Status of Exotic Round Goby and Tubenose Goby in Pennsylvania

Jay R. Stauffer Jr.[1,*], Jeanette Schnars[2], Casey Wilson[1], Richard Taylor[1], and Charles K. Murray[3]

Abstract - The relative abundance of *Neogobius melanostomus* (Round Goby) in the Pennsylvanian waters of Lake Erie, has increased dramatically since 1996. Associated with this increase, all benthic species in the main portion of the lake, except *Percopsis omiscomaycus* (Trout-perch), decreased in occurrence or were extirpated. *Proterorhinus semilunaris* (Tubenose Goby), which has established a reproducing population in Presque Isle Bay, Lake Erie, coexists with the Round Goby and *Etheostoma exile* (Iowa Darter), a candidate species for rarity listing by the Pennsylvania Fish and Boat Commission. Conversely, the decline in potadromous populations of *Percina caprodes* (Logperch) may be exacerbated by direct competition in the lake, and the presence of Round Gobies in the breeding grounds of tributaries (e.g., Twentymile Creek). In Elk Creek, the presence of Round Goby is associated with dietary shifts of *Etheostoma caeruleum* (Rainbow Darter), although Rainbow Darters co-exist with the Round Goby. The Round Goby has established a reproducing population in LeBoef Creek, a tributary of French Creek (Allegheny River), and we documented its presence in the main channel of French Creek. We suggest that natural barriers (e.g., waterfalls) may prevent the upstream migration of gobies. Furthermore, providing substrate to facilitate spawning and recruitment of native benthic species may impede the spread of invasive species throughout the tributaries of Lake Erie.

Introduction

The homogenization of the Earth's biota by the introduction and spread of non-native species is one the most damaging anthropogenic impacts on biodiversity today (Kolar and Lodge 2002, Mills et al. 1994). Degradation of aquatic ecosystems by the introduction of non-native fish species is exemplified in the Laurentian Great Lakes. Native fish communities in this region have been irreparably harmed by introductions, both accidental and intentional, of exotic species (Jude et al. 1995). Infamous piscine invaders such as *Petromyzon marinus* L. (Sea Lamprey), *Alosa pseudoharengus* (Wilson) (Alewife), and *Osmerus mordax* (Mitchill) (Rainbow Smelt) have had cascading detrimental effects on the native biota of the Great Lakes (Fuller et al. 1999, Jude et al. 1995). The most recent round of aquatic invaders that have impacted the integrity of the Great Lakes are mainly Ponto-Caspian natives including 2 bivalve species (*Dreissena polymorpha* Pallas [Zebra Mussel] and *Dreissena bugenis* Andrusov [Quagga Mussel]) and 3 fish species

[1]Ecosystem Science and Management, Penn State University, University Park, PA 16802-4302. [2]Tom Ridge Environmental Center, 301 Peninsula Drive, Suite 9, Erie, PA 16505. [3]Pennsylvania Fish and Boat Commission, 2000 Lohrer Road, Fairview, PA 16415. [*]Corresponding author - vc5@psu.edu.

Manuscript Editor: David B. Halliwell

(*Gymnocephalus cernuus* L. [Ruffe], *Neogobius melanostomus* [Round Goby], and *Proterorhinus semilunaris* [Heckel] [Western Tubenose Goby]). Of the 3 most recent fish introductions, Round Gobies are the most prolific and widespread, and currently occur throughout the Laurentian Great Lakes and their tributaries, many Eurasian rivers, and the Baltic Sea (Charlebois et al. 1997). Introduced Round Goby have also established numerous populations in Eurasia (Kornis et al. 2012).

The Round Goby is a small, benthic, nocturnally feeding fish that is native to the Sea of Azov, the Caspian Sea, the Black Sea, and the Sea of Marmara (Charlebois et al. 1997, Hayden and Miner 2009, Hensler and Jude 2007). Brown and Stepien (2009) and Kornis et al. (2012) listed the likely source of Round Goby in the Great Lakes as the Dnieper River, Kerson, Ukraine.

Round Goby were first discovered by anglers in the Laurentian Great Lakes in 1990 in the St. Clair River at Sarnia, ON, Canada, where they were assumed to have been introduced from ballast waters of freighters (Charlebois et al. 1997, Hayden and Miner 2009, Hensler and Jude 2007, Jude et al. 1992, Mills et al. 1993). The Round Goby was thought to be confined to the St. Clair River; however, in 1993 new populations were documented in the Calumet River near Lake Michigan and in Grand River Harbor, OH (Charlebois et al. 1997), and they were found in western Lake Michigan and eastern Lake Erie in 1995 (Charlebois et al. 1997). Since that time, Round Goby have spread rapidly to all of the Great Lakes, presumably by inter-basin ballast transfer (Clapp et. al 2001, Kornis et al. 2012). However, based on our observations in Pennsylvania, natural dispersal and release/escape from bait buckets could have also aided their dispersal. The first Round Goby found in the Pennsylvania waters of Lake Erie was by the Pennsylvania Fish and Boat Commission (PFBC) in 1996.

Harka and Bíró (2007) indicated that in its native range, Round Goby are found in lakes and large, slow-flowing rivers. In Eurasia, they are rare in faster-flowing waters; however, they have invaded several tributaries 10–40 stream km above the stream mouths, including those to Lake Michigan (Kornis et al. 2013) and the Ontario side of Lake Erie (Poos et al. 2010). Based on our collections from 2006–2016, Round Goby are abundant in the mouths and below the first riffle above the mouth in small tributaries (e.g., Elk Creek, Sixteen Mile Creek, Twentymile Creek) of Lake Erie.

The presence of Round Goby has been associated with the extirpation of *Cottus bairdi* (Mottled Sculpin) in Calumet Harbor in southern Lake Michigan (Jansen and Jude 2001) and the decline of *Etheostoma nigrum* Rafinesque (Johnny Darter; Lauer et al. 2004). Round Goby have been found to prey on eggs of *Percina caprodes* (Logperch) and those of several other native species (Chotkowski and Marsden 1999). Under experimental conditions, Round Goby prey on *Etheostoma caeruleum* (Rainbow Darter) and *Etheostoma blenniodes* Rafinesque (Greenside Darter) (Jude et al. 1995). Studies have demonstrated competition between Round Goby and native species for food and habitat (French and Jude 2001, Jansen and Jude 2001).

Conversely, the spread of the Tubenose Goby has been slow compared to that of the Round Goby (Grant et al. 2012) and has been partially restricted to the

connections between Lake Huron and Lake Erie, and the western portions of Lake Erie and Lake Superior (Grant et al. 2012, Kocovsky et al. 2011). The potential for the Tubenose Goby to displace native species is not well understood, but the species may have the potential to compete for habitat and food (French and Jude 2001, Grant et al. 2012, Kocovsky et al. 2011).

The objectives of this study are to report on the status of the Round Goby in the Lake Erie watershed of Pennsylvania, to determine if there was a shift in diet of the native fishes when Round Goby were present in selected Pennsylvanian tributaries (i.e., Elk Creek, Twentymile Creek) of Lake Erie, and to compare the diet of the Tubenose Goby in Lake Erie with the syntopic native Iowa Darter.

Materials and Methods

We anesthetized in MS222, fixed in a 10% formalin solution for 2 weeks, and transferred to 70% ethanol for later identification all fishes kept for further analyses. Voucher specimens of the sampled fish were catalogued into the Penn State University Fish Museum. We followed all protocols required by the Animal Use and Care Committee at Penn State (IACUC# 35338).

Presence/absence of benthic fishes in Lake Erie

We employed trawls (trawl aperture = 5.88 m^2, wingspread = 5.44 m, gape height = 1.08 m, mesh size in the cod-end liner = 0.64 cm) to sample Round Goby in off-shore habitats in Pennsylvania's portion of Lake Erie. Pennsylvania's portion of Lake Erie totals 1193 km^2, or 7.8% of the total area of the lake, and includes the southeastern portion of the central basin and southwestern portion of the eastern basin. We conducted most of the trawls near long-term monitoring stations off Walnut Creek (42°4'37.28"N, 80°14'22.95"W), Trout Run (42°3'32.49"N, 80°16'22.02"W), Presque Isle Peninsula (42°10'14.97"N, 80°5'59.82"W), Eightmile Creek (42°10'49.60"N, 79°59'6.38"W), and Sixteenmile Creek (42°14'33.92"N, 79°49'55.41"W) (Fig. 1). We conducted an average of 14 trawls annually from 1985 through 2012, ranging from as few as 2 trawls in 1997 to as many as 28 in 1987. Due to logistical constraints, no trawling was conducted in 2006, 2010, and 2011. Annual assessment by the PFBC Lake Erie Research Unit (LERU) included offshore (>12 m) bottom-trawling during the summer and fall. The program was not specifically designed to determine the density of benthic fishes; thus, we used the percentage of the trawl samples in which benthic fishes were present as an indicator of relative abundance.

Impact of Round Goby on fishes in Twentymile Creek

We collected fishes in Twentymile Creek on 17 July 2003 from the mouth of the stream to the waterfall (site 1: 42º15'38.71"N, W9º46'49.33"W) and above the waterfall just below an old railroad bridge (site 2: 42º15'29.48"N, 79º46'39.68"W) with a battery-powered backpack electro-fishing unit (Aquashock Solutions; 300 volts DC). We chose the 2 sites based on physical similarities and our previous investigations, which indicated a similar species composition and the absence of

Round Goby at the upstream site. At each site, we shocked from shore to shore while moving upstream. We did not use block nets to segregate the area shocked. We continued to collect at both sites, until we were convinced that further sampling would not yield additional species (Barila et al. 1981, Hocutt 1978). We identified to species fishes collected, then counted and released all except for the voucher specimens we retained for each species. For each site, we calculated percent community composition, population estimates, and Brillouin's diversity indices (H = *N*ln [*N*!*N*!*N*2!...Ns!]), where H = diversity index, *N* = the total number of individuals in the sample; N_1, N_2…, is the number of individuals in species 1, 2, …, and s is the total number of species in the collection; Pielou 1977). Based on the work of Pielou (1975, 1977), Kaesler et al. (1978) concluded that Brillouin's index is the preferred metric for the type of data we obtained because it actually measures the diversity of the sample rather than just statistically estimating it.

Diet selectivity

We used non-treated plywood to construct 9 boxes with 2 m x 4 m x 10 cm inside dimensions and an open top. We filled them with 3 different types of substrate: 2b gravel (small substrate), #1 gravel (medium substrate), and rip-rap (rocks 4–10 cm diameter). In May 2012, we submerged the boxes in a 3 x 3 design in Elk Creek at the first riffle above the mouth (42°1'10.65"N, 80°22'17.09"W). Sampling began 30 d after we placed the plots in the stream; we conducted a 24-h sample once per month from June until September 2012. On sampling days, we electrofished 3 of the 9 plots every 8 h, 1 from each substrate type (small, medium, and rip-rap). We positioned a seine downstream to collect the fishes. At the end of the 24-h hour sampling period, we used D-frame kick-nets to collect macroinvertebrates residing in the substrate of each plot. We preserved samples from the kick-nets in 70% ethanol, and examined them under dissecting microscopes in the laboratory to

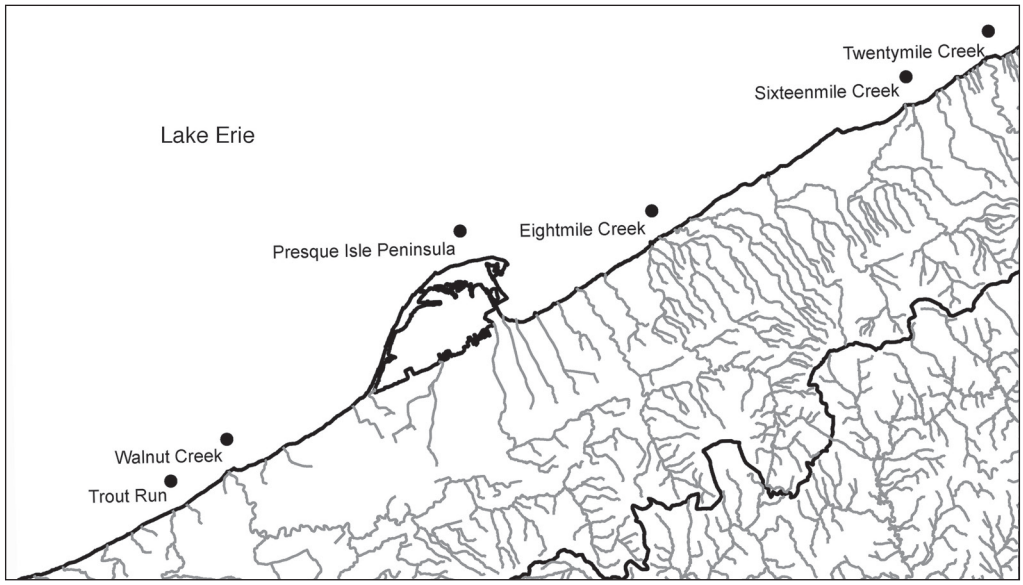

Figure 1. Trawl sites sampled by the Pennsylvania Fish and Boat Commission in Lake Erie.

search for macroinvertebrates. Although we placed no substrate boxes upstream of the waterfalls in Elk Creek (42°0'24.90"N, 80°21'13.89"W), we collected macroinvertebrates and fishes there in June 2012 with a D-frame kick-net and backpack electro-fishing unit, respectively, and preserved samples as described above.

In the laboratory, we dissected and removed the stomachs of all benthic fishes. We examined macroinvertebrates from the gut contents and the D-frame kick-net collections, and enumerated and identified them to the lowest possible taxon (family or genus) using Merritt et al. (2008). We compared the relative abundance of selected organisms in the stomachs to the relative abundance in the environment by calculating electivity indices (Ilev 1961) using the formula $(r_i - p_i) / (r_i + p_i)$, where r_i is the percent composition of a macroinvertebrate taxon in the gut and p_i is the percent composition of the taxon in the D-frame kick-net sample. Thus, we were able to determine if macroinvertebrate taxa were being selected, avoided, or eaten in the same ratio of abundance that they were found in the environment. If taxa were absent from either the D-frame kick net samples or the stomachs, an electivity index could not be calculated.

Tubenose Gobies were not present in any lotic systems; thus, we sampled fishes in Presque Isle Bay during the periods 9–10 September and 7–8 October 2011 to search for Tubenose Gobies. We employed a benthic electric trawl that generated an electrical field to stun fishes and increase capture efficiency as described by Freedman et al. (2009). We conducted the trawls just west of Perry Monument on the north side of the bay in Presque Isle State Park (42°9'13.96"N, 80°5'24.80"W). We preserved fishes as described above.

Results

Presence/absence of benthic fishes in Lake Erie

Round Gobies were first found in the Pennsylvanian portion of Lake Erie 1996, when they were present in less than 20% of the trawls taken by the PFBC (Fig. 2). Of the native benthic fishes, *Percopsis omiscomaycus* (Wahlbaum) (Trout-perch) was present in the highest proportion of the trawls prior to the occurrence of the Round Goby in 1996. Its presence in the trawl samples was comparable before and after 1996. The Mottled Sculpin was routinely collected with the trawls, but disappeared entirely after 1999. The Logperch was erratically present, but was last captured in 2003 (Fig. 2). The Johnny Darter disappeared in all trawl samples after 1999 and *Ammocrypta pellucida* (Putnam) (Eastern Sand Darter) was last collected in 2005 (Fig. 2).

Impact of Round Goby on fishes in Twentymile Creek

We found Round Goby only downstream of the first waterfalls in Twentymile Creek. We collected 17 species below and 18 species above the waterfall (Table 1). In addition to the Round Goby, we documented *Lepisosteus osseus* (Longnose Gar), *Cyprinella spiloptera* (Spotfin Shiner), *Luxilus cornutus* (Common Shiner), *Notropis atherinoides* (Emerald Shiner), *Hypentelium nigricans* (Northern Hog Sucker), *Noturus flavus* (Stonecat), and *Micropterus dolomieu* (Smallmouth Bass) at the

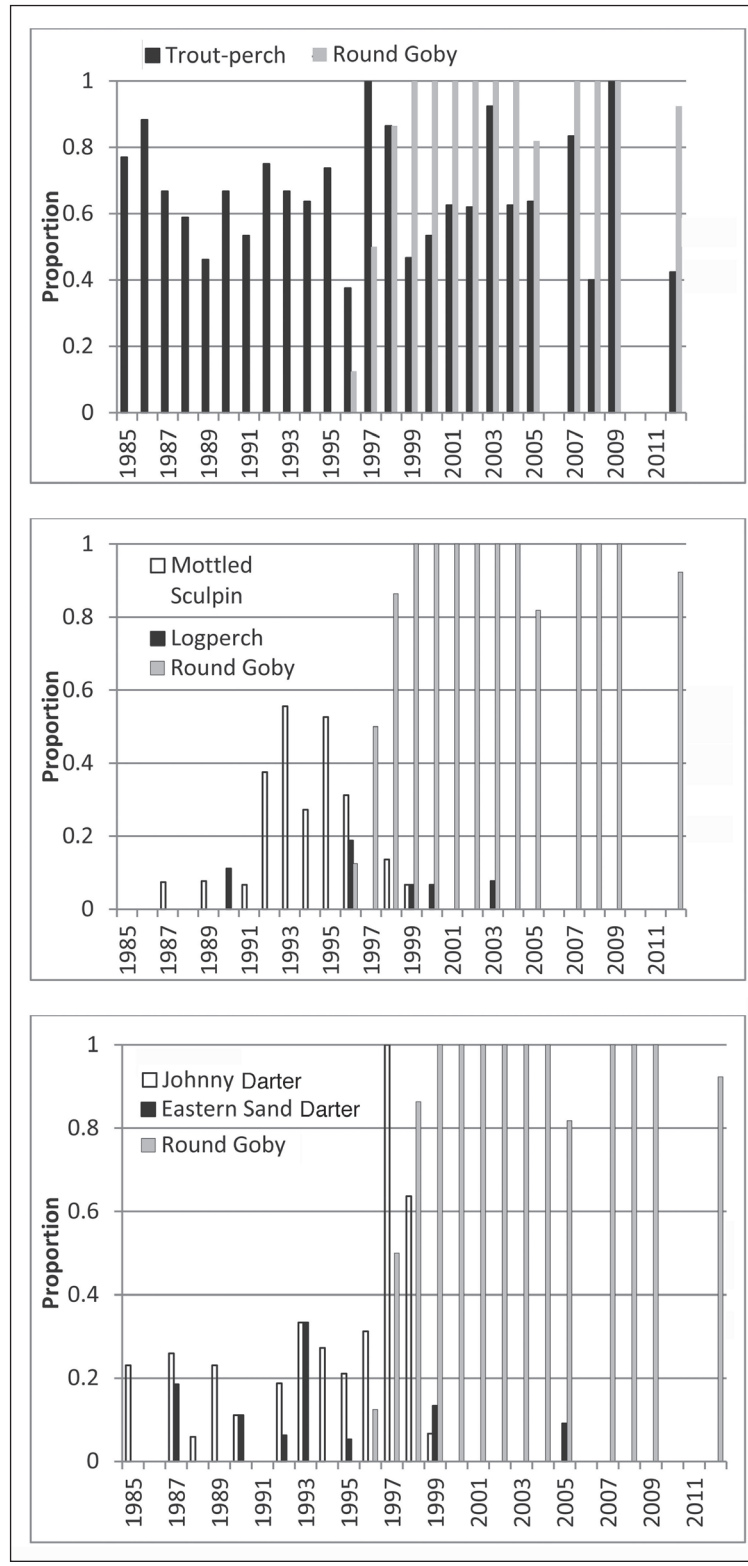

Figure 2. Proportion of trawls where Round Goby and native benthic fishes (Trout Perch, Mottled Sculpin, Logperch, Johnny Darter, and Eastern Sand Darter) were captured.

downstream site but not above the waterfalls. We collected *Salmo trutta* (Brown Trout), *Luxilus chrysocephalus* (Striped Shiner), *Pimephales notatus* (Bluntnose Minnow), *Rhinichthys cararactae* (Longnose Dace), *Semotilus atromaculatus* Mitchill, *Catostomus commersoni* (White Sucker), *Ameiurus nebulosus* (Brown Bullhead), Logperch, and Mottled Sculpin above the falls, but not below the falls. Round Goby comprised 45% of the total fishes at the lower site, while Rainbow Darters comprised 35%. In total, Rainbow Darters constituted the greatest percentage of the benthic-species composition at both sites, when Round Goby were excluded from the downstream site data. Brillouin's diversity index values below the falls and above the falls were 1.39 and 2.11, respectively.

Diet selectivity

The July kick-net samples downstream in Elk Creek yielded primarily dipterans (Chironomidae) and ephemeropterans (Baetidae, Caenidae) (Table 2). The only taxon that had a positive electivity index for the Round Goby was Chironomidae. The Rainbow Darter selectively fed on Tricoptera and Ephemeroptera. The kick-net

Table 1. Fishes collected downstream and upstream of the waterfall on Twentymile Creek, 22 June 2003.

Species	Downstream	Upstream
Ambloplites rupestris (Rafinesque) (Rock Bass)	1	1
Ameiurus nebulosus (Lesuer) (Brown Bullhead)	0	2
Campostoma anomalum (Rafinesque) (Stoneroller)	17	53
Catostomus commersoni (Lacepède) (White Sucker)	0	1
Cottus bairdi Girard (Mottled Sculpin)	0	11
Cyprinella spiloptera (Cope) (Spotfin Shiner)	1	0
Etheostoma caeruleum Storer (Rainbow Darter)	88	48
Etheostoma flabellare Rafinesque (Fantail Darter)	2	6
Hypentelium nigricans (Lesuer) (Northern Hog Sucker)	1	0
Lepisosteus osseus (L.) (Longnose Gar)	1	0
Lepomis gibosus (L.) (Pumpkinseed Sunfish)	2	2
Lepomis macrochirus Rafinesque (Bluegill)	2	1
Luxilus chrysocephalus Rafinesque (Striped Shiner)	0	22
Luxilus cornutus (Mitchill) (Common Shiner)	1	0
Micropterus dolomieu Lacepède (Smallmouth Bass)	7	0
Neogobius melanostomus (Pallas) (Round Goby)	113	0
Nocomis micropogon (Cope) (River Chub)	4	124
Notropis atherinoides Rafinesque (Emerald Shiner)	1	0
Noturus flavus Rafinesque (Stonecat)	3	0
Oncorhyncus mykiss (Walbaum) (Rainbow Trout)	4	15
Percina caprodes (Rafinesque) (Log Perch)	0	4
Pimephales notatus (Rafinesque) (Bluntnose Minnow)	0	1
Rhinichthys atratulus (Hermann) (Blacknose Dace)	2	59
Rhinichthys cataractae (Valenciennes) (Longnose Dace)	0	26
Salmo trutta L. (Brown Trout)	0	1
Semotilus atromaculatus (Mitchill) (Creek Chub)	0	4
Total number of species	17	18
Total number of individuals	250	388
Brillouin's diversity index	1.39	2.11

samples taken in September at the downstream site in Elk Creek yielded primarily Ephemeroptera and Diptera (Table 3). The only taxon that had a positive electivity index for the Round Goby was Chironomidae. The Rainbow Darter selectively fed on Diptera. The June kick-net samples upstream in Elk Creek (Table 4) yielded primarily Diptera, Trichoptera, and Coleoptera. The Rainbow Darters in this reach consumed primarily Ephemeroptera and Plecoptera.

Table 2. Comparison between percentages of macroinvertebrates from kick-net samples in July 2012 and stomach contents of Rainbow Darter and Round Goby with calculated electivity-index.

		% in stomach			
Macroinvertebrates Order/Family	% in environment	Rainbow Darter (*n* =32)	Electivity index	Round Goby (*n* = 24)	Electivity index
Amphipoda					
Gammaridae	0.52				
Coleoptera					
Elmidae	0.78				
Diptera					
Chironomidae	82.72	67.12	0.09	87.40	0.03
Nymphomyudae	0.04				
Tipulidae	0.04				
Simulidae	-	0.58			
TOTAL Diptera	82.80				
Ephemeroptera	1.78				
Baetidae	2.08				
Heptageniidae	1.08				
Leptohyphidae	4.94	17.58	0.27	9.00	-0.06
Siphlonuridae	0.22				
TOTAL Ephemeroptera	10.10				
Hirudinea	0.04				
Isopoda					
Asellidae	0.04				
Megaloptera					
Corydalidae	0.74				
Sialidae	0.87				
TOTAL Megaloptera	1.61				
Bivalva	0.04				
Odonata					
Coenagrionidae	0.04				
Aeshnidae	-				
TOTAL Odonata	0.04				
Plecoptera	0.13				
Perlidae	0.13				
Pternoarcyidae	0.09				
TOTAL Plecoptera	0.35				
Trichoptera	0.09				
Hydopsychidae	0.26				
Hydophilidae	-				
Polycentropodidae	0.13	3.48	0.74	0.40	-0.13
Hydroptilidae	0.04				
TOTAL Trichoptera	0.52				
Unidentified macroinvertebrate		9.55		3.20	

Grant et al. (2012) reported Tubenose Goby in the Pennsylvanian portion of Lake Erie on 28 June 2012. As of this writing, Tubenose Goby had not been collected outside of Presque Isle Bay in Pennsylvania. Our collections with the electric trawl in Presque Isle Bay on 9–10 September 2011 and 7–8 October 2011, resulted in the capture of Tubenose Goby. The Round Goby, Tubenose Goby, and the native Iowa Darter all consumed Zebra Mussels, but these mussels comprised almost the entire diet of the 2 goby species (Table 5). Iowa Darter fed primarily on freshwater shrimp species.

Discussion

Within Lake Erie in Pennsylvania, Round Goby have occurred in the vast majority of the trawls since 1998. Although Trout-perch are still routinely collected in off-shore trawls, the occurrence of Logperch, Mottled Sculpin, Johnny Darter, and

Table 3. Comparison between percentages of macroinvertebrates from kick-net samples for data collected in Elk Creek in September 2012 and stomach contents of Rainbow Darter and Round Goby with calculated electivity-index.

		% in stomach			
Macroinvertebrates Order/Family	% in environment	Rainbow Darter (n = 7)	Electivity index	Round Goby (n = 17)	Electivity index
Amphipoda					
Gammaridae	0.26				
Coleoptera					
Elmidae	0.68				
Hydrophilidae	0.83				
Psephenidae	0.15				
TOTAL Coleoptera	1.66				
Diptera					
Chironomidae	5.69	69.29	0.85	43.82	0.77
Ephemeroptera					
Baetidae	0.12				
Caenidae	60.61				
Heptigeniidae	0.79				
Leptohyphidae	27.37				
TOTAL Ephemeroptera	88.89	17.14	-0.68	50.29	-0.28
Gastropoda					
Physidae	0.87				
Planorbidae	0.08				
TOTAL Gastropoda	0.95				
Hirudinea	0.04				
Isopoda					
Asellidae	0.15				
Odonata					
Coenagrionidae	2.34				
Gomphidae	0.04				
Libellulidae	0.04				
TOTAL Odonata	2.42				
Trichoptera					
Hydroptilidae	-	13.57	-	5.88	-

Eastern Sand Darter have decreased since the establishment of the Round Goby and these 4 native species have not been found at all in the trawl samples since 2007.

In Twentymile Creek, the Mottled Sculpin is found upstream of the falls but is absent downstream of the falls, where Round Goby is established. We also collected Logperch above the falls, but not below the falls. Over the past 15 years, we have observed a population of Logperch that are resident in the tributaries year-round, and a lake population, which migrates into tributaries to spawn. Perhaps the decreased occurrence of the Logperch in Lake Erie is attributable both to direct competition with the Round Goby in the lake and the invasion of Round Goby into the spawning grounds in the tributaries. As stated previously,

Table 4. Percentages of macroinvertebrates from kick-net samples and stomachs from Rainbow Darters (n = 17) in Elk Creek above first waterfall.

Macroinvertebrates Order/Family	% in environment	% in stomach	Electivity index
Tricladida	11.72	0.00	-1.00
Trichoptera			
Hydopsychidae	8.45		
Polycentropodidae	15.80	14.00	-0.27
TOTAL	24.25		
Coleoptera			
Psepehenidae	7.08	0.00	-1.00
Elmidae larvae	1.63		
Elmidae adult	0.27		
TOTAL	8.98		
Ephemeroptera			
Baetidae	15.53	58.50	0.60
Plecoptera			
Perlidae	0.54	1.10	0.30
Diptera			
Chironomidae	37.60	17.60	-0.37
Simulidae	0.27		
TOTAL	37.87		
Amphipoda			
Gammaridae	0.27	0.00	-1.00
Oligochaeta	0.82	0.00	-1.00
Megaloptera	0.00	3.10	-
Odonata			
Coenagrionidae	0.00	6.20	-

Table 5. Average percentages of items found in stomach contents of Iowa Darters, Round Goby, and Tubenose Goby collected 11 September 2011 from Presque Isle Bay, Lake Erie.

Prey taxon	Iowa Darter (n = 13)	Round Goby (n = 26)	Tubenose Goby (n = 5)
Zebra Mussel	3.8	67.0	27.0
Mussel species	0.0	2.9	0.0
Freshwater shrimp	30.4	0.0	0.0
Insect species	0.4	0.8	0.0
Fish eggs	0.0	0.0	1.0

Chotkowski and Marsden (1999) documented the predation of Logperch eggs by Round Goby.

In Elk Creek, the Round Goby selected chironomids during July and September. Our data indicate that the Round Goby was a selective feeder; Rosca et al. (2010) reached the same conclusion for populations on the Black Sea Coast. In the same reach, Rainbow Darters chose Trichoptera and Ephemeroptera. Above the waterfalls in Elk Creek, where Round Goby were absent, Rainbow Darters avoided Trichoptera and fed primarily on Ephemeroptera and Plecoptera. Nevertheless, the Rainbow Darter has been successful in co-habiting with the Round Goby. In the Lake Erie basin, Rainbow Darters in lotic environments and Iowa Darters in lentic habitats apparently continue to maintain viable populations. Unlike many other benthic species (e.g., Mottled Sculpin, Logperch, and Eastern Sand Darter), we consistently collect Rainbow Darters in areas invaded by Round Goby.

To date, the Round Goby has not been successful in colonizing upstream of the first natural barrier (e.g., waterfalls) in Pennsylvania's tributaries of Lake Erie. In 2014, we documented Round Goby in LeBoef Creek, a tributary of French Creek (Allegheny River), and by July 2015 we found them in the main channel French Creek below LeBoef Creek. Round Gobies were first found in the lake drained by LeBoef Creek, and we hypothesize that their presence was a result of bait-bucket introductions. The invasion of the Round Goby into the Allegheny River drainage suggests that the upstream areas of the tributaries of Lake Erie are vulnerable to colonization via bait-bucket transfer.

Irrespective of the means of transfer (e.g., bait bucket, ballast water) the success of an introduced population of Round Goby depends to some extent on the biological components that presently inhabit the area in question. Certain environments are saturated with species, while other areas are considered to be depauperate. At one time, it was assumed that the predominant factor that controlled the organization of natural communities was interspecific competition (Dunham et al. 1979). This assumption was inferred from niche shifts and morphological changes in the form of character displacement, which were correlated with geographic variation (Dunham et al. 1979). Simberloff and Wilson (1969), however, suggested that competition might not be as important as previously thought, at least for insular areas. Based on work by several authors, Pianka (1981) stated that the outcome of interspecific competition depends upon (1) initial population densities (Neyman et al. 1956), (2) environmental conditions (Park et al. 1964), and (3) the genetic constitution of competing populations (Park et al. 1964). Thus, one management strategy that may impede the establishment of viable populations of invasive species may be to artificially raise and stock native fishes to increase their density. A diverse and abundant native benthic fish fauna may in fact slow the spread of species such as the Round Goby.

Acknowledgments

Funding was provided by the Pennsylvania Water Resources Research Center, Coastal Zone Management, and The Pennsylvania State University Sea Grant Program. We extend special thanks to Elizabeth Boyer and Robert Light.

Literature Cited

Barila, T.Y., R.D. Williams, and J.R. Stauffer Jr. 1981. The influence of stream order and selected stream-bed parameters on fish diversity in Raystown Branch, Susquehanna River Drainage, Pennsylvania. Journal of Applied Ecology 18:125–131.

Brown, J.E., and C.A. Stepien. 2009. Invasion genetics of the Eurasian Round Goby in North America: Tracing sources and spread patterns. Molecular Ecology 18:64–79.

Charlebois, P.M., J.E. Marsden, R.G. Goettel, R.K. Wolfe, D.J. Jude, and S. Rudnika. 1997. The Round Goby, *Neogobius melanostomus* (Pallas): A review of European and North American literature. Illinois-Indiana Sea Grant Program and Illinois Natural History Survey Special Publication 20. Champaign, IL. 76 pp.

Chotkowski, M.A., and J.E. Marsden. 1999. Round Goby and Mottled Sculpin predation on Lake Trout eggs and fry: Field predictions from laboratory experiments. Journal of Great Lakes Research 25:26–35.

Clapp, D.F., P.J. Schneeberger, D.J. Jude, G. Madison, and C. Pistis. 2001. Monitoring Round Goby expansion in Eastern and Northern Lake Michigan. Journal of Great Lakes Research 27:335–341.

Dunham, A.E., G.R. Smith, and J.N. Taylor. 1979. Evidence for ecological character displacement in western American catostomid fishes. Evolution 33:87–896.

Freedman, J.A., T.D. Stecko, B.D. Lorson, and J.R. Stauffer Jr. 2009. Development and efficacy of an electrified benthic trawl for sampling large-river fish assemblages. North American Journal of Fisheries Management 29:1001–1005.

French, J.R.P., and D.J. Jude. 2001. Diet and diet overlap of nonindigenous Goby and small benthic native fishes co-inhabiting the St. Clair River, Michigan. Journal of Great Lakes Research 27:300–311.

Fuller, P.L., L.G. Nico, and J.D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society, Special Publication 27, Bethesda, MD. [# PP?]

Grant, K.A., M.J. Shadle, and G. Andraso. 2012. First report of Tubenose Goby (*Proterorhinus semilunaris*) in the eastern basin of Lake Erie. Journal of Great Lakes Research 38:821–824.

Harka, A., and P. Bíró. 2007. New patterns in Danubian distribution of Ponto-Caspian Goby: A result of global climatic change and/or canalization? Electronic Journal of Ichthyology 1:1–14.

Hayden, T.A., and J.G. Miner 2009. Rapid dispersal and establishment of a benthic Ponto-Caspian goby in Lake Erie: Diel vertical migration of early juvenile Round Goby. Biological Invasions 11:1767–1776.

Hensler, S.R., and D.J. Jude. 2007. Diel vertical migration of Round Goby larvae in the Great Lakes. Journal of Great Lakes Research 33:295–302

Hocutt, C.H. 1978. Fish. Pp. 80–103, *In* W.T. Mason Jr. (Ed.). Methods for the Assessment and Prediction of Mineral Mining Impacts on Aquatic Communities: A review and analysis. Biological Services Program FWS/OBS-78/30. US Department of the Interior, Fish and Wildlife Service, Washington, DC. 157 pp.

Ilev, V.S. 1961. Experimental Ecology of the Feeding of Fishes. Yale University Press, New Haven, CT. 302 pp.

Jannsen, J., and D.J. Jude. 2001. Recruitment failure of Mottled Sculpins, *Cottus bairdi*, in Calumet Harbor, southern Lake Michigan, induced by the newly introduced Round Goby, *Neogobius melanostomus*. Journal of Great Lakes Research 27:391–328.

Jude, D.J., R.H. Reider, and G.R. Smith. 1992. Establishment of Gobiidae in the Great Lakes basin. Canadian Journal of Fisheries and Aquatic Sciences 49:416–421.

Jude, D.J., J. Janssen, and G. Crawford. 1995. Ecology, distribution, and impact of the newly introduced Round and Tubenose Goby on the biota of the St. Claire and Detroit rivers. Pp. 447–460, *In* M. Munawar, T. Edsall, and J. Leach (Eds.). The Lake Huron Ecosystem: Ecology, Fisheries, and Management. Ecovision World Monograph Series, Amsterdam, Netherlands. 503 pp.

Kaesler, R.L., E.E. Herricks, and J.S. Crossman. 1978. Use of indices of diversity and hierarchical diversity in stream surveys. Biological Data in Water Pollution Assessment. ASTM (American Society of Testing and Materials). Special Technical Publication 652:92–112.

Kocovsky, P.M., J.A. Tallman, D.J. Jude, D.M. Murphy, J.E. Brown, and C.A. Stepien. 2011. Expansion of the Tubenose Gobies, *Proterorhinus semilunaris*, into western Lake Erie and potential effects on native species. Biological Invasions 13:2775–2784.

Kolar, C.S., and D.M. Lodge. 2002. Ecological predictions and risk assessment for alien fishes in North America. Science 289:1233–1236.

Kornis, M.S., N. Mercado-Silva, and M.J. Vander Zanden. 2012. Twenty years of invasion: A review of Round Goby, *Neogobius melanostomus*, biology, spread, and ecological implications. Journal of Fish Biology 80:235–285.

Kornis, M.S., S. Sharma, and M.J. Vander Zanden. 2013. Invasion success and impact of an invasive fish, Round Goby, in Great Lakes tributaries. Diversity and Distributions 19:184–198.

Lauer, T.E., P.H. Allen, and T.S. McComish. 2004. Changes in Mottled Sculpin and Johnny Darter trawl catches after the appearance of Round Gobies in the Indiana waters of Lake Michigan. Transactions of the American Fisheries Society 133:185–189.

Merritt, R.W., K.W. Cummins, and M.B. Berg (Eds.). 2008. An Introduction to the Aquatic Insects of North America, 4th Edition. Kendall Hunt, Dubuque, IA. 1158 pp.

Mills, E.L., J.H. Leach, J.T. Carlton, and C.L. Secor. 1993. Exotic species in the Great Lakes: A history of biotic crisis and anthropogenic introductions. Journal of Great Lakes Research 19:1–54.

Mills, E.L., J.H. Leach, J.T. Carlton , and C.L. Secor. 1994. Exotic species and the integrity of the Great Lakes: Lessons from the past. Bioscience 44(10):666–676.

Neyman, J., T. Park, and E.L. Scott. 1956. Struggle for existence. The *Tribolium* model: Biological and statistical aspects. Pp. 41–79, *In* Proceedings of the 3rd Berkeley Symposium on Mathematical Statistics and Probability, Volume 4. University of California Press, Berkeley, CA. 208 pp.

Park, T., P.L. Leslie, and D.B. Metz. 1964. Genetic strains and competition in populations of *Tribolium*. Physiological Zoology 37:97–162.

Pianka, E. 1981. Competition and niche theory. Pp. 167–196, *In* R.M. May (Ed.). Theoretical Ecology. Sinauer Associates, Sunderland, MA.

Pielou, E.C. 1975. Ecological Diversity. Wiley Interscience, New York, NY.

Pielou, E.C. 1977. Mathematical Ecology. Wiley Interscience, New York, NY. 385 pp.

Poos, M., A.J. Dextrase, A.N. Schwalb, and J.D. Ackerman. 2010. Secondary invasion of the Round Goby into high diversity Great Lakes tributaries and species-at-risk hotspots: Potential new concerns for endangered freshwater species. Biological Invasions 12:1269–1284.

Rosca, I., A. Novac, and V. Surugiu. 2010. Feeding selectivity of some benthic fish from the rocky bottom of the Romanian Black Sea Coast (Agigea Area). Rapport Commission International Mer Méditerranée 39:648.

Simberloff, D.S., and E.O. Wilson. 1969. Experimental zoogeography of islands: The colonization of empty islands. Ecology 50:278–295.