Journal of Great Lakes Research 41 (2015) 1087–1093

Contents lists available at ScienceDirect

Journal of Great Lakes Research

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

Differential habitat use by the round goby (*Neogobius melanostomus*) and *Dreissena* spp. in coastal habitats of eastern Lake Michigan

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ARTICLE INFO

Article history:
Received 23 December 2014
Accepted 10 August 2015
Available online 29 August 2015

Communicated by Stephen Charles Riley

Index words:
Aquatic invasive species
Lake Michigan
Pierhead
Drowned river mouth
Shoreline hardening

ABSTRACT

Shoreline modifications in Lake Michigan drowned river mouth (DRM) lakes can indirectly create habitats for the invasive round goby (*Neogobius melanostomus*) and dreissenid mussels (*Dreissena* spp.), possibly resulting in their proliferation. To test this hypothesis, we sampled round gobies and dreissenids in Lake Michigan nearshore waters at pierheads and at adjacent DRM lake habitats containing natural and hardened shoreline features. Dreissenids were sampled by SCUBA diving and collecting specimens by hand, while round gobies were sampled using overnight replicate baited minnow traps. Round goby overall catch per unit effort (CPUE, number/trap night) was significantly higher at pierheads compared to the two DRM lake habitats; however, there was no significant difference in CPUE between the natural and the hardened DRM lake habitats. Similarly, dreissenid density was significantly higher at pierheads compared to natural DRM habitats; however, there was no significant difference between the hardened and the natural DRM lake habitats. We did not find any differences in the mean size or age of round goby among habitats. Stomach content analysis showed that soft-bodied prey comprised a larger portion of the round goby diet at pierheads, suggesting that round goby show preference for soft-bodied prey. Our results suggest that the current level of shoreline modification at DRM lake habitats may not be sufficient to evoke a biological response akin to what we found at pierheads; however, given continued shoreline hardening, DRM lake habitats will likely facilitate the proliferation of these invasive species.

Introduction

The round goby (*Neogobius melanostomus*) was first reported in Lake Michigan in 1993 (Charlebois et al., 1997) and has since continued to expand its range into connecting lakes, coastal areas, and channels (Clapp et al., 2001; Cooper et al., 2007; Janetski and Ruetz, 2014). Much of the round goby's spread throughout the Great Lakes has been attributed to facilitative interaction with two other Ponto-Caspian species, the zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena bugensis*) (hereafter, dreissenids) (Ricciardi, 2001). Round goby and dreissenids have had a large impact (independent and combined) on several native species (Janssen and Jude, 2001; Vanderploeg et al., 2002; Krakowiak and Pennuto, 2008; Kornis et al., 2013) and also on food web structure (Johnson et al., 2005a; Dietrich et al., 2006; Campbell et al., 2009). Several studies have shown that round goby prefer hard substrates such as rock and artificial riprap presumably because these habitats also are colonized by dreissenids, known to form an important component of the round goby diet (Ray and Corkum, 1997; French and Jude, 2001; Naddafi and Rudstam, 2014). Other studies, however, have shown that round gobies may be equally abundant on mud (Johnson et al., 2005b) and sandy substrates (Ray and Corkum, 2001), possibly due to the availability of zooplankton and dipterans, which form an important alternate component of the round goby diet (Cooper et al., 2009). While quantitative estimates of round goby and dreissenid densities have been made at a number of locations across the Great Lakes basin, estimates are needed that incorporate systematic sampling in contrasting habitats to evaluate spatial heterogeneity in round goby and dreissenid populations.

A prominent feature on Lake Michigan's eastern shoreline is the drowned river mouth (DRM) lake, which is a coastal lake that connects a tributary to Lake Michigan. DRM lakes are heterogeneous habitats containing areas of dense emergent and submergent macrophytes and areas completely devoid of vegetation with mostly sandy substrate. These systems contain stretches of shoreline and channelized areas that have been modified with hardening structures such as rocks, riprap (i.e., large rocks and boulders) and metal sheet piling as part of urban and industrial development (Carter et al., 2006; Steinman et al., 2008). Ruetz et al. (2009) found that the energy density of round gobies collected from artificially modified channel areas varied from the energy density of round gobies in the adjacent DRM lake and was likely attributable to the consumption of dreissenids in the channel habitat.

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http://dx.doi.org/10.1016/j.jglr.2015.08.005
0380-1330/

Predator–prey experiments suggest spatial variation in the predation of dreissenids by round gobies across habitat types; dreissenids were hypothesized to make up a significant portion of the round goby diet at rocky habitats compared with habitats lacking hard substrates (Ruetz et al., 2012). The size and age structure of round goby populations may also vary spatially depending on habitat type (Ruetz et al., 2012); larger, older round gobies prefer complex habitats with cover, such as those provided by areas with rocks and riprap (Jude and DeBoe, 1996; Ray and Corkum, 2001; Taraborelli et al., 2008) and are known to force younger, smaller round gobies into less complex habitats (Ray and Corkum, 2001; Johnson et al., 2005b).

The main goal of our study was to determine whether shoreline modifications in DRM lakes can facilitate the proliferation of the round goby and dreissenids. Specifically, we tested the aforementioned hypotheses put forth by Ruetz et al. (2009, 2012), by assessing the population structure of round gobies and dreissenids at pierhead habitats and two types of DRM lake habitats. The DRM lake habitats were identified *a priori*, as "natural" DRM and "hardened" DRM lake habitats, based on the adjacent shoreline features and corresponding predictions of dreissenid densities. An area within a DRM lake characterized by natural shoreline features was hypothesized to have a lower density of dreissenids compared with an area characterized by hardened shoreline features, resembling pierhead habitats, where dreissenid density was hypothesized to be higher. The round goby typically undergoes an ontogenetic diet shift from 50 to 100 mm, switching from soft-bodied invertebrates to hard-bodied prey such as dreissenids (Ghedotti et al., 1995; Ray and Corkum, 1997; Andraso et al., 2011a). Therefore, we also conjectured that due to the presence of preferred spawning substrate and expected high abundances of their main food (i.e., dreissenids), larger and older round gobies would be found at high densities at pierhead locations, followed by hardened and natural DRM lake habitats. In contrast, we expected younger, smaller round gobies to be found in high densities at the DRM lake habitats that were expected to have relatively lower dreissenid densities compared to pierhead locations. Given our contention that round goby density and size distribution is a function of dreissenid density at a particular habitat, we predicted that there would be a strong positive correlation between round goby density and dreissenid density across all habitats. Similarly, we also predicted that there would be a strong positive correlation between round goby size and dreissenid density. Finally, we predicted a greater density of dreissenids in the diet of round gobies sampled at pierheads, followed by the hardened and natural DRM lake habitats. Consumption of dreissenids by the round goby also was expected to be strongly correlated to dreissenid density as well as round goby size and age.

Methods

Site selection

We sampled six sites (each with pierhead and two DRM lake habitats) along the eastern shore of Lake Michigan (Fig. 1, Electronic Supplementary Material (ESM) Table S1). The pierhead habitats at each site contained either large boulders or metal sheet piling (e.g., ESM Fig. S1a). The two DRM lake habitats sampled at each site were identified *a priori* as "natural" if the adjacent shoreline features resembled a natural shoreline (e.g., ESM Fig. S1b) and "hardened" if the adjacent shoreline was modified with hard structures such as rocks, boulders, riprap, or metal sheet piling (e.g., ESM Fig. S1c).

Field sampling

We collected samples of dreissenids from the three habitats at six sites during July 12–29, 2010. At pierhead habitats, six 0.119-m^2 quadrats were thrown haphazardly against outer pier walls (i.e., facing Lake Michigan) from the boat. Due to rough conditions, only five quadrats were sampled at the Lake Macatawa pierhead. In natural and hardened DRM lake habitats, the six quadrats were haphazardly thrown from the boat within a diameter of 5 m. At each habitat, dreissenids were then collected by SCUBA diving at the location of each quadrat and removing all attached dreissenids within the quadrat area by hand. Samples from each quadrat were placed in individual fine-mesh bags (9.65 cm × 15 cm × 2 cm; 8 holes/cm^2) upon immediate collection underwater. Each quadrat sample was then transferred to a plastic bag and preserved with 95% ethanol for storage and subsequent analysis in the laboratory.

Round gobies were sampled at all three habitats in each of the six sites during July 19–29, 2010, using replicate baited (chicken liver) minnow traps (3.8-cm diameter opening; 6-mm mesh) that were set overnight (18–24 h). We fished six minnow traps in each habitat (i.e., 3 habitats × 6 minnow traps = 18 minnow traps/site). At pierhead habitats, minnow traps were set along the pier wall approximately 10-m apart. At DRM lake habitats, minnow traps were set approximately 10-m apart along a transect parallel to the shoreline. The depth at which dreissenids and round gobies were sampled ranged from 0.6 to 4.9 m at the pierheads, from 0.5 to 1.4 m at the hardened DRM lake habitats, and from 0.6 to 3.8 m at the natural DRM lake habitats (ESM Table S1). At the following sites, only five of the six minnow traps were recovered: Muskegon Lake natural DRM, Pere Marquette Lake natural DRM, Pentwater Lake pierhead, White Lake pierhead, Spring Lake pierhead. Round gobies captured in minnow traps were euthanized in a solution of MS-222. Each round goby was then measured for total length and stored in 95% ethanol for subsequent laboratory analysis. To prevent continued digestion of the stomach contents and ensure preservation of all consumed prey, a small slit was made in the ventral region of each individual prior to storage in ethanol.

Laboratory processing

Each sample of dreissenids was rinsed in water and then dried in an oven at 105 °C for 12 h. Dried samples were then spread out on a tray (50.8 cm × 40.6 cm) divided into 30 equal square grids. Any sample that contained >50 dreissenids in a single square grid was subsampled such that all dreissenids that covered three randomly selected grids were counted. Following counts, each sample, including the counted dreissenids, was redistributed on the tray and grids were again randomly selected for a minimum of 30 dreissenids to be subsequently measured for maximum shell length. Only dreissenids with maximum lengths > 6 mm were measured. Measurements were taken with dial calipers (to the nearest 0.1 mm).

Round gobies were processed in the laboratory by weighing (wet weight, nearest g) and measuring total length (to the nearest 1 mm) of all specimens followed by removal and storage of digestive tracts into vials containing 95% ethanol for later analysis of gut contents. Scales were removed from the area behind the left pectoral fin and stored in scale envelopes for aging. Scales were mounted between two glass slides and examined under a microscope (magnification: 4×) for age determination. Stomach content analysis was conducted on specimens by identifying and enumerating prey at the taxonomic level of order or family. Percent volume of prey in each specimen was visually estimated using a gridded petri dish (sensu Gillespie and Fox, 2003). Fish with empty stomachs (i.e., no prey) were excluded from stomach content analysis. For the purpose of comparing major prey differences among habitats, all prey types within each sample were grouped into nine major categories: zooplankton (Cladocera, Copepoda, Ostracoda), Chironomidae, other macroinvertebrates (Ephemeroptera, Trichoptera, Plecoptera, Hempitera, Coleoptera, Isopoda, Oligochaeta, Diptera [excluding Chironomidae]), dreissenids, other hard-bodied prey (Pelecypoda and Gastropoda), fish scales, eggs, algae, and other (rocks, unidentifiable prey).