Estuarine, Coastal and Shelf Science 196 (2017) 173–181

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Acute thermal tolerance of tropical estuarine fish occupying a man-made tidal lake, and increased exposure risk with climate change

Nathan J. Waltham [a, b, *], Marcus Sheaves [a, b]

[a] Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Queensland, 4811, Australia
[b] College of Science & Engineering, James Cook University, Townsville, Queensland, 4811, Australia

ARTICLE INFO

Article history:
Received 7 November 2016
Received in revised form
8 May 2017
Accepted 25 June 2017
Available online 27 June 2017

Keywords:
Acute Effect Temperature (AET)
Fish
Thermal refugia
Tropical estuary
Climate change

ABSTRACT

Understanding acute hyperthermic exposure risk to animals, including fish in tropical estuaries, is increasingly necessary under future climate change. To examine this hypothesis, fish (upper water column species - glassfish, *Ambassis vachellii*; river mullet, *Chelon subviridis*; diamond scale mullet, *Ellochelon vaigiensis*; and ponyfish, *Leiognathus equulus*; and lower water bottom dwelling species – whiting *Sillago analis*) were caught in an artificial tidal lake in tropical north Queensland (Australia), and transported to a laboratory tank to acclimate (3wks). After acclimation, fish (between 10 and 17 individuals each time) were transferred to a temperature ramping experimental tank, where a thermoline increased (2.5 °C/hr; which is the average summer water temperature increasing rate measured in the urban lakes) tank water temperature to establish threshold points where each fish species lost equilibrium (defined here as Acute Effect Temperature; AET). The coolest AET among all species was 33.1 °C (*S. analis*), while the highest was 39.9 °C (*A. vachellii*). High frequency loggers were deployed (November and March representing Austral summer) in the same urban lake where fish were sourced, to measure continuous (20min) surface (0.15 m) and bottom (0.1 m) temperature to derive thermal frequency curves to examine how often lake temperatures exceed AET thresholds. For most fish species examined, water temperature that could be lethal were exceeded at the surface, but rarely, if ever, at the bottom waters suggesting deep, cooler, water provides thermal refugia for fish. An energy-balance model was used to estimate daily mean lake water temperature with good accuracy (±1 °C; $R^2 = 0.91$, modelled vs lake measured temperature). The model was used to predict climate change effects on lake water temperature, and the exceedance of thermal threshold change. A 2.3 °C climate warming (based on 2100 local climate prediction) raised lake water temperature by 1.3 °C. However, small as this increase might seem, it led to a doubling of time that water temperatures were in excess of AET thresholds at the surface, but also the bottom waters that presently provide thermal refugia for fish.

1. Introduction

Despite being incredibly productive habitats for fish (Blaber et al., 2010; Manson et al., 2005; Nagelkerken et al., 2015), across much of the world tropical estuaries continue to be modified for human gain (Rozas, 1992; Wen et al., 2010). An example of this modification occurs where property developers excavate large tracts of natural wetlands (e.g., mangroves, saltmarsh), or dig out terrestrial habitat to create artificial, urban water development, designed to increase extent of usable waterfront land (Lindall et al., 1973; Waltham and Connolly, 2013). Residential urban waterways have been built on most continents, and collectively contribute to over 4000 km linear of engineered habitat for fish (Waltham and Connolly, 2011). In utilising these built waterways fish (Claassens, 2016; Waltham and Connolly, 2006) are susceptible to contamination and poor water quality (Maxted et al., 1997), and hydraulic connectivity with downstream estuaries may be altered (Zigic et al., 2002). Furthermore, their position in low lying areas of coastal floodplains raise concerns about vulnerability to sea level rise, shoreline erosion (Harvey and Stocker, 2015), and that climate change might reduce the utility of these man-made habitats for fish (Waltham and Connolly, 2011).

Animals spend a significant proportion of time (and energy) avoiding or escaping stimuli (predation, chemical contamination,

* Corresponding author. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Queensland, 4811, Australia.
E-mail address: nathan.waltham@jcu.edu.au (N.J. Waltham).

http://dx.doi.org/10.1016/j.ecss.2017.06.032
0272-7714/

noise) that could cause physical harm that reduces fitness or causes death (Connell, 1993). One causal stimulus contributing to animal avoidance is exposure to high temperature (Brett, 1956). Determining effects of temperature on animal behaviour and movement has received increasing attention prompted by climate change concerns and how future, warmer temperature may cause range shifts in distribution of native (James et al., 2017; Stewart et al., 2013; Welbergen et al., 2008), or invasive species (Carveth et al., 2006), or in some cases extinction of vulnerable species (Thomas et al., 2004). For many aquatic species, including fish, temperature directly controls metabolic rate, and can influence growth, resource allocation for reproduction and ultimately, population size (Armstrong et al., 2013; Jobling, 1995). Evidence shows that growth rate and development in fish tend to increase with temperature up to an optimum, provided sufficient food is available (Eaton and Scheller, 1996). However, the long term (chronic) effects of exposure to elevated water temperature can include reduced year class strength (Brown et al., 2016; Nunn et al., 2003), cessation of growth, and increased susceptibility to environmental stresses such as low concentrations of dissolved oxygen (Pearson et al., 2003). Exposure to extreme temperature causes acute hyperthermic (or hypothermic) response, requiring animals to thermoregulate or they will die (Coulter et al., 2016; McCauley and Casselman, 1981). Determining the temperature threshold (defined here as Acute Effect Temperature, AET) provides insight into thermal exposure risk, necessary for species protection and conservation.

This paper reports fine time-interval resolution (20 min) continuous water temperature measurements made in a residential man-made tidal lake in Townsville, northern Queensland, Australia. We used these data to quantify how water temperature changes as the austral summer evolves, and how water temperature varies between the surface and bottom layer in tidal built lakes. We then determine the AET for five common estuarine fish that occupy the lakes using laboratory manipulative experiments, to assess how often lake water temperature approach and exceed these thresholds. Advancements in water thermal energy modelling provides the opportunity to predict temperature exposure risk to aquatic animals using readily available daily weather data (McJannet et al., 2012, 2014; Wallace et al., 2015). We then use an energy balance model to simulate how climate change might influence the thermal exposure risk for fish occupying engineered tidal lakes.

2. Methods

2.1. Study area

Ross Creek is a small (8 km linear) transitional (Elliott and Whitfield, 2011) estuary in tropical north Queensland (-19.270688° S, 146.788279° E) that flows into Cleveland Bay, and the Great Barrier Reef lagoon, Fig. 1a (Sheaves and Johnston, 2010). Located adjacent to Ross Creek is a large constructed residential tidal lake estate, built in the early 1990s as a way to increase residential real estate with waterfrontage (Waltham and Sheaves, 2015), and to treat water quality (sediment and nutrient load reductions) discharged from the surrounding urban and industrial estates before reaching the main estuary and Great Barrier Reef lagoon. The lake system is approximately 7.5 ha, average water depth is between 1.9 and 2.5 m (150 ML). The lake has two sections that are connected via a narrow concrete open channel (approximately 150 m long, 10 m width and 1 m depth) which allows water exchange and fish passage between the lakes. A long concrete channel extends from the lake, joining with Ross Creek approximately 3.5 km upstream from the mouth of the creek. A series of four engineered hydraulic arms separate the concrete channel from Ross Creek estuary, and are synchronised to open based on the tidal height of the downstream Ross Creek (though can be manually opened during extreme flood events) (Causeway Floodgate Procedures, Townsville City Council, unpublished manual). The hydraulic control structure permits tidal exchange with Ross Creek, in such a way that it reduces the tidal prism, which is necessary to circumvent situations where increased tidal prism compromises engineering rock walls or bridge foundations, and contributes to erosion along the lake edges (Zigic et al., 2002). Fish visit the lakes and can return to the estuary during times when the hydraulic gates are open. The lakes holds a subset of fish species found in the adjacent estuaries (Sheaves et al., 2012) including a number of diadromous species common throughout the region (Sheaves and Johnston, 2010; Sheaves et al., 2010; Waltham and Davis, 2016). During summer months the lakes become hypoxic, a consequence of high ambient air and water temperature (which reduces the solubility of oxygen in water available for fish), in addition to high densities of oxygen consuming phytoplankton and sediment benthic algae; a trait that contributes to poor water quality and fish kills in coastal waters of Queensland (Dunn et al., 2012).

2.2. Estuary fish acute temperature effects experiments

In this study, a subset of local estuarine fish species were examined, including glass perch (*Ambassis vachellii*), river mullet (*Chelon subviridis*), diamond scale mullet (*Ellochelon vaigiensis*), and pony fish (*Leiognathus equulus*) – representing upper water column assemblage; and the whiting (*Sillago analis*) – representing benthic dwelling assemblage. Fish were collected in the lake using a seine net (10 mm mesh, 1.8 m drop), and transported to the laboratory for acclimation (from the collection site to the laboratory was 30 min, using three 90 L containers each with battery aerators). The laboratory had a single 800 L saltwater tank (salinity 33), set up on a recirculatory system with water exchange set approximately 10 L/min (MARFU, James Cook University).

In the laboratory, fish were acclimated to a constant temperature (28 °C; ±2 °C) for three weeks prior to the Acute Effect Temperature (AET) exposure experiment. This acclimation temperature represents approximately the summer average daily water column temperature in the lakes (based on historical water quality monitoring undertaken by Townsville City Council since 1994 - unpublished data). Fish were fed aquaculture pellets (Ridley AgriProducts Pty Ltd) every 2–3 days; all fish were feeding during the acclimation period suggesting that they were not stressed prior to the temperature exposure experiment.

In the AET experiment an experimental glass aquarium tank (0.7 x 0.4 × 0.6 m; ~150 L) was designed specifically for the experiment. Two circulatory pumps were placed in the tank to ensure the tank was well mixed. Water in the experiment tank was continuously replaced at a rate of 2 L/min with water on the acclimation tank system. Photoperiod in the aquarium laboratory was maintained at 12:12 h dark:light cycle. The experimental tank was cleaned after each experiment, resulting in an approximate 80% water exchange.

Between 10 and 16 individual fish were transplanted from the acclimation tank to the experimental tank 2–3 days prior to the AET experiment tank so that fish would acclimate to the new tank setting. During the experimental tank acclimation period, conditions (i.e., water temperature (28 °C) and photoperiod) remained the same as the acclimation tank.

At the start of each AET experiment, the water circulation pipe was closed so the tank was a single experimental unit. A programmable thermo-controller (Thermoline, Eurotherm 3216 Control) was used to increase the water temperature at a linear rate of approximately 2–3 °C per hour with the experiment commencing at the acclimation temperature (this rate is similar to diurnal water temperature changes experienced in the lake, see below). The time