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RATE OF GAIN OF HEAT-TOLERANCE IN GOLDFISH *(CARASSIUS AURATUS)*

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Abstract

Experiments were designed to determine the rate of gain of heat-tolerance for three different groups of goldfish, *Carassius auratus*, respectively acclimated to 4°C., 12°C., and 20°C., and subsequently moved to a temperature 8°C. higher. The rate of change of heat-tolerance showed a marked difference in the three groups, twenty or more days being required for complete acclimation in the 4°C. group, seven days for the 12°C. group, and just over three days for the 20°C. group. These results have been compared with those of Doudoroff (1942) and other investigators on rates of acclimation in fishes and an interpretation made of the natural changes in temperature acclimation of the bullhead, *Ameiurus nebulosus*, in lake Opeongo from May to September, 1941.

Introduction

Various phases of the problem of rate of acclimation in fishes to temperature change have been subjected to experiment. Doudoroff (1942) demonstrated that the rate of change of cold-tolerance for the greenfish, *Girella nigricans*, with both upward and downward changes in the thermal environment (14°C. to 26°C. and 26°C. to 14°C.) required approximately twenty days before acclimation approached completion. Similar results in rate of acclimation were obtained by Brett (1944) when considering the rate of change of heat-tolerance for the fathead minnow, *Pimephales promelas*, when taken from a temperature of 24°C. and put at 16°C.

When moving up the temperature scale from 20°C. to 28°C., the necessary time for acclimation with respect to heat-tolerance in the bullhead was found to be relatively short, the period being in the order of twenty-four hours (Brett, 1944). A fast rate of acclimation for an upward change of temperature of 10°C. (20°C. to 30°C.) was also discovered to characterize the marine goby, *Gillichthys mirabilis* (Sumner and Doudoroff, 1938) as well as the common mummichog, *Fundulus heteroclitus* (Loeb and Wasteneys, 1912). This fast rate also appears to be present for the large-mouth black bass, *Huro salmoides*, from the work of Hathaway (1927) on changes in the lethal temperature of this species. None of these papers, however, deals with changes in heat-tolerance when moving up the scale at comparatively low levels of temperature and, as yet, there is little to be found concerning comparative rates of acclimation to temperature change for a given species over its biokinetic range.

In order to explore further the problem of rates of temperature acclimation, a series of experiments was designed to investigate the rate of change of heat-tolerance for different levels of temperature change from 4°C. up to 28°C. in goldfish, *Carassius auratus* (L.). This species of fish was chosen for experimental tests because of the ease in handling when in captivity and also because of the work on temperature tolerance already described by Fry, Brett, and Clawson (1942) for goldfish.

In any study of rate of acclimation to temperature change, primarily, the thermal history of the species to be considered must be known and established, then the resistance to either a high or a low temperature (heat-tolerance or cold-tolerance) may be followed while moving either up or down the temperature scale. Any combination of temperature changes within the lethal limits may be used. The possible variations in approach to the problem are therefore considerable and, in some measure, account for the difficulty experienced when comparing the results of different investigators.

This paper, in addition to describing experiments on the goldfish, also reviews information presented on rates of acclimation in certain of the publications already mentioned. The liberty has been taken to present pertinent data and figures from these in an effort to illustrate the complexity yet to clarify the field.

The laboratory equipment necessary to carry out these experiments was provided by the Ontario Fisheries Research Laboratory under the direction of Professor W. J. K. Harkness to whom I am greatly indebted both for the facilities extended and also for criticism of the manuscript.

EXPERIMENTAL PROCEDURE

The experiments on rate of change of heat tolerance in goldfish were designed to obtain the rate of acclimation for equal changes in environmental temperature for different levels of temperature acclimation. Three different groups of fish were individually acclimated to one of 4°C., 12°C., and 20°C. Having established complete acclimation at each of these levels experimentally the rate of change of heat-tolerance for an upward change of 8°C. in environmental temperature was traced. Thus, the 4°C. group was moved to 12°C., the 12°C. group to 20°C., and the 20°C. group to 28°C.

The method employed in this investigation for following the rate of acclimation to each new level was that originally used by Loeb and Wasteneys (1912). This is done by tracing the change in the average rate of mortality at a given high temperature until no change in the rate is obtained.

In practice, by studying the lethal temperature relations for different states of acclimation a given temperature can be picked at which mortality is fast at the start of an experiment on rate of acclimation, but which does not cause any mortality, or at most very slight mortality, when adaptation is complete. An example of this may be had from the first experiment on goldfish in which fish from 4°C. were moved to 12°C. The respective lethal temperatures for these two states of acclimation are 28.5°C. and 31.8°C. From the definition of lethal temperature, 50 per cent of a sample of 12°C. acclimated goldfish would die in twelve hours if exposed to a temperature of 31.8°C. This then is too high for a test temperature on rate of acclimation and a temperature previously referred to as "critical" temperature (Brett, 1944) must be selected, the latter being usually about 1.5°C. below the lethal temperature and one at which there is only a questionable likelihood of mortality.

The two lethal temperature curves for goldfish acclimated to the above temperatures (4°C. and 12°C.) have been plotted in figure 1 from the work of Fry *et al.* (1942) with the lethal and critical temperatures indicated. As acclimation proceeds, the percentage survival increases in the direction of the arrow and the mortality curve metaphorically progresses across the page to assume that for the higher state of temperature adaptation.

Although "percentage survival" has been used in the case of determining lethal temperatures, as in figure 1, almost similar type curves would be obtained by using the "average survival time." The distinction and use of these two have been discussed by Brett (1941). Since the latter best describes the data by utilizing the actual time of death of each fish, it has been employed in tracing the rate of acclimation to temperature change.

RESULTS

Three hundred goldfish which had been maintained for over two months at between 4°C. and 5°C. and which averaged 3.3 grams in weight were used in the three series of experiments. The thermal histories and data pertaining to the rate of acclimation for each of these groups are contained in tables 1, 2, and 3 respectively.

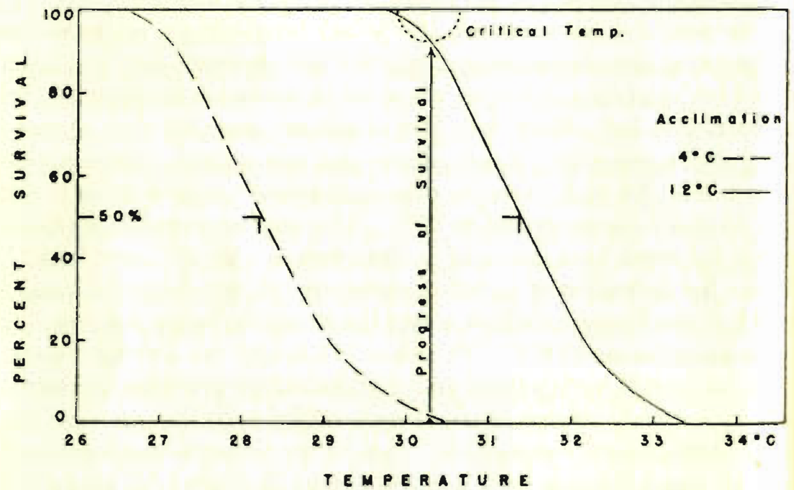

FIGURE 1.—Typical lethal temperature curves for goldfish acclimated to 4°C. and 12°C. The arrow marked "Progress of Survival" indicates the change in survival at 30.3°C. of goldfish when moved from an acclimation temperature of 4°C. to one of 12°C.

Group 1 which were moved from 4°C. to 12°C. were tested for rate of acclimation by tracing the extent and time of mortality of a sample of fish at 30.3°C. The first real indication of a change in heat-tolerance (increase) came between the seventh and eighth days and the latter continued to change steadily until about the twentieth day when acclimation to 12°C. was virtually complete (figure 2, table 1).

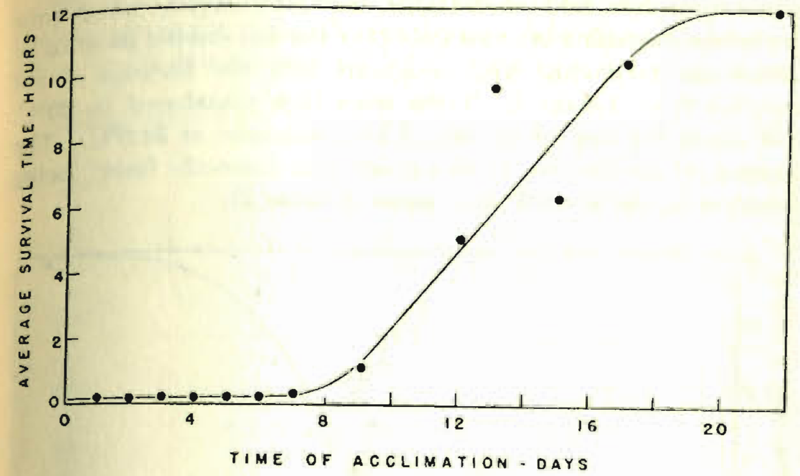

FIGURE 2.—The average survival time at 30.3°C. of goldfish when taken from 4°C. and put at 12°C.

TABLE 1.—Rate of gain of heat-tolerance in Group I.
Previous thermal history: 4-5°C. for 2 + months

Number of fish	Number of days at 12°C.	Average survival time at 30.3°C. in hours	Number dead at end of 12 hours
6	1	0.1	6
6	2	0.1	6
5	3	0.25	5
6	4	0.20	6
6	5	0.20	6
6	6	0.25	6
6	7	0.33	6
4	9	1.1	4
5	12	5.0	3
5	13	9.6	1
6	15	6.3	3
5	17	10.4	1
4	22	12.0	0

Group 2 were held at 12°C. for twenty-six days at which time preliminary experiments on a sample of ten fish showed them to be completely acclimated and in accord with the findings of the experiment on Group 1. These were then transferred to 20°C. and tested for rate of change of heat-tolerance at 34.0°C. The progress of acclimation in this group was distinctly faster, being complete by the seventh day (figure 3, table 2).

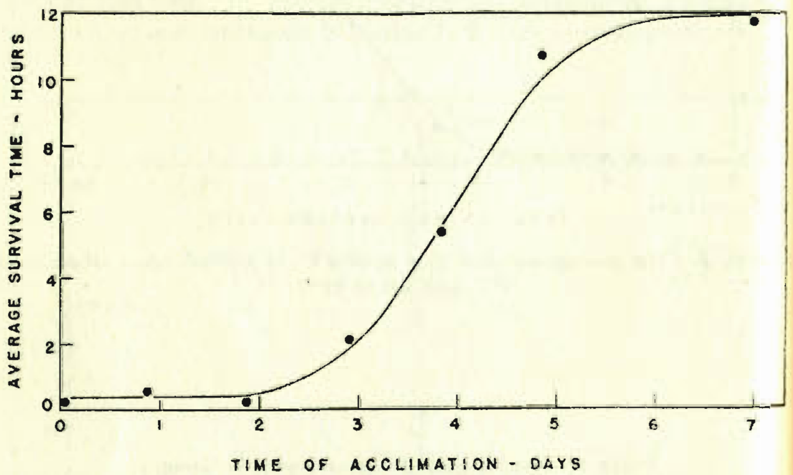

FIGURE 3.—The average survival time at 34.0°C. of goldfish when taken from 12°C. and put at 20°C.

TABLE 2.—Rate of gain of heat-tolerance in Group 2.
Previous thermal history: 1st—4-5°C. for 2 + months
2nd—12°C. for 26 days

Number of fish	Number of hours at 20°C.	Average survival time at 34°C. in hours	Number dead at end of 12 hours
10	0.0	0.1	10
10	20.0	0.25	10
10	44.0	0.10	10
6	68.5	2.1	5
7	91.5	5.4	4
7	115.5	10.7	1
10	168.0	11.7	1

The final group, *Group 3*, having been first held at an intermediate temperature of 13°C. for ten days were then transferred to their "base" temperature of 20°C. for a period of two weeks.

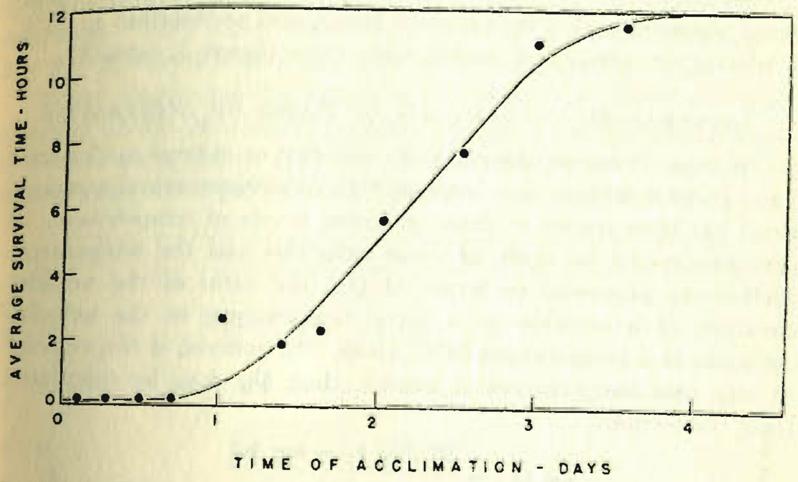

FIGURE 4.—The average survival time at 37.0°C. of goldfish when taken from 20°C. and put at 28°C.

TABLE 3.—Rate of gain of heat-tolerance in Group 3.
Previous thermal history: 1st—4-5°C. for 2 + months.
2nd—13°C. for 10 days.
3rd—20°C. for 14 days.

Number of fish	Number of hours at 28°C.	Average survival time at 37°C. in hours	Number dead at end of 12 hours
10	3	0.1	10
10	7	0.1	10
3	12	0.2	3
3	16	0.2	3
10	23	2.6	10
14	34	1.8	13
10	40	2.2	9
13	49	5.6	10
13	61	7.6	6
10	71.5	11.1	1
8	85	11.5	1

following which the experiment on acclimation rate (from 20°C. to 28°C.) was performed at the critical temperature of 37.0°C. In accordance with previous results at higher levels of temperature change the rate of adaptation was relatively fast, a definite change being obtained within twenty-four hours, and acclimation to 28°C. bordering on completion within three days (figure 4, table 3).

TEMPERATURE COEFFICIENTS OF RATES OF ACCLIMATION

In these three experiments the velocity or rate of acclimation for a given condition (a change of 8°C. in environmental temperature) has been traced at three different levels of temperature. A comparison can be made of these velocities and the temperature coefficients expressed in terms of Q_{10}, the ratio of the velocity constant of a reaction at a given temperature to the velocity constant at a temperature 10°C. lower. In general, if the velocity at any two temperatures is known, then Q_{10} may be calculated from the formula

$$\log Q_{10} = \frac{10\,(\log k_1 - \log k_2)}{t_1 - t_2}$$

in which k_1 and k_2 are the velocity constants at temperatures t_1 and t_2.

A problem is at once presented concerning the velocity of the acclimation. The manifest result of the reaction, as tested in the manner described, expresses the velocity in terms of progressive resistance to a given high temperature, the rate of this progressive resistance not being constant, but rather the reverse. At first there is no apparent change in the resistance. Then there follows an increase in resistance, the path of which traces out a sigmoid curve, yet it cannot be said that in the first phases of the reaction that acclimation is not taking place. To avoid difficulties in such a comparison, the over-all or average velocity has been considered for the time from the start to the finish of acclimation. Figure 5 illustrates the difference in rate of acclimation for the three groups when plotted for common axes, the point of completion of each acclimation being marked by small arrows.

The Q_{10} values listed in table 4 average approximately 3.0 which is comparatively high in view of the fact that most biological

reactions usually fall *between* 2 and 3. This indicates a process which increases relatively rapidly with increase of temperature.

A factor of interest in this comparative study of rates of change in heat-tolerance is the "latent period" preceding the initial rise in tolerance. This latter was found to be in a geometric series of 1 : 3 : 9, indicated in figure 5 by a "V" and listed in table 4.

What constitutes the nature of the underlying process or processes in acclimation to temperature change is not within the scope of these experiments. However, a hint with regard to one of the factors relative to gain of heat-tolerance was obtained while con-

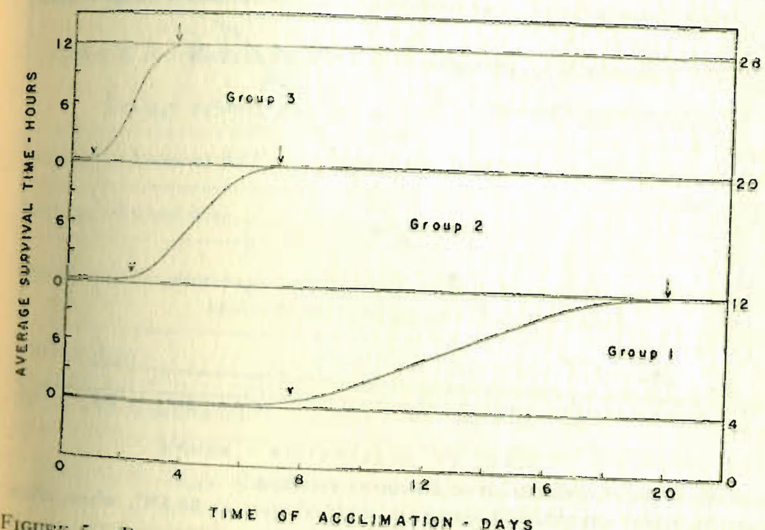

FIGURE 5.—Rate of gain of heat-tolerance for the three groups of goldfish. Arrows indicate point of completion while "V"s mark upward inflection from "latent period."

TABLE 4.—Temperate coefficients, Q_{10}, of rates of acclimation and "latent periods" compared.

Groups compared	Q_{10} value	Latent period ratio (hours)
3:2	2.1	20:58 = .3
2:1	4.0	58:180 = .3
3:1	3.0	20:180 = .9

ducting experiments on the bullhead (Brett, 1944). In the course of these experiments it was discovered that a continuous low oxygen saturation of the water in the acclimation tank (the second or new level of temperature) inhibited temperature acclimation for this species up to twenty-three hours at least. Figure 6 illustrates the results of an experiment done under conditions of low oxygen in the acclimation tank only, and shows the distinct lack of acclimation in comparison with that for conditions of adequate oxygen saturation. In table 5 the results of these experiments are presented with a record of the oxygen determinations (Winkler method).

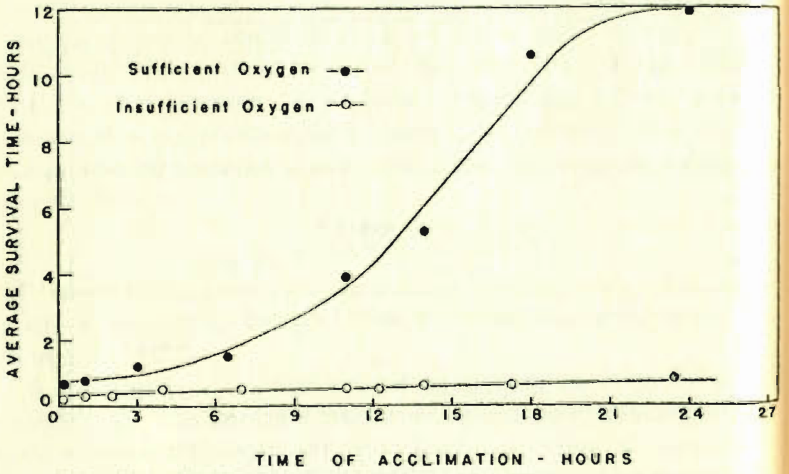

FIGURE 6.—Rate of acclimation of *Ameiurus nebulosus*.
(1) Sufficient oxygen. The average survival time at 35.5°C. when taken from 20°C. and put at 28°C.
(2) Insufficient oxygen. The average survival time at 35.0°C. when taken from 17°C. and put at 27°C.

From this limited series of experiments it seems apparent that oxygen plays some role in the mechanism of acclimation to a high temperature, but confirmatory evidence is necessary before weight can be put on this finding.

COMPARATIVE RATES OF ACCLIMATION

Difficulty is immediately experienced in any attempt to compare rates of acclimation among different species of fish for there has

been no common factor, either in the method of approach or experimentation, or in the range and level of temperatures used. With the exception of one or two cases direct comparisons cannot be made; nevertheless some generalities can be set forth from the data available.

In planning the temperatures for the goldfish experiments, those for group 3 were set at 20°C. and 28°C. since in previous work with bullheads (Brett, 1944) this range had already been used and direct comparison was therefore afforded. The data and graphical plots for these two experiments are presented in figures 4 and 6, and tables 3 and 5.

TABLE 5, A.—Rate of acclimation of *Ameiurus nebulosus* when taken from water of 20°C. and put at 28°C.
Average survival time in hours of 10 fish determined at 35.5°C.

Number of hours at 28°C.	0.0	1.0	3.0	6.5	11.0	14.0	18.0	24.0
Average survival time	0.7	0.8	1.2	1.5	3.9	5.3	10.6	11.9

Record of the percentage saturation of oxygen in the water of the acclimation tank—determined by the Winkler method.

Time in hours	0.0	1.0	3.0	6.0	11.0	18.0
Percentage of saturation	74	72	72	64	68	74

TABLE 5, B.—Rate of acclimation of *Ameiurus nebulosus* when taken from water of 17°C. and put at 27°C.
Average survival time in hours of 10 fish determined at 35.0°C.

Number of hours at 27°C.	0.0	1.0	2.0	4.0	7.0	11.0	12.2	14.0	17.2	22.5
Average survival time	0.2	0.3	0.3	0.5	0.5	0.5	0.5	0.6	0.6	0.8

Record of the percentage saturation of oxygen in the water of the acclimation tank—determined by the Winkler method.

Time in hours	0.0	10.0	13.0	16.0	19.0	22.0	24.0
Percentage saturation	7	6	2	13	18	23	26

The first point necessary for comparison is the establishment of the respective acclimations of these two species to the base temperature of 20°C. In both cases the lethal temperature indicated an acclimation to this temperature. It must not be thought, however, that this in itself is sufficient, although no further effort was made in this case to have the fish on a more comparable basis. The thermal histories of the two species were entirely different up to the time of being held at 20°C. In the case of the goldfish it was a question of waiting until the acclimation had risen up to the necessary level, not, as in the case of the bullhead, where it was a matter of lowering the environmental temperature to 20°C. Thus they approached the common state from opposite directions, and it is with this reservation in mind that a comparison is made.

The one striking difference, although both rates are comparatively fast, is that the bullhead reaches complete acclimation in about one-third the time required for the goldfish. There appears to be little or no "latent period" for the bullhead while that for the goldfish amounts to nearly seventeen hours. The two species were found to be very hardy and almost equally tolerant to high temperatures (Fry *et al*, 1942; Brett, 1944), the goldfish being the more resistant of the two. Here, then, was a marked difference in temperature response in contrast to the previous similarity.

Doudoroff (1942) reports that the rate of change of heat-tolerance with an acclimation change of 14°C. to 26°C. in the greenfish, *Girella nigricans*, is very rapid, acclimation being apparently complete after about one day.

As previously referred to, comparatively rapid rates of acclimation with respect to heat-tolerance in the upper levels of temperature resistance were found to be true for the common mummichog, *Fundulus heteroclitus* (Loeb and Wastenays, 1912) in which it was discovered that the duration of life at 31°C. when moved from a temperature of 20°C. (reported as room temperature) to 27°C. was extended from thirteen minutes at zero time to an indefinite period by seventy-two hours. This rate was therefore more similar to that for the goldfish than the relatively faster rate of the bullhead.

In tracing the course of temperature acclimation and changes in respiratory metabolism of the long-jawed goby, *Gillichthys mirabilis*, for temperature changes of 10°C. (20°C. to 30°C.) Sumner and Doudoroff (1938) obtained results which indicated a completion of acclimation for this species in approximately twenty-four hours and consequently in the class of rapidity with the bullhead.

In general it can be said for upward changes of temperature acclimation, in the region of 20°C. and above, that the rate of adaptation is rapid, the completion of acclimation with respect to heat-tolerance for a change of 8°C. to 10°C. usually taking place within one to three days, depending on the species concerned.

From the results with goldfish, for upward changes of temperature in the region of 10°C., the rate is markedly depressed and is progressively slower the lower the range of temperature change, necessitating a period of time up to twenty days or more for completion of acclimation.

RATE OF LOSS OF HEAT-TOLERANCE

Rate of loss of heat-tolerance might otherwise be expressed as rate of acclimation to a low temperature in terms of tolerance to a high temperature. With the exception of slight and scattered information which is in no way conclusive, the only data available for this field of acclimation rate in fishes are those for *Girella nigricans* (Doudoroff, 1942) and *Pimephales promelas* (Brett, 1944). Each of these, for approximately the same change in temperature conditions, 26°C. to 14°C. for *G. nigricans* and 24°C. to 16°C. for *P. promelas*, exhibits a slow loss in ability to resist a high temperature, a period of twenty or more days being required for the completion of the reaction.

RATE OF CHANGE OF COLD-TOLERANCE

In contrast to tracing rate of acclimation to a low temperature by the above method, change in acclimation might be followed by tracing the rate of change (gain) in cold-tolerance (as opposed to loss of heat-tolerance).

To complete the picture, there remains one other field, the rate of change of cold-tolerance (loss) when moving *upward* in the temperature scale. This also completes the four basic rates of acclimation to temperature which for clarity are listed as:—(1) Rate of gain of heat-tolerance (moving upward in temperature scale); (2) rate of loss of heat-tolerance (moving downward in temperature scale); (3) rate of gain of cold-tolerance (moving downward in temperature scale); (4) rate of loss of cold-tolerance (moving upward in temperature scale).

With regard to the last two, under the general heading of rate of change of cold-tolerance, Doudoroff (1942) states: "Changes of cold-tolerance, resulting from continued exposure to high and low temperatures, have been observed in fishes by Wells (1935) and Sumner and Doudoroff (1938), but accurate quantitative studies of their magnitude were not undertaken. There is also surprisingly little information available regarding the effect of recent thermal history upon susceptibility to chilling in other animals." From the results of experiments described in Doudoroff's paper for *G. nigricans* it might be concluded that both the rate of gain and the rate of loss of cold-tolerance are relatively slow. At least twenty days, probably more, are required for completetion of the acclimation when moving either from 26°C. to 14°C. or the reverse.

Perhaps one of the reasons for the lack of information on changes in cold-tolerance in fishes is the problem of working with temperatures low enough to be lethal. *G. nigricans* is admirably suited to such an experiment by reason of its intolerance to low temperatures. This is far from the truth for *A. nebulosus* in which acclimations below 22°C. would require temperatures below 0°C. to be lethal. The difference in lower lethal temperature for these two species when acclimated to the same temperature is considerably more marked than the difference in their upper lethal temperatures (Brett, 1944).

Particular caution must be exercised when working with the rate of change of heat-tolerance for it has been shown (Fry *et al.*, 1942; Brett, 1944) that after a certain temperature has been reached, although the temperature of acclimation may be raised, the upper lethal temperature, or heat-tolerance, does not alter. Thus, no acclimation would apparently take place if traced by heat-tolerance in this zone; it would, however, be apparent if followed by the index of cold-tolerance since the latter changes progressively up to the highest state of temperature acclimation. To avoid such a possible pitfall it is most necessary that the relation of lethal and acclimation temperatures be known for a given species of fish before undertaking a study of rates of acclimation for that species.

DISCUSSION

Different phases of rate of acclimation to temperature change have been demonstrated and in one case, the rate of change of heat-tolerance for ascending temperature conditions, account has been taken of the level of temperature change within the lethal limits for a given species. Although the temperature changes in this instance included a range from 4°C. to 28°C., the extent of change in each case was exactly 8°C. which provides no evidence for acclimation rates of lesser extent, in the realm of 1°C. to 3°C., which are more characteristic of the fluctuating conditions in a natural state. Thus, on top of each of the four basic conditions must also be imposed these other two variables, level of temperature and extent of temperature change, before the field of study is complete.

Doudoroff (1942) when considering the rate of change of cold-tolerance, varied the conditions of his experiments to include temperature changes of 12°C. (14°C. to 26°C. and 26°C. to 14°C.) and 6°C. (14°C. to 20°C. and 20°C. to 14°C.) from the results of which he concludes that the rate of change in cold-tolerance (gain or loss) "in any given time does not vary greatly with the direction or the magnitude of the total change." A general statement that the rate of change in cold tolerance is a comparatively slow one, no matter what the varying conditions of temperature are, might be made, contrasting greatly with the conditions found to be true for rate of change in heat-tolerance.

Figure 7 has been composed from this accumulated information to illustrate the general picture of rate of acclimation to temperature change, showing the rate of change in heat-tolerance (gain and loss) and the rate of change in cold-tolerance (loss and gain) with ascending and descending temperatures. The graphs are all repetitions of those already discussed or published and are here presented, plotted on similarly divided time axes. The two curves on rate of acclimation pictured in graph "A" are those for the goldfish when moved from 4°C. to 12°C. and 20°C. to 28°C. from data presented in this paper (cf. figures 2 and 4). Graph "B" traces the rate of loss of heat-tolerance for the fathead minnow when moved from 24°C. to 16°C. (Brett, 1944) while graphs "C" and "D" are each plotted from data published by Doudoroff (1942) on changes in cold-tolerance of the greenfish for changes in environmental temperature of 14°C. to 26°C. and 26°C. to 14°C.

In 1941 experiments were performed to follow the seasonal variation in lethal temperature for different species of fish from lakes in Algonquin Park, Ontario (Brett, 1944). In each case the lethal temperature variations were found to be reflected by the major temperature changes of the lake water and a direct correlation was made. The most complete study was that of the bullhead for which the relation between natural lake water acclimations and maximum recorded lake temperatures was demonstrated, an

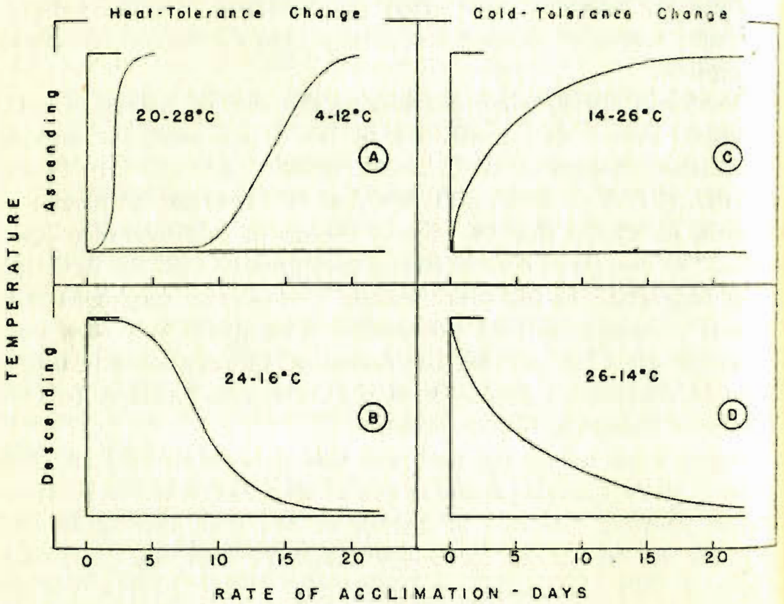

FIGURE 7.—The four basic rates of acclimation to temperature. Heat-tolerance changes determined as average survival times; cold-tolerance changes determined as twenty-four hour lower median tolerance limit. Level of temperature change marked for each curve.

A. Gain of heat-tolerance for *Carassius auratus* (present paper).
B. Loss of heat-tolerance for *Ameiurus nebulosus* (Brett, 1944).
C. Gain of cold-tolerance for *Girella nigricans* (Doudoroff, 1942).
D. Loss of cold-tolerance for *Girella nigricans* (Doudoroff, 1942).

illustration of this being included in figure 8. The relation as it exists in nature may now be further interpreted on the basis of the information presented in this paper and some conception of the natural state obtained through the experimental approach.

It was found (table 6) that in the early part of the season, following the ice break-up, the maximum recorded temperatures

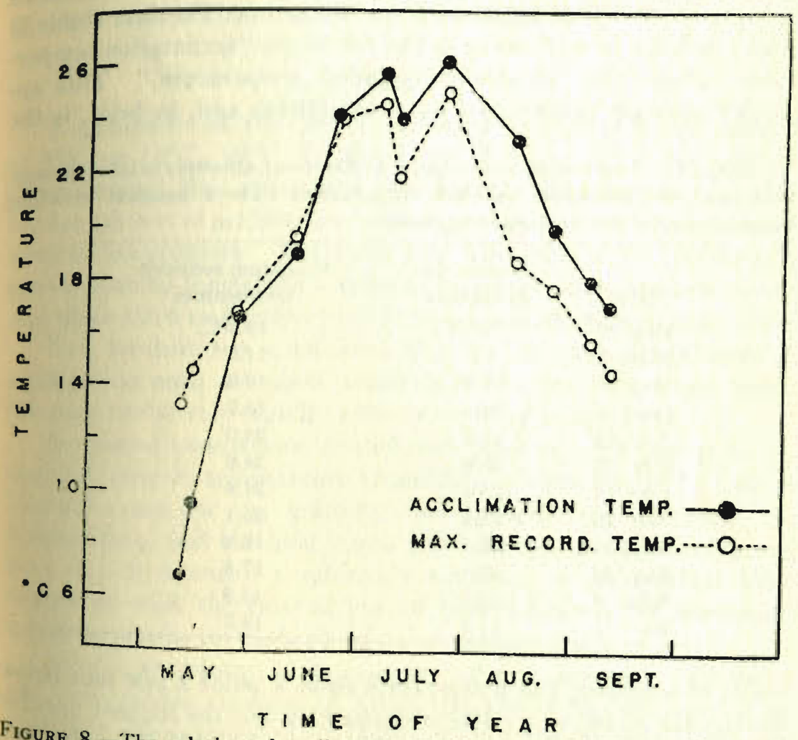

FIGURE 8.—The relation of acclimation temperature and corresponding maximum recorded temperature for *Ameiurus nebulosus*, lake Opeongo, 1941.

(region of 14°C.) were considerably above the acclimation state of the fish, which lagged behind the former by as much as 6°C. Nearly a month after the ice-break-up the maximum recorded and acclimation temperatures became equal (approximately 17°C.) and remained as such for two weeks or more despite the very rapid and continued rise in lake temperature.

From the experimental evidence this could be explained by the slow rate of acclimation (gain in heat-tolerance) for the lower temperature levels, the velocity of which was not sufficient to keep pace with the ascent of environmental temperature. As the environmental temperature continued to rise an acceleration in the progress of the acclimation took place until the rate was sufficient to bring about a close approximation of the two. The data (table 6) might perhaps be misleading in the rise of the "acclimation temperature" above the "maximum recorded temperature." This apparent anomaly is discussed by Brett (1944) and, in brief, is the

TABLE 6.—Acclimation temperatures of *Ameiurus nebulosus* in lake Opeongo, 1941, and the maximum recorded temperatures from a constant recording thermometer for the corresponding dates.

Date	Acclimation temperature	Maximum recorded temperature
May 12	6.9°C.	13.3°C.
May 15	9.6	14.6
May 28	16.6	16.8
June 14	19.1	19.7
June 25	24.2	24.0
July 8	25.8	24.6
July 12	25.0	21.8
July 25	26.3	25.1
Aug. 15	23.4	18.8
Aug. 26	20.0	17.8
Sept. 6	18.1	15.9
Sept. 11	17.2	14.7

result of recording the temperature from a point a few feet below the surface of the water and consequently not the highest possible temperature to which the fish might be subjected through short excursions to the surface.

Having once become acclimated to this higher level of temperature, cold spells of relatively short duration in the lake water were reflected only by slow and small changes in the acclimation temperature until the continuous descent of lake temperature toward the fall freeze-up brought about a similar continuous fall in acclimation temperature, this latter lagging behind and above the former by a time interval of two to three weeks.

In view of the latent period of response in the falling off of heat-tolerance shown in the experiment on the fathead minnow (Brett, 1944) and the slow rate of acclimation of that species, it might be inferred that the same was true for the bullhead and that an explanation could therefore be made of the response in nature on the basis of a slow loss in acclimation at all levels of temperature; thus the two to three weeks' lag in acclimation.

SUMMARY

Experiments on the rate of acclimation to temperature changes of 4°C. to 12°C., 12°C. to 20°C., and 20°C. to 28°C. for goldfish demonstrated that there was considerable difference in the time for completion of acclimation with respect to heat-tolerance at each level of temperature. The three separate steps of 8°C. increase in environmental temperature required approximately twenty, seven, and three days respectively for complete acclimation to take place.

The temperature coefficient, Q_{10}, for the velocity change in acclimation rate averaged about 3, indicating a process which increased relatively rapidly with increase of temperature.

A general comparison of different rates of acclimation for an upward jump in temperature (from 20°C.) when traced by gain in heat-tolerance for the goldfish, the bullhead, the greenfish, the mummichog, and the long-jawed goby showed distinct variations, but, on the average, a relatively fast rate of acclimation when compared with the rate of loss of heat-tolerance for descending temperatures in the fathead minnow and greenfish.

From a knowledge of the various rates of acclimation for different temperature changes an interpretation of the changes in acclimation temperature of the bullhead from May to September, lake Opeongo, 1941, has been set forth in an analysis of a natural phenomenon.

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