

Temperature Tolerance and Hypoxia Tolerance Within and Among the Species of Ribbon Fish



Zoology

KEYWORDS : Ribbon fish , Thermal tolerance , Hypoxia, CTmax (critical maximum temperature) OCLTT (oxygen and capacity limited thermal temperature)

Mrs. Nagma Tamkeen Dept of Zoology , Rizvi College of Arts/ SC/Com, Bandra(W), Mumbai-400050

Dr.S. Rangoonwala Dept of Zoology , Rizvi College of Arts/ SC/Com, Bandra(W), Mumbai-400050

Dr.Ansariya Rana Dept of Zoology , Rizvi College of Arts/ SC/Com, Bandra(W), Mumbai-400050

ABSTRACT

Climate change and its influence on ecosystems, requires evaluation of species and their ability to cope with the changing temperatures. In fishes, performance failure at high temperature is associated to thermal tolerance CTmax (critical maximum temperature) and hypoxia tolerance supporting OCLTT concept (oxygen and capacity limited thermal temperature). Ribbon fish occurs widely along the Khar- Danda sea coast 18.96° N & 72.82° E of the western sea coast of Mumbai, Maharashtra. It is represented in Indian water by six species out of which four species namely *Trichiurus lepturus*, *Trichiurus savala* (Cuvier) *Eplurogamus maticus* (Gray) and *Eplurogamus intermides* (Gray) are common to Mumbai coast of Maharashtra. Gupta (1967), James (1967), Rao et al (1977). The temperature here varies between 25°C to 35°C. Due to climate change it has increased to a maximum of 41.3°C in March 2011 (Highest in decade). The species have been greatly affected by thermally limited oxygen delivery (26,30) which closely matches with environmental temperature of the place. It has brought a decrease in their population, growth pattern and aerobic performance. Thus the warming sea will be the first step to cause extinction of the marine life (11, 37). The difference between the demand for oxygen and the capacity of oxygen supply to tissues is the first mechanism to restrict animal tolerance to thermal extremes.

INTRODUCTION

With the changing atmospheric conditions, effecting the climate, Mumbai has been found among the list of cities that are at risk of extreme physical and economic condition due to climatic change....latest report by risk consultancy firm Maplecroft.

According to it, Mumbai's proximity to the coast and the surrounding hilly terrain are the reasons why it is featured in the Maplecroft's sixth annual Climate Change Vulnerability report.

"Pollution generated locally is usually swept away by wind blowing in from the sea. In Mumbai's case, however, it is surrounded by hilly terrains and numerous mountain ranges that lock this air within the area. Also, the extreme humidity tends to hold on to particulate matter for a longer time. These factors put it, at risk of extreme weather events and climate change," explained Gufran Beig, scientist at the Indian Institute of Tropical Meteorology.

Cities exposed to risk of Climate change

- Dhaka
- Kolkata
- Manila and
- Bangkok
- Cities at a lower risk.
- London and
- Paris

This influences the ecosystems, which requires evaluation of species (2,13) and their ability to cope with the changing temperatures. (15) When temperature increases beyond the optimum temperature range (14) or oxygen declines below optimal levels, growth, development (5) and reproductive capacity decrease and susceptibility to disease increases in fish (1,4) (Brander, 2007; Pörtner and Knust, 2007). Ribbon fish occurs widely along the Khar- Danda sea coast 18.96° N & 72.82° E of the western sea-coast of Mumbai, Maharashtra. It is represented in Indian water by six species out of which four species namely *Trichiurus lepturus*, *Trichiurus savala* (Cuvier) *Eplurogamus maticus* (Gray) and *Eplurogamus intermides* (Gray) are common to Mumbai coast of Maharashtra (. Gupta (1967), James (1967), Rao

et al (1977). Performance failure at high temperature (3,13) is associated to thermal tolerance CTmax (critical maximum temperature) and hypoxia tolerance (4,12) supporting OCLTT concept (oxygen and capacity limited thermal temperature)

MATERIALS AND METHODS

The research was conducted at the Research laboratory at Rizvi College of A/S/C, Bandra(w) & CIFE, Versova with 4 different species of Trichuiridae family (*Trichiurus* .L.) in May 2014 (mean fork length and mass were 60.8±0.9 cm and 137.9±0.8 gms respectively) (10,13,32). The fish were locally procured from the Khar-Danda sea coast. They are kept in glass tank in filtered sea water of salinity 30‰ to 35‰ at a water temperature of 24.8±0.3°C at time of the experiments. Fish were fed (8) with small prawns /commercial feed once a day (7,16,17 et al;) and were fasted 24 h before experiments (32). Treatment of all experimental animals was in accordance with the approved protocol of animals ethics.

MEASUREMENT OF CRITICAL MAXIMUM TEMPERATURE

Temperature tolerance Experiment

The temperature tolerance (26,30) of fish was tested with a critical maximum temperature (CTmax) protocol (24,29) That warmed the fish until they exhibited sustained loss of equilibrium (LOE) and lost the capacity to escape conditions that would eventually lead to death. (1,2) (Beitinger et al., 2000). Briefly, each evening one fish from each species was randomly selected and transferred from the rearing

tanks into an experimental tank (88 l) with constant flow-through freshwater at the holding temperature (25°C). Temperature in each treatment was maintained using temperature controller fitted with sensors (Selectron Process Controls Pvt. Ltd., Mumbai, India). All the experiments were performed between 09:45 and 13:45 h for each day.

Determination of CTmax

After an overnight acclimation period in the experimental tank, the water flow was turned off and the temperature of the water was increased at a constant rate of 0.3°C min⁻¹ to 40°C. thereafter until the fish exhibited LOE (loss of equilibrium). (6,8). Water temperature was controlled with a ther-

mostat. Dissolved oxygen concentration was maintained at 5.8±0.2 mg /l by continuous aeration.(23) Water homogeneity and oxygenation were assured by bubbling air vigorously into the tanks, keeping oxygenation level above 80% saturation throughout the experiment. The oxygen content was measured using a digital oxymeter .After a fish lost equilibrium, it was quickly removed. from the tank, and placed in a recovery tank at the acclimation temperature. After the experiment, all the fish were lightly anesthetized with 50 p.p.m. MS-222 (Sigma Aldrich) buffered with sodium bicarbonate The mass and length of the fish were recorded (10)before returning the fish back into the rearing tank. Four fish per species were tested for CTmax (total 16 fish) and only one mortality was recorded in the days that followed the CTmax determination.

TABLE-1 CRITICAL MAXIMUM TEMPERATURE CTmax AMONG SPECIES OF RIBBON FISH

NO OF EXPERIMENTS	NAME OF THE SPECIES	NO OF INDIVIDUALS SELECTED	CRITICAL MAXIMUM TEMPERATURE (in °C) CT (Mean ± SE)	LOE for CT (Loss of equilibrium time)
1.	Trichurus lepturus	4	31.43±0.06 (Min) to 38.63 ± 0.05 (Max)	45 mins
2.	Trichurus savala	4	32.20±0.5 (Min) to 39.05 ± 0.03 (Max)	68.2 mins
3.	Eplurogamus maticus	4	33.50±0.06 (Min) to 40.86±0.03 (Max)	112 mins
4.	Eplurogamus intermides	4	32.97±0.06 (Min) to 40.27±0.15 (Max)	108.3mins

Determination of Hypoxia

To test hypoxia tolerance(23) one fish per species was transferred to same experimental tanks as used in CTmax experiment and allowed to adjust to new conditions overnight. The flow of water into the tank was shut down on the following morning and there after the water temperature was kept constant at 25°C with a Thermostat. The level of oxygen in the water was then decreased at the constant rate of 1.5% air saturation per minute until 10% air saturation (1.3 mg /l) was reached by bubbling nitrogen in the tank. The time until the fish exhibited LOE after the 10% air saturation level was reached was measured. After a fish lost equilibrium, it was removed from the tank, and placed into a recovery tank. After the experiment, all the fish were lightly anesthetized as before, so that mass and length could be recorded before returning the fish back into the rearing tank. Hypoxia tolerance was tested in eight fish per species(32 fish in total) with no mortality in the days that followed the experiment.

In the experiment, 87.5% of fish exhibited LOE (21)within 1.5 h. Therefore, to complete these hypoxia assessments within a similar time window as the CTmax measurements, the hypoxic duration was set to 2hrs, once 10% air saturation was reached. However, during the actual measurements some of fish did not exhibit LOE after 2hrs. The initial and final oxygen content was measured using a digital oxymeter 330 (sensitivity 0.01 mg O2 mg / L). Oxygen consumption(18) was calculated as

$$\text{Oxygen consumption during Hypoxia} = \frac{\text{Final oxygen concentration} - \text{Initial oxygen concentration}}{\text{Weight of fish (Kg) x Time (H)}}$$

TABLE-2 Hypoxia Tolerance and LOE among the species

No of Experiments	Name of the species	No of individuals selected	Hypoxia Tolerance (time of hypoxia to LOE i.e Loss of equilibrium)
1.	Trichurus lepturus	8	45.03mins
2.	Trichurus savala	8	49.56mins
3.	Eplurogamus maticus	8	120 mins
4.	Eplurogamus intermides	8	104.3mins

TABLE-3 Hypoxia Tolerance and LOE among the individuals of the same species

Name of the species	No of Experiments	No of individuals selected	Hypoxia to LOE(Loss of equilibrium) time in mins
Trichurus lepturus	4	8	45.03mins to 109 mins
Trichurus savala	4	8	45.16 to 103.5 mins
Eplurogamus maticus	4	8	48.23 to 116.3 mins
Eplurogamus intermides	4	8	47.18 to 104.3mins

Ratio of Ventricle mass to Body mass

After the CTmax and Hypoxia experiment, two fish from each species (one the most temperature tolerant (16) and the least tolerant one) were euthanized with a lethal dose of buffered MS-222 (200 p.p.m., Sigma-Aldrich) (N=48). The mass and length of the fish were measured, cardiac muscles were removed and the ventricles were weighed and Relative ventricle mass (RVM) were calculated using the formula $RVM=(M_v/M_b) \times 1000$, where M_v is ventricle mass (mg) and M_b is body mass (g).

RESULTS & DISCUSSIONS

CT_{max} and hypoxia toleranceBoth CTmax and hypoxia time to LOE varied significantly among and between the species **Table- 1,2 & 3** Species mean values ranged between 31.43±0.06 and 40.15±0.3°C for CTmax and median values for hypoxic time to LOE ranged from 45 to 120 min among the species.At the individual level, CTmax showed a range of 7.3°C (between the highest and lowest performing individuals in the complete data set) and time to LOE in hypoxia showed a range of 116.3 min.Moreover, there was a significant correlation between CTmax and hypoxia time to LOE at the species level. **Table -1,2 & 3**Neither length nor mass of the fish was correlated with CTmax or time to LOE. Here, our observations supports the OCLTT hypothesis. It shows that fish with larger ventricles have a higher capacity to tolerate elevated temperatures.Thus, both total and relative ventricular mass correlated with CTmax, such that a fish with a small heart relative to body mass had a significantly lower CTmax .The variation in ventricle mass could explain the variation in the CTmax. Previously it has been shown that fish with larger ventricles have larger stroke volumes (**Franklin and Davie, 1992**).And because cardiac output is a product of stroke volume and heart rate, fish with larger ventricles could have the capacity

for a higher cardiac output which in turn might support a better oxygen supply to tissues at high temperature. This would then translate to a higher temperature tolerance as observed here. This connection lends support to the hypothesis that maximum temperature tolerance is indeed a capacity which oxygen limited fish possess having a larger RVM. But their upper temperature tolerance is reduced (e.g. Farrell et al., 1988; Klaiman et al., 2011), volume. Perhaps the association between RVM and CTmax among individuals and species are more tolerant of warm temperatures.

Summary

The variability of CTmax and hypoxia tolerance LOE time among species were tested. The correlation analysis between CTmax and hypoxia time to LOE were performed using a Spearman's correlation test with the species ranked according to tolerances of the individuals in each species. Thus, these correlations were made at the species level. Other correlations were examined at the individual level. Pearson's correlation test was used to look for the following variables: size, mass & RVM. There was a significant positive correlation between critical maximum temperature (CTmax) and hypoxia tolerance, highly variable at

species level supporting the OCLTT concept. By comparing the temperature tolerance among the individuals of the same species and individuals from different species of Ribbonfish, we characterized how the trait varies significantly among species and among individuals within the species(31). Here, CTmax ranged from a low of 31.43°C to a high of 40.27°C. High CTmax variability have also been observed incutthroattrout, *Oncorhynchus clarkii* (Underwood et al., 2012), with tolerance varying 8°C among individuals which is close to with 7.3°C in Ribbon fish. However, in cutthroat trout the size of the fish varied, which explained some of the phenotypic variation found, as CTmax correlated significantly and negatively with the size of the fish. In the present study we observed no such correlation between size and CTmax. In fact, in the present study body size was quite similar between individuals. (32) Thus, our data indicate that even within the same size group CTmax varies significantly. The OCLTT concept

(the theory of oxygen and capacity limited thermal tolerance) was discovered, as the relative ventricle mass (RVM) and hypoxia tolerance levels both correlated positively with CTmax. A large RVM is associated with high cardiac output. This might facilitate tissue oxygen supply during elevated oxygen demand at high temperatures during hypoxia.(26,27)The RVM and hypoxia tolerance are correlated with increased upper temperature tolerance in fishes.

Conclusion

The present study shows that both temperature tolerance and hypoxia tolerance in ribbon fish varied significantly among and between the species. As a result, ribbon fish may possess at least some capacity to adapt to environmental changes such as global warming. Individuals or populations with a larger heart and hypoxia tolerance might be fit to survive such conditions. Therefore the data here strongly supports the concept of OCLTT .

References

1. Al-Nahdi, A., Al-Marzouqi, E. Al-Rasadi & J. C. Groeneveld.2009. The size composition ,reproductive biology, age and growth of largehead cutlassfish *Trichiurus lepturus* Linnaeus from the Arabian Sea coast of Oman. Indian Journal of Fisheries,56:73-79.
2. Bakhoum, S. A. 2007. Diet overlap of immigrant narrow-barred Spanish mackerel *Scomberomorus commerson* (Lac., 1802) and the largehead

- hairtail ribbonfish *Trichiurus lepturus* (L., 1758) in the Egyptian Mediterranean coast. Animal Biodiversity and Conservation, 30: 147-160.
3. Beitinger, T.L., Bennett, W.A., McCauley,R.W.,2000.Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. Environ.Biol. Fish 58, 237-275.
4. Bennett, W.A., Beitinger, T.L., 1997. Temperature tolerance of the sheepshead minnow, *Cyprinodon variegatus*. Copeia,77-87.
5. Brett, J.R., 1979. Environmental factors and growth. In: Hoar,W.S., Randall, D.J., Brett, J.R. (Eds.), Fish Physiology, vol.VIII. Academic Press, London, pp. 599-675.
6. Burel, C., Ruyet, P.L., Gaumet, F., Roux, A.L., Severe, A.,Boeuf, G., 1996. Effects of temperature on growth and metabolism in juvenile turbot. J. Fish Biol. 49, 678-692.
7. Chakraborty, R.D., Sen, P.R., Rao, N.G.S., Ghosh, S.R., 1976.Intensive culture of Indian major carps. Advances in Aquaculture. (T.V.R. Pillay & Wm.A. Dill. 1970). FAO Fishing News Books Ltd.
8. Chiou, W. D., C. Y. Chen, C. M. Wang, & C. T. Chen. 2006. Food and feeding habits of ribbonfish *Trichiurus lepturus* in coastal waters of southwestern Taiwan. Fisheries Science, 72: 373- 381.
9. Cox, D.K., 1974. Effects of three heating rates on the critical thermal maximum of bluegill.
10. Cui, Y., Wootton, R.J., 1988. Effects of ration, temperature and body size on the body composition and energy content 382 T.
11. Das et al. / Journal of Thermal Biology 30 (2005) 378-383 of the minnow, *Phoxinus phoxinus* (L.).
12. Das, T., Pal, A.K., Chakraborty, S.K., Manush, S.M.,Chatterjee, N., Mukherjee, S.C., 2004. Thermal tolerance and oxygen consumption of Indian Major Carps acclimated to four different temperatures. J. Therm. Biol. 23, 157-163.
13. Heath, A.G., Turner, B.J., Davis,W.P.,1993.Temperature preference and tolerances of three fish species inhabiting hyperthermal ponds on mangrove islands. Hydrobiologia 259, 47-55.
14. Herrera, F.D., Uribe, E.S., Ramirez, L.F.B., Mora, A.G., 1998.Critical thermal maxima and minima of *Macrobrachium rosenbergii* (Decapoda: Palaemonidae). J. Therm. Biol. 23,381-385.
15. Hutchinson, V.H., 1976. Factors influencing thermal tolerances of individual organisms. In: Esch, G.W., Mc Farlane, R.W.(Eds.), Thermal Ecology, ERDA Symposium Series,pp. 10-26.
16. Jhingran, V.G., 1975. Fish culture in freshwater ponds.
17. Jhingran, V.G. (Ed.), Fish and Fisheries ofIndia,276pp.
18. Kasim, H.M., 2002. Thermal ecology: a vital prerequisite foraquaculture and related practices.
19. Kwok, K. Y. & I. Ni. 2000. Age and growth of cutlassfishes,*Trichiurus* spp., from the South China. Sea. Fishery Bulletin, 98: 748-758.
20. Lizars, K.R., Bennett, M.T.,Rausch, R.N., Keeley, E.R., 2004. Thermal tolerance and metabolic physiology among red band trout populations in south eastern Oregon. J. Fish Biol. 64
21. Kellog, R.L.,Gift,J.J.,1983. Relationships between optimum temperatures for growth and preferred temperatures for theyoung of four fish species. Trans. Am. Fish. Soc. 112, 424-430.
22. Kita,J.,Tsuchida,S.,Setoguma, T., 1996. Temperature preference and tolerance and oxygen consumption of the marbled rock-fish, *Sebastes marmoratus*. Mar. Biol. 125,467-471.
23. Kutty, M.N., 1968. Respiratory quotient in gold fish and rainbow trout. J. Fish. Res. Board Canada 25, 2689-2728.
24. Kutty, M.N., 1981. Energy metabolism in mullet.
25. Lowe, C.H., Heath, W.G., 1969. Behavioural and physiological responses to temperature in desert pupfish, *Cyprinodonmacularis*. Physiol. Zool. 42, 53-59.
26. Manush, S.M., Pal, A.K., Chatterjee, N., Das, T., Mukherjee,S.C., 2004. Thermal tolerance and oxygen consumption of *Macrobrachium rosenbergii* acclimated to three temperatures.J. Therm. Biol. 29, 15-19.
27. Merkens, J.C., Downing, K.M., 1957. The effect of tension of dissolved oxygen on the toxicity of unionized ammonia to several species of fish. Ann. Appl. Biol. 45, 521-527.
28. Nakamura, I. & N. V. Parin. 1993. FAO Species Catalogue. Vol. 15. Snake mackerels and cutlassfishes of the world (families Gempylidae and Trichiuridae). An annotated and illustrated catalogue of the snake mackerels, snoeks, escolars,gemfishes, sackfishes, domine, oilfish, cutlassfishes, scabbard fishes hairtails, and frostfishes known to date. FAO Fisheries Synop-

- sis, 125(15): 136 p
29. **Portsev, P. I. 1980.** The feeding of cutlass fish, *Trichiurus lepturus* (Trichiuridae), off the west coast of India. *Journal of Ichthyology*,20: 60-65.
 30. **Paladino, F.V., Spotila, J.R., Schubauer, J.P., Kowalski, K.T.,1980.** The critical thermal maximum: a technique used to elucidate physiological stress and adaptation in fish. *Rev. Can. Biol.* 39, 115-122.
 31. **Rodnick, K.J., Gamperl, A.K., Lizars, K.R., Bennett, M.T.,Rausch, R.N., Keeley, E.R., 2004.** Thermal tolerance and metabolic physiology among red band trout populations in south eastern Oregon. *J. Fish Biol.* 64, 310-317.
 32. **Schreck, C.B., Moyle, P.B. (Eds.),**Methods for Fish Biology. American Fisheries Society, Bethesda,MD, pp. 335-356.
 34. **Srivastava, A.K. et al (1986)** : Floristic and Faunistic studies in relation to physico-chemical variables of river Ganga. *Proceedings of National Seminar on Environmental Pollution Control and Monitoring.*
 35. **Trivedi, R.K. and P.K. Goel (1984)** : Chemical and biological methods for water pollution studies, Environmental Publications, Karad.
 36. **Tsuchida, S., 1995.** The relationship between upper temperature tolerance and final preferendum of Japanese marine fish. *J. Therm.Biol.* 20, 35-41
 37. **Venkataramani, B.,Sukumarn, N. (Eds.),** Thermal Ecology. BRNS, DAE Mumbai Publishers, pp. 222-234.
 38. **Zhang, B. 2004.** Feeding habits and ontogenetic diet shift of hairtail fish (*Trichiurus lepturus*) in East China Sea and Yellow Sea. *Marine Fisheries Research*, 25: 6-12. (in Chinese with English abstract).Submitted August 22, 2011 Accepted February 13, 2012 Published March 30, 20