge keels apparently caused the school to sink down beyond the reach of the dip net. By this time the boobies had left, but we watched the white-tip continue to gnaw away at the school for several more minutes.

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SOME TEMPERATURE STUDIES ON THE BEETLE, *POPILIUS DISJUNCTUS*

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Introduction

These studies were initiated to investigate effects of prior temperature history upon the preferred temperature range of adult *Popilius disjunctus* (= *Passulus cornutus*). The relationship between upper lethal temperature and duration of exposure was also examined. These data for *P. disjunctus* ("Betsy beetles") are of particular interest, since the species is the only temperature zone representative of an otherwise tropical group. Adults dwell in rough tunnels in damp, rotting logs and stumps of deciduous trees, a habitat characterized by temperature and moisture stability. Since logs are not attacked until they reach a relatively advanced state of decay, the insect is not regarded as being of economic importance. The insect is an excellent experimental animal, being hardy, readily obtained, and easily handled (32-36 mm in length), and can be maintained with a minimum of difficulty in containers of moist, rotting wood.

Determination of Preferred Temperature Range

The temperature gradient employed was similar to that of Fulton (1928), consisting of a galvanized metal trough (47 inches long, 6 inches wide, 3 inches deep). At one end, the trough extended 6 inches into a galvanized metal box (12″ × 10″ × 10″) which served as a container for salt-ice mixture. The box was insulated with half-inch fiber board and equipped with a drain spout for water removal. The large trough contained a glass tube, 3 inches in diameter and 42 inches long, embedded in moist sand with only the upper curvature exposed. A 5-inch space between the end of the glass tube and the hot end of the trough facilitated introduction of test insects into the tube or test chamber. The smooth, curved sides of the chamber served to discourage climbing and aggregation. The test chamber was marked off into 6-inch sections numbered from 1-7 from the cold to the hot end. Each of these major subdivisions was in turn marked

off into 6 one-inch subdivisions. A 150 watt bulb was located immediately beneath section 7 (the hot end), a 75 watt bulb beneath section 6, and a 40 watt bulb beneath section 5. Since *P. disjunctus* exhibited a negative light reaction, the exposed dorsal portion and both ends of the glass tube were covered with removable metal covers, excluding all light from the test chamber.

After adjustment, a gradient of 1° C increment per inch was obtained, except for a greater magnitude of change toward either end. Extreme temperatures near the ends of the test chamber proved to be outside the normal activity range, and those below 9° C and above 33° C were generally avoided. Since the test insects were introduced into the hot end of the test chamber, it was frequently necessary to push them beyond the zone of high temperature to prevent injury that might occur before they could become properly oriented. Occasionally, an individual tipped onto its back in the cold zone and had to be righted and pushed into the more temperate range. These immobilized individuals were not included in tabulating data. Temperatures were read from a battery of 5 thermometers embedded in the sand along the tube. Another thermometer, placed in the test chamber, served as a reference point for detecting possible variation in internal and external temperatures. A Schultheis rapid recording thermometer (0-50° C) was used to take readings between the permanently located thermometers. Water was added to the sand as needed to replace evaporation loss and to insure maximum heat conduction.

When the device attained equilibrium, 10 beetles were introduced into the test chamber and left undisturbed for a 6-hour test except to record positions of the insects at half-hour intervals. Thus, with the position of each insect recorded at half-hour intervals, a total of 120 observations per replication was possible. Acclimation was accomplished by keeping beetles for several weeks in special thermostatically controlled temperature cabinets in which variation did not exceed ±1° C. Insects were acclimated at 3 temperatures as follows: 14-28° C (room temperature), 13-15° C, and 3-5° C. Figure 1 and Table I summarize the results of all preferred temperature range tests.

TABLE I. Summary of temperature selection data
Statistical symbols are those of Li (1957), y being the
sample mean, s the standard deviation

	Test No. 1	Test No. 2	Test No. 3
Acclimation temperature (°C)........	14-28	13-15	3-5
Length of acclimation...............	4 weeks	2 weeks	3 weeks
Number of insects..................	50	30	30
$\bar{y}$ (after 1 hour)...................	24.1	21.3	21.7
$\bar{y}$ (after 6 hours)..................	20.3	17.8	15.7
$\bar{y} \pm s$ (after 1 hour)...............	20.2-28.0	15.9-26.8	16.9-26.6
$\bar{y} \pm s$ (after 6 hours)...............	16.9-23.7	13.0-22.5	12.1-19.4
Activity range (after 1 hour)........	13-30	12-30	11-30
Activity range (after 6 hours).......	15-29	10-27	9-28

In order to learn whether the behavior of test insects was actually in response to the heat gradient rather than some tendency to remain near the center of the test chamber, 10 beetles were tested as previously described, but without ice or heat being added so that the temperature remained uniform throughout the length of the gradient. The results revealed random movements over the entire length of the test chamber, with a tendency for the insects to aggregate near the ends.

DETERMINATION OF UPPER LETHAL TEMPERATURE

Upper lethal temperature experiments were run in an electrically heated, thermostatically controlled temperature cabinet in which variation did not exceed ±1° C for a particular setting. For each temperature tested, 10 insects were placed in a battery jar and kept in the cabinet for one hour. The upper lethal temperature was taken to be that at which 80-100% of the test insects were killed. All insects were kept at room temperature (14-28° C) for at least one month prior to being tested. Low humidity prevailed in these tests, although it doubtlessly varied somewhat. No attempt was made to determine the effect of different humidity levels on the upper lethal temperature.

In the first series of tests, 10 beetles were exposed to a temperature of 40° C for one hour. The procedure was then repeated, using 10 new insects, at 41° C, and so forth, until a temperature was reached that killed 100% of the test insects. After exposure of each group, the insects were observed and placed in containers of rotting wood to be observed again after 24 and 48 hours. Beetles were considered dead when mouth parts, antennae and legs failed to respond to extensive probing. The results of these tests are shown in Table II.

Another series of experiments was performed in order to determine the upper lethal temperature for a 12-hour period of exposure. These were identical to the one hour exposure tests described above, except that testing was begun at 35° C and repeated with a new group of test in-
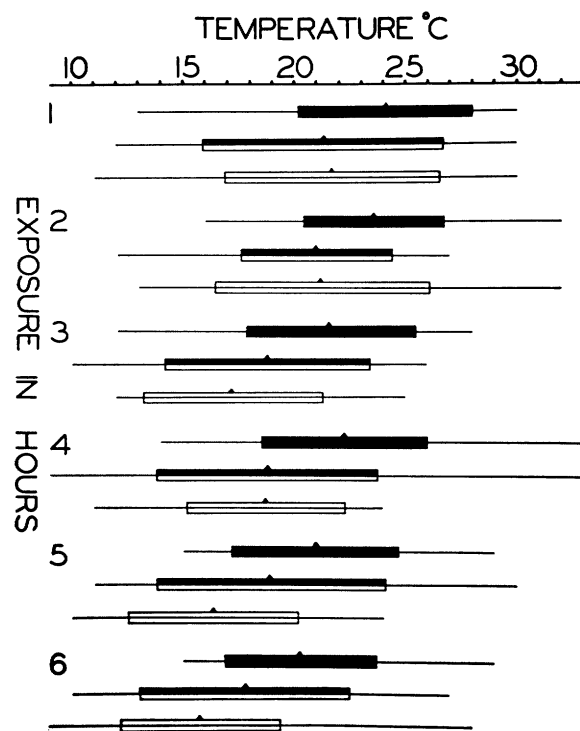

FIG. 1. Temperatures selected by adult *Popilius disjunctus* during 6 hours exposure in a temperature gradient. The point on the bar represents the sample mean ($\bar{y}$); the bar itself represents one standard deviation on either side of the mean ($\bar{y} \pm s$); the line through the bar indicates the activity range. Black bars: Test No. 1 (insects kept at 14-28° C); Black and open bars: Test No. 2 (insects acclimated at 13-15° C); Open bars: Test No. 3 (insects acclimated at 3-5° C).

TABLE II. Effects of one-hour exposure to high temperature

Temperature ° C	Condition at conclusion of one hour exposure	Condition 24 hours later
42..........	No visible effects.	No visible effects.
43..........	None able to crawl actively.	All alive and apparently unharmed.
44..........	2 move well; 5 move feebly; 3 barely able to move antennae, legs and mouthparts.	All alive after 24 hours (6 dead after 48 hours).
45..........	8 move antennae, legs and mouthparts in a feeble manner; 2 dead.	1 able to move antennae, legs and mouthparts in a feeble manner; 9 dead.

TABLE III. Effects of 12-hour exposure to high temperature

Temperature ° C	Condition at conclusion of 12 hours exposure	Condition 24 hours later
36..........	No visible effects.	No visible effects.
37..........	7 show no visible effects; 3 show reduced movement.	1 shows no visible effects; 3 walk with difficulty; 5 move legs, antennae and mouthparts feebly; 1 dead.
38..........	2 able to crawl actively; 4 move only legs, antennae and mouthparts; 4 dead.	2 able to move fairly well; 1 moves only legs, antennae and mouthparts in a feeble manner; 7 dead.
39..........	3 move appendages in a feeble fashion; 1 able to move mouthparts feebly; 6 dead.	All dead.

sects for each 1° C increase in temperature. The following results (Table III) were obtained:

DISCUSSION

P. disjunctus will select a preferred temperature range if given a wide series of temperatures from which to choose. Insects kept at low temperatures selected a lower range than those kept at intermediate or high temperatures; those kept at higher temperatures preferred a higher range than those kept at intermediate or low temperatures. Whereas the preferred temperature range is usually defined as a zone selected by 50-80% of the tested

individuals, in the present study, the preferred range is expressed as $\bar{y} \pm s$, which includes approximately 68% of the autoselected temperature preferences. The value of 68% is one of convenience and has no special physiological significance.

The findings indicate that regardless of previous temperature history, the mean selected temperature shows a tendency to decrease progressively during the course of a 6-hour exposure period (Figure 1). Because of this tendency, any statement of mean selected temperature or preferred range should be accompanied by a statement of duration of exposure if it is to be useful in comparative analyses. This apparent change in the preferendum was interpreted as a possible response to lower humidities at the cold end of the test chamber. Gunn and Cosway (1938) explained a similar shift to lower temperatures, and hence to a higher humidity, as an effort to avoid desiccation, initiated by critical reduction in water content of the insect's body.

The effect of length of exposure upon the upper lethal temperature is well demonstrated in the experimental findings. Whereas a one hour exposure to $45 \pm 1°$ C is lethal to nearly all test insects, only $38 \pm 1°$ C is lethal to most for a 12-hour exposure. According to Mellanby (1938), the difference is due to the increased role of desiccation as a contributing lethal factor in longer exposures. Humidity was not controlled in these experiments although low humidities prevailed in the temperature cabinet used. The upper lethals for both 1 and 12 hours of exposure approximate similar values reported for other temperate zone Coleoptera, but fall considerably short of those reported for most weevils (Spector 1956).

SUMMARY

When Betsy beetles were placed in a temperature gradient, they selected a temperature range, the nature of which depended upon past temperature history. A progressive decrease in preferendum, apparently in response to effects of desiccation, points out the necessity for accompanying preferendum data with a statement of exposure length. The upper lethal temperature for one hour exposure was approximately 45° C; that for 12 hours exposure was approximately 39° C. Temperature characteristics of *P. disjunctus* do not differ greatly from those reported for most other temperate zone beetles.

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