

INFLUENCE OF TEMPERATURE AND SALINITY ON SURVIVAL OF THE FRESHWATER MULLET, *RHINOMUGIL CORSULA* (HAMILTON)

M.N. KUTTY*, N. SUKUMARAN* and H.M. KASIM**

*Fisheries College, Tamil Nadu Agricultural University, Tuticorin 628003 (India)

**Central Marine Fisheries Research Institute, Cochin 682018 (India)

(Accepted 7 November 1979)

ABSTRACT

Kutty, M.N., Sukumaran, N. and Kasim, H.M., 1980. Influence of temperature and salinity on survival of the freshwater mullet, *Rhinomugil corsula* (Hamilton). *Aquaculture*, 20: 261–274.

The upper incipient lethal temperatures of the freshwater mullet, *Rhinomugil corsula*, acclimated to 15, 20, 25, 30 and 35°C in fresh water, were 32.4, 34.1, 36.0, 36.2 and 36.5°C respectively, and the corresponding lower lethal temperatures were 10.5, 11.5, 13.2, 15.8 and 19.5°C. The mullet has a total tolerance (area of thermal polygon) of 569°C with an upper and lower thermal tolerance of 253 and 316°C². Likewise, the total resistance of the mullet was 391°C², with upper and lower resistance zones of 181 and 210°C respectively. The upper critical temperatures of swimming inhibition of *R. corsula* (17.2 cm; acclimation 30°C), determined in a swimming tunnel, were 35.2, 34.6 and 34.2 for water current velocities of 38, 62 and 77 cm s⁻¹ respectively. The corresponding lower critical temperatures were 26.2, 27.5 and 28.1°C. These results indicated the stenothermal nature of the mullet by comparison with other fishes, e.g. *Tilapia mosambica*.

In tests on the influence of ambient salinity on thermal resistance, *R. corsula* survived longest at 7‰ (iso-osmotic salinity). At salinities above and below this point, survival times were shorter at any lethal temperature. In a tentative scheme for quantification of stress due to temperature and salinity at death (after acclimation to 30°C and tested at 37°C), the hypo-osmotic and hyper-osmotic stress were estimated to be 50 and 31% of the thermal stress (100%) respectively.

INTRODUCTION

Temperature regulates survival through both lethal and controlling factors. It influences metabolism and thereby growth and production potential, and it is also a directive factor influencing thermal preference (Fry, 1947, 1971). An ecological factor which often interacts with temperature, influencing the survival of fish, is salinity. In the present study lethal temperature and resistance times at upper and lower thermal extremes, and at certain temperature–salinity combinations, were investigated for the freshwater mullet, *Rhinomugil corsula* (Hamilton). Certain behavioural responses which influence

the survival of the fish at the thermal extremes were also studied. The present investigation is a part of a larger study of comparative tolerance of fry and fingerlings of selected freshwater fishes to temperature and salinity extremes. The result of this study will be useful in improving culture practices for tropical fishes.

MATERIAL AND METHOD

The mullet, *Rhinomugil corsula*, were obtained from Vaigai Reservoir near Madurai, Tamil Nadu, India. Unless otherwise specified, the fish were acclimated to the conditions under test for at least one week before the experiments were begun.

RESULTS AND DISCUSSION

Influence of temperature

Resistance times at upper and lower incipient lethal temperatures of *R. corsula* (9.4 ± 1.8 cm in length and 7.2 ± 4.2 g in weight) were studied following the methods described by Fry et al. (1942), Brett (1952), and Ananthakrishnan and Kutty (1976). The individual facilities consisted of well aerated, insulated aquaria, each provided with a thermostat. Groups of ten fish were acclimated to specific temperatures and transferred to the test tanks. The times of death of individual fish were recorded over a maximum period of one week (10,000 minutes).

Data on times to death of individual freshwater mullet acclimated to five different temperatures (15–35°C) and exposed to various high lethal temperatures from 32 to 42°C were obtained. As an example of the results, the data for 35°C acclimation, and tested at various temperatures (36.5–42°C), are shown graphically in Fig. 1.

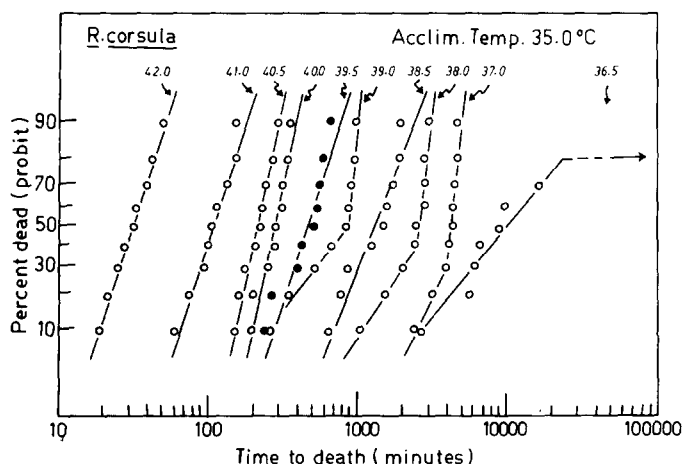


Fig. 1. Times to death at different high lethal test temperatures for mullet fingerlings acclimated to 35°C.

Median resistance times (time to 50% death) estimated from the probit curves of high lethal temperatures from 32 to 42°C for the five acclimations are summarised and illustrated in a semi-logarithmic grid (Fig. 2). The regression lines have been fitted through the plots in Fig. 2 for the five acclimation series according to equations given in Table I. Upper incipient lethal temperatures, i.e. temperature at which 50% of exposed fish would live indefinitely (Fry et al., 1942; Brett, 1952), were estimated according to the method described by Miller and Tainter (1944). The values for the species are 32.4,

TABLE I

Formulae for the regression lines describing the thermal resistance of *R. corsula* acclimated and tested to various temperatures (x is the temperature in °C; y is the log time in minutes)

Acclimation temp. (°C)	Upper	Lower
35.0	$y = 19.8178 - 0.4340x$	$y = -0.0125 + 0.1804x$
30.0	$y = 23.6483 - 0.5372x$	$y = -1.4160 + 0.3280x$
25.0	$y = 24.8173 - 0.5760x$	$y = -0.9090 + 0.3434x$
20.0	$y = 17.2835 - 0.3938x$	$y = -1.5533 + 0.4616x$
15.0	$y = 18.7382 - 0.4571x$	$y = -0.3002 + 0.3854x$

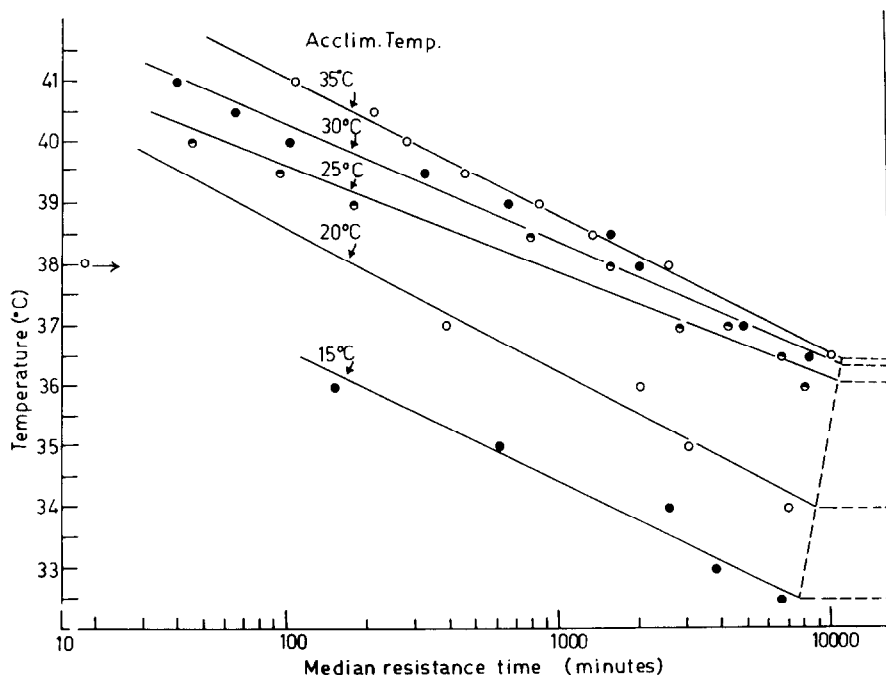


Fig. 2. Median resistance times to high temperatures for mullet fingerlings acclimated to temperatures indicated.

34.1, 36.0, 36.2, 36.5°C for the acclimations 15, 20, 25, 30 and 35°C respectively, and are shown in Fig. 2 as a broken boundary line which terminates the regression lines at the lower ends. This broken line differentiates the zone of tolerance from the resistance zone.

Similar studies on freshwater mullet acclimated to 15, 20, 25, 30 and 35°C, and exposed to low lethal temperatures ranging from 8.5 to 19.5°C were also conducted. The lower incipient lethal temperatures estimated for the upper series are 10.5, 11.5, 13.2, 15.8 and 19.5°C for the acclimations 15, 20, 25, 30 and 35°C respectively.

Thermal tolerance and resistance

Temperature responses of organisms are divisible into tolerance and resistance; quantified values of these two physiological parameters have been used to describe the thermal characteristics of several fishes by various workers (Fry et al., 1942, 1946; Doudoroff, 1942, 1945; Brett, 1944, 1952; Hart, 1952; Charlton, 1968; Ananthakrishnan and Kutty, 1976). Similar descriptions are presented for the mullet in Fig. 3. Plots of incipient lethal temperatures (tolerance limit), and temperatures at which immediate death takes place (resistance limit), are made against the respective acclimation temperatures. The zones of tolerance and resistance become outlined. The zone of thermal tolerance is bounded by upper and lower incipient lethal temperatures for the widest possible range of temperature acclimation and terminated by ultimate lethal temperatures. The zone of resistance is the area surrounding the zone of tolerance, bounded by upper and lower incipient lethal temperatures of immediate death as the outer boundary for both high and low temperatures. Further, the zones of resistance and tolerance can be divided into 'upper' and 'lower' zones of resistance and tolerance with the aid of the isotherm-line, which is constructed at an angle of 45° for both the axes (after McErlean et al., 1969) as shown in Fig. 3.

The areas of the zones of thermal tolerance and resistance, along with the thermal triangles (upper and lower thermal tolerance areas) in °C², were calculated for *Rhinomugil corsula*. The total tolerance area was estimated as 569°C², while the lower and upper tolerance areas were calculated to be 253°C² and 316°C² respectively. Similarly, the total area of the zone of resistance is 391°C², while the upper and lower zones of resistance are 181 and 210°C² respectively. The upper and lower ultimate lethal temperatures obtained from the thermal tolerance polygon (Fig. 3) are 36.3 and 9.0°C respectively.

Among the few tropical species subjected to the study of thermal responses (Allanson and Noble, 1964; Ananthakrishnan and Kutty, 1974, 1976; Ananthakrishnan and Srinivasan, 1977) the complete thermal requirement of the species to the level of 'zone of thermal tolerance' has not been calculated except for the studies on *Ophiocephalus punctatus* by Ananthakrishnan and Kutty (1976), and on mrigal, rohu, fringe-lipped carp and common carp

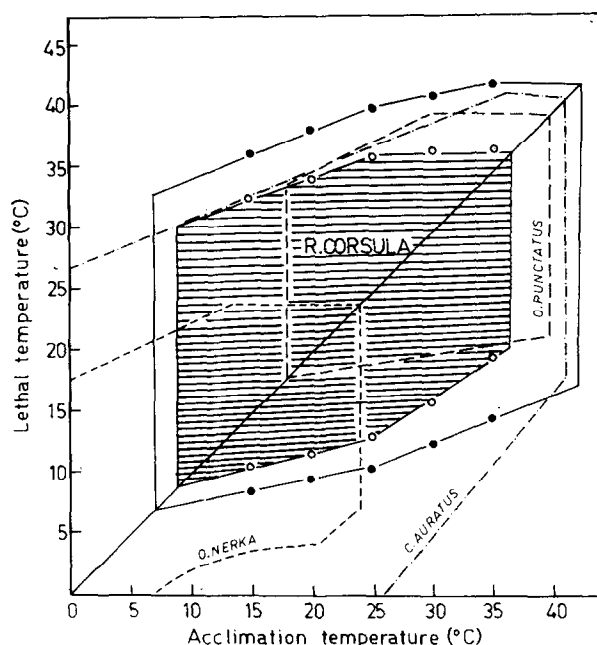


Fig. 3. Zones of thermal tolerance (hatched area) and resistance (polygon bounded by curve through closed circles) of *Rhinomugil corsula* in freshwater. The tolerance zones of *Carassius auratus* (from Fry et al., 1942), *Onchorhynchus nerka* (from Brett, 1952) and *Ophiocephalus punctatus* (from Ananthakrishnan and Kutty, 1976) are indicated for comparison.

fingerlings by Kasim (1978); the air breathing fish (*O. punctatus*) has a tolerance area of 410°C^2 , which is much less than that obtained for these fish ($812, 850, 731$ and 1075°C^2 respectively) and freshwater mullet (569°C^2) used in the present study. The available information on tropical species indicates that the eurythermal carps, namely mrigal, rohu, fringe-lipped carp and common carp, have a greater tolerance area than the stenothermal freshwater mullet and the air breather *O. punctatus*. Further, this comparison among the tropical species can be extended to include sub-tropical species such as *Carassius auratus* and temperate species such as *Onchorhynchus nerka* (Fig. 3). It is noteworthy that *R. corsula* like *O. nerka* and *O. punctatus* is stenothermal, but the cold water salmonid, *O. nerka* has its tolerance zone situated nearer to the low temperatures. Geography does not seem to have any direct relationship to the relative upper and lower thermal tolerance among the species, as shown by the data on subtropical goldfish and common carp in Kasim, 1978.

Thermal inhibition of swimming

The way a swimming fish stops swimming at the increase or decrease of temperature was tested for *Rhinomugil corsula* (17.2 ± 0.3 cm in length

and 43.0 ± 1.8 g in weight). Experimental procedures have been described by Kutty and Sukumaran (1975). The mullet was forced to swim in the tunnel apparatus of Blazka et al., 1960. The apparatus is a double cylinder unit having a capacity of 7.3 l and tunnel length of 28 cm. A fish introduced into the tunnel is forced to swim continuously at the desired current speed. The results were similar to those encountered for *T. mossambica* (Kutty and Sukumaran, 1975), and similar to the inhibition described for decreases in ambient oxygen (Kutty, 1968; Kutty and Saunders, 1973). At the approach of the critical temperature, the fish fall back in the tunnel. As soon as the thermal stress is released by bringing the ambient temperature back to the acclimation level, the fish swim regularly again. It is assumed that the swimming failure is a behavioural response and not a fatigue response. Since the failure to swim does not incapacitate the fish from further swimming, and the critical temperatures can be taken as points in a temperature gradient in running water, it is possible that these critical temperatures are avoidance temperatures under the specific conditions.

Behavioural responses of *R. corsula*, forced to swim in a current speed of 61 cm s^{-1} at temperatures above the acclimation level, are indicated in Fig. 4. This indicates the swimming failure at critical temperature, as shown by 'reverse' and 'grid touches'. If the temperature is raised above the critical level the fish might collapse, but the tests were not taken to this point. The average levels of stress factors concerned in the first consecutive grid touches are taken as the critical level of earlier studies.

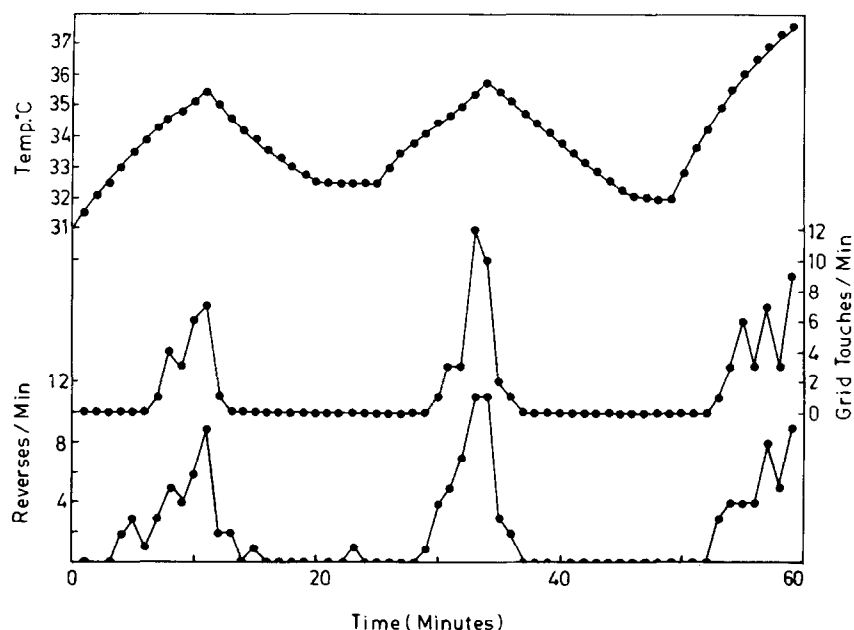


Fig. 4. Behavioural responses of *Rhinomugil corsula* in a current speed of 61 cm s^{-1} at temperatures above the acclimation level (30°C).

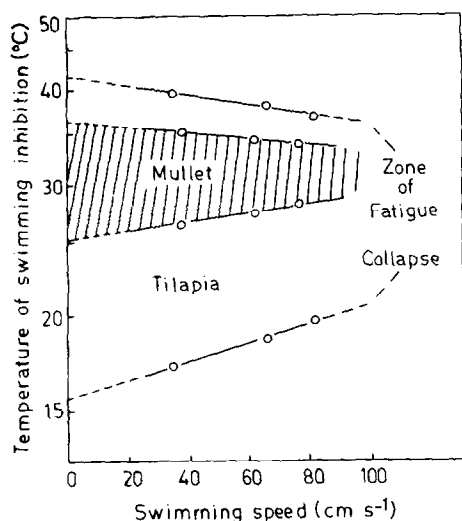


Fig. 5. Relation of temperature to swimming activity of *Tilapia mossambica* and *Rhinomugil corsula*, acclimated to 30°C.

The critical temperatures obtained for both upper and lower extremes for the freshwater mullet acclimated to 30°C are presented in Tables II and III. It is seen that the upper critical temperatures decrease with increase in swimming speed, and the lower critical temperatures increase at corresponding swimming speeds. The upper and lower critical temperatures of swimming inhibition of mullet are plotted against corresponding swimming speeds in Fig. 5. Similar data obtained for *T. mossambica* (Kutty and Sukumaran, 1975) are also presented in Fig. 5. It is evident that the mullet has a narrow zone of activity, when compared with that of *T. mossambica*. In both *R. corsula* and *T. mossambica*, the decrease in the upper critical temperature and the increase in lower critical temperature, narrowing the zone within which the fish is active and increasing the intensity of activity (Fig. 5), suggest an interaction of the two stress factors.

TABLE II

Upper critical temperatures of *Rhinomugil corsula* acclimated to 30°C and forced to swim at speeds indicated. 1, 2 and 3 are successive tests on individual fish. Data are means (\pm one standard error) of 3 determinations on separate fish

Swimming speed (cm s ⁻¹)	Temperature at which the fish failed to swim (°C)		
	1	2	3
38	35.2 \pm 0.21	35.3 \pm 0.14	35.6 \pm 0.10
62	34.6 \pm 0.24	34.8 \pm 0.14	35.2 \pm 0.04
77	34.2 \pm 0.12	34.4 \pm 0.28	34.7 \pm 0.31

TABLE III

Lower critical temperatures of *Rhinomugil corsula* acclimated to 30°C and forced to swim at speeds indicated. 1, 2 and 3 are successive tests on individual fish. Data shown are means (\pm one standard error) of 3 determinations on separate fish

Swimming speed (cm s ⁻¹)	Temperature at which the fish failed to swim (°C)		
	1	2	3
38	26.9 \pm 0.88	26.7 \pm 0.95	26.5 \pm 0.89
62	27.5 \pm 0.41	27.3 \pm 0.49	27.0 \pm 0.50
77	28.1 \pm 0.30	27.8 \pm 0.31	27.6 \pm 0.26

Since critical temperatures of swimming inhibition can be points in a thermal gradient in flowing water, differential distribution of fishes avoiding temperatures can be expected, as shown for the mullet and Tilapia in Fig. 6. It is assumed that ambient temperature changes at a rate of 1°C per 10 m from the source of the heated effluent, starting with an initial temperature of 41°C. *R. corsula* will be restricted to lower temperatures than *T. mossambica* in a current of water with a thermal gradient. For example, in Fig. 6, in a current of water at a velocity of 50 cm s⁻¹, *R. corsula* will fail to swim at 35°C and avoid high temperatures, while *T. mossambica* will do so only at 39°C. At a gradient of 1°C per 10 m, the upper thermal margins of distribution can be about 40 m apart, according to the assumptions made. The model is yet to be tested fully, but it is hoped that the present approach to understanding thermal inhibition of swimming and fish distribution in water currents by rheotactic avoidance (Kutty and Sukumaran, 1975) will be useful in studies on the effect of heated effluents.

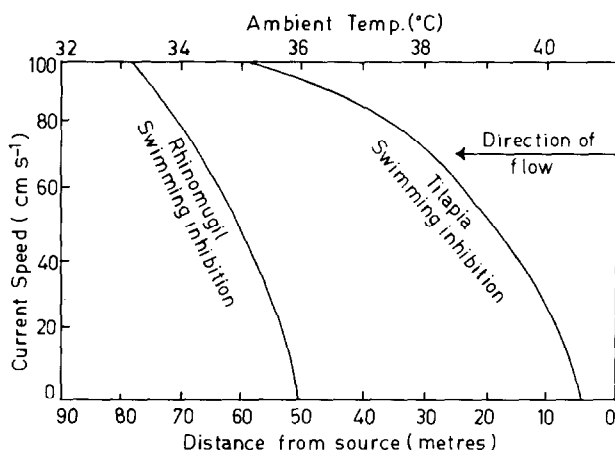


Fig. 6. Comparison of the thermal inhibition curves of *Tilapia mossambica* and *Rhinomugil corsula* acclimated to 30°C.

Salinity effect on thermal resistance

A study of salinity effects on thermal resistance was carried out using freshwater mullet acclimated to freshwater at 20, 25, 30 and 35°C, and tested at different salinities from freshwater to 25‰ at lethal temperatures, 37, 39 and 41°C. The data for mullet acclimated to 20°C exposed in groups to various salinities (freshwater, 3, 5, 7, 10, 12, 18, 20 and 25‰) at 37°C (lethal temperature) are shown in Fig. 7. The median resistance times of mullet exposed to 3, 5, 7, 10 and 12‰ are higher than that of the freshwater group; for those salinities above 12‰ the resistance times are lower than for freshwater.

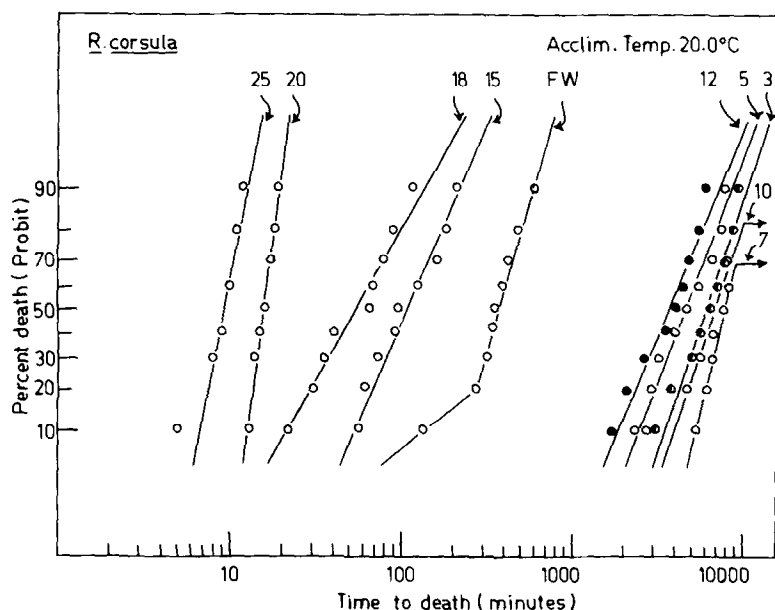


Fig. 7. Times to death in fresh and different salt water media at lethal test temperature 37°C for fingerlings acclimated to freshwater at 20°C.

The median resistance times obtained from the time—mortality curves for different lethal levels of salinity and temperatures at all four acclimation levels (20, 25, 30 and 35°C) are summarised in Table IV. The median resistance time increases as the salinity decreases to 7‰, and afterwards decreases at lower salinities. This indicates that the highest resistance to lethal temperature is exhibited by this species at 7‰.

The data on the median resistance time to lethal test temperatures (37°C and 39°C) in fresh and salt water media for mullet acclimated to 20° and 25°C respectively, are shown in Fig. 8A and B. It is significant that the curves (Fig. 8A and B) of the data obtained for acclimations 20 and 25 are bimodal, having peaks at 3 and 7‰. The cause of the bimodality and a dip in both the

TABLE IV

Median resistance times to death among fingerlings of freshwater mullet, *R. corsula*, acclimated and tested at different lethal temperature and salinity concentrations

Acclima- tion temp. (°C)	Test temp. (°C)	Median resistance times (minutes) and salinity (‰)									
		25	20	18	15	12	10	7	5	3	Fresh water
35	41	—	—	—	46	—	—	158	—	—	104
	39	—	—	—	700	—	—	930	—	—	840
	37	—	—	—	2380	—	—	4800	—	—	4250
30	41	—	—	—	31	—	—	53	—	—	38
	39	—	—	—	385	—	—	1475	—	—	640
	37	—	—	—	1880	—	—	5950	—	—	3000
25	39	—	14	—	90	470	780	870	570	660	175
20	37	9	16	53	105	3350	6680	7600	4500	6000	360

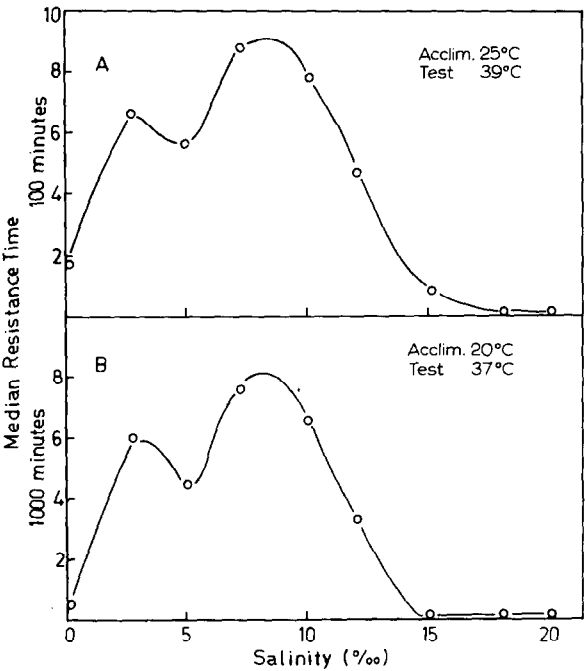


Fig. 8. Median resistance times in fresh and salt water media to (A) lethal test temperature of 39°C for mullet acclimated to freshwater at 25°C, and (B) lethal test temperature of 37°C for mullet acclimated at 20°C.

curves at 5‰, a salinity so close to isosmotic level, is not known. It is possible that some basic changes in ambient water at low salinity (5‰), such as a change in ionic ratio, could account for the abrupt decrease in the mortality time.

Median resistance times of *R. corsula* acclimated to freshwater at 30 and 35°C and tested at lethal temperatures of 37, 39 and 41°C and at various salinities, (freshwater, 7 and 15‰) are plotted in Fig. 9. While resistance time is always high at 7‰ (iso-osmotic level), acclimating to lower temperature (30°C) enables mullet to survive longer at the lower test temperatures than at the higher; and vice versa, as is obvious from results of 30°C and 35°C acclimations.

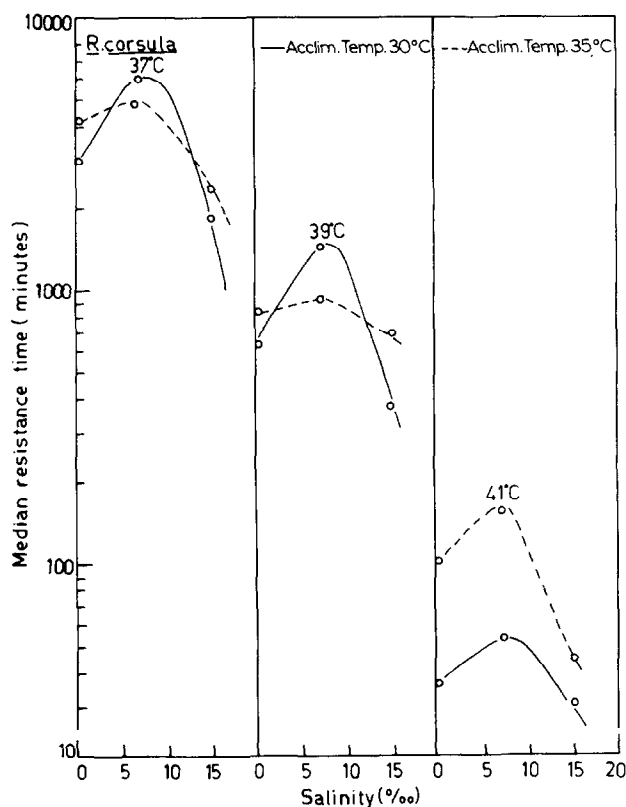


Fig. 9. Median resistance times to different lethal test temperatures (37, 39 and 41°C) in various salinities for fingerlings acclimated to freshwater at 30 and 35°C.

A tentative scheme for the relative stresses of lethal temperature and salinity is shown in Fig. 10. For example, data on resistance times of mullet acclimated to 30 and 35°C and tested at 37°C at different salinities (see Fig. 9), are illustrated in Fig. 10. It is assumed that lethal temperature contributes equal stress at all salinities, but stress of salinity increases as the medium

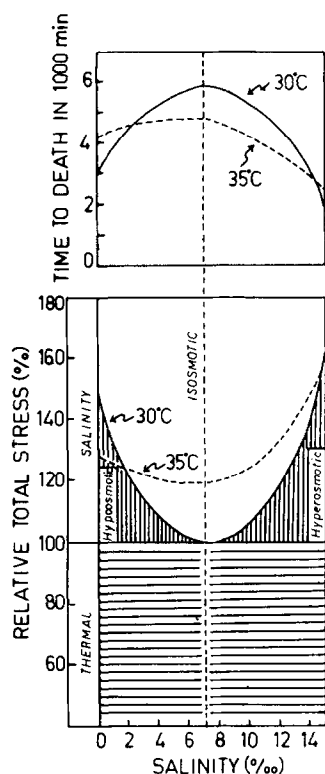


Fig. 10. Scheme of the relative stress contributed by lethal temperature and salinity of *R. corsula*, acclimated to freshwater at 30 and 35°C and tested at 37°C at different salinities. The data on the left panel in Fig. 9 are taken for illustration.

moves away from the iso-osmotic level (7‰). An attempt is made to quantify the relative stress values for salinity and temperature using resistance time as an index. The highest resistance at 7‰ is taken as base (100%), and percentage decreases in resistance time in fresh water and 15‰ are taken as relative increases in stress due to hypo-osmotic and hyper-osmotic conditions respectively. It is shown that, while temperature stress at 30°C remains at a base value of 100%, the hypo-osmotic and hyper-osmotic stresses contribute to 50 and 61% of total stress in *R. corsula* acclimated to fresh water and 30°C and tested at 37°C. Corresponding values for mullet acclimated to 35°C are also shown in Fig. 10. While these results agree in general with those for fish acclimated to 30°C, mullet acclimated to the higher temperature do not fare as well, as shown by the decreased resistance time at iso-osmotic level.

From Fig. 10 it is evident that *R. corsula* regulates better at hyper-osmotic levels than at hypo-osmotic. For example, from the tentative scheme on stress separation, the osmotic stress increases at the rate 7% per 1‰ at a salinity below iso-osmotic level, when the corresponding value for hyper-osmotic condition is estimated to be 4% per 1‰ S in *R. corsula* acclimated to 30°C when tested at 37°C.

CONCLUSIONS

The present study on the freshwater mullet emphasizes the thermal inter-relationships of the fish.

The data on thermal tolerance and resistance of *R. corsula* show that the mullet is a stenothermal fish and, in a comparative study with Indian carps and common carp, it appears that the mullet's thermal environment is restricted although its thermal resistance appears to be high. This inverse relationship of thermal tolerance and thermal resistance among fishes appears to be a general phenomenon (Fry, 1971).

The effects of temperature extremes on swimming behaviour are similar to those obtained for *Tilapia mossambica* under similar conditions (Kutty and Sukumaran, 1975). It appears that the pattern of swimming inhibition, the swimming failure at the approach of critical temperature, either high or low, is similar to that observed in exercised fish exposed to other stress conditions such as low oxygen (Kutty, 1968; Kutty and Saunders, 1973) and chemical pollutants (Rema Devi and Sukumaran, unpublished observations). Therefore, the whole complex of swimming inhibition, under the control of the central nervous system, may be responding in the same pattern to certain stimuli in the environment for any unfavorable stress condition in running water. It appears that fish can avoid running waters where unfavourable conditions prevail by failing to swim ahead at the critical point. The model of distribution of *R. corsula* and *T. mossambica* in running water with a temperature gradient is tentative, but it can perhaps be used to study this aspect more closely.

The present study on temperature inter-relationships of *R. corsula*, forms a part of a larger study for selected freshwater fishes. These observations will help studying the impacts of thermal pollution.

The influence of salinity was studied to determine any interaction between salinity and lethal temperature. Salinities below and above 7‰ caused a shortening of resistance time. The resistance time was used as an index of stress, assuming that the shorter the resistance time the greater the stress; we have attempted to separate quantitatively the stress due to temperature and salinity at the time of death. The concept is not new. Fry (1947) worked out a rate of death in fish based on values of thermal resistance times. Relative stresses due to various factors acting in combination can be estimated along the lines suggested, but interactions between two or more ecological factors can modify the effect of factors acting individually. It is recognized that several different physiological mechanisms are involved when more than one factor is acting on an organism, and these may be changing individually and in combination under different conditions of acclimation and under the experimental conditions themselves.

ACKNOWLEDGEMENTS

This study was conducted with the aid of a grant (Agreement No. 5) from the International Foundation for Science, Stockholm, Sweden.

REFERENCES

- Allanson, B.R. and Noble, R.G., 1964. The tolerance of *Tilapia mossambica* (Peters) to high temperature. Trans. Am. Fish. Soc., 93: 323-332.
- Ananthakrishnan, K.R. and Kutty, M.N., 1974. Mortality and breathing rate at high ambient temperatures in the cichlid fish, *Tilapia mossambica* (Peters). Indian J. Exp. Biol., 12: 55-59.
- Ananthakrishnan, K.R. and Kutty, M.N., 1976. Temperature tolerance of the air-breathing fish *Ophiocephalus punctatus*. Comp. Physiol. Ecol., 1: 18-22.
- Ananthakrishnan, K.R. and Srinivasan, K., 1977. Effect of dilutions of sea water on the upper lethal temperature of the cichlid fish, *Tilapia mossambica*. Comp. Physiol. Ecol., 2: 154-157.
- Blazka, P.M., Volf, M. and Cepela, M., 1960. A new type of respirometer for the determination of the metabolism of fish in an active state. Physiol. Bohemoslov., 9: 553-560.
- Brett, J.R., 1944. Some lethal temperature relations of Algonquin park fishes. Univ. Toronto Stud. Biol. Ser. No. 52. Publ. Ont. Fish. Res. Lab. No. 63, 49 pp.
- Brett, J.R., 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. J. Fish. Res. Board Can., 2(6): 265-323.
- Charlon, N., 1968. Resistance due poisson-chat (*Ameiurus nebulosus* L.) a de brusques variations de temperature. Bull. Fr. Piscic., Nos. 230 and 231, pp. 1-41.
- Doudoroff, P., 1942. The resistance and acclimatization of marine fishes to temperature changes. 1. Experiments with *Girella nigricans* (Ayres). Biol. Bull., 83: 219-244.
- Doudoroff, P., 1945. The resistance and acclimatization of marine fishes to temperature changes. 2. Experiments with *Fundulus* and *Atherinops*. Biol. Bull., 88(2): 194-206.
- Fry, F.E.J., 1947. Effects of the environment on animal activity. Univ. Toronto. Stud. Biol. Ser. No. 55. Publ. Ont. Fish. Res. Lab. No. 68, 62 pp.
- Fry, F.E.J., 1971. The effect of environmental factors on the physiology of fish. In: W.S. Hoar and J.D. Randall (Editors), Fish Physiology Vol. VI. Academic Press, London, pp. 1-98.
- Fry, F.E.J., Brett, J.R. and Clausen, G.H., 1942. Lethal limits of temperature for young goldfish. Rev. Can. Biol., 1: 50-56.
- Fry, F.E.J., Hart, J.S. and Walker, K.F., 1946. Lethal temperature relations for a sample of young speckled trout, *Salvelinus fontinalis*. Univ. Toronto Stud. Biol. Ser. No. 54. Publ. Ont. Fish. Res. Lab. No. 66, pp. 9-35.
- Hart, J.S., 1952. Geographic variations of some physiological and morphological characters in certain fresh water fish. Univ. Toronto Biol. Ser. No. 60, Publ. Ont. Fish. Res. Lab. No. 72, pp. 1-79.
- Kasim, H.M., 1978. Ecophysiological studies on fry and fingerlings of some freshwater fishes with special reference to temperature tolerance. Ph.D. Thesis, Madurai University, Madurai, India, 140 pp.
- Kutty, M.N., 1968. Influence of ambient oxygen on the swimming performance of goldfish and rainbow trout. Can. J. Zool., 46: 647-653.
- Kutty, M.N. and Saunders, R.L., 1973. Swimming performance of young Atlantic salmon (*Salmo salar*) as affected by reduced ambient oxygen concentration. J. Fish. Res. Board Can., 30: 223-227.
- Kutty, M.N. and Sukumaran, N., 1975. Influence of upper and lower temperature extremes on the swimming performance of *Tilapia mossambica*. Trans. Am. Fish. Soc., 104(4): 755-761.
- McErlean, A.J., Mihursky, J.A. and Brinkley, H.J., 1969. Determination of upper temperature tolerance triangles for aquatic organisms. Chesapeake Sci., 10: 293-296.
- Miller, L.C. and Tainter, M.L., 1944. Estimation of ED 50 and its error by means of logarithmic-probit graph paper. Proc. Soc. Exp. Biol. Med., 57: 261-264.