LETHAL TEMPERATURES OF LAMELLIBRANCHIATA

LETHAL TEMPERATURES OF LAMELLIBRANCHIATA.

Thesis presented for the degree of Master of Science,

McGill University,

April, 1926.

by Jean Tasker Henderson, B.A.

Department of Zoology,

April 30, 1926.

LETHAL TEMPERATURES OF LAMELLIBRANCHIATA

by

Jean T. Henderson, B.A.,

Department of Zoology, McGill University.

Introduction.

During the investigations into the subject of the limiting factors of marine animals, which are being conducted under the Biological Board of Canada, the effect of temperature upon the organism has come under consideration.

Lethal points have been obtained for a number of groups of Invertebrata, and for some Vertebrata(principally fishes), according to findings made by Dr.A.G.Huntsman and Mr.M.I.Sparks. The object of the problem undertaken, the results of which are treated in this paper, was to continue this work for the group Mollusca. Consequently, during the summer of I925, at the Biological Station at St.Andrews, N.B., determinations were made of the relative resistance to high temperatures of certain of the bivalve molluscs. Such determinations had as their primary object the recording of the death-point -- the "lethal temperature" -- with a view to the possible effect of warm waters upon the distribution of the species.

Method.

The method of obtaining the results followed closely that used by Dr.Huntsman and Mr.Sparks (I924) in their previous experiments;namely, a slow heating regulated as far as possible to raise the temperature of the water in which the organism lay, and thus that of the organism itself, at a rate of I°C in 5 minutes.

Some difficulties arose in connection with the molluscs, however, which had not been apparent for any of the other forms studied Chief among these was the fact that there was no reliable way of determining the death-point of each separate individual. In forms studied up to this time, either such a stimulus as a pin-prick was sufficient to cause visible movement so long as life was retained, as in the case of the fishes; or else death was denoted by opacity, as in the case of the crustacea. The shell of the bivalve mollusc, however, is neither sensible to pin-pricks, nor does it become opaque at death. Most of them are already opaque. Moreover, the closing of the shells necessitates an injury to the organism in opening them to expose the soft tissue within.

Added to this, the electric light bulb failed to produce a temperature sufficiently high to kill the specimens. This was overcome by using a large, fairly shallow pan for the larger types, and a water-bath, consisting of two glass beakers, for the smaller, heating both indirectly by a bunsen burner. The water was constantly stirred in order to maintain an even temperature throughout.

The former difficulty involved a change of routine. The water was heated to a point where the individuals showed signs of distress. Heating was then continued, during which period, at every rise of $1^{o}C$ in temperature, or for every 5 minutes, one individual was removed from the hot bath, and replaced in water of about $15^{o}C$. This proceeded from some point above that at which the animals first seemed to be suffering ill effects, until the last was removed. Later, usually in about 3 or 4 hours, or after an over-night period, these were examined. Those which had not revived were presumed dead, upon failure to respond to stimulus.

The lethal point was then known to be between the highest temperature from which the animal recovered when replaced in cold water, and the lowest point from which it failed to revive.

(The usual means of determining life in these specimens was first to observe them, without touching them. If they were very active, it was at once evident, either by the moving of the foot -- as, for example, in Yoldia -- or by the siphons --for instance, in Macoma. The valves were tapped, and if the shell closed,the animal was living. If such measures failed, the valves were pulled apart, after which the foot was touched with a needle. Contraction of the muscle indicated life.)

Such a method gives a result only for the species as a whole, not the lethal temperatures for each individual tested. However, in cases where two or more experiments were carried out for the same species, the results were found to approximate one another quite closely, leading one to believe that the death-point is fairly sharply defined, with little variation from one individual of the species to another.

As a whole, the temperature points obtained were higher than those for any other group in the animal kingdom so far investigated. The lowest lethal point recorded was that of Leda tenuisulcata, which revived at 31.0°C, but not above that. This is considerably higher than the majority of forms studied by Mr.Sparks(1924), a great many of the latter having had lethal points below 30°C, The highest death-point was reached in the oyster, Ostrea virginiana,which survived to 48.0°C. With the exception of Fundulus heteroclitus (L), a fish, which was not even killed by a temperature of 42°C, and of Corophium volutator Pall., an amphipod, with a point of 37.2°C,

and of one individual of Gasterosteus bispinosus Walbaum, a fish, with a point of 37.1°C, all the species tested by Dr.Huntsman and Mr.Sparks had lethal points under 35°C.

The species of Lamellibranchiata investigated will be seen to be divisible into four main classes according to their distribution. Theseclasses may, for convenience, be called:

1. Dredged forms,-- deep- or cold- water forms.

2. Lower littoral forms,-- those which are bared only at low-water spring-tide (L.W.S.T.), or are never uncovered, being on reefs or bars which are awash at the lowest tides.

3. Upper littoral forms,-- those inhabiting the upper tidal zone, which are bared during at least half the inter-tidal period, thus being exposed to a certain amount of atmospheric heating, over a more or less prolonged period of time.

4. Warm-water forms,-- which are not found at St.Andrews.

A most interesting gradation is apparent in the lethal temperature records of the various members included under these general headings. The lowest figures are given for dredged forms, which, of course, in the Bay of Fundy as elsewhere, live at comparatively low temperatures. Slightly higher figures are recorded for those species referred to as "lower littoral forms"; the difference being only slight because under the conditions mentioned, in the vicinity of St.Andrews, the temperature does not vary greatly from the bottom temperature at, for instance, fifteen fathoms. Appreciably higher than these are the points obtained for "upper littoral forms"; while those for "warm-water" bivalves are very high.

The effects of heating seem to be the same for practically all forms. The valves close shortly after heating has begun, and, except for occasional spasmodic jerks of the foot in some species, remain so until the temperature has reached a point 12°C or less below the lethal temperature, when they commence to gape. At the beginning of the period of gaping the valves will shut smartly at a tap, but gradually the adductor muscles weaken, until a point is reached when no closing of the valves takes place.

In forms where a siphon is present, it is protuded when the gape begins; and a characteristic indication of the approach of the death-point is an apparent inability to retract the siphons. In the case of Macoma fusca they jerked convulsively at about 3°C below lethal point.

The results of the experiments will probably best be seen if a summary of the tests is given, together with reference to the known distribution of the numerous forms studied, as set forth by A.E.Verrill (Rep.U.S.Fish.Comm.XVIII.1872--pp.295--778). Such an analysis follows, the species being given in ascending order of lethal temperatures. The limits of the work were necessarily laid down by the availability, or non-availability, of the various species in Passamaquoddy Bay and its vicinity. In cases where but one or two individuals of a species were tested, it was because those species did not occur more frequently in the dredge-material. The individuals were removed singly, at fairly regular intervals over a certain period of time. The number of individuals used in each experiment is given in the following synopsis, together with the upper and lower limits of temperature during the period of removal. The inital temperature of the sea water used in the experiments was about 10°C.

A chart demonstrating the results of the experiments is appended at the end of the report.

Synopsis.

A. "Dredged forms"

I. Leda tenuisulcata Stimpson. Verrill, p.690.

1. 9 individuals. At 26.6°C, a convulsive jerking of the foot, as in swimming movemrnt, was noted, and at 29.0°C all were gaping widely. Removal commenced at 31.0°C and continued to 39.5°C. Individuals lived to 31°C, and were dead at 32°C and above. The lethal point is 31.5°C.

These were dredged at about 10 fathoms on a muddy bottom, so that the water from which they came was cold. L. tenuisulcata is a fairly northerly form occurring from Rhode Island to the Gulf of St.Lawrence, including the cold water of Casco Bay and the Bay of Fundy, in water from 6 to 80 fathoms. In such a distribution area the temperature is low.

II. Modiolaria discors Beck. Verrill p.694.

1. 7 individuals. Commenced to gape at 27.4°C. First specimen removed at 29.0°C, last at 39.0°C. Later examination showed those to be living which were removed at 29.0°C and 31.3°C. The remainder, from 34.9°C to 39.0°C were dead. From 31.3°C to 34.9°C those remaining in the water-bath appeared to be alive, which accounts for the long interval between these two removals.

2. 11 individuals. Removal commenced at 29.1 C.; continued

regularly to 36.0°C. Individuals lived to 30.5°C, but were all dead from 31.2°C.

The average lethal temperature is 31.9°C.

The distribution is given as circumpolar, (from low water to 100 fathoms), not occurring south of Cape Cod, which adduces the evidence that it is a cold-water form. It is, in fact, one of the most northerly forms studied, and it is, therefore, not surprising that it should claim one of the lowest lethal temperatures.

All Modiolaria discors used were obtained from a large submerged log, evidently in use at some time as an anchor of some description, which had dragged up a sand-bar, so as to be bare at L.W.S.T. A length of chain attached indicated the direction from which the wood had come. With Modiolaria were a large number of Saxicava rugosa.

III. Cardita borealis Conrad. Verrill, p. 683.

1. 11 individuals. Removal commenced at 29.9°C, continuing regularly to 40.0°C. Survived to 30.9°C. Presumed dead from 31.9°C up.
2. 12 individuals, all of very small size. Removal ran from 29.6°C to 36.5°C. This gave a doubtful result, as all appeared dead except one which was removed at 33.5°C. Another taken out at the same time was dead. The very thick shells, and very small dimensions of these specimens made it rather difficult to determine the presence or absence of life.
3. 9 individuals. Removed at regular intervals from 28.0°C to 33.8°C. Lived to 31.5°C, dead from 32.1°C up.

The lethal temperature shows an average of about 31.6°C.

The distribution is stated to be from New Jersey to Labrador, a fairly northern form, and one not occurring between tide-marks. Its depth is from 3 to 80 fathoms, which denotes a colder water form. The specimens used during the experiments were dredged from numerous localities in Passamaquoddy Bay, always being found on a mud bottom, at depths varying from 8 to 25 fathoms.

lV. Saxicava rugosa Lamarck. Verrill, p. 671.

1. 4individuals. Electric bulb method.(Sparks, 1924). This method was discarded, because it did not produce a sufficiently high temperature. All the individuals were gaping widely at 28.5° C. At 32.2° C. the first was removed, when it showed no response to a tap. At 34.0° C. another was removed. At this point great difficulty in regulating the temperature was experienced, and although the heating was continued for one hour, a rise of only 4.0° C. is recorded. One individual was removed after 10 minutes, at 33.0° C., and the last at 38.0° C., 50 minutes later. Examination later showed that death had taken place in those specimens removed from 34.0° C. and up, one only (that taken out at 32.2° C) surviving.

2. 6 individuals. Removal carried out at regular intervals from 29.5° C., when response to touch was almost nil, to 34.5° C., when there was no response. Living to 32.5° C., dead at 33.5° C. and 34.5° C.

3. 7 individuals. At 29.5° C. the first was replaced in cold water, and the procedure continued with each rise of 0.5° C. This was to obtain a more finely-drawn value for the lethal point. The result agrees very well with the two preceding it, as all the individuals up to 32.5° C. lived and that at 33.0° C. died.

Hence the average lethal temperature is 32.8° C.

Further experiments upon S. rugosa, using the ciliary method, are later demonstrated (page 22).

Saxicava rugosa occurrs from Georgia and South Carolina to the Arctic Ocean, on the east coast of North America, from low-water mark to 50 fathoms. It is not frequent south of Cape Cod, although it is found on the Pacific Coast south to California. It is thus seen to be a more northerly cold-water form. The specimens used were found on the under side of rocks and stones bare only at L.W.S.T., and with Modiolaria discors as previously mentioned. Specimens were often found also attached by the byssus to Modiola modiolus, brought up on the trawl.

V. Astarte undata Gould. Verrill, p.684.

1. 11 individuals. No gaping was observed. Removal was commenced at 33.6° C. and continued to 41.7° C. These, as far as could be judged, were all dead, but such judgment was difficult, as they were all of small size, averaging 7 mm. long X 6 mm. high.
2. 7 individuals. Removal was carried out from 30.1° C. to 36.2° C. Alive to 32.0° C., dead from 33.6° C.

At 34.5° C. two were removed at once, one of which appeared to be very feebly alive, when examined. However, in calculating the averages, such aberrants are disregarded.

3. 6 individuals. At 31.5° C. gaping was noted, and the first was removed. Removal continued to 35.8°C. These lived to 33.5°C, but were dead at 34.1°C and 35.8°C.

The average lethal point is 33.5°C.

A.undata is distributed from Long Island Sound to the southern part of the Gulf of Saint Lawrence, in water from 5 to 100 fathoms in depth. Those obtained in the vicinity of St.Andrews were dredged from a mud bottom at about 20 fathoms.

VI. Crenella glandula Adams. Verrill; p.695.

1. 2 individuals. (Five were put in, but three of these proved to be empty.) Gaping commenced at 30.5°C. At 31.5°C, one C.glandula was taken out, and the other at 33.2°C. The former survived, the latter did not.

2. 9 individuals. At 30.5°C gaping was noticed, and the first was removed. This continued to 37.8°C. Individuals at 30.5°C, 31.5° C., 32.2° C. lived, that at 33.0° C. was doubtful, and from 34.0° C. up, death had taken place.

The average lethal point is 32.8° C.

The distribution of C. glandula is practically the same as that of Astarte undata, namely--Connecticut to the Gulf of St. Lawrence, at from 3 to 60 fathoms. It was taken at St. Andrews

in the same dredge material with Astarte.

VII. Cardium pinnulatum Conrad. Verrill, p.683.

1. 9 individuals (one of which was later crushed in the stirring). At 26.0° C. a slight gape was apparent. Removal was begun at 30.0° C., and continued to 38.0° C. Death occurred from 33.8° C. up, while those at 30.0° C., 31.2° C. and 32.5° C. lived.

   The lethal temperature here is 33.2° C.

Cardium pinnulatum occurrs from LOng Island Sound to Southern Labrador, at a depth of from 2 to 80 fathoms, which again indicates temperature conditions similar to those of Astarte undata.

VIII. Pandora trilineata Say. Verrill, p.673.

1. 2 individuals. These gaped at 33.5° C. and were removed at 34.9° C. and 36.0° C. Both died, thus giving merely a negative result.
2. 4 individuals. These were taken out at from 31.0° C. to 34.0° C. The last died; the remainder appeared to be alive, although the fact was difficult to prove owing to the brittleness of the thin shell.

   The lethal point was 33.5° C.

Pandora trilineata inhabits the water from low-water mark to 30 fathoms, from Florida to the Gulf of St. Lawrence. It also is dredged with Astarte, although not occurring frequently about St. Andrews.

IX. Yoldia sapotilla Stimpson. Verrill, p. 689.

Specimens taken in Passamaquoddy Bay proved to show two varieties of liver colouration, visible through the shell, one being pink, and the other blackish or of a dark brown tinge. No difference in reaction to heat was observed between the two.

1. 11 individuals. At 22.4° C., the siphons of all protruded, and were not quickly retracted. Removal was begun at 32.7° C. and was carried out to 42.8° C. Death took place from 35.6° C. up, whereas from 34.6° C. down, the animals lived.

2. 10 individuals, with liver of pinkish tinge. Removal from 30.0° C. to 39.3° C. Death ensued from 35.3° C. up, life being retained from 34.3° C. down.

3. 10 individuals, with liver showing black. Removal from 31.3° C. to 40.8° C. Those removed up to 33.8° C. lived, and those from 34.8° C. up were dead.

In experiments (2) and (3) a considerable gape of the valves was noticed at 27.0° C.

4. 10 individuals, five of which had pink liver, and five black.

At 27.8° C. the gape was apparent, and from 31.6° C. to 36.6° C. one of each type was removed. Life was retained to 34.5° C., above which death ensued, in both types. The average lethal point was 34.8° C.

In this case quite extraordinary uniformity is displayed in the effects of the application of heat, which would seem to indicate that the various individuals of a species show but slight var-

iations in their reactions.

Y. sapotilla is found from Long Island Sound to the Arctic Ocean, to a depth of 100 fathoms; and, rarely, in deep water south of Cape Cod. At St. Andrews it was obtained from the same muddy bottom as Astarte.

X. Modiolaria nigra Lovén. Verrill, p. 694.

2 individuals. These were removed at 34.0° C. and 35.0° C. The latter died, while the former lived, though very feeble when examined. This gives a lethal temperature of 34.5° C.

This cannot be said to be a very definite finding, as these two were the only specimens obtained throughout the summer, from a dredging made on a mud bottom in the St. Croix River, at a depth of 10 to 14 fathoms. Consequently, the experiment could not be repeated for corroboration. However, it is an indication of the probable upper temperature range, if, as has been noted for the preceding Yoldia, variation is limited.

The habitat of M. nigra is given as circumpolar, with occurrence southward to the Bay of Fundy and the Maine coast, from low water to 100 fathoms.

This completes the list of"dredged forms" investigated. All, with the exception of Modiolaria discors and Saxicava rugosa, were obtained by dredging at various points in Passamaquoddy Bay, on a mud bottom, at depths varying from 6 fathoms to 25 fathoms. The apparent discrepancy of including M. discors with the"dredged forms" is explained by the fact that the log from which it was taken had obviously been rolled up from a deeper position. Marks

in the sand were still visible under water, and the broken chain ended some distance below the L.W.S.T. mark. This is borne out by the lethal temperature point. The low lethal point of Saxicava can be accounted for by the fact that those occurring on the under side of rock ledges bared only at L.W.S.T. are probably not subjected to any very high atmospheric temperature, since the sun never strikes them, and evaporation from the surrounding wet rock would serve to cool the air.

The lethal temperatures of all species thus far have been not higher than 35.0° C. The series passes with a very slight increase into the "lower littoral" forms, as will be seen in the following experiments.

B. Lower Littoral Forms.

X1. Zirfoea crispata Gray. Verrill, p. 671.

9 individuals. Removed at 29.0° C. and 31.8° C.(these were quite limp); and from 34.0° C. to 38.5° C. Living to 35.0° C., dead at 36.0° C. and above.

The lethal point is therefore 35.5° C.

These were boring in sandstone at Indian Point, St. Andrews, and were available at L.W.S.T. As can be seen, the first group merges almost insensibly into the "lower littoral" group. The species is found from Connecticut, to the Gulf of St. Lawerence; further north, in Iceland, and the northern coasts of Europe, as well as in other districts, including California.

XII. Modiola modiolus Turton. "Horse Mussel". Verrill, p.693.

1. 10 individuals. Removal effected from 28.8° C. to 35.9° C. All lived up to 35.0° C., but the one removed at 35.9° C. died.
2. 11 individuals. Those which were taken out from 31.5° C. to 36.5° C. lived, whereas the three at 37.8° C., 38.8° C. and 39.5° C. died.

The average lethal point is 36.3° C.

The specimens used were obtained from a pebbly bar which is not quite bare at L.W.S.T., and over which the water is very cold. This situation is readily related to the distribution indicated for M. modiolus, which is: circumpolar, southward to New Jersey. However, on the Pacific coast of North America, M. modiolus is found as far south as California, in which it resembles Saxicava, which indicates its ability to withstand somewhat higher temperatures than the purely deep-water forms.

XIII. Mactra solidissima Chemnitz. "Hen Clam". Verrill, p.680.

1. 5 individuals. For this experiment the temperature was raised only 0.5° C. per five minute interval, in order to ensure complete penetration, since the specimens were so large, and the shells so thick that a quick heating might have failed to affect them. The largest of these had a length of 7.2 inches, a height of 4.8 inches, and a breadth of 2.6 inches. Removal took place from 32.0° C. to 36.5° C., commencing at the point where no response

was made to stimulus. All of these individuals, however, upon being replaced in cold water (15.0° C.) and later examined, were found to have survived.

2. 5 individuals. The same unit rise of temperature was induced, and removal was effected from 37.5° C. to 39.0° C. All specimens died, which points to a lethal temperature at a point between 36.5° C. and 37.5° C. It is therefore taken to be 37.0° C.

An interesting phenomenon occurred during experiment (1) when the temperature of 22.8° C. was reached. From two individuals there were simultaneous discharges of ova, which latter were so numerous as completely to cloud the water, and even to make observation difficult. Similarly, during Experiment (2), at a temperature of 21.9° C., ova were discharged in considerable quantities from one specimen.

Previous to this, at temperatures of 17.0° C. and 18.0° C., two individuals had extruded sperms in an equally violent stream, rendering the water quite milky.

In view of the fact that the female products were discharged at approximately the same temperature for three individuals, and the milt, at a somewhat lower point, from two males, a comparatively early effect of heat upon the genital organs may be considered possible.

Mactra solidissima occurs from Florida and the Gulf of Mexico to Labrador, being found in the Bay of Fundy from low-water mark to 10 fathoms on a sandy bottom. Those used here were obtained at L.W.S.T. from a sandy beach on Hardwood Island, Passama-

quoddy Bay. Thus its occurrence and its lethal point are observed to be comparable to those of Modiola modiolus and Zirfoea crispata.

Between these "lower littoral" forms and those of the "upper littoral" zone, a very marked difference in lethal temperatures is observed. This is doubtless because the latter are subjected to prolonged rises in temperature as the sun beats upon their position during the inter-tidal period. Their resistance to heat is the "sine qua non" of their existence.

C. Upper Littoral Forms.

XlV. Mytilus edulis Linné. Edible Mussel. Verrill, p. 692.

1. 10 individuals. Removal went on from 28.4° C. to 41.0° C. All up to 39.3° C. revived instantly upon being placed in water of 15.0° C. and that at 40.4° C. also lived, as revealed by later examination. 41.0° C. had, however, induced death in the remaining specimen.
2. Another experiment with 10 individuals also gave a result of 9 individuals living at temperatures mounting to 40.5° C., while the last one was dead at 41.5° C.

The average lethal point is 40.8° C.

The distribution is circumpolar, but running south to California, China and Japan in the Pacific Ocean; to North Carolina in the Atlantic; and to the Mediterranean. Its range of temperature , therefore, must be very wide.

At St. Andrews there are many beds of mussels, bare for

varying fractions of the inter-tidal period.

XV. Mya arenaria Linné. Common clam. Verrill, p.672.

1. 10 individuals. Lived to 39.0° C., the tenth, removed at 40.0° C., being dead. The vitality of these had undoubtedly been impaired, as they had been in a tank for some time without water.
2. 10 individuals. Removal went on from 33.0° C. to 41.1° C. All lived up to 40.0° C., but two removed at 40.9° C. and 41.1° C. died.
3. 14 individuals, in three groups according to size. Removed in groups of three, from 38.6° C. to 41.5° C., the last two coming out at 42.5° C. and 43.5° C. All lived from 40.2° C. down, all from 41.5° C. up being dead. Thus it was seen that there was no appreciable difference in the resistance offered by Mya at different ages.
4. 14 individuals. Life maintained up to 41.0° C. Death followed temperatures from 42.0° C. to 45.0° C. This presents an average lethal point of 40.6° C.

M. arenaria is found from South Carolina to the Arctic Ocean--another widely distributed form, occurring from half-tide mark to 40 fathoms.

XVI. Macoma fusca Adams. Verrill, p.676.

1. 10 individuals. One was removed at 37.5° C., the remainder at regular intervals from 39.5° C. to 47.5° C. These lived to 41.5° C. and died from 42.5° C.up.

2. 10 individuals. These were taken out from 36.9° C. to 46.0° C., and survived to 42.0° C.; the remainder were dead from 43.2° C.

The average lethal temperature is 42.3° C.

All specimens used were obtained from high up in the littoral zone, from muddy flats which became comparatively warm between tides. The species ranges from Georgia to Greenland, being very abundant in the New England region.

D. Warm-Water Forms.

XVll. Venus mercenaria Linné. "Quahog-clam". Verrill, p.681.

6 individuals. Due to the thickness of the shell the rate of heating was 0.5° C. in 5 minutes. At 40.0° C. one which exhibited a wide gape was removed; and at 40.5° C. all gaped, two being taken out, followed by another at 41.0° C. At 41.5° C. the two remaining still showed response to stimulus. These were removed at 44.5° C. and 46.0° C. All lived except the last.

The lethal point is taken to be 45.2° C.

These specimens were obtained from Buctouche, N.B., where the water is warmer. The species does not occur in Passamaquoddy Bay. The distribution is from Florida to Massachusetts Bay, with sporadic occurrences as far north as the Gulf of St. Lawrence. It is pre-eminently, then, a warm-water form, a fact which is substantiated by its high lethal point.

XVlll. Ostrea virginiana Lister. Common oyster of Chesapeake Bay. Verrill, p.697.

6 individuals. One was removed at 41.8° C., the rest from 46.0° C. to 49.0° C. Life was maintained to 48.0° C., death having ensued at 49.0° C.

The lethal point is therefore in the neighbourhood of 48.5° C.

These were also shipped from Buctouche, N.B., and do not occur in the Bay of Fundy. Their resistance is remarkable when it is considered that their lethal point (119.3° F.) is considerably higher than the temperature of the human body.

Oysters occur from Florida and the Gulf of Mexico to Massachusetts Bay, and locally farther north to the Gulf of St. Lawrence-- again a warm-water form.

The foregoing is a summary of experiments giving positive results. Added to these, are a number which yielded negative findings only, due to the fact that the species was not obtained in sufficient quantity during the summer to make a definite conclusion. These were:

1. Nucula proxima Say. One individual gaped at 33.2° C., and was dead at 35.5° C.

2. Pecten tenuicostatus Mighels. Two specimens recovered completely after being removed at 29.3° C. and at 30.3° C. Both had appeared entirely limp and lifeless.

3. Cytherea convexa Say. Three individuals lived to 35.3° C.

4. Leda caudata Loven. Six individuals died at 39.0° C. and upwards to 41.5° C.

5. Cochlodesma leanum Couthouy. One individual dead at 41.0° C.

CILIARY METHOD.

During these investigations it was thought that a ratio might be worked out between the lethal point of the ciliated tissues, and that of the organism as a whole. This would make possible the use of single specimens of a species-- an important fact in those cases where only occasional individuals are taken-- since the actual death point of each organism could be computed.

Consequently, a number of methods were tried in order to ascertain the point at which the cilia of certain parts ceased to move. The labial palps proved to be the region of the mollusc's anatomy most readily accessible; and a system was finally evolved whereby the tissue could be heated at the same rate as that which obtained for the whole animal, while the cilia were continually under microscopic observation.

The apparatus was prepared by attaching to the stage of a microscope a copper plate about twice as long as the width of the stage, so adjusted as to allow the maximum amount of projection from one side, and with a hole cut in it to coincide with the illumination aperture of the microscope. A deep petri dish was fitted with a wire frame which held a hollow slide just at the surface of the ~~of the~~ water in the dish (that is, in contact with the water). A bunsen burner was then applied to the projecting

end of the copper plate, and the water in the petri dish heated slowly, uniformity of heat distribution being ensured by constant stirring. The dish was held in position by plasficene, and was padded around the sides to prevent loss of heat by radiation.

Mya arenaria, Saxicava rugosa, Ostrea virginiana, and Cyprina islandica, of which a solitary specimen was obtained, were subjected to this method.

In all cases the cilia underwent alternate periods of rapid beating and slowing down. Indeed, complete cessation for momentary intervals, with subsequent active phases, was manifested in O. virginiana, the final slowing up occurring quite suddenly at 49.0° C. At 49.6° C. the cilia ceased to beat, and there was no further revival. A control specimen at this point displayed ciliary action as vigorous as before.

The cilia of Saxicava rugosa gave widely varying results. In one case they ceased at 33.9° C.; but in another trial they continued until 33.7° C. had been reached, and even these, having been allowed to cool down to 21.7° C. were later found to have revived. However, a large number of flagellates present here may have obscured the correct result.

Mya arenaria gave cessation points of 40.8° C. and 41.2° C. on two occassions. During another trial one entire specimen was heated simultaneously with a labial palp from another individual. These had been kept for a considerable length of time in a tank in the laboratory, and consequently were not in the best condition. At 38.0° C. the whole specimen showed practically no response to stimulus, and at 39.0° C. it was removed. The cilia at 39.5° C. commenced to slow down, and at 41.5° had completely stopped.

The individual revived; the cilia did not.

From this it will be seen that the cilia of certain portions of a bivalve mollusc will continue to beat until a slightly higher temperature is reached than that which causes the organism to be presumed dead. Therefore it is to be expected that the lethal point of Cyprina islandica Lamarck will be somewhere below 38.0° C., since the cilia ceased to beat at that point. This is comparable to the second result obtained for Saxicava rugosa , and on such a basis Cyprina might be presumed to belong in the same general distribution group as the latter--which, according to its distribution limits, it does.

The ciliary investigations, however, still required much work to be done upon them, before the results could be considered at all conclusive.

CONCLUSION

It is thus evident that there exists a relationship between the normal living temperatures of the bivalves, and the temperature at which death occurs upon heating. Such lethal points are so high as to preclude the possibility that any species would be prevented from existing in any waters upon the globe by the temperature factor alone. Nevertheless, it is equally clear that they are most numerous at the optimum point. If reference is made to the four classes into which the Lamellibranchiata were divided, with regard to distribution

(p. 4), it will at once be noted that the grouping of the lethal temperatures corresponds thereto.

ACKNOWLEDGMENT

I wish to express my gratitude to Dr. A.G. Huntsman, Director of the Atlantic Biological Station, and to Dr. A.H. Leim, Assistant Director, for the tireless assistance which they afforded me during the progress of these investigations.

CHARTS

BIBLIOGRAPHY

1. Arnold, Augusta Foote--- The Sea- Beach at Ebb-Tide. Century Co., New York, 1903.

2. Detweiler, John D. -- Preliminary Notes on the Mollusca of St. Andrews and Vicinity, N.B. Contr.Can. Biol. 1911 - 1914, p.43 - 46.

3. Gould, Augusta A. -- Ed. II - Binney, W.G., Boston, 1870, p.28 - 206.

4. Hanley, Sylvanus -- Recent Bivalve Shells. London,1842 - 56. Williams and Norgate.

5. Huntsman, A.G. -- The Limiting Factors for Marine Animals. Pt. 1. The Lethal Effect of Sunlight. Contr. Can. Biol., New Series, Vol.11, No. 4, p.83 - 88, 1924.

6. Huntsman, A.G., and Sparks, M.I. -- The Limiting Factors for Marine Animals. Pt. 3. Relative Resistance to HighmTemperatures. Contr. Can. Biol., New Series, Vol. II, No. 6, p.97 - 114, 1924.

7. Letson, Elizabeth J. -- Check List of the Mollusca of New York. N.Y. State Mus. Bull. 88, Zool. 11, p.1 - 112.

8. Rogers, Julia Ellen -- The Shell Book. Doubleday and Co., New York, 1908,p.1 - 485.

9. Spitzbergens Mollusker, 1859. -- Marine Zoology, 1873.

10. Stimpson, William -- Testaceous Mollusks of New England - Shells of New England. Boston, 1851. Phillips, Samson and Co.

11. Stimpson, William -- Invertebrata of Grand Manan, 1853.

12. Verrill, A.E. -- Report upon the Invertebrate Animals of Vineyard Sound. Rep. U.S. Fish. Comm. XVlll, 1872, p.295 - 778.

13. Woodward, S.P., and Tate, Ralph -- Manual of the Mollusca. London,1890, Crosley, Lockwood and Son.

I.

Chart of 34 Experiments.

□ - Life maintained.

■ - Lapse between highest point from which recovery took place and lowest point from which there was no recovery.

SPECIES.

°Cent.- 30° 31° 32° 33° 34° 35° 36° 37° 38° 39° 40° 41° 42° 43° 44° 45° 46° 47° 48° 49° 50°

I Leda tenuisulcata

II Modiolaria discors

III Cardita borealis

IV Saxicava rugosa

V Astarte undata

VI Crenella glandula

VII Cardium pinnulatum

VIII Pandora trilineata

IX Yoldia sapotilla

X Modiolaria nigra

XI Modiola modiolus

XII Zirfœa crispata

XIII Mactra solidissima

XIV Mytilus edulis

XV Mya arenaria

XVI Macoma fusca

XVII Venus mercenaria

XVIII Ostrea virginiana

°Cent. 30° 31° 32° 33° 34° 35° 36° 37° 38° 39° 40° 41° 42° 43° 44° 45° 46° 47° 48° 49° 50°

THE HUGHES OWENS CO. LIMITED
No. 815 B 10 LINES 1 INCH.

II.

Chart of Average Lethal Temperatures.