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Fish and Macroinvertebrate Communities in Tributary Streams of Eastern Lake Erie with and without Round Gobies (*Neogobius melanostomus*, Pallas 1814)

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***ABSTRACT**. Round gobies have had significant impacts on benthic fish and invertebrate communities in nearshore habitats of the Great Lakes. As round gobies have become more abundant in lake habitats, there has been an expansion of their populations into tributary streams and rivers. We compared stream invertebrate and fish communities in New York tributaries to Lake Erie with round gobies present and absent. Four of six benthic invertebrate metrics differed between streams with and without round gobies. Streams with round gobies present had reduced Shannon diversity, EPT richness, and EPT/chironomid ratios, and increased macroinvertebrate density relative to streams without round gobies, but there was no difference in non-Diptera density, or total taxa richness. None of the four fish metrics examined differed between streams with and without round gobies. However, darters occurred in all streams lacking round gobies, but did not occur in any streams with round gobies. Comparisons with historical fish and macroinvertebrate distributional data support our suspicion of goby-induced community changes. In these New York streams, round gobies seem to have had significant impacts on invertebrate communities via their consumptive behavior, whereas the impacts on fish communities are less evident. If round gobies continue to expand their distribution inland, the resultant alterations in macroinvertebrate communities may impact the suitability of tributary streams as spawning and nursery habitat for several sport fish species and for energy dynamics in tributary streams.*

***INDEX WORDS:** Non-indigenous species, round goby, stream community ecology.*

INTRODUCTION

Within a decade of its initial introduction, the round goby (hereafter referred to as goby) has become established in all of the Great Lakes, and in many nearshore habitats it is sometimes the most abundant fish encountered, reaching high population densities (Johnson *et al.* 2005, USGS 2006). Their abundance, in part, has led to significant impacts on nearshore benthic invertebrate and fish communities. Ratti and Barton (2003) reported a decline in the richness of benthic invertebrates in the wave-zone of eastern Lake Erie, finding 122 taxa pre-goby (1974) and 83 taxa post-goby (2001). Some taxa increased in abundance (especially the co-invasive *Dreissena bugensis* and *Echinogammarus ischnus*), but Ephemeroptera, Trichoptera, and other insects decreased in abundance. Kuhns and Berg (1999) documented a similar decline in non-mussel invertebrates with goby presence in southern Lake Michigan. Fish species also have been impacted. Mottled sculpin (*Cottus bairdi*) and Johnny darter (*Etheostoma nigrum*) populations have declined in areas of Lake Michigan since round gobies were first netted in 1998 (Lauer 2004). Chotkowski and Marsden (1999) showed

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that lake trout egg predation by round gobies was substantial and Steinhart *et al*. (2004) documented declines in smallmouth bass embryo survival within minutes after guarding males were angled from nests. These studies highlight field correlations between goby abundance and the decline of native macroinvertebrate and fish species.

Recent distributional studies indicate round gobies are migrating up Great Lake tributary streams. Phillips *et al*. (2003) showed that four of six Pennsylvania tributaries sampled had gobies present. In Elk Creek, gobies comprised almost 20% of the number of fish caught and were found 2.25 km upstream from the mouth of the creek. Similarly, Weimer (2003) showed gobies had invaded up to 1.5 km upstream in Eighteen Mile Creek, New York, and gobies currently are found about 40 km up the New York State Canal (Erie Canal) and continue to spread eastward (M. Goehle, USFWS, pers. comm., 2006). Several streams and rivers in Michigan now have gobies present (D. Jude, pers. comm., U Michigan, 2006). It is unclear whether round gobies will change stream fish and macroinvertebrate communities or disrupt stream ecosystem energy flow to the extent they have in the Great Lakes.

Like their lake counterparts, round gobies in stream habitats have diverse, macroinvertebrate-dominated diets composed mainly of chironomids and mayflies (Phillips *et al*. 2003, Weimer 2003, Carman *et al*. 2006, Lederer *et al*. 2006). As lake-dwelling gobies increase in size, they exhibit an ontogenetic diet shift at about 60 to 70 mm SL, switching to a predominantly mollusc-based diet consisting of *Dreissena* mussels (Jude *et al*. 1995, French and Jude 2001). Most streams draining into the Great Lakes are devoid of *Dreissena* mussels, and thus large stream-dwelling gobies need to consume alternative prey. In Pennsylvania streams, gobies > 75 mm had diets composed primarily of Heptageniidae and Caenidae nymphs whereas those < 75 mm contained mostly chironomid larvae (Phillips *et al*. 2003). In the Flint River, Michigan, Carman *et al*. (2006) demonstrated that goby size was not the only factor affecting diet composition. Prey choice varied depending on the availability of different prey items throughout the day with hydropsychid caddisfly and chironomid larvae predominating during the day, chironomid pupae towards the evening, and heptageniid mayfly larvae at night.

Expansion of goby populations into tributary streams of the Great Lakes has several implications. Egg predation by round gobies poses a threat to many species of game fish that spawn in these streams. Rainbow trout (*Oncorhynchus mykiss*) and smallmouth bass (*Micropterus dolomieui*) are two important sport fish that spawn in tributary streams of Lake Erie, and their populations ultimately may be reduced through egg predation by round gobies. Juveniles of these same species, as well as smaller benthic fish like darters and sculpins, prey upon macroinvertebrates, the primary food source of round gobies in stream communities. It is important that we understand the potential effects of this invasive fish in this new class of habitat, tributary streams, to more fully understand its impact within the Great Lakes watershed.

The goal of this study was to examine the macroinvertebrate and fish communities in tributary streams to Lake Erie with and without round gobies. The abundance, taxa richness, taxa diversity, and occurrence of specific taxa of macroinvertebrates and fish were compared between streams with and without gobies. Because gobies have had significant impacts on benthic communities in lake habitats, we hypothesized that streams with this invasive fish present would also exhibit reduced macroinvertebrate and fish abundance, richness, and diversity relative to streams with gobies absent.

METHODS

Using 7.5 minute Quad maps, we identified nine potential streams with enough flow to support fish populations (Fig. 1), and which drained directly into Lake Erie between Buffalo, NY and the state line with Pennsylvania. Streams varied in size, substrate, and hydrologic condition, but had similar chemical environments (Table 1). We sampled fish and macroinvertebrate communities in a 50-m stream section within each stream near the stream mouth but upstream enough to avoid lake influence on flow. Sampling continued until we had at least four streams with and four streams without round gobies. We then compared macroinvertebrate and fish community composition among sites differing in goby presence or absence.

Streams were sampled once between 31 May and 13 July, 2005. We assessed fish communities using a Coffelt Electronics BP-6 backpack electroshocker (170 volts, 500 pps, DC-pulse, 150-350 seconds). All macrohabitats (e.g., pools, riffles, runs) were shocked within the 50-m reach working in an upstream direction. All fish, other than round gobies, were identified in the field, measured, weighed, and released. Round gobies were weighed and mea-

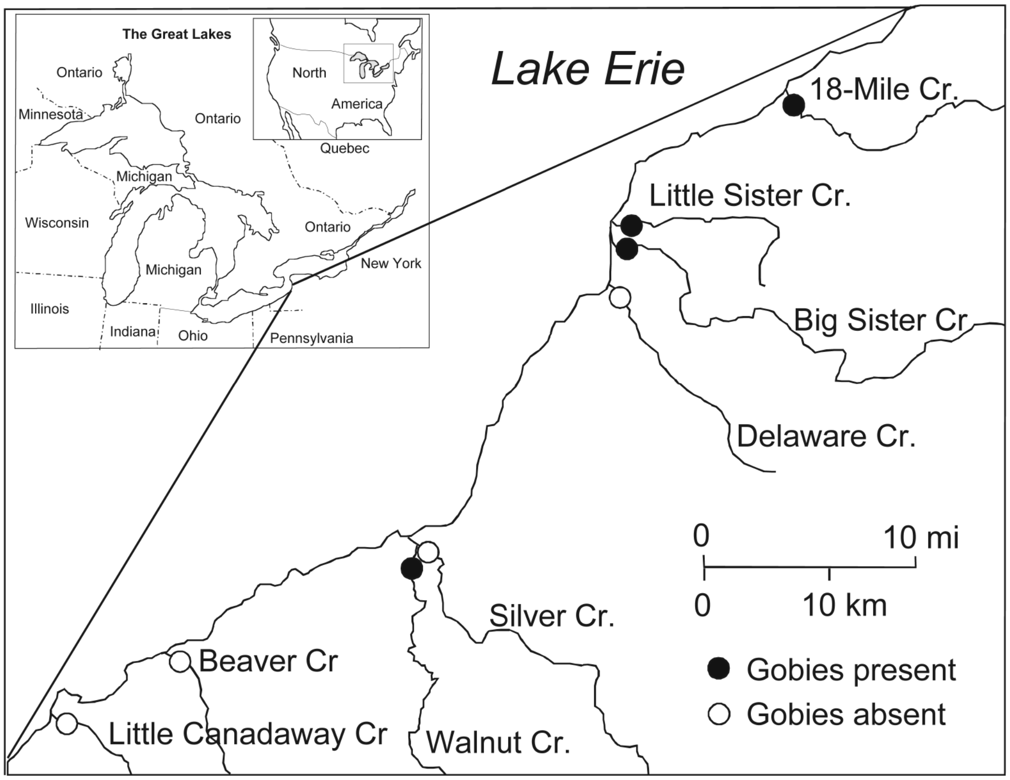

FIG. 1. Site locations on Lake Erie tributary streams with and without round gobies sampled in May–July 2005.

sured, and then preserved in 90% ethyl alcohol. Any fish that could not be identified in the field was preserved for later identification. For historical comparisons, fish community data from pre-goby invasion (1995) were obtained from the NY DEC (J. Evans, personal comm.) for all streams with existing data. Pre-goby fish samples were collected either via seining or electrofishing and no effort was taken to provide comparable abundance estimates with the current data. Thus, only qualitative presence/absence comparisons were made between current and historical data.

Ten Surber samples (0.5 mm mesh, 0.093 m^2) were collected from random locations at each site, disturbing substrate to a depth of ~10 cm, where possible. Additionally, a single 5-m traveling kick sample (0.5-mm mesh, 45-cm opening) was collected from riffle habitats in each stream following Surber collections and according to the New York DEC protocol of Bode *et al* (2002). Invertebrates and debris were transferred into Whirlpak bags, preserved in 90% ethyl alcohol, and sorted and identified in the laboratory. All macroinvertebrates were identified to the taxonomic level indicated in Table 2 using keys of Peckarsky *et al.* (1990) and Merritt and Cummings (1996). Typically, insect larvae were identified to genus.

Kick samples were treated according to the bioassessment protocol of Bode *et al.* (2002). Samples were placed in a gridded sorting tray and a random square was examined for all macroinvertebrates. Random squares were processed in this manner until 100 organisms had been obtained. Metrics of Shannon diversity, taxa richness, percent EPT (Ephemeroptera, Plecoptera, Trichoptera), and percent Chironomidae were then determined. We also obtained pre-goby (1993) macroinvertebrate data from the NY DEC (B. Bode, Stream Biomonitoring Unit, NY DEC) for sites in their sampling program that were at the same location as our sampling sites (RIBS, Bode *et al.* 2002). Walnut, Eighteen Mile, Delaware, and Silver creeks were sampled in the same locations in 1993 and 2005. No sites had round gobies present in 1993, but Walnut and Eighteen Mile creeks contained gobies in 2005.

TABLE 1. Environmental parameters, hydrologic conditions, and substrate composition of eight Lake Erie tributary streams.

Stream	Goby present	Discharge (m^3/s)	Mean velocity (m/s)	Maximum velocity (m/s)	Mean channel width (m)	Mean depth (cm)	Land use[a]	Canopy %	Cond.[b] (μS/cm)	D.O. (mg/L)	Water temp. (°C)	Turbidity (NTU)	pH
18 Mile	Y	0.71	0.13	0.30	30	22	1	0	576	9.17	24.8	0.37	8.3
Little Sister	Y	0.29	0.075	0.18	10	74	1	54.6	620	6.05	24.0	29.8	8.4
Big Sister	Y	0.24	0.046	0.10	30	43	1	26.5	713	9.57	16.6	2.46	8.2
Walnut	Y	0.10	0.25	0.38	15	6	2	75.0	470	9.27	22.1	0.13	8.3
Delaware	N	0.01	0.036	0.13	10	5	2	80.4	500	8.10	19.3	8.23	8.4
Silver	N	0.11	0.13	0.45	25	14	2	44.2	417	9.58	18.5	0.01	8.1
Beaver	N	0.10	0.16	0.21	15	7	3	40.4	490	8.93	20.8	0.41	7.8
Little Canadaway	N	0.01	0.12	0.16	15	5	1	67.5	500	7.75	26.8	0.44	7.6

[a] 1 = forested, 2 = residential, 3 = agricultural; [b] conductivity.

Substrate (%)

Stream	Cobble	Gravel	Sand	Silt/Mud	Bedrock
18 Mile	5	57	0	5	33
Little Sister	20	60	10	10	0
Big Sister	5	20	25	45	5
Walnut	30	35	25	0	10
Delaware	10	25	10	60	0
Silver	50	25	20	5	0
Beaver	5	65	15	5	10
Little Canadaway	25	15	10	0	50

Nineteen water quality measurements and habitat condition variables were measured at each site, prior to fish or invertebrate sampling. A single, mid-depth grab sample was collected for determination of water temperature and dissolved oxygen (YSI Model 50B dissolved oxygen meter), conductivity (Oakton Con5 Acorn Series conductivity meter), and turbidity (LaMotte Model 2020 turbidity meter). Habitat metrics were recorded after fish and macroinvertebrate sampling had occurred. Wetted stream width was measured perpendicular to stream flow at 10-meter intervals throughout the study reach. Stream velocity (cm/s) and depth were measured at 1-m intervals across the stream width (Swoffer Model 2100 flow meter). We derived stream discharge (Q; m^3/s) from stream depth and velocity measurements. Canopy cover was estimated using a crown densitometer at ten equidistant points, zig-zagged across the 50-m stretch of stream. The surrounding land use, such as residential, agricultural, or forested, was noted as well. Lastly, percent substrate particle size was estimated visually into seven categories: bedrock, boulder, cobble, pebble, sand, silt/mud, and detritus.

Statistical Analyses

Patterns within the fish and macroinvertebrate community data, and their relationship to environmental parameters, were first constrained with nonmetric multidimensional scaling using algorithms of Mather (1976) to determine how well the environmental data "explained" the observed community data. This analysis was performed with the software PC-ORD Ver. 4 (McCune and Medford 1999). All abundance data were ln (x+1)-transformed prior to ordination procedures and only taxa occurring in $\geq$ 3 streams were entered into the ordination. Categorical environmental data were not used in the ordination analysis. Data restrictions resulted in a 15-variable, environmental matrix, and fish and macroinvertebrate matrices of 10 and 20 taxa, respectively. For both ordinations, Bray-Curtis distance measures were applied. Bray-Curtis distance (also called Sørensen distance) measure the dissimilarity between any two items in a sample matrix and is commonly employed in ecological studies (e.g., Magurran 1988, McCune and Grace 2002).

Maximized stress reductions were used to deci-

TABLE 2. Summary of macroinvertebrate counts in 10 pooled Surber samples from New York tributary streams in summer 2005.

Taxa	18 Mile Creek	Little Sister Creek	Big Sister Creek	Walnut Creek	Delaware Creek	Silver Creek	Beaver Creek	Little Canadaway Creek
COLEOPTERA								
Chrysomelidae								
Pyrrhalta	0	0	0	0	0	1	0	0
Curculionidae	0	0	0	0	0	1	0	0
Elmidae								
Ancyronyx sp.	0	0	0	1	0	0	0	0
Dubiraphia sp.	0	0	0	0	1	0	1	0
Optioservus sp. (Optio)	0	0	1	2	2	1	0	0
Stenelmis sp.(Stenel)	9	6	17	1	11	2	9	2
Gyrinidae								
Dineutus sp.	0	0	9	0	0	0	0	0
Hydrophilidae								
Laccophilus sp.	0	3	0	0	2	0	1	0
Unidentified hydrophilid	0	0	2	0	1	0	0	0
Psephenidae								
Psephenus sp. (Pseph)	4	1	16	2	23	3	16	13
DIPTERA								
Ceratopogonidae	0	0	0	2	0	0	0	0
Chironomidae (Chiro)	809	236	909	389	71	518	297	158
Empididae (Empid)	0	0	0	20	0	0	29	9
Simuliidae (Simul)	32	0	0	62	0	4	1	0
Tipulidae (Tipul)	0	0	0	3	1	12	5	3
EPHEMEROPTERA								
Baetidae								
Baetis sp. (Baet1)	98	0	0	2	0	0	21	0
Unidentified baetid (Baet2)	0	0	0	70	6	61	0	7
Caenidae								
Caenis sp. (Caenis)	1	38	1	50	0	151	24	27
Ephemerellidae								
Ephemerella sp.	0	0	0	9	0	131	0	0
Ephemeridae								
Ephemera sp.	0	0	0	0	2	0	0	0
Leptophlebiidae								
Choroterpes sp.	0	0	0	0	0	0	9	0
Paraleptophlebia sp.	0	0	0	0	0	0	1	0
Unidentified leptophlebiid (Lepto)	0	0	2	2	0	1	1	3
Oligoneuriidae								
Isonychia sp.	0	0	0	0	0	2	0	0
Heptageniidae								
Stenacron sp. (Stena)	0	3	0	0	12	0	0	10
Stenonema sp. (Steno)	123	75	1	15	30	346	67	4
HEMIPTERA								
Corixidae								
Sigara sp.	0	6	0	0	0	0	0	0
Gerridae								
Gerris sp.	0	0	0	0	0	0	3	1
Trepobates sp.	0	0	0	0	1	0	1	0

(Continued)

TABLE 2. Continued.

Taxa	18 Mile Creek	Little Sister Creek	Big Sister Creek	Walnut Creek	Delaware Creek	Silver Creek	Beaver Creek	Little Canadaway Creek
HEMIPTERA (Continued)								
Notonectidae	0	0	0	0	0	1	0	0
Veliidae								
Microvelia sp.	0	0	0	0	0	1	0	1
Rhagovelia sp.	0	0	0	0	4	0	0	1
MEGALOPTERA								
Corydalidae								
Nigronia serricornis	1	0	0	0	2	0	0	1
Sialidae								
Sialis sp.	0	0	1	0	2	0	0	0
ODONATA								
Aeshnidae								
Boyeria sp.	0	0	0	0	1	0	0	0
Caleopterygidae								
Caleopteryx sp.	0	0	0	0	1	0	0	0
Coenagrionidae								
Argia sp.	0	0	6	0	0	0	0	0
Gomphidae	0	1	0	0	0	0	1	0
PLECOPTERA								
Capniidae								
Allocapnia sp.	1	0	0	2	1	0	0	0
Perlidae								
Agnetina sp.	1	0	0	1	0	0	0	0
Perlesta sp.	0	1	0	0	0	0	0	0
TRICHOPTERA								
Helicopsychidae								
Helicopsyche sp. (Helico)	9	0	3	0	0	2	0	0
Hydropsychidae								
Cheumatopsyche sp. (Cheum)	32	18	0	9	4	37	192	15
Hydropsyche sp. (Hydro)	43	0	0	101	0	115	66	15
Limnephilidae	0	0	0	0	1	0	0	0
Philopotamidae								
Chimarra sp. (Chim)	0	0	0	3	0	1	0	20
Polycentropodidae								
Polycentropus sp. (Poly)	1	0	0	0	0	2	56	17
Rhyacophilidae								
Rhyacophila sp.	0	0	0	0	0	1	0	0
AMPHIPODA								
Gammaridae								
Gammarus sp. (Gamm)	0	56	1	0	0	0	22	0
DECAPODA								
Cambaridae								
Cambarus robustus	0	1	0	0	2	0	0	0
Orconectes propinquus (Opro)	0	4	3	0	5	0	0	0

(Continued)

TABLE 2. Continued.

Taxa	18 Mile Creek	Little Sister Creek	Big Sister Creek	Walnut Creek	Delaware Creek	Silver Creek	Beaver Creek	Little Canadaway Creek
HIRUDINEA								
Erpobdellidae								
Erpobdella punctata	0	1	0	0	0	0	0	0
HYDRACHNIDIA								
Limnesiidae								
Limnesia sp.	0	0	0	0	0	2	0	0
ISOPODA								
Asellidae								
Caecidotea sp.	0	35	1	0	0	0	0	0
MOLLUSCA								
Physidae								
Physa gyrina	0	9	0	0	1	0	0	0
Valvatidae								
Valvata lewisi	0	0	0	0	0	0	1	0
Valvata sincera	0	0	0	0	0	0	1	0
Benthic density (#/m^2)	1,254	532	1,047	803	200	1,503	901	330
Non-diptera density (#/m^2)	323	258	64	270	114	862	505	137
Taxa richness	14	17	15	20	24	23	23	18
Shannon diversity	1.14	1.74	0.38	1.67	2.15	1.77	1.99	1.88
EPT richness	9	5	4	11	7	11	9	9
EPT/Chironomidae ratio	0.41	0.63	0.01	0.77	1.06	1.84	1.57	0.81

pher the appropriate number of axes useful in explaining patterns in the data. A Monte Carlo simulation of 50 randomized runs of the data was used to infer stress reduction, seeking random runs which had stress values significantly less than the original data at $p < 0.05$. Pearson correlations were used to correlate environmental, macroinvertebrate, and fish community data against the resultant ordination axes. Additionally, Pearson correlations were applied to all environmental parameters and community data to assist interpretation of the ordination axes. In ordination plots, only environmental variables with R^2 values ≥ 0.50 were graphed as this represented the appropriate correlation for an $\alpha = 0.05$.

Several indices were used to assess both fish and macroinvertebrate community differences in streams with and without round gobies. Total macroinvertebrate density, non-Diptera density, taxa richness, Shannon diversity, EPT richness, and the EPT/Chironomidae ratio were used to compare macroinvertebrate communities in goby-present and goby-absent streams. Additionally, pre- and post-goby invasion taxa richness, Shannon diversity, percent EPT and percent Chironomidae were compared for the four sites with 1993 and 2005 data. Fish communities in goby-present and goby-absent streams were assessed using taxa richness, Shannon diversity, catch per unit effort (CPUE), and biomass per unit effort (BPUE). Additionally, observed fish species presence/absence was compared to historical NY DEC presence/absence data for all streams for which data could be obtained (J. Evans, NY DEC, personal comm.).

A series of 2-level nested ANOVAs was used to compare the Surber macroinvertebrate data metrics from streams with and without round gobies. Analyses were performed on log (x+1)-transformed data to meet variance assumptions. The analysis deciphered the differences among “goby/no goby streams” and among “all streams.” It also provided estimates of the error within and among all streams. When a significant among stream or among goby/no goby term was detected, an adjusted Bonferroni post-hoc test was computed. Each pre- and post-goby invasion macroinvertebrate metric was compared using a G-test testing whether any change in a metric was independent of goby presence. The fish metrics were assessed using one-tailed Students's t-tests and a Bonferroni-adjusted significance level of $p < 0.0125$ (0.05/4) after determining variance homogeneity and normality of the data.

RESULTS

The eight tributary streams sampled had similar chemical environments, but exhibited high variability in hydrologic and physical conditions (Table 1). All sites had pH values between 7.5 and 8.5, and water clarity was < 10 NTU at all sites except Little Sister Creek (NTU = 29.8). Streams with round gobies had higher discharge levels, greater mean depth and were predominantly forested (Table 1).

Some environmental parameters were correlated to each other. Dissolved oxygen was negatively correlated with turbidity whereas it was positively correlated with percent sand substrate ($r = -0.862$, $p = 0.01$; $r = 0.797$, $p = 0.03$, respectively). Percent cobble substrate was positively correlated with maximum velocity ($r = 0.814$, $p = 0.03$). Lastly, mean channel width was positively correlated with mean depth ($r = 0.860$, $p = 0.01$).

Gobies were present in four of the eight tributary streams that were sampled. Eighteen Mile, Big Sister, Little Sister, and Walnut creeks had goby populations (Fig. 1). When gobies were present, they made up at least 50% of the number of fish collected. No quantitative data were collected in Eighteen Mile Creek due to a malfunction of the backpack electroshocker; however, round gobies were observed visually and collected by seining.

Non-metric Multi-dimensional Scaling

The ordination of fish community and environmental data yielded only a single axis that provided significant explanatory power. Fish communities aligned along this axis based on stream size, and gobies were found only in the largest streams. Thus, there was a strong autocorrelation between fish community structure, presence of round gobies, and stream size. The single axis resulting from the fish ordination explained less than 20% of the pattern in fish communities ($R^2 = 0.182$). The axis primarily represented substrate composition and hydrologic variables. Only mean velocity and percent silt/mud had significant correlations with the resultant axis ($r = -0.707$ and 0.833, respectively; both $p < 0.05$). No individual fish species ordination score had a significant correlation with the resultant ordination axis (all $p > 0.05$).

Three axes were formed by the ordination of macroinvertebrate density and environmental data. The stress value was low (1.239), as was the final instability score (0.037), indicating that the 3-axis ordination captured a majority of the variability in the data. A Monte-Carlo simulation of 50 random permutations of the data suggested that the final stress value was not computed by chance ($p = 0.039$). The three axes cumulatively explained 95% of the variation between ordination distances and the original data ($R^2 = 0.950$), but Axes 2 and 3 explained most of the variation (cumulative $R^2 = 0.858$, Fig. 2). Percent silt/mud, mean depth, and conductivity were significantly correlated with Axis 2 ($r = 0.746$, 0.787, and 0.817; all $p < 0.05$), whereas mean velocity, dissolved oxygen content, and turbidity were significantly correlated with Axis 3 ($r = 0.818$, 0.722, and –0.720, respectively; all $p < 0.05$). *Hydropsyche*, *Chimarra*, *Orconectes propinquus*, Empididae, and *Stenelmis* were the only invertebrate taxa significantly correlated with Axis 2 ($r = -0.710$, –0.795, 0.748, –0.739, and 0.857, respectively; all $p < 0.05$, except *Stenelmis* < 0.01). Five taxa, *Hydropsyche*, *Baetis*, *Gammarus*, *Psephenus,* and Simulidae, had a significant correlation with Axis 3 ($r = 0.796$, 0.711, –0.745, –0.719, and 0.843, respectively; all $p < 0.05$, except Simulidae $p < 0.01$). The invertebrate ordination among these streams indicated a slight tendency to cluster as "small," non-silt bottom, rapid flow stream communities (to the left and above the centroid) and "large," soft-substrate, slow flow stream communities (to the right and below the centroid, Fig. 2).

Streams with and without round gobies did not cluster well in ordination space (Fig. 2). Four of the eight streams fell to the right or left of the ordination centroid and four were above or below the centroid. Interestingly, three of four goby-present streams were found right of the centroid along Axis 2, indicating that this axis may have some utility in describing goby presence. This axis was associated with stream size data. The "largest" streams were the deepest, had the largest percent silt/mud substrate, and the greatest conductivity. Alternatively, three of the four goby-absent streams appeared below the centroid along Axis 3 (Fig. 2), indicating this axis was a better descriptor of goby absence. This area of the graph was represented most by turbidity.

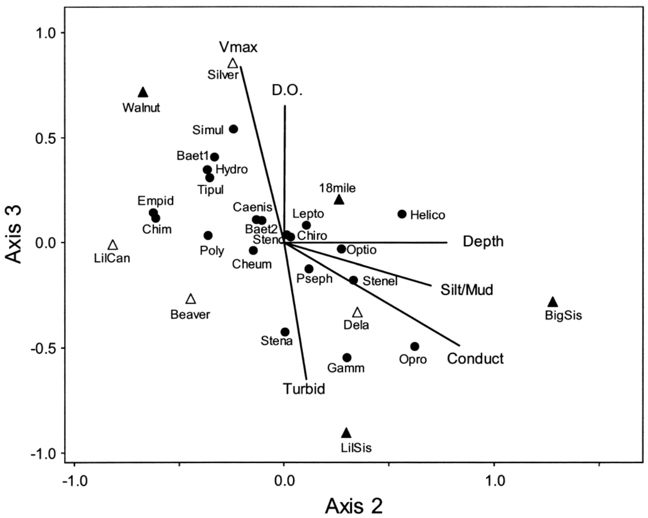

FIG. 2. Bray-Curtis ordination of macroinvertebrate communities and environmental data for all taxa occurring in ≥ 3 streams. Only environmental vectors with an $R^2 \geq 0.500$ are shown. Solid circles represent the macroinvertebrate taxa and triangles represent the streams. See Table 2 for abbreviations. Open triangles are streams without round gobies whereas filled triangles are streams with round gobies. These two axes represented ~86% of the variation in species abundance.

Round Goby Relationship to Macroinvertebrate Communities

A total of 57 invertebrate taxa was collected among the eight streams (Table 2). Of these, 10 were found only in streams with round gobies present, 19 were found only in streams without gobies, and 28 occurred in both stream types. Several macroinvertebrate community indices were correlated to some of the environmental variables. Total invertebrate density was positively correlated with mean channel width and negatively correlated with the percent canopy cover (r = 0.770 and –0.763; both $p = 0.04$). Non-Diptera density was positively correlated with maximum stream velocity (r = 0.799, $p = 0.03$). Macroinvertebrate taxa richness was negatively correlated with conductivity (r = –0.814, $p = 0.03$). Shannon diversity was negatively correlated with mean channel width, mean depth, and conductivity (r = –0.798, –0.952, and –0.767, respectively; p = 0.03, 0.001, and 0.04). EPT richness was positively correlated with the maximum velocity of the stream and negatively correlated with conductivity (r = 0.786, $p = 0.04$; r = –0.884, $p = 0.008$, respectively). The EPT/chironomid ratio was negatively correlated with conductivity (r = –0.852, $p = 0.02$).

Most, but not all, of the macroinvertebrate community indices varied among streams and between streams with and without gobies. The range of total macroinvertebrate density was similar among the goby-present and goby-absent streams (Table 2). However, there was a significant goby-presence effect on mean macroinvertebrate density ($p < 0.001$, Table 3); goby presence explained 7% of the variability in the data. Among-stream variability accounted for 54% of the overall variability. Post-hoc comparisons revealed three groups of streams with significant differences between them ($p < 0.0065$). Of these, Delaware and Little Canadaway (both non-goby streams), were significantly different from the others. Likewise, the density of non-Diptera invertebrates was similar in goby-present and goby-absent streams (Table 2), with significant among-stream variability ($p < 0.001$, Table 3). There was not a significant difference in the mean density of non-Diptera macroinvertebrates * m^{-2} in streams with or without round gobies (Table 3).

There was significant variability in macroinvertebrate taxa richness among streams ($p < 0.001$, Table 3), but there was no significant difference in taxa richness between goby-present and goby-absent streams (Table 3). Streams with gobies present had, on average, fewer taxa than streams without gobies (Fig. 3). EPT richness and Shannon diversity values both exhibited significant among-streams variability ($p < 0.001$, Table 3) and significant differences between streams with and without gobies. These metrics were higher in streams without gobies relative to streams with gobies (Fig. 3). Post-hoc comparisons of Shannon diversity revealed just two significantly different stream groupings, with Big Sister (a goby-present stream) lower than all of the other streams. The EPT richness post-hoc comparisons resulted in three significantly different stream groups ($p < 0.0065$), with Big Sister and Little Sister creeks (both goby-present streams) having lower EPT richness than the remaining streams. The EPT/chironomid ratio was significantly lower in streams with gobies relative to streams without gobies ($p = 0.023$, Table 3; Fig. 3).

Walnut and Eighteen Mile creeks, on average, showed significant changes in percent Chironomidae and percent EPT from pre-goby invasion (1993) to current (2005) conditions. Percent midges increased roughly threefold in streams invaded by round gobies (Fig. 4) and this was a significant increase compared to the change observed in

TABLE 3. Results of 2-level nested ANOVAs examining macroinvertebrate community indices in streams with and without round gobies. All df = 1, 6, and 71 for goby presence, among streams, and within streams, respectively.

Source	MS	F	P	Source	MS	F	P
Taxa richness				**EPT richness**			
Goby presence	10.432	1.84	0.179	Goby presence	21.241	13.06	**< 0.001**
Among streams	29.858	5.26	**< 0.001**	Among streams	35.465	21.81	**< 0.001**
Within streams	5.674			Within streams	1.626		
Non-Diptera density				**Total density**			
Goby presence	0.274	3.17	0.079	Goby presence	1.387	20.99	**< 0.001**
Among streams	1.435	16.56	**< 0.001**	Among streams	0.945	14.31	**< 0.001**
Within streams	0.087			Within streams	0.066		
EPT/chironomid ratio				**Shannon diversity**			
Goby presence	37.598	5.44	**0.023**	Goby presence	3.482	35.30	**< 0.001**
Among streams	8.428	1.22	0.306	Among streams	1.326	13.44	**< 0.001**
Within streams	6.906			Within streams	0.098		

Delaware and Silver creeks, which were not invaded by gobies (G_{adj} = 11.88, df = 1, $p < 0.001$). Percent EPT declined approximately threefold in streams with gobies compared to streams without gobies over the same time period (Fig. 4) and this was a significant change (G_{adj} = 5.70, df = 1, p = 0.017). Neither taxa richness nor Shannon diversity showed a significant change in streams with gobies compared to streams without gobies (both $p >$ 0.05), although over time, both richness and diversity values were slightly higher in streams without gobies relative to streams with gobies.

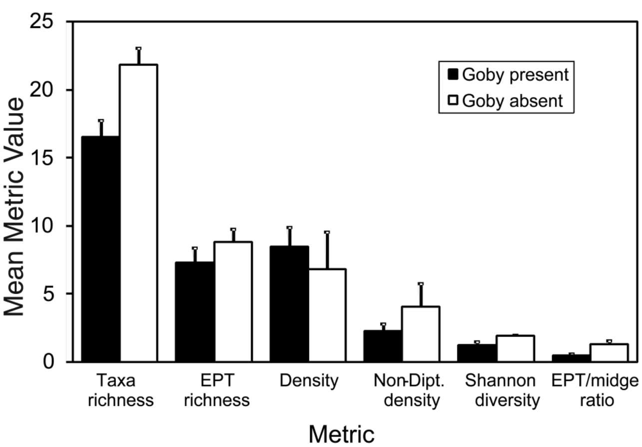

FIG. 3. Mean (+ S.E.) macroinvertebrate metric scores for Lake Erie tributary streams in New York with and without round gobies. Density = # organisms/m²/100. Non-Dipt. Density = # non-Diptera/m²/100.

Round Goby Relationship to Fish Communities

A total of 23 fish taxa was collected across all streams (Table 4). Three species (smallmouth bass, emerald shiner, and tadpole madtom) were found only in streams that also held gobies, whereas seven species (rock bass, mottled sculpin, spottail shiner, an unidentified dace, creek chub, Johnny darter, and rainbow darter) occurred only in streams without gobies. Some fish community indices were correlated with the environmental variables. Fish taxa richness was negatively correlated with the conductivity (r = –.825, p = 0.02, Table 2). The biomass per unit effort (BPUE) rate was positively correlated to water temperature and negatively correlated with the percent of sand substrate (r = 0.755, p = 0.05; r = –0.890, p = 0.007, respectively).

There was no significant difference in the four fish community metrics (i.e., taxa richness, Shannon diversity, CPUE, and BPUE) between goby-present and goby-absent streams (all $p > 0.0125$). However, all metrics were lower in streams containing gobies compared to streams without gobies (Table 5). Eighteen Mile Creek was excluded from the analyses because electroshocking was not performed. Historical NY DEC data indicated darter species occurred in all eight streams sampled prior to 1995. In the current collections, no Johnny darters (*Etheostoma nigrum* Rafinesque) or rainbow darters (*E. caeruleum* Storer) were collected from any stream also containing round gobies. Rainbow darters were collected in all the streams without go-

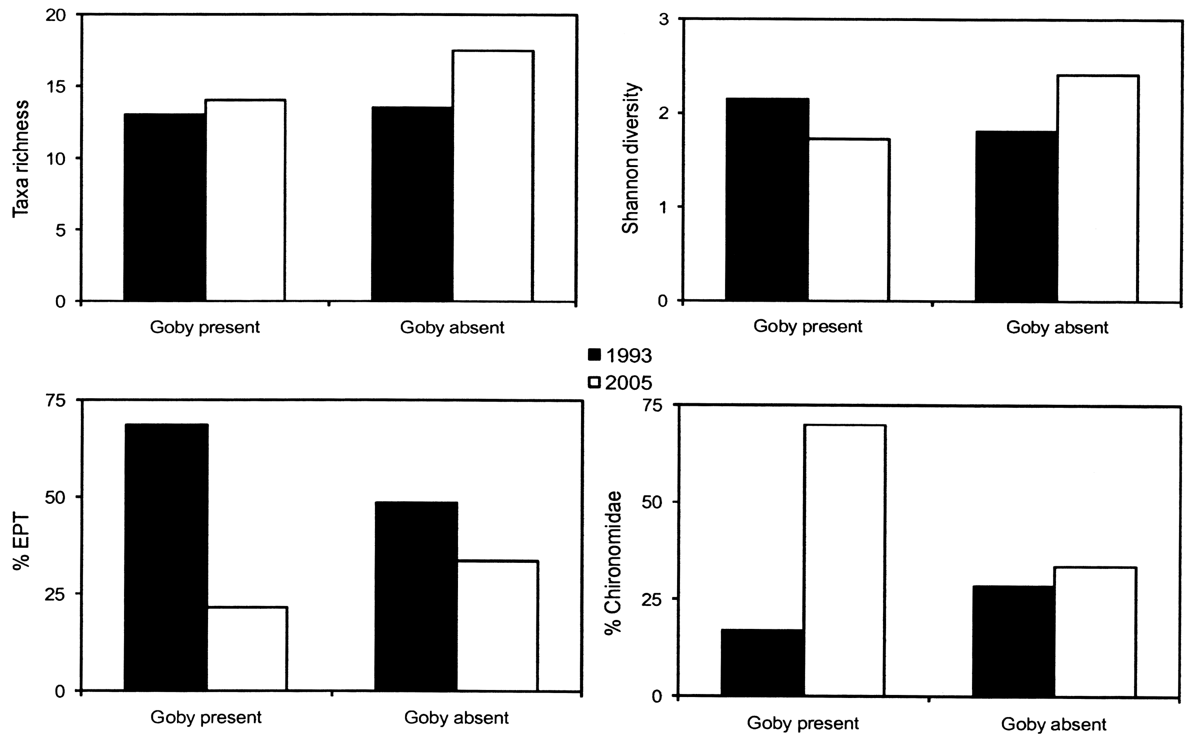

FIG. 4. Pre- and post-goby invasion macroinvertebrate metrics for Lake Erie tributary streams. Values are means of each metric for the same pre- and post invasion sampling sites on Walnut and Eighteen Mile creeks (goby present in 2005, but not 1993) and Delaware and Silver creeks (goby absent in both 1993 and 2005).

bies and Johnny darters were collected in Little Canadaway Creek (Table 4).

DISCUSSION

No studies have focused on the effects of round gobies on tributary stream macroinvertebrate and fish communities, although several distribution and diet studies exist (Philips *et al.* 2003, Weimer 2003, Carman *et al.* 2006, Lederer *et al.* 2006). Round gobies occurred in four of the eight tributary streams sampled and represented between 22% and 80% of the total fish abundance in these streams. These results are similar to the work of Phillips *et al.* (2003) who found gobies in four of six Pennsylvania streams, but abundances in the Pennsylvania streams only accounted for ~13–30% of the total fish catch. The similarities in presence among streams might indicate that the tributary systems in these neighboring states have been experiencing round goby invasions for comparable time periods. In three of the New York streams (Big Sister, Little Sister, and Walnut), round goby relative abundances were higher than in the Pennsylvania streams, representing 80%, 50%, and 54% of the catch, respectively. Possibly, habitat suitability contributed to the high relative abundances in these streams compared to abundance values in PA. Several of the Pennsylvania streams had high bedrock occurrence in their lower reaches that may be unsuitable goby habitat, at least at high fish densities (Phillips *et al.* 2003). Bedrock occurrence was least in the three NY streams with the highest goby abundance. Overall fish community structure also was, in part, dictated by bedrock occurrence.

In our ordination procedure, only a single axis provided explanatory power for fish community structure. Communities were related to variables describing stream size (e.g., maximum depth, discharge, percent occurrence of bedrock) and, in general, fish communities grouped into species associated with small bedrock streams or larger, cobble-dominated streams with gobies found in the latter. However, this ordination needs cautious interpretation because only ten fish species occurred

TABLE 4. Summary of fish counts from electroshocking of New York tributary streams in summer 2005. Electroshocking was not performed at 18 Mile Creek, therefore, CPUE and BPUE were not calculated. Fish counts in 18 Mile Creek are from seine hauls and visual observations.

Fish Code	Taxa	18 Mile Creek	Little Sister Creek	Big Sister Creek	Walnut Creek	Delaware Creek	Silver Creek	Beaver Creek	Little Canadaway Creek
	Catostomidae								
WHS	*Catostomus commersoni*	3	0	0	1	1	1	4	0
NHS	*Hypentelium nigricans*	0	0	0	3	0	1	0	0
SCK1	Unknown sucker spp. 1	0	0	1	0	0	3	0	0
	Centrarchidae								
SMB	*Micropterus dolomieu*	1	0	1	0	0	0	0	0
ROB	*Ambloplites rupestris*	0	0	0	0	1	0	0	0
	Cottidae								
SCU	*Cottus* spp.	0	0	0	0	0	0	1	0
	Cyprinidae								
EMS	*Notropis atherinoides*	25	0	0	5	0	0	0	0
SPS	*Notropis hudsonius*	0	0	0	0	1	1	0	0
BKD	*Rhinichthys atratulus*	3	0	0	5	0	2	141	7
DAC1	Unknown dace spp. 1	0	0	0	0	0	1	0	0
CHB1	Unknown chub spp. 1	0	0	0	2	0	1	0	0
CRC	*Semotilus atromaculatus*	0	0	0	0	0	0	0	4
MIN1	Unknown minnow spp. 1	7	8	0	0	0	1	80	30
MIN2	Unknown minnow spp. 2	7	0	0	0	0	20	31	0
MIN3	Unknown minnow spp. 3	8	0	0	0	0	0	62	0
SHI2	*Rhinichthys cataractae*	0	0	0	0	0	0	6	7
SHI1	Unknown shiner spp. 1	0	0	0	1	0	13	30	0
	Gobiidae								
ROG	*Neogobius melanostomas*	17	8	8	31	0	0	0	0
	Ictaluridae								
TPM	*Noturus gyrinus*	1	0	0	0	0	0	0	0
	Percidae								
JOD	*Etheostoma nigrum*	0	0	0	0	0	0	0	1
RAD	*Etheostoma caeruleum*	0	0	0	0	10	3	9	6
LOP	*Percina caprodes*	5	0	0	8	0	2	0	2
	Salmonidae								
RBT	*Oncorhynchus mykiss*	0	0	0	1	0	0	16	2
Total abundance		77	16	10	57	13	49	380	59
Taxa richness		11	2	3	9	4	12	10	8
Shannon diversity		1.91	0.69	0.46	1.52	0.79	1.80	1.75	1.56
CPUE		—	0.18	0.03	0.05	0.16	0.04	0.39	0.24
BPUE		—	0.65	0.12	0.18	0.59	0.41	0.63	1.03
% abundance of round gobies		22.1	50	80	54.4	—	—	—	—
% biomass of round gobies		—	23.8	56.3	67.1	—	—	—	—

TABLE 5. Results of one-tailed Student's t-tests examining fish community indices in streams with and without round gobies. Data are means and (s.e.).

	Goby Present	Goby Absent	df	*t*	*p*
Taxa richness	4.7 (2.19)	8.5 (1.71)	5	1.41	0.109
Shannon diversity	0.89 (0.32)	1.48 (0.23)	5	1.51	0.095
CPUE	0.08 (0.05)	0.21 (0.07)	5	1.27	0.131
BPUE	0.32 (0.17)	0.67 (0.13)	5	1.67	0.078

with enough frequency among the streams to be included in the analysis.

The fish community indices from goby-present streams did not differ from those of the goby-absent streams, although all the indices (fish taxa richness, Shannon diversity, CPUE, and BPUE) were higher in streams lacking round gobies. Gobies certainly have not occupied tributary streams as long as they have occupied the Great Lakes, so their impacts still may be in the early stages and more pronounced impacts may occur in the future. Alternatively, our ability to detect significant differences between fish community metrics in streams with and without gobies may be limited by our small sample size and the tendency of metrics to collapse community variability. The reciprocal transfer of energy and nutrients between streams and their watersheds suggests that invasive fish may have impacts which extend beyond the shoreline (Townsend 1996). For example, Baxter *et al.* (2004) demonstrated that the invasion of rainbow trout (*O. mykiss*) into streams of Japan affected many aspects of stream ecosystem functioning. Rainbow trout directly competed with Dolly Varden char (*Salvelinus malma*) for macroinvertebrates, causing Dolly Varden to shift their diets to include more benthic invertebrates. The reduction of benthic macroinvertebrates indirectly led to an increase in algal biomass. Rainbow trout also reduced the amount of macroinvertebrates emerging from the stream, leading to a decline in riparian spiders in the nearby forest (Baxter *et al.* 2004). Similarly, energy and nutrient export from streams in New Zealand have been altered as a result of invasive fish (Townsend 1996). We are currently investigating energy consumption patterns by round gobies in tributary streams and hypothesize that ultimately gobies may have impacts in Great Lake tributary streams as significant as those they have had in lakes. As gobies become more prominent in tributary streams, similar to the lakes, their aggressive nature and wide diet breadth may allow them to outcompete native fishes for food as well as nesting sites.

Several studies within the Great Lakes have documented round gobies outcompeting other native, benthic fishes, such as logperch, sculpins, and darters (e.g., Dubs and Corkum 1996, Balshine *et al.* 2005). In this study, rainbow and Johnny darters were not found in any of the streams containing the round goby, whereas they were found in all of the goby-absent streams. Based on historical data, all eight of the streams sampled in this study normally harbor darters, but especially rainbow darters (J. Evans, pers. comm., NYDEC 2007). Thus, we may be witnessing the early stages of benthic fish species displacement by round gobies. Additionally, logperch (*Percina caprodes*, Rafinesque) were found in two of the goby-present streams (Eighteen Mile and Walnut creeks), whereas historically they were found in all four streams currently containing gobies. They also occurred in two of the four non-goby streams both historically and in the current collection. Collectively, these data suggest that round gobies may be displacing other small, benthic species, even though overall fish richness has not been altered. Perhaps the absence or reduction of benthic species, like darters, enables other species like minnows, shiners, and suckers to move in and inhabit these streams.

Most macroinvertebrate community indices were different in streams with or without round gobies. EPT taxa richness, Shannon diversity, and EPT/chironomid ratios were lower in goby-present streams compared to streams lacking gobies, whereas total macroinvertebrate density was higher. Collectively, these data suggest gobies have impacted EPT species the most and this has subsequently led to a dominance by chironomids. Goby diets vary with body size, but smaller fish (< 7 cm TL) have been found to prey upon a variety of benthic invertebrates in both lake and stream studies (Kuhns and Berg 1999, French and Jude 2001, Philips *et al.* 2003, Weimer 2003, Carman *et al.* 2006, Lederer *et al.* 2006). Although dreissenid mussels are the main diet item of adult round gobies (> 7 cm TL) in the Great Lakes (Jude *et al.* 1995, French and Jude 2001), other prey, particularly insect larvae, dominate diets in tributary streams due to the absence of these mussels. Because many native stream fishes, such as dace, darters, logperch, and sculpins, prey upon macroinvertebrates, changes in the community structure of macroinvertebrates may have detrimental effects on these native fishes.

A closer examination of the macroinvertebrate community data reveals some patterns of occurrence which suggest round gobies may be having further impacts in these tributary streams. Streams without gobies had nearly twice as many mayfly taxa as streams with gobies (n = 11 and 6, respectively). The mayfly taxa missing from the goby streams (*Ephemera*, *Choroterpes*, *Paraleptophlebia*, and *Isonychia*) are primarily grazers and filter-feeders and at least three taxa potentially would be exposed on rock surfaces available to goby predation. The net-spinning caddisflies (*Cheumatopsyche*, *Hydropsyche*, and *Polycentropus*) were about 2.5 times more abundant in streams without gobies compared to streams with gobies. Previous work by Carman *et al*. (2006) showed round gobies in the Flint River consumed significant numbers of hydropsychid caddisfly larvae. Our ordination data showed that of the net-spinning caddisflies, only *Hydropsyche* abundance was strongly related to the resultant axes and presumably was affected by stream velocity patterns since flow is necessary for the functioning of their capture nets. Neither *Cheumatopsyche* nor *Polycentropus* abundance was strongly related to the resultant ordination axes (i.e., they occur near the centroid) and they were found in seven of the eight streams sampled. Thus, these two genera appear less strongly driven by environmental conditions relative to *Hydropsyche*. Only a single specimen of *Polycentropus* was collected from a goby-present stream, whereas it was present in three non-goby streams and fairly abundant in two of them. The reduced abundance of these common caddisfly taxa in streams with gobies compared to streams without gobies probably accounts for the significant EPT and EPT/Chironomidae ratio evident in our survey data. Additional support for this hypothesis is found in comparing pre-goby invasion and current macroinvertebrate data. Compared with pre-goby invasion macroinvertebrate data, the current percent EPT was lower in streams with round gobies and the percent Chironomidae was higher. These results suggest that streams invaded by round gobies have experienced a reduction in mayfly/stonefly/caddisfly abundance with a resultant dominance by midges, while the relative abundance of these groups has not changed appreciably in streams lacking gobies.

Our study has documented not only the presence of gobies within some of the tributary streams of Lake Erie, but also a range of impacts on the fish and macroinvertebrate communities. In general, these tributary streams do not appear immune to round goby invasion, as Cooper *et al*. (2007) suggest for coastal Great Lake wetlands. The ability of the round goby to adapt to a variety of habitats and environmental conditions poses a threat to inland lakes and river systems. Further knowledge about the seasonal and long-term movement of gobies within streams, rather than just presence, is needed to better understand their use and potential impacts on tributary streams. If gobies are able to use the tributary streams as travel corridors, inland water bodies may be the next sites for round goby range expansion.

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