Journal of Great Lakes Research xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

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

Relationships between habitat characteristics and round goby abundance in Lakes Michigan and Huron

David P. Coulter *, Brent A. Murry [1], Donald G. Uzarski [2]

Institute for Great Lakes Research, Central Michigan University Biological Station, and Department of Biology, Central Michigan University, Brooks Hall 217, Mt. Pleasant, MI 48859, USA

ARTICLE INFO

Article history:
Received 29 April 2014
Accepted 13 May 2015
Available online xxxx

Communicated by: John Janssen

Keywords:
Neogobius melanostomus
Great Lakes
Wetland
Exotic species
Invasion
Environmental conditions

ABSTRACT

Expanding round goby (*Neogobius melanostomus*) populations threaten many native species throughout the Great Lakes. The qualities that make a habitat suitable for round gobies are oftentimes considered as single factors (e.g., substrate type or dreissenid mussels). A more thorough understanding of the environmental characteristics related to round goby abundance can help identify habitats that are less susceptible to invasion. This study examined the habitat characteristics associated with round goby abundance in the Beaver Archipelago of Lake Michigan and the Les Cheneaux and Saginaw Bay regions of Lake Huron. Chemical and physical variables, zooplankton, macroinvertebrate, and fish assemblages were sampled from open water and wetland habitats. Gradients in habitat characteristics, determined using ordination analyses and diversity indices, were correlated with round goby catch per unit effort (CPUE) using fyke nets. Round goby CPUE in the Beaver Archipelago was positively related to increasing productivity and a more diverse fish community. Round goby CPUE at Les Cheneaux was related to wave disturbance and fish species associated with greater habitat complexity, though habitat type alone did not explain these relationships. In contrast, round goby CPUE in highly productive Saginaw Bay wetlands was very low where fish diversity was high and assemblages were dominated by littoral species tolerant of eutrophic conditions. Overall, CPUE was related to indices of biological productivity, with the direction of these relationships varying among regions. Areas with high productivity, including some wetlands, may be less hospitable for round gobies and could serve as refugia for native species.

Introduction

Since first observed in the St Clair River over two decades ago (Jude et al., 1992), round gobies (*Neogobius melanostomus*) continue to disrupt ecosystem dynamics in the Laurentian Great Lakes. Round gobies negatively affect native fishes through competition and/or predation on eggs and larvae (Janssen and Jude, 2001; Steinhart et al., 2004; Kornis et al., 2012), have been linked to decreased macroinvertebrate densities and diversity (Barton et al., 2005; Lederer et al., 2006), can aid in disease transmission (Hannett et al., 2011), and possibly facilitate the transfer of toxicants through food webs (Hogan et al., 2007; Kwon et al., 2006). Thus, round gobies pose a substantial threat to many organisms.

Not all habitats, however, are equally suitable for round gobies. Round gobies are commonly associated with unvegetated areas with cobble substrate (Kornis et al., 2012) but have been observed to a lesser degree over sand and silt substrates (Ray and Corkum, 2001; Coulter et al., 2012) and among submerged and emergent vegetation (Cooper et al., 2007, 2009; Young et al., 2010). Baldwin et al. (2012) observed reduced round goby survival and increased gill ventilation rates, an indicator of physiological stress, when dissolved calcium concentrations dropped below 8 mg L^{-1}, thus water chemistry also influences habitat use. In addition to physical and chemical conditions, prey abundance is probably a strong determinant of habitat use because round gobies frequently consume dreissenid mussels and are commonly found in habitats with high mussel densities (Johnson et al., 2005; Walsh et al., 2007). However, importance of dreissenid mussels as a prey item can depend on other habitat conditions including substrate complexity and water clarity (Diggins et al., 2002).

Ultimately, habitat selection and use by round gobies are likely based on a suite of environmental conditions. For example, Dopazo et al. (2008) evaluated how fish assemblages and multiple water quality variables related to round goby abundance in Lakes Huron and Erie and found abundance to be highest in deeper, less turbid, and generally colder habitats where fish assemblages were dominated by rock bass (*Ambloplites rupestris*) and yellow perch (*Perca flavescens*). Few other studies have explored how combinations of factors affect round goby abundance. Determining these relationships can help identify habitats

* Corresponding author at: Purdue University, Department of Forestry and Natural Resources, 195 Marsteller St., West Lafayette, IN 47907, USA. Tel.: +1 765 494 8086.
E-mail addresses: dcoulte@purdue.edu (D.P. Coulter), brent_murry@fws.gov (B.A. Murry), uzars1dg@cmich.edu (D.G. Uzarski).
[1] Current address: US Fish and Wildlife Service, Caribbean Landscape Conservation Cooperative, International Institute for Tropical Forestry, Rio Piedras, 00926, Puerto Rico. Tel.: +1 787 764 7738.
[2] Tel.: +1 989 774 2504.

http://dx.doi.org/10.1016/j.jglr.2015.06.001

that are less suitable for round gobies and, therefore, warrant conservation.

Great Lakes coastal wetlands are unique habitats hypothesized to have some resistance to round goby invasion. Cooper et al. (2007) posited this hypothesis after observing low round goby catch per unit effort (CPUE) in drowned river mouth wetlands of eastern Lake Michigan compared with adjacent open water sites. Subsequent evaluations of round goby catches from other coastal wetlands in Lakes Michigan and Huron appear to support the hypothesis (Cooper et al., 2009). Despite growing evidence, the mechanism causing round gobies to invade some wetlands over others remains unclear. It is unlikely that round goby colonization of wetlands is due to a single habitat characteristic. For example, substrate type does not appear to completely determine habitat use. While round gobies prefer cobble areas, they have been observed in substantial numbers in some coastal wetlands that have sand or silt substrates (Brammel et al., 2009; Young et al., 2010; Coulter et al., 2012). Instead, multiple environmental conditions likely work in concert to affect the degree to which round gobies invade wetlands and could be a function of biodiversity (Elton, 1958; Ricciardi and MacIsaac, 2008) or habitat productivity (e.g., Cleland et al., 2004).

This study provides an examination of the environmental characteristics related to round goby use of nearshore habitats in the Great Lakes. It further explores the differences between conditions of wetland and open water habitats in order to investigate why round gobies may not equally invade coastal wetlands. To identify gradients in habitat use and environmental conditions, wetland and open water sites were sampled from three geographic regions throughout Lakes Michigan and Huron. The objectives of this study were to 1) determine the suite of abiotic (chemical and physical) conditions and biotic (zooplankton, macroinvertebrate, and fish) assemblages associated with round goby abundance, and 2) evaluate whether these relationships were dependent upon habitat type (wetland or open water).

Methods

Sample collection

Abiotic conditions and biotic assemblages were sampled between mid-June and late July (Table 1) from 40 study sites spanning three geographic regions: 11 sites in the Beaver Archipelago and 2 at St. Ignace, MI in northern Lake Michigan sampled in 2008, 9 sites in the Les Cheneaux islands region of northern Lake Huron sampled in 2009, and 18 sites in Saginaw Bay of western Lake Huron sampled in 2009 (Fig. 1). Beaver Archipelago and St. Ignace sites primarily had rock substrate which is considered ideal spawning habitat for round gobies (Kornis et al., 2012). These were primarily forested regions with minor urban development. At the Beaver Archipelago, water is advected in from Lake Michigan on occasion; and St. Ignace receives water from both Lakes Michigan and Huron (Beletsky et al., 1999). Les Cheneaux sites had a mix of rock, sand, and silt substrate and were protected from the rocky areas of Lake Huron proper by barrier islands. Les Cheneaux was heavily forested with minor urban development and receives water from Lake Huron and some from Lake Michigan (Beletsky et al., 1999). Saginaw Bay sites consisted of sand and silt substrate and were not within close proximity to large areas of rocky substrate. Saginaw Bay land use was heavily agricultural and most water input in this region is from the Saginaw River (Danek and Saylor, 1977). Both wetlands and open water (unvegetated) habitats were sampled in all regions and were primarily sampled as a paired wetland and open water site (Coulter et al., 2012). Sites were selected so that a paired wetland and open water site had the same substrate type and were located within 200 m from one another. The outer margins of wetlands were primarily sampled although Beaver Archipelago and Les Cheneaux wetlands generally extended a shorter distance from shore than Saginaw Bay wetlands. Therefore, the majority of Beaver Archipelago and Les Cheneaux wetlands were sampled, whereas only the outer portions of Saginaw Bay wetlands were sampled. All sites, regardless of habitat type, had water depths between 0.2 and 1.0 m. For statistical analyses, the two St. Ignace sites were included with Beaver Archipelago sites because initial analyses indicated that substrate, vegetation, and chemical and physical conditions at these two sites were similar to conditions in the Beaver Archipelago, while also being in close proximity.

Chemical and physical water conditions, including temperature, pH, dissolved oxygen concentration, turbidity, chlorophyll-*a* concentration, oxidation-reduction potential, and specific conductance, were measured *in situ* at each study site using a YSI 6600 multiparameter sonde (Yellow Springs, OH). Water samples were collected at each site to measure total alkalinity and nutrient concentrations. Total alkalinity was determined by titration with 0.02 N sulfuric acid. Water samples for nutrient analyses were filtered through a 0.45 μm Millipore filter. Nitrate-N (NO_3-N), ammonium-N, and soluble reactive phosphorus (SRP) concentrations were measured in the laboratory using a QuAAtro Continuous Flow Analyzer (SEAL Analytical). Sediment samples were also collected to quantify the amount of organic material deposited at each site. A sediment core 10 cm deep and 7 cm in diameter was taken at each sampling location, placed on ice during transport to minimize respiration, and frozen. Once in the laboratory, entire sediment cores were oven-dried at 105 °C for approximately 24 h or until a constant weight was achieved. Any large aggregates of sediment remaining (except for rock) were homogenized using a mortar and pestle, and samples were then dried at 105 °C for an additional 24 h, cooled under desiccation, and weighed. Entire oven-dried sediment cores were then placed in a muffle furnace at 550 °C for 24 h, cooled under desiccation, and weighed. Loss on ignition was determined as the percentage of organic matter in each sediment sample. Vegetation at each site was quantified using a square, 0.25 m^2 quadrat, with emergent vegetation measured as the number of stems per 0.25 m^2 and submerged vegetation, including algae, visually estimated as the percent cover per 0.25 m^2 quadrat. Substrate type was visually estimated as the percentage of silt, sand, and cobble within a 0.25 m^2 quadrat. At each site, vegetation density and the percentage of submerged vegetation and substrate type were averaged among three replicate 0.25 m^2 quadrats.

Zooplankton assemblages at each site were sampled using a Wisconsin plankton net (153 μm mesh) pulled horizontally through the water column while walking for approximately 30 m. Tow distances were measured to calculate zooplankton densities, and three replicate tows

Table 1
Dates sampling occurred at wetland and open water habitats at sites in the Beaver Archipelago of Lake Michigan in 2008 and in Les Cheneaux and Saginaw Bay of Lake Huron in 2009.

Location	Site	Date
Beaver Archipelago	St. Ignace	7-Jul
	St. James 1	13-Jul
	Indian Harbor	17-Jul
	Garden Harbor	17-Jul
	Manitou Bay	22-Jul
	St. James 2	24-Jul
	Jensen Harbor 1	27-Jul
	Jensen Harbor 2	27-Jul
Les Cheneaux	Sheppard Bay	6-Jul
	Hessel Channel	9-Jul
	Mackinaw Bay	10-Jul
	Urie Bay	22-Jul
	Cedarville	23-Jul
Saginaw Bay	Fillion	21-Jun
	Bayport	23-Jun
	Sumac	30-Jun
	Vanderbilt Park	2-Jul
	Pinconning	17-Jul
	Coggins	18-Jul
	Quanicassee	28-Jul
	Vanderbilt Park 2	29-Jul
	Vanderbilt Park 3	29-Jul