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The effects of cool and variable temperatures on the hatch date, growth and overwinter mortality of a warmwater fish in small coastal embayments of Lake Ontario

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ABSTRACT

Little is known about the ecology of warmwater fish in small coastal embayments (<32 ha) where temperatures are lowered by exchange with the adjacent lake. Using pumpkinseed (*Lepomis gibbous*) as a model warmwater fish, we compare hatch dates and overwinter survival in two embayments with higher and lower amounts of cold-water input from Lake Ontario, in a warmer and cooler year. In 2007, the embayments differed by approximately 2–5 °C until late-July. In that year, temperatures in the cooler embayment delayed hatching times until July 18–August 20, approximately eight weeks later (May 24–August 20) than in the warmer embayment. Almost all offspring in the cooler embayment were likely too small to survive the winter. In 2008 both embayments had similar temperatures. In that year, pumpkinseed started hatching in early-June, and most were likely large enough to survive the winter. The findings from the two intensively sampled embayments were confirmed with a 21-year fish monitoring dataset; adult pumpkinseed were captured in the littoral zone of warm embayments 6–8 weeks earlier than in cooler embayments. Relative to pumpkinseed in the small inland lakes of eastern and central Ontario, spawning is delayed by at least two weeks in coastal embayments. Using water temperatures as a surrogate for growth, we calculated that only 5 of the 17 embayments for which we have temperature records were able to consistently produce successfully overwintering age-0 fish. Nevertheless, we found pumpkinseed age ≥ 1 in embayments too cold to produce age-0 pumpkinseed, suggesting immigration from warmer embayments.

Introduction

Dozens of small coastal embayments (<32 ha) have been and will continue to be constructed along the northwest shoreline of Lake Ontario to restore and create warmwater fish habitat. Because very little is known about the ecology of the warmwater fish in small coastal embayments of the Great Lakes, the designers of these habitats have had to rely largely on our understanding of warmwater fishes in the many studies of small inland lakes and ponds. This paper is the second in a series aimed at evaluating the success of these designs; the first paper describes the thermal regime of these small coastal embayments, uses bioenergetic modeling to predict if thermal differences among embayments are sufficient to have substantial effects on young-of-the-year (YOY) fish growth and correlates embayment temperature with their bathymetric characteristics (Murphy et al., 2011).

Inferences from inland lakes about suitable depth gradients, and the benefits of macrophyte beds in designing embayments for warmwater fish are likely valid. However, an embayment's connection to the adjacent lake creates a cooler and more variable thermal regime than in inland lakes (Murphy et al., 2011), which might severely compromise an embayment's habitat quality for warmwater fishes (Hennyey, 2006). Whereas the thermal regime of small inland lakes during ice-free months can be reasonably described with a symmetrical sine wave (Shuter et al., 1983), the thermal regimes of coastal embayments are less predictable because their connection to a much larger lake allows the input of cool water. During the heating part of the year, the shallow embayments warm quickly, so exchange with the much larger (and slower warming) Great Lake cools the embayments (Murphy et al., 2011; Rueda and Cowen, 2005). Conversely, during the cooling period of the year, embayments cool faster than the connected lake, so exchange keeps the embayments warmer than they would otherwise be. However, the overall effect of exchange with the adjacent is cooling (Murphy et al., 2011). In addition, when a Great Lake upwells cold hypolimnetic water, (which occurs especially frequently along the

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northwest shoreline of Lake Ontario (Rao and Murthy, 2001)), the temperatures in coastal embayments can decrease by over 10 °C in just a few hours (Lawrence et al., 2004; Murphy et al., 2011; Rueda and Cowen, 2005).

Cool and variable temperatures are likely to be important to warmwater fishes for several reasons. For warmwater centrarchids, spawning begins when a threshold temperature is reached; thresholds for various species range from 12 to 22 °C (Burns, 1976; Danylchuk and Fox, 1994; DeVries et al., 2009; Mittelbach and Persson, 1998). Earlier-hatched fish usually contribute disproportionately to recruitment because they are able to grow for longer periods of time during their first summer, increasing their size and, therefore, overwinter survivorship (Ludsin and DeVries, 1997; Miller and Storck, 1982), but there are exceptions (Garvey et al., 2002; Santucci and Wahl, 2003).

Mortality of eggs, larvae and young fish is also associated with cool and variable thermal conditions. Centrarchids spawn in nests and males guard their young from predators (Colgan and Brown, 1988; Scott and Crossman, 1998). Sudden changes in temperature of as little as 2–4 °C (Henderson and Foster, 1957; Rawson, 1945), particularly when temperatures fall below 10–15 °C (Latta, 1963; Shuter et al., 1980), can cause the defending males to abandon the nests, leaving their eggs exposed to nest predators (Bain and Helfrich, 1983; Gross and MacMillan, 1981; Steinhart et al., 2004). Low temperatures also slow the development and growth of eggs and larvae (Gillooly and Dodson, 2000; Gillooly et al., 2002) and YOY fish (Beitinger and Fitzpatrick, 1979; Neuheimer and Taggart, 2007; Pessah and Powles, 1974), increasing exposure to nest and gape-limited predators (Dewey et al., 1997; Mittelbach and Persson, 1998; Shuter et al., 1980).

Studies of warmwater fish ecology in small inland lakes indicate that, at Great Lakes latitudes, suboptimal temperatures often limit growth and survival of YOY warmwater fish (Sharma et al., 2007; Shuter et al., 1980). Therefore, in the many coastal embayments of the Great Lakes, where exchange of water with the adjacent lake lowers embayment temperatures through the warming period of the year (Murphy et al., 2011), temperature is likely to be an even more important ecological influence. In this paper, we select two embayments with different thermal regimes that represent the warmer half of the thermal range of embayments along the shoreline of Toronto, and quantitatively evaluate the impact of thermal differences between embayments on the hatch date, growth and overwinter survival of YOY pumpkinseed (*Lepomis gibbous*). We extend this comparison between a warm and a cool year. We also use temperature records to predict YOY pumpkinseed growth in all the small embayments along the shoreline of Toronto and show that the inferences about pumpkinseed productivity and seasonal periods of occupancy based on thermal differences between the two embayments are consistent with strong patterns in a 21-year long record of fish collections.

Methods

Study sites

This study extends along 40 km of coastline near Toronto, Ontario (Fig. 1) and involves seventeen coastal embayments and some exposed portions of the shoreline of Lake Ontario (hereafter the Lake). The embayments have been assigned to a Warm, Intermediate or Cold thermal grouping specified in Murphy et al. (2011), and are numbered in ascending order from warmest to coolest within their thermal group. The temperatures in the Cold embayment group are similar to those of the Lake, those in the Warm embayment group are similar to that of a Reference Embayment, which is temporarily disconnected from the Lake as it undergoes remediation and restoration, and those in the Intermediate embayment group are intermediate. Approximately half of the seventeen embayments are found in the Toronto Islands or Tommy Thompson Park, a 5 km constructed peninsula. The Toronto Islands are a 230 ha natural land feature that includes a variety of small waterbodies that have been modified by dredging and sill construction to ensure a limited, but permanent, connection to the Lake. The embayments and exposed shoreline support a variety of fish species from cold-, cool-, and warmwater thermal guilds (Dietrich et al., 2008; Hennyey, 2006). The hydrological properties and thermal characteristics of the seventeen embayments are described in Murphy et al. (2011).

We selected two of the seventeen embayments for intensive biological sampling — one that is substantially cooled by the Lake and another more isolated from the Lake. Hereafter, we refer to these as the Higher Exchange Embayment and Lower Exchange Embayment, respectively. The Higher Exchange Embayment is in the Intermediate embayment group, located in Tommy Thompson Park and connects to Lake Ontario through a channel 77 m wide and 33 m long (Fig. 1). The Lower Exchange Embayment is in the Warm embayment group, located in the Toronto Islands and is buffered from Lake exchange by a 75–100 m wide and 1800 m long canal and a large harbor. We focused our biological sampling on only two embayments so that we could collect enough fish in each to develop robust relationships between the physical environment of the embayments and growth, which we could then extend to the other fifteen embayments mentioned above. The Higher and Lower Exchange Embayments were selected for focused biological sampling because YOY warmwater fish are abundant in both, they contrast in temperature (Fig. 2), they are easily accessed, and there are historical temperature data and fish collection records for both.

Temperature collection

We collected surface water temperature measurements (°C) at 1 m depth in all 17 embayments in 2006–2008 (Table 1). We recorded temperatures every half-hour with submersible temperature loggers with a +0.2 °C accuracy (Optic StowAway or Hobo U22 Water Temp Pro v2 by Onset Computer Corporation). We deployed the loggers in early spring and retrieved them in late fall.

We used two statistics to summarize our temperature records, the daily-average water temperature and growing degree-days (GDD). Daily-average water temperature summarizes temperature on a short time scale; growing degree-days is a heat index that accumulates daily temperature above a baseline temperature that represents a threshold for growth or reproduction. Temperature is a major influence on size-at-age in fishes, and GDD was shown to be a reliable predictor of size-at-age for a number of fish species in a wide range of physical environments and locations (Neuheimer and Taggart, 2007). We selected a baseline temperature of 14 °C, the minimum temperature at which both male and female pumpkinseed begin their final stages of gonad development (Burns, 1976). Therefore ΣGDD_{14}, is calculated as:

$$\sum_{ti}^{tn} (\text{daily average water temperature} - 14\,^{\circ}\text{C}), \quad (1)$$
$$\text{for all days when daily average water temperature} > 14\,^{\circ}\text{C}.$$

Fish collection

Warmwater fish were the focus of this study because they are the most likely to be thermally limited by the temperatures in coastal embayments. We selected the warmwater pumpkinseed (Centrarchidae: *L. gibbosus*) to study because it is one of the most common warmwater fish species captured along the Toronto shoreline in embayments or sites with limited wave exposure, and is also one of the most commonly collected and well-studied littoral species from inland lakes in Ontario.

We collected YOY pumpkinseed from the Higher and Lower Exchange Embayments to determine their summer growth rates and hatch dates (described below). YOY pumpkinseed were seined from the littoral zone with a 22 m×1.0 m bag seine (5×5 mm mesh),