

Effect of body size on reef fish tolerance to extreme low and high temperatures

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Synopsis

Understanding the thermal physiology of tropical marine organisms has become an issue of major interest due to the potential impact of current global changes in temperature. In this study we report the effect of body size on the thermal tolerance (as critical thermal maximum (CTMax) and minimum (CTMin)) of seven reef fish species from Gorgona Island (tropical eastern Pacific Ocean). Within the studied species we found little variation in CTMax and CTMin among fishes ranging from juveniles to adults. This suggests that thermal tolerance of small tropical reef fishes is not significantly affected by differences in body size. The reduced intra-specific variation in thermal tolerance found in these species also suggests a limited capability to adapt to extreme thermal conditions and raises concerns regarding current global changes in temperature.

Introduction

Many reefs around the world are exposed to the effects of thermal phenomena such as global warming, El Niño, La Niña, and some more localized thermal pollutants (Forchhammer et al. 2000, Hughes 2000). Given the intensity and frequency of these disturbances and the ecological and economic importance of coral reefs it is critically important to understand the different aspects of the thermal physiology of tropical reef organisms. At present, however, this understanding is quite limited particularly when compared to more temperate regions. Due to major taxonomic and phylogenetic differences, studies based on temperate organisms are of limited applicability to tropical areas.

The Critical Thermal, either Maximum (CTMax) or Minimum (CTMin), is the most common physiological index used to quantify fish tolerance to extreme high or low temperatures (Bennett & Judd 1992, Mora & Ospina 2001, 2002) and to determine fish resistance to different thermal phenomena (Bennett et al. 1997, Mora & Ospina 2001, 2002). This index is quantified as the mean temperature at which individual fish show

symptoms of stress after being exposed to a gradual change in temperature (Hutchinson 1976, Bennett & Judd 1992, Mora & Ospina 2001, 2002). The CTs of a given species may vary, however, depending on several attributes related to body size such as age, sexual maturity, and other causal physiological factors (Cox 1974, Hutchinson 1976, Becker & Genoway 1979). In poikilotherms the time required for a temperature to be lethal depends on the time it takes to diffuse throughout the entire body (Becker & Genoway 1979). In turn, fish of different sizes (with different area/volume ratios) may die at different times when exposed to a similar temperature. This can also cause differences in CTs depending on the rate in which temperature is changed in experimental trials.

At present the extent to which body size affects the thermal tolerance of fishes is based on limited data of temperate and freshwater species. However, there seems to be no general rules about the effects of body size on thermal tolerance. For instance, Barrionuevo & Fernandes (1995) found a significant effect of body size on the CTMin but not on the CTMax of *Prochilodus scofra*. In contrast, Cox (1974) found a

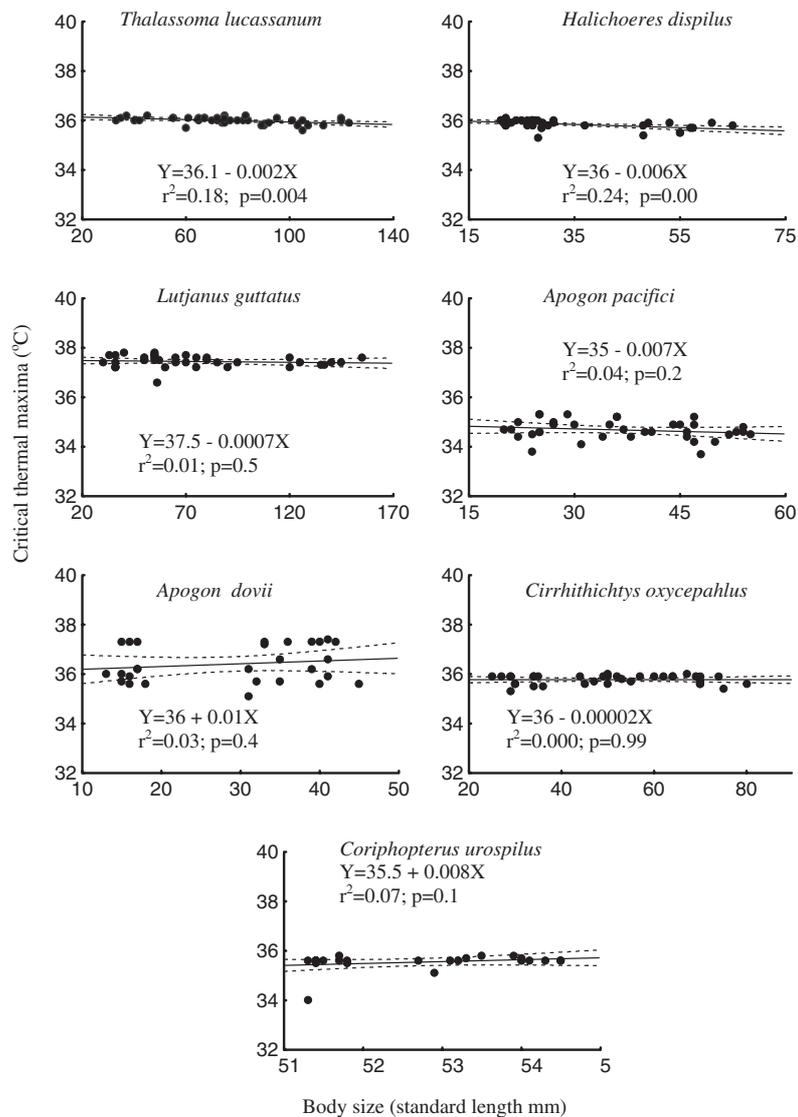


Figure 1. Variation of CTMax with body size in seven reef fish species from Gorgona Island, Colombia.

significant effect of body size on the CTMax of bluegill, *Lepomis macrochirus*. Thus, the relative importance of body size on CTM may not be universally applicable to all organisms. In this paper we report for the first time the effects of body size on the CTMax and CTMin of tropical reef fishes.

Methods

We estimated CTMax and CTMin by exposing a group of fish to a gradual increase or decrease of water

temperature until a non-lethal point was reached. At such a non-lethal point locomotory movements become disorganized and fish lose the ability to escape from conditions that ultimately lead to death. Loss of equilibrium and onset of muscular spasms are commonly used as CT endpoints (Bennett & Judd 1992). We chose loss of equilibrium because it is a behavior easily observable when fishes reach critical low and high temperatures. In a previous paper (Mora & Ospina 2002), we reported muscular spasms as the endpoint for experiments on CTMin. This was based on the fact that some fishes lost their dorso-ventral orientation due

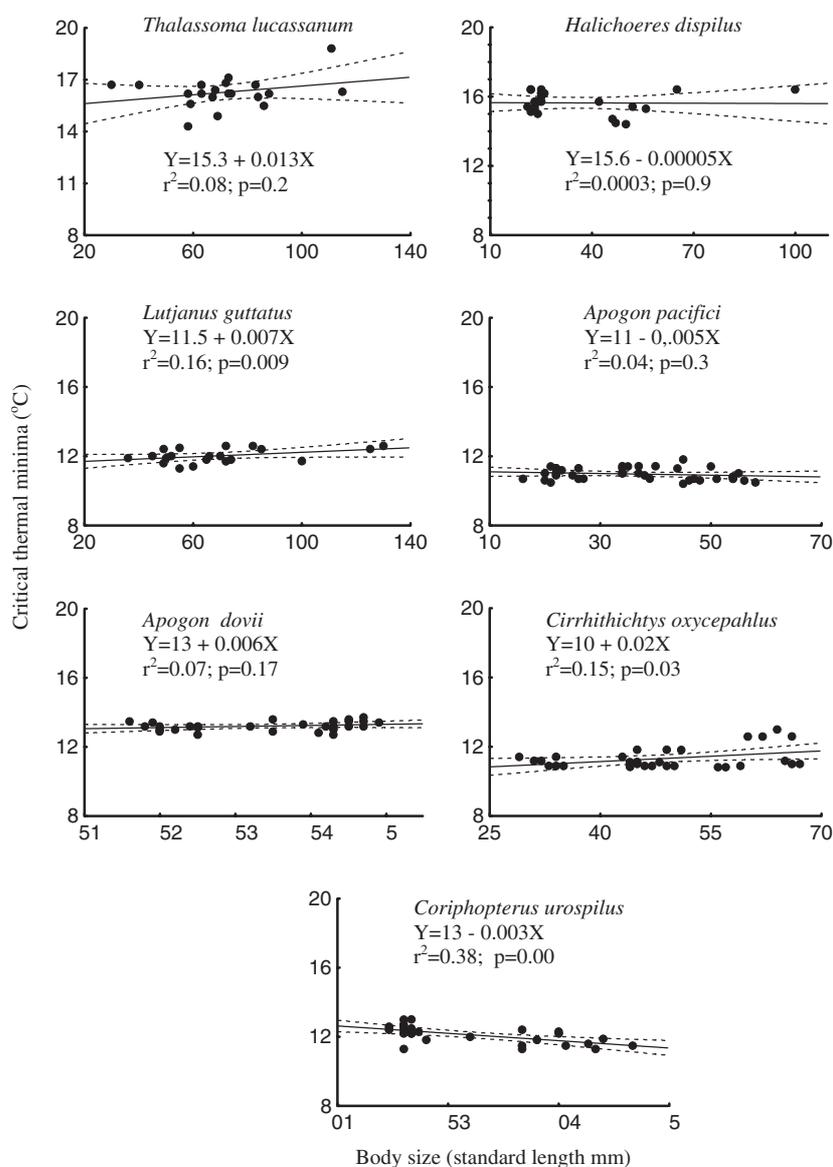


Figure 2. Variation of CTMin with body size in seven reef fish species from Gorgona Island, Colombia.

to a loss of movement, which we presumed was related to muscular spasms. However, muscular spasms have not been reported to occur in fish subjected to low temperatures (Bennett & Judd 1992). Therefore, our previous observation would be best redefined as loss of equilibrium and not muscle spasms.

We studied seven species belonging to five families, *Apogon pacifici*, *Apogon dovii* (Apogonidae), *Thalassoma lucassanum*, *Halichoeres dispilus* (Labridae), *Lutjanus guttatus* (Lutjanidae), *Cirrhithichthys*

oxycephalus (Cirrhitidae), and *Coriphopterus urospilus* (Gobiidae). We collected a total of 135 individuals per species (ranging from juvenile to adults) with hand nets in Gorgona Island reefs and randomly placed them into nine 100 l aquaria (15 individuals of different sizes per aquarium). Glynn et al. (1982) provided a detailed description of the study site. Fishes were allowed to acclimate to laboratory conditions for 24 h. We controlled water temperature with electronic cooling and heating systems (precision: $\pm 0.01^\circ\text{C}$) and during the

acclimation period was kept at a temperature similar to that of the capture site ($26.5 \pm 0.5^\circ\text{C}$). We covered aquaria with plastic lids to avoid changes in salinity due to evaporation and aerated them constantly to keep water temperature homogenous and oxygen levels at air saturation. We determined the CTMax by increasing water temperature at a rate of 1°C h^{-1} in three randomly selected aquaria. In three other aquaria we decreased water temperature at a similar rate to determine the CTMin. We kept the three remaining aquaria at a stable temperature as experimental controls. We carried out this approach independently for each species. To assess the relationship between body size and thermal tolerance we compared the body size of each individual fish with its level of thermal tolerance (CTMax or CTMin) using regression analysis.

Results

None of the fishes died or showed symptoms of stress (e.g. unusual behaviors or changes in normal coloration) during the acclimation period or in control aquaria during the experiment. Among species CTMax ranged from 35°C in *A. pacifici* to 37.5°C in *L. guttatus*. The intra-specific variation in CTMax was very low (usually less than 1°C) and was poorly related to body size in all species (Figure 1). CTMin varied from 15.6°C in *H. dispilus* to 10°C in *C. oxycephalus*. Within species the variation in CTMin was more variable (more than 1°C) although it was also poorly related to body size in all but one species (*C. urospilus*; Figure 2).

Discussion

The tolerance of fishes to extreme low and high temperatures can be affected by multiple factors (Hutchison 1976). Among these factors body size is considered one of the most critical (Cox 1974, Hutchison 1976, Becker & Genoway 1979). Body size may affect thermal tolerance due to either ontogenetic differences in physiology or to differences in the area/volume ratio (Cox 1974, Hutchison 1976, Becker & Genoway 1979). However, among the species we studied we found most relationships between body size and levels of thermal tolerance to be weak suggesting that thermal tolerance of small tropical reef fishes is affected very little by differences in body size.

The study of body size in relation to thermal tolerance is important for two main reasons. Firstly, it

assesses potential bias in data due to the use of fishes of different body sizes in experimental trials. Secondly, it assesses the intra-specific and ontogenetic variation in thermal tolerance, potential resilience to extreme thermal phenomena, and the significance of body size as a selective trait under these phenomena. The reduced intra-specific ($\sim 1^\circ\text{C}$ in all species) and ontogenetic variation (r^2 between body size and CTMax or CTMin < 0.2 in all but one species) in thermal tolerance we found among the studied species demonstrates the reliability of experimental data in which fishes have been used regardless of their body size (e.g. Mora & Ospina 2001, 2002). This limited intra-specific variation in thermal tolerance also raise concerns regarding the capability of small tropical reef fishes to adapt to global changes in temperature (Forchhammer et al. 2000, Hughes 2000) that are in some cases already close to the maximum levels of tolerance (Mora & Ospina 2001, 2002).

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References

- Barrionuevo, W.R. & M.N. Fernandes. 1995. Critical thermal maxima and minima for curimbata, *Prochilodus scrofa* Steindachneri, of two different sizes. *Aquacul. Res.* 26: 447–450.
- Becker, D. & R. Genoway. 1979. Evaluation of the critical thermal maximum for determining thermal tolerance of freshwater fish. *Environ. Biol. Fish.* 4: 245–256.
- Bennett, W.A. & F.W. Judd. 1992. Comparison of methods for determining low temperature tolerance: Experiments with Pinfish, *Lagodon rhomboides*. *Copeia* 1992: 1059–1065.
- Bennett, W., R.J. Currier & T.L. Beitinger. 1997. Cold tolerance and potential overwinter of red-bellied piranha, *Pygocentrus nattereri*, in the United States. *Trans. Amer. Fish. Soc.* 126: 841–849.

- Cox, D.K. 1974. Effects of three heating rates on the critical thermal maximum of bluegill. pp. 158–163. *In*: J.W. Gibbons & R.R. Sharitz (ed.) *Thermal Ecology*, U.S. Atomic Energy Commission, Savannah, Georgia.
- Forchhammer, M.C., E. Potts, M.V. Kozlov & L. Hughes. 2000. Climatic signatures in ecology. *Trends Ecol. Evol.* 15: 286–287.
- Glynn, P.W., F. H. von Prahl & F. Guhl. 1982. Coral reefs of Gorgona Island, Colombia, with special reference to corallivores and their influence on community structure and reef development. *Anales del Instituto de Investigaciones Marinas Punta de Betin* 12: 185–214.
- Hughes, L. 2000. Biological consequences of global warming: Is the signal already apparent? *Trends Ecol. Evol.* 15: 56–61.
- Hutchison, V. 1976. Factors influencing thermal tolerance of individual organisms. pp. 10–26. *In*: G.W. Esch & R. McFarlane (ed.) *Symposium Series of the National Technical Information Service*, Springfield, VA.
- Mora, C. & A.F. Ospina. 2001. Thermal tolerance and potential impact of sea warming on reef fishes from Gorgona Island (Eastern Pacific ocean). *Mar. Biol.* 139: 765–769.
- Mora, C. & A.F. Ospina. 2002. Experimental effects of La Niña cold temperatures on the survival of reef fishes from Gorgona Island (Tropical Eastern Pacific). *Mar. Biol.* 141: 789–793.