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Thermal biology of bonefish (*Albula vulpes*) in Bahamian coastal waters and tidal creeks: An integrated laboratory and field study

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ABSTRACT

Little is known about the thermal tolerances of fish that occupy tropical intertidal habitats or how their distribution, physiological condition, and survival are influenced by water temperature. We used a combination of laboratory and field approaches to study the thermal biology of bonefish, *Albula vulpes*, a fish species that relies on nearshore intertidal habitats throughout the Caribbean. The critical thermal maximum (CTMax) for bonefish was determined to be 36.4 ± 0.5 and 37.9 ± 0.5 °C for fish acclimated to 27.3 ± 1.3 and 30.2 ± 1.4 °C, respectively, and these tolerances are below maximal temperatures recorded in the tropical tidal habitats where bonefish frequently reside (i.e., up to 40.6 °C). In addition, daily temperatures can fluctuate up to 11.4 °C over a 24-h period emphasizing the dramatic range of temperatures that could be experienced by bonefish on a diel basis. Use of an acoustic telemetry array to monitor bonefish movements coupled with hourly temperature data collected within tidal creeks revealed a significant positive relationship between the amount of time bonefish spent in the upper portions of the creeks with the increasing maximal water temperature. This behavior is likely in response to feeding requirements necessary to fuel elevated metabolic demands when water temperatures generally warm, and also to avoid predators. For fish held in the laboratory, reaching CTMax temperatures elicited a secondary stress response that included an increase in blood lactate, glucose, and potassium levels. A field study that involved exposing fish to a standardized handling stressor at temperatures approaching their CTMax generated severe physiological disturbances relative to fish exposed to the same stressor at cooler temperatures. In addition, evaluation of the short-term survival of bonefish after surgical implantation of telemetry tags revealed that there was a positive relationship between water temperature at time of tagging and mortality. Collectively, the data from these laboratory and field studies suggest that bonefish occupy habitats that approach their laboratory-determined CTMax and can apparently do so without significant sub-lethal physiological consequences or mortality, except when exposed to additional stressors.

1. Introduction

Water temperature exerts more control over fish than any other single abiotic factor (Beitinger and Fitzpatrick, 1979; Magnuson et al., 1979) as it influences nearly all biochemical, physiological, and life history activities of fish (Fry, 1967; Brett, 1971) and is a potential source of disturbance (Beyers and Rice, 2002). All fish species have a temperature range within which individuals do not exhibit any signs of stress and/or aversion behavior (Portz et al., 2006). The ability of fish to respond to thermal change is dependent on a number of factors (see Hutchison, 1976), including thermal history or acclimation temperature (Chung, 2001). Each species will exhibit different capacities for acclimation based on how close they are currently living to their thermal tolerance limits (Somero, 2005). Fish inhabiting water bodies that warm gradually in spring/summer and cool in fall/winter may use thermal changes to

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coordinate seasonal activities, whereas fish that migrate between thermally distinct habitats have to adapt to these thermal changes to exploit the new environment (Guderley et al., 2001).

Thermal tolerance data are limited for fish inhabiting tropical marine areas, particularly when compared to those inhabiting temperate regions (Ospina and Mora, 2004). Given the ecological and economic importance of coastal areas (see Holmlund and Hammer, 1999; Moberg and Folke, 1999), coupled with the influence of thermal phenomena such as El Niño and the impact of global warming in these ecosystems (Mora and Ospina, 2001), the lack of information on thermal tolerances demands a broader investigation into the thermal physiology and ecology of fish from the tropics (Roessig et al., 2004). Bonefish (*Albula* spp.) are a group of fishes that occupy subtropical and tropical nearshore areas around the world (Pfeiler et al., 2000). Bonefish are common benthivorous fish in many tropical areas, moving into shallow water habitats (e.g., tidal creeks and 'flats') to feed on invertebrates and small fish during high tide, and then moving into deeper water at low tide (Humston et al., 2005). During these daily movements, bonefish potentially face large shifts in ambient water temperatures as they may occupy waters less than 0.1 m deep (Colton and Alevizon, 1983). In addition, bonefish are the object of a popular sport fishery (Pfeiler et al., 2000). The combination of exposure to diurnal and seasonal fluctuations in water temperatures in tropical waters and exposure to multiple stressors associated with recreational angling (e.g., capture and handling; see Danylchuk et al., 2007; Suski et al., 2007), make bonefish an interesting model for thermal tolerance investigations.

Fish temperature tolerance can either be estimated from field observations or quantified by laboratory studies (Beitinger et al., 2000). Field observations of fish kills resulting from exposure to extreme high or low temperatures or the examination of minimum and maximum water temperatures within a species' natural distribution both provide estimates of a species' thermal tolerance. These approaches, however, are not precise nor do they rule out other potential abiotic or biotic factors that may contribute to the fish's behavior (Beitinger et al., 2000). Because of the limitations of purely empirical studies, two laboratory methods have been accepted universally as the most accurate approach to quantifying temperature tolerances of fish: the incipient lethal temperature technique (ILT) and the critical thermal method (CTM) (Bennett and Judd, 1992; Currie et al., 2004). The CTM approach is the most common index used as lethal temperatures are estimated without actually killing fish (Beitinger et al., 2000). Critical thermal limits are determined as the mean temperature in which individual fish display signs of stress after being exposed to a constant linear temperature change (Mora and Ospina, 2002; Cook et al., 2006). When temperature is increased linearly, the critical thermal maximum (CTMax) is determined. When temperatures are decreased linearly, the critical thermal minimum (CTMin) is attained. Because the upper tolerance limits of a species increase with acclimation temperature (Beitinger and Bennett, 2000), thermal tolerances are typically determined at a number of acclimation temperatures. An issue of growing concern exists, however, in the applicability of laboratory-determined thermal tolerance ranges to fish in natural settings, because diel temperature fluctuations are common in various fish habitats (Wehrly et al., 2007). Vast amounts of literature determining the thermal tolerance of various fish species have been generated (see Beitinger et al., 2000), not only as a result of interest in understanding this critical aspect of fish ecology, but also by the current need to predict the biological effects of climate change (Cook et al., 2006; Mora and Maya, 2006). Unfortunately, there are few studies that link laboratory research on thermal biology with field studies of behavior, or studies that further extend this work to consider the potential impacts of climate change on wild fish.

The purpose of this study was to (1) determine the critical CTMax of bonefish at two different seasonal acclimation temperatures; (2) examine the stress physiology associated with bonefish reaching CTMax; (3) examine the combined effects of thermal stress and capture/holding stress; and (4) link the spatial ecology of bonefish with the thermal regimes experienced in tidal creeks and coastal areas.

2. Materials and methods

This study took place on the island of Eleuthera, The Bahamas (N 24°50′05″ and W 76°20′32″) in the laboratory facilities at the Cape Eleuthera Institute (CEI), as well as in a number of tidal creek

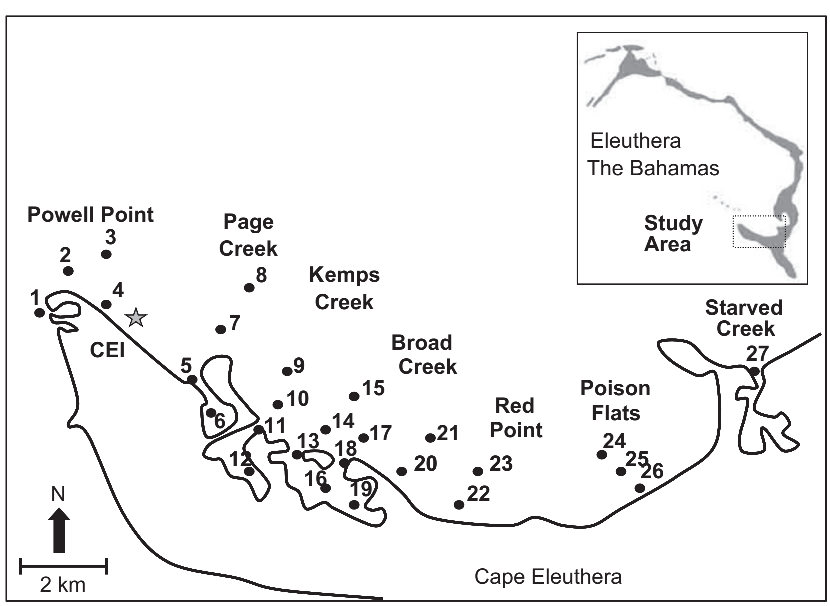

Fig. 1. Study area along the north coast of Cape Eleuthera, Eleuthera, The Bahamas (N 24°50′05″ and W 76°20′32″), showing the locations of the 27 hydrophone receivers (black circles), the various tidal creeks, and the location of the Cape Eleuthera Institute (CEI). Receivers were roughly numbered sequentially from west to east. Hydrophone receivers with associated temperature loggers are #5 and #6 (Page Creek mouth and backwaters, respectively), #11 and #12 (Kemps Creek mouth and backwaters, respectively), and #16, #18, and #19 (the two mouths of Broad Creek and the backwater, respectively). An additional temperature logger, deployed along an open stretch of coastline off of CEI, is denoted by a star. The inset map displays the entire island of Eleuthera with the study area highlighted.