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Effects of water clarity on the length and abundance of age-0 yellow perch in the Western Basin of Lake Erie

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ABSTRACT

Water clarity is an important environmental variable that may affect fish populations by altering the visual environment. Effects can change feeding ability, as well as alter predation risk. The western basin of Lake Erie provides a valuable model system for studying the effects of transparency because the two main tributaries, the Maumee and Detroit rivers, differ substantially in clarity. We used Generalized Additive Models (GAMs) to quantify the relationship between transparency and the observed abundance and length of age-0 yellow perch (*Perca flavescens*) in August, based on surveys from 1986 to 2006. Secchi data from June to August were included in the models that best explained the variation in yellow perch abundance and length. August values for bottom oxygen and bottom temperature also increased model fit for abundance, whereas only bottom temperature improved model fit for length. Our models indicate that transparency was positively related to the August length while abundance of age-0 yellow perch was inversely related to transparency. Highest abundance was observed in areas with the lowest transparency, with peak abundances observed in areas with less than 1 m of Secchi depth. This is in contrast to August length, which increased as transparency increased, to an asymptote at around 3 m of Secchi depth. The split nature of water clarity conditions in the western basin of Lake Erie has resulted in areas with higher growth potential, versus areas with higher apparent survival.

Introduction

Water clarity is a defining feature of aquatic habitats and shapes the physical environment fish encounter through changes to primary productivity, habitat availability, and light limitation. Such environmental changes subsequently affect fish behaviors including predator avoidance, habitat selection, and foraging time and ability. Experimental and field-based studies have shown that water clarity affects foraging by young fish (Harvey and Brown, 2004; Mayer et al., 2000; Mills et al., 1986; Miner and Stein, 1993; Wellington et al., 2010) and, in turn, the growth, recruitment, and subsequent year class strength of a population (Crecco and Savoy, 1985; Noble, 1975; Reichert et al., 2010; Tyson and Knight, 2001).

Multiple factors mediate the effect of water clarity on fish foraging, including fish species (DeRobertis et al., 2003; Rowe and Dean, 1998), developmental stage (Boehlert and Morgan, 1985; Crowl, 1989; Utne-Palm, 2002), and turbidity type and intensity (Carton, 2005; Radke and Gaupisch, 2005). For example, in a series of laboratory experiments with larval and juvenile yellow perch (*Perca flavescens*), Wellington et al. (2010) found that sediment and algal turbidity differentially affected foraging in larval and juvenile yellow perch. Specifically, high sediment turbidity did not reduce the foraging rate of larval yellow perch, but did reduce the foraging of juveniles (Wellington et al, 2010). Alternatively, algal driven turbidity (at all intensity levels) reduced the foraging ability of both larvae and juveniles (Wellington et al., 2010). While turbidity, in general, lowers food consumption, the negative effects on visual foraging become more pronounced as fish size increases (Chiu and Abrahams, 2010; DeRobertis et al., 2003; Diehl, 1988; Hartman and Margraf, 1993; Wahl et al., 1993) and so, age-0 survival may increase as clarity decreases, due to a reduction in predation pressure from larger, visually foraging species. Consequently, age-0 fish may experience a tradeoff with greater food consumption and higher growth in clear water but greater survival and hence higher abundance in turbid water.

Water clarity offers an important management lever for fish populations. Unlike many of the factors that influence the survival of age-0 fish, such as temperature, water movement and zooplankton abundance (Clapp and Detmers, 2004; Hargeby et al., 2007; Hoffman et al., 2001; Olson et al., 2001; Paukert and Willis, 2001) water clarity can be changed by altering land use practices. Agriculture, forestry, construction, and channel dredging, lead to influxes of sediment and nutrients into aquatic habitats (Baker and Richards, 2002; Ouyang et al., 2005) that promote sediment plumes and phytoplankton blooms, resulting in low water clarity (Heisler et al., 2008; Nichols and Hopkins, 1993). These anthropogenically driven sediment plumes and algal blooms have become wide spread in coastal

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systems that are often important nursery areas for age-0 fish (Jones et al., 2003; Nack et al., 1993). The Mississippi Delta (Green et al., 2006), Chesapeake Bay (Gitelson et al., 2007), and the western basin of Lake Erie (Ludsin et al., 2001) have all experienced problems with sedimentation and harmful algal blooms. Such coastal systems are economically and ecologically valuable and so it is important to understand how sediment and algal turbidity affects the fish populations that utilize these areas.

The western basin of Lake Erie presents a valuable system for the study of water clarity effects on fish because the two major tributaries entering the lake, the Maumee and Detroit Rivers, differ widely in flow volume, total suspended solids and phosphorus concentrations (Reichert et al., 2010). While the Maumee River contributes less than 15% of the total water that flows into the western basin of Lake Erie, it contributes more than half of the suspended sediments input, and more than 2240 t of phosphorus annually (Moorhead et al., 2003) influencing sediment plumes (Paul et al., 1982) and algal blooms in the western basin (Correll, 1998; Smith, 1982). The Detroit River discharge averages 5324 m^3/s, much higher than the Maumee's average discharge of 150 m^3/s, and has much lower concentrations of both sediment and phosphorus (OEPA, 2010). The contrast between these tributaries produces a split in western Lake Erie, with the southern shore dominated by the warm, turbid water of the Maumee, and the northern shore reflecting the cold, clearer water of the Detroit River (Reichert et al., 2010). In this study we take advantage of long-term, basin-wide surveys of an abundant and ecologically important visually feeding fish (yellow perch) in the western basin of Lake Erie to build predictive models of the response of age-0 fish to varying water clarity.

We suggest that yellow perch caught from clearer water will be larger than those in turbid areas, perhaps due to an increased ability to forage, and greater size selective predation by visually foraging predators. Alternatively, fish may be more abundant in turbid water that affords some refuge from predation, but will be smaller due to reduced foraging ability. Also, given the high contrast in water clarity in the western basin of Lake Erie, we hypothesize that water clarity will be more important than other physical factors in explaining variability in age-0 yellow perch size and abundance. We quantified the relationships between turbidity and abundance and length of age-0 yellow perch using Generalized Additive Models (GAMs). This approach allowed us to: 1) quantify the shape and fit of the relationships of age-0 yellow perch abundance and size-at-age with water clarity and, 2) determine if turbidity explains more variability in age-0 yellow perch size and abundance than other environmental factors by comparing a suite of candidate GAMs to find the best-fit model.

Methods

Environmental and fisheries data were provided by the Ohio Department of Natural Resources (ODNR) and the Ontario Ministry of Natural Resources (OMNR). Inter-agency trawl data were collected during June, July and August, 1986–2006, using techniques described in Tyson et al. (2006). Environmental data used in this research include: bottom oxygen levels (mg/L), bottom water temperature (°C), water depth (m), Secchi depth (m) (used as a surrogate for transparency), and geographic location (decimal degrees). Fisheries data recorded included fish species caught, individual fish age as determined by ODNR personnel, individual fish lengths (mm), trawling speed, time and gear used, and total catch numbers. For this study, environmental data for all months were included in our analyses, while only fish data from August were considered because this is when age-0 yellow perch have become demersal and are first regularly captured by the trawls. Catch numbers for the age-0 yellow perch were converted into catch per unit effort (CPUE) by standardizing total catch by swept area and time for each trawl (Tyson et al., 2006), and used to assess total abundance of age-0 yellow perch during August. The individual fish lengths and CPUE were also relativized across all years, to remove the effect of year-to-year variation while still maintaining any long-term trends in the data. Using these data, we did three general analyses: 1) visualized the data using GIS to aid in candidate model selection, 2) tested for differences in the distribution of lengths in August of yellow perch between the fish caught in areas influenced by the Detroit River compared to the Maumee River, and 3) used Generalized Additive Models to analyze the relationships between environmental variables and abundance and size of yellow perch.

Data visualization & trend analysis

The data points for environmental and fish variables were visualized in ArcGIS 9.3 (Johnson et al., 1995) and tested for spatial autocorrelation using the geoR package in R (Ribeiro and Diggle, 2001). Given the obvious trends in water clarity in Lake Erie, we tested our length, CPUE and Secchi depth locations for spatial autocorrelation using the method describe in Kaluzny et al. (1998). First we used General Linear Models to remove the trends in the data using the general equation: $f(x) = Latitude + Longitude$. Semi-variograms of the residuals of these models were assessed for spatial autocorrelation. No autocorrelation was detected for length, CPUE or Secchi depth after accounting for the general trends. The water clarity data points from the inter-agency trawls were then used to create predictive surfaces, i.e. maps, of the western basin using universal kriging. Universal kriging accounts for both trends and auto-correlation between known points to predict values of a specified parameter in areas not directly measured (Johnston et al., 2003).

Kolmogorov–Smirnov test

One obvious pattern observed in our GIS analysis is the difference in water clarity between the clearer output of the Detroit River and the more turbid output of the Maumee River. To quantify differences between these areas, we defined four regions of the western basin of Lake Erie, the northern and southern halves separated to distinguish the Detroit River inputs from the Maumee River, and the eastern and western halves separating the basin via the portion of the basin influenced by a series of islands (Fig. 1A). All four regions included at least 45 unique sample locations and more than 300 observations across all included years. A Kolmogorov–Smirnov (KS) test was performed using R (v. 11.1) to determine whether size distributions of age-0 yellow perch from different regions of the basin were statistically different. For this test we focused on the two regions identified in the data visualization with the greatest difference in mean age-0 yellow perch length in August which were the NW and SE quadrants.

Model construction

Generalized Additive Models were used to analyze the relationships between environmental variables and abundance and size of yellow perch because of their flexibility when handling non-normal data (Yee and Mitchell, 1991). GAMs allow the inclusion of both parametric and non-parametric data, which allows for a potentially better fit to non-normal data sets (Faraway, 2006). The non-parametric nature of GAMs allows for the determination of the shape of the response curves from the data as opposed to a priori, parametric linear models. A GAM fits a number of linear regressions to the data and then uses a series of smoothing splines to fit a regression line that best describes non-normal data (Faraway, 2006). In this application, GAMs were used to model the effect of a suite of environmental variables on yellow perch abundance and length in August. We used the *gam* function of the mgcv package (Wood, 2006) in R (v. 11.1 R core team, 2012), specifying a Gaussian family with an identity link function. The *gam* function fit a cubic smoothing spline to the dynamic factors included in each of the candidate models