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Impacts of predation by the Eurasian round goby (*Neogobius melanostomus*) on molluscs in the upper St. Lawrence River

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ABSTRACT

An invasive Eurasian fish, the round goby *Neogobius melanostomus*, has recently spread from the Great Lakes into the St. Lawrence River. We quantified prey preferences of this benthivore and determined whether its predatory impacts on molluscs in the river are similar to those in the Great Lakes. We measured the size structure of gastropods and dreissenid mussels at 13 St. Lawrence River sites where round goby densities ranged from 0 to 6 m^{-2}. For four of these sites, data were available for multiple years before and after invasion. Contrary to studies in the Great Lakes, there were no consistent effects of round goby density on the size structure of dreissenids, although there was an ontogenetic diet shift toward dreissenids. However, the abundance and richness of small gastropods (≤14 mm) was negatively correlated with round goby density across all sites, and declined over time at three of four sites sampled before and after invasion. Median gastropod size also declined across sites with increasing round goby density. Gastropods (as well as chironomid larvae, caddisfly larvae, and ostracods) were consistently among the most preferred prey items consumed by gobies, whereas dreissenids (as well as leeches and freshwater mites) were consistently avoided. These results indicate the major role of the round goby in structuring gastropod populations in the St. Lawrence River, and highlight large-scale spatial variation in its predatory impact on dreissenid populations.

Introduction

The round goby (*Neogobius melanostomus*), a benthivorous fish native to the Black and Caspian Seas region, was discovered in the St. Clair River in 1990 (Jude et al., 1992) and subsequently spread throughout the Great Lakes basin within 5 years (Charlebois et al., 2001). The species was likely introduced in ballast water released by transoceanic vessels (Corkum et al., 2004). Its range extension into the upper St. Lawrence River has occurred slowly, as it was not detected at Cornwall, Ontario until 2004 (Hickey and Fowlie, 2005).

A conspicuous impact of round goby invasion in the Great Lakes has been a negative effect on macroinvertebrate communities (Barton et al., 2005; Ghedotti et al., 1995; Krakowiak and Pennuto, 2008; Kuhns and Berg, 1999; Lederer et al., 2006, 2008). Round gobies consume a broad variety of benthic macroinvertebrates, particularly molluscs, but dreissenid mussels (the zebra mussel *Dreissena polymorpha* and the quagga mussel *Dreissena bugensis*) frequently compose the largest proportion of their diet (Barton et al., 2005; Rakauskas et al., 2008; Ray and Corkum, 1997). The relative importance of different prey items varies with round goby size, habitat conditions, season, and time since invasion (French and Jude, 2001; Janssen and Jude, 2001; Jude et al., 1995; Raby et al., 2010). Round goby diet appears to vary across the Great Lakes, reflecting their flexible and opportunistic feeding habits. Indeed, round gobies exploit a wide variety of habitat types within the Great Lakes basin, from stream environments where their diet is composed almost entirely of aquatic insects (Carman et al., 2006; Pennuto et al., 2010; Phillips et al., 2003) to profundal zones of Lakes Ontario and Huron, where they primarily consume molluscs and crustaceans (Schaeffer et al., 2005; Walsh et al., 2007).

Several studies have investigated round goby predation on dreissenids and some have attempted to relate these prey preferences to observed changes in the size structure of dreissenid populations. In the Great Lakes, round gobies generally reach maximum lengths of ~150–180 mm. An ontogenetic shift toward a predominantly dreissenid-based diet occurs at lengths of 60–80 mm (Barton et al., 2005; French and Jude, 2001; Janssen and Jude, 2001; Jude et al., 1995; Ray and Corkum, 1997), although fish as small as 40–50 mm may consume dreissenids (Djuricich and Janssen, 2001; Lederer et al., 2006; Taraborelli and Schaner, 2002). The maximum size of dreissenids consumed is limited by the gape size of the fish and ranges from 10 to 20 mm with a mean of 14 mm across field and

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laboratory studies from the Great Lakes region (Clark, 2007; Djuricich and Janssen, 2001; Ghedotti et al., 1995; Jude et al., 1995; Ray and Corkum, 1997; Taraborelli and Schaner, 2002; Thomas, 1997).

Studies that have examined the impacts of round gobies on dreissenid size distributions generally record larger effects on the smallest mussels. In nearshore eastern Lake Erie, the size distribution of quagga mussels changed through time as round goby density increased from 6 m^{-2} in 2001 to 14 m^{-2} in later years; over this time period, there was a decline in the abundance of mussels of 3–15 mm length (Barton et al., 2005). A subsequent lakewide survey in 2002 found very low abundances of dreissenids in the 3–12 mm range, in combination with an increase in the average size of mature mussels, likely due to round goby predation (Patterson et al., 2005). In nearshore Lake Ontario, Wilson et al. (2006) found that the proportion of young-of-the-year quagga mussels (≤10 mm) was negatively related to round goby abundance. In the Cheboygan River, Michigan, the size distribution of dreissenids peaked at 14–17 mm, while that in round goby GI tracts peaked at 8–11 mm (Clark, 2007). Similarly, in the Bay of Quinte, Lake Ontario, dreissenid size distribution peaked at 12–16 mm, while that in round goby GI tracts peaked at 8–9 mm (Taraborelli and Schaner, 2002). These studies suggest a tendency for gobies to preferentially remove smaller mussels and thus alter mussel size distributions in the field. More recently, Andraso et al. (2011) found that round gobies in Presque Isle Bay, Lake Erie, preferentially selected 8–11 mm dreissenids for consumption.

The work reported here complements a field survey conducted in the upper St. Lawrence River that aimed to investigate impacts of round gobies on the entire macroinvertebrate community (Kipp and Ricciardi, in press). Among other impacts, the field survey found significant negative relationships between the biomass of gastropods and round gobies, and no significant relationships between the biomass of dreissenids and round gobies — which is surprising in view of impacts reported from the Great Lakes. Based on the premise that impacts on dreissenids in the St. Lawrence might be limited to smaller molluscs, we examined differential predation by round gobies on the size distribution of molluscs in the field. Thus, our study linked spatial and temporal patterns of gastropod and dreissenid size structure on cobble substrates to the diets of gobies at multiple sites. We hypothesized that dreissenids and gastropods would rank among the most preferred prey items in round goby diets (i.e. these taxa would comprise a larger proportion of the diet relative to their proportional availability in the field; Ivlev, 1961). We predicted that 1) the size, abundance, and proportion of dreissenids and gastropods consumed by gobies would increase with fish total length; and 2) dreissenid and gastropod consumption would be more prevalent in gobies >70 mm in total length. Moreover, as round goby density increased across sites and over time, 3) the density of small (≤14 mm) dreissenids and gastropods, as well as the taxa richness of small gastropods, would be reduced; 4) gastropod taxa with a maximum size of ≤14 mm would be absent more frequently than larger taxa; and 5) dreissenid and gastropod sizes would increase as smaller molluscs would be disproportionately removed through round goby predation.

Material and methods

Study area

Our study made use of the same sampling techniques and sites as those in a larger field survey that examined impacts of round gobies on the entire macroinvertebrate community in the upper St. Lawrence River (Kipp and Ricciardi, in press). In 2008, we sampled 13 sites across a range of round goby densities in the upper St. Lawrence River between Prescott, Ontario and Montreal, Quebec, in order to determine mollusc size structure (Table 1; Fig. 1). Given that round gobies are frequently associated with rocky substrates (Jude et al., 1992; Ray and Corkum, 2001), and mollusc assemblages on cobble (diameter ~65–260 mm) are diverse in this area (Ricciardi et al., 1997), sites having some cobble were chosen (Table 1). Four of these sites were resampled in 2009 (Table 1). Data from cobble at 3 sites in 2005 (K. Harper and A. Ricciardi, unpublished data) and a blank brick colonization experiment in 2006 (Ward and Ricciardi, 2010) were available for interannual comparisons (Table 1). Calcium ion concentration [Ca^{2+}] was sufficiently high at all sites and in all years (mean 29.6 $mg \cdot L^{-1}$; range 20.6–32.0 $mg \cdot L^{-1}$) such that it was not expected to limit mollusc abundance or diversity (Clarke, 1981; Jones and Ricciardi, 2005; Mellina and Rasmussen, 1994).

Round goby density quantification and diet analysis

Round goby density m^{-2} (Table 1) was quantified visually by a SCUBA diver swimming at a constant depth of 1 m above the substrate along two 30-m transects while holding a 1-m pole at arms' length perpendicular to each transect and parallel to the bottom. All round gobies that passed under the pole were counted (cf. Barton et al., 2005). Round goby counts were always conducted by the same diver at each site on the same day that molluscs were collected, and before molluscs were sampled, in order to avoid disturbing the fish. We recognize that visual estimates of round goby densities using transect counts can be problematic because of the cryptic nature of round gobies (Ray and Corkum, 2001) and their attraction to SCUBA divers (Johnson et al., 2005a). This method was chosen because it is unobtrusive and inexpensive, and allowed density estimates to be compared with each other (although not to those made using other sampling methods in the Great Lakes). Transects were placed in 1–2 m of water parallel to shore, either end-to-end at sites with steep slopes, or at the same points along the shore at sites with gentle slopes. For one analysis, sites were ranked in terms of their degree of invasion. They were classified into two categories based on both round goby density and time since invasion, in which gobies were: (i) present for 0–2 years at densities ≤1.6 m^{-2} at early-invasion sites, or (ii) present for 2 or more years at densities >1.6 m^{-2} at late-invasion sites (Table 1). Time since invasion (Table 1) was estimated using information from Hickey and Fowlie (2005) and Fuller et al. (2010), as well as from personal observations.

In late August 2009, 130 round gobies were sampled for analysis of GI tract contents at four sites in Lac Saint-Louis — a fluvial lake near Montreal. These sites were chosen because they were those for which 2009 macroinvertebrate community and mollusc size structure data were available. Round gobies were captured during the day with unbaited minnow traps or gill nets (length 14.25 m, height 1.80 m, mesh size 5.5 mm) deployed at 1–2 m depth for 1 h (Table 1). We measured the total lengths (to 1 mm) of gobies using a fish ruler and gape height (to 0.1 mm) using digital calipers. Upon dissection in the laboratory, GI tracts were placed in 95% ethanol; within 13 months, their contents were subsequently analyzed under dissecting microscopes (45×). These samples were analyzed randomly so that any potential changes in biomass due to preservation would not exert consistent effects at specific sites. Each prey item was identified to the lowest taxon possible and weighed to the nearest mg (preserved wet weight). The longest axes of all dreissenid mussel fragments and all whole gastropods found in GI tracts were measured to 0.1 mm with digital calipers.

Mollusc collection

Along the transects laid out for round goby density counts, a SCUBA diver haphazardly tossed a 0.25 m^2 quadrat to sample cobbles eight times along one transect and seven times along the other. Only cobbles found entirely inside the quadrat were chosen for sampling and only one cobble per quadrat was retained. Each cobble sample was placed in doubled sealable plastic bags underwater and transported in coolers back to the laboratory. Percent cobble (Table 1)