Impact of round goby *Neogobius melanostomus* on the feeding habits of predatory fish in nearshore waters of western Lake Michigan

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The round goby *Neogobius melanostomus* is a wide-ranging invasive fish species that was probably transported to the Laurentian Great Lakes from the Caspian Sea through ballast water dumping (Kornis et al. 2012). It was first discovered in North America in 1990 in the St. Clair River which connects Lakes Huron and Erie (Jude et al. 1992). Since then they have spread throughout the Great Lakes and have significantly impacted the nearshore food web. The round goby was first encountered in Lake Michigan waters off Milwaukee on July 16, 1999 by the Southern Lake Michigan fisheries unit of Wisconsin Department of Natural Resources (WDNR LMWU) while conducting a fisheries survey. Since then the round goby population has expanded in the Milwaukee harbor. The WDNR LMWU conducted surveys to collect stomach contents of predatory fish in the Milwaukee harbor as part of an investigation on the predatory impact on recently stocked salmonids smolts. These studies were conducted from 1999 through 2009 in both spring and fall. Round goby was documented for the first time in a stomach sample of a smallmouth bass captured in the Milwaukee harbor in 2004. Round gobies found in stomach samples in these surveys were used to elucidate the changes in feeding habits of predatory fish.

Study area and the study background

The study area included the Milwaukee harbor and the waters of three rivers, the Milwaukee, the Menomonee and the Kinnickinnic, from their confluence up to the first Dam (Figure 1). The lower Milwaukee River has undergone major changes since the removal of the North Avenue Dam which was at 5km from the confluence of the river with Lake Michigan. The Dam was breached open in 1990 and was completely removed in 1996 (Hirethota et al. 2005). As a result of habitat enhancement projects and the improved water quality, the river once again provided opportunities to restore native fish species such as walleye and Lake sturgeon. These species had probably become extinct in part due to dams fragmenting their riverine habitat. To help restore a naturally reproducing walleye population, WDNR began a stocking program of extended growth walleye fingerlings in 1995 (Hirethota and Burzynski 2004). Since the walleye are a predatory fish, there was a public concern about the potential negative impact on the stocked salmon and trout fingerlings that were traditionally stocked in the lower Milwaukee River. The WDNR committed to monitoring the predatory impact by capturing and examining the stomach content of all predatory fish species in the area immediately following the stocking of these salmonids. The main objective of the study

was to document and qualitatively describe the stomach content of predatory fish in the lower Milwaukee River and harbor.

Methods

Fish samples for stomach content analysis were collected at night using a pulsed DC electroshocker (Boomshocker boat). Sampling effort primarily focused in the Milwaukee harbor and stretches of the three rivers (Figure 1). Predatory fish sampling was conducted within one or two nights following salmonid stocking before the stocked fish dispersed into the main lake. All species of predatory fish greater than 254mm long were captured and transferred to a live tank on the boat with circulating lake water. From 1999 to 2004 fish were sampled only in the spring, while from 2005 to 2009 samples were collected both in spring and fall. All fish were identified to species, checked for finclips and/or tags, measured (mm), weighed (g) and clipped upper caudal fin to prevent multiple sampling of the same fish on the same night. Stomach contents were expelled from the stomach by using a non-lethal stomach pump (SOLO Pressure Sprayer, 1 gallon with ¼ inch diameter tube). A jaw spreader was used on larger individuals. Contents were forced out and collected into an enamel tray and then transferred into a whirl pack bag and stored on ice until analyzed the following day. Our goal was to examine approximately 30 fish per species after each stocking event. In the laboratory, organisms in the stomach contents were identified to the lowest taxonomic level when possible. To verify the sample to species, two individuals familiar with fish identification looked at each sample. Data were summarized and tabulated by each predatory fish examined.

Results

Predatory fish stomach sample analysis

Various species of predatory fish of all sizes in the Milwaukee harbor and the vicinity were collected both in spring and fall (Table 1). The Milwaukee harbor has a diverse group of predatory fish. The number and composition of fish species varied for each sampling event even though the effort and the area sampled remained relatively consistent. We examined primarily walleye, largemouth bass, smallmouth bass, northern pike, brown trout and rainbow trout since these species occurred frequently in the sample. Other species that occurred sporadically in the sample included rock bass, black crappie, brook trout, lake trout, coho salmon, Chinook salmon and black bullhead.

Stomach samples of predatory fish revealed that fish diet is composed of a variety of food items including alewife, 9-spine stickleback, Spottail shiner, gizzard shad and round goby (Table 2 and 3).

Contribution of round goby to the predatory fish diet

We observed a variety of food items, often at various degrees of digestion. Whenever it was possible to identify to species, we counted the number of individuals. Until 2004 the five common predatory species examined in this study were walleye, northern pike,

smallmouth bass, largemouth bass and brown trout, and they contained a variety of prey fish species in their diet (Table 2). Alewife, gizzard shad and 9-spine stickleback were common in the diet of all predators. In 2004, for the first time, one round goby was identified in the stomach sample of a smallmouth bass captured in McKinley Marina (Table 2). Although goby presence was reported in 1999, we had not encountered them until 2004. By the spring of 2005, round goby was a common food item in the stomachs of all predatory fish (Table 3). We documented that 28% of brown trout, 13% of smallmouth bass, 15% of largemouth bass and 6% of northern pike had one or more round goby in their stomach. In the fall of 2005, gobies were the dominant food item in largemouth bass stomach samples. With the explosive expansion of round goby in the Milwaukee harbor, round goby became the single most dominant food item in brown trout, smallmouth bass, largemouth bass, northern pike, rainbow trout and walleye (Table 4). The proportion of brown trout stomach samples containing one or more round goby ranged from 57% to 88% between 2005 and 2009. Similarly, the proportion of smallmouth bass stomach samples containing one or more round goby ranged from 35% to 85% between 2004 and 2009. The greatest number of round goby found in any stomach sample was eighteen fish from a 726 mm brown trout captured on April 4, 2006. Similarly, the greatest number of round goby found in a single 428 mm smallmouth bass was five. We did not notice any distinct pattern between the spring and fall in the frequency of occurrence of gobies in the stomachs among various species examined.

Management implications

The Milwaukee harbor has a diverse predatory fish community. Until 2004, the stomach contents of predatory fish comprised a variety of food items. Once round gobies were established in the area and started to expand rapidly, the diet composition skewed to predominantly round goby beginning in the spring of 2005. Round gobies in the system appear to 1) serve as a buffer for salmonids smolts, 2) provide another food component, and 3) support additional biomass of predatory fish in the form of more brown trout, walleye, or bass.

Round goby invasion to the Great Lakes has led to potential new energy pathways both by competing with the native species as well as short-circuiting the potential bioaccumulation process (Johnson et al. 2005). For example, round goby and native mottled sculpin (*Cottus bairdi*) have a similar habitat requirement, and round goby appear to out-compete the sculpin (Janssen and Jude 2001). Gobies may compete with young native fish by feeding on smaller invertebrates or predating on nests such as smallmouth bass. Gobies eat zebra mussel and accumulate contaminants which will move up the food chain quickly (Charlebois et al. 2001). Smallmouth bass feed on gobies contributing to a faster growth rate of bass (Steinhart et al. 2004). Pothoven and Mandenjian (2013) reported that the adult whitefish in Lake Huron that had eaten fish increased from 10% in 2002-2006 to 20% in 2007-2011 as a result of round goby expansion. In our study gobies became a large part of the diet of all the predatory species, especially brown trout and smallmouth bass. The collective impact of goby expansion in the Milwaukee estuary is difficult to assess. However, it appears that overall available food for piscivorous fish has remarkably increased.

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Table 1. Number of predatory fish examined as part of diet survey from 1999-2009 in the Lower Milwaukee River and harbor.

Species	1999	2000	2001	2003	2004	2005		2006		2007		2008		2009
	Spring	Spring	Spring	Spring	Spring	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
Black bullhead	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Northern pike	6	3	5	8	2	22	5	37	4	27	6	27	1	0
Chinook salmon	0	0	0	1	0	0	0	2	0	0	0	0	0	0
Coho salmon	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Rainbow trout	0	0	0	0	0	7	5	12	7	3	2	6	0	15
Brook trout	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Lake trout	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Brown trout	7	10	1	2	3	62	75	70	34	77	2	36	21	17
Black crappie	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Rock bass	0	0	0	0	0	8	0	0	0	0	0	0	0	0
Smallmouth bass	24	36	0	5	3	16	11	42	4	13	2	30	1	0
Largemouth bass	3	22	8	5	3	34	78	17	12	12	2	37	4	4
Walleye	7	5	0	0	1	12	16	69	69	70	34	222	7	8
TOTAL	50	76	14	21	12	162	196	249	130	202	48	358	34	44

No sampling was conducted in 2002

Table 2. Stomach contents of predatory fish captured in spring in the Milwaukee Estuary from 1999 to 2004.

		Predatory fish species				
Year		Walleye	Northern pike	Smallmouth bass	Largemouth bass	Brown trout
1999 - Spring	# caught	7	6	24	3	7
	# full stomachs	6	5	15	1	6
	Food items	Fish parts	Alewife	9-spine stickleback	Fish parts	9-spine and 3-spine stickleback
2000 - Spring	# caught	5	3	36	22	10
	# full stomach	5	3	35	22	9
	Food items	Alewife	Shiners	9-spine stickleback, alewife	9-spine stickleback, alewife	Alewife, 9-spine stickleback
2001 - Spring	# caught	0	5	0	8	1
	# full stomach	0	1	0	7	1
	Food items	0	Alewife	0	9-spine stickleback, Spottail shiner, alewife	Fish parts
2003 - Spring	# caught	0	8	5	5	2
	# full stomach	0	2	2	2	1
	Food items	0	Gizzard shad	9-spine stickleback, Spottail shiner	Gizzard shad	Alewife
2004 - Spring	# caught	1	2	3	3	3
	# full stomach	1	1	2	2	1
	Food items	Fish parts	alewife	9-spine stickleback, round goby**	9-spine stickleback	Alewife

** First time a round goby was observed
No sampling was conducted in 2002

Table 3. Stomach contents of predatory fish captured in spring and fall in the Milwaukee Estuary from 2005 to 2009.

		Predatory fish species					
Year		Walleye	Northern pike	Smallmouth bass	Largemouth bass	Brown trout	Rainbow trout
2005 - Spring	# caught	12	22	16	34	62	7
	# full stomachs	2	8	12	17	20	7
	Food items	Gizzard shad	Goby	Goby	Goby	Goby, alewife, stickleback	0
	# stomachs with goby (%)	0	4 (50%)	2 (17%)	5 (29%)		0
2005 - Fall	# caught	16	5	11	78	75	5
	# full stomach	13	4	5	27	1	1
	Food items	Rainbow smelt	Rainbow smelt, alewife	Goby	Goby	0	Goby
	# stomachs with goby (%)	0	0	3 (60%)	17 (63%)	0	1 (100%)
2006 - Spring	# caught	3	18	17	10	57	9
	# full stomach	1	6	11	3	39	3
	Food items	Gizzard shad	Goby	Goby	Goby	Goby	Goby
	# stomachs with goby (%)	0	4 (67%)	9 (82%)	3 (100%)	37 (95%)	1 (33%)
2006 - Fall	# caught	69	4	4	7	34	7
	# full stomach	33	4	2	4	3	2
	Food items	Gizzard shad, goby	Fish parts	Goby	Goby	Gizzard shad	Goby
	# stomachs with goby (%)	4 (12%)	0	2 (100%)	4 (100%)	0	1 (50%)
2007 - Spring	# caught	8	18	6	12	76	3
	# full stomach	2	3	3	4	40	1
	Food items	Goby	Fish parts, goby	Goby	Goby	Goby, alewife	Fish parts
	# stomachs with goby	1 (50%)	1 (33%)	2 (67%)	2 (50%)	33 (83%)	0

	(%)						
2007 - Fall	# caught	34	2		2	0	1
	# full stomach	11	0		2	0	0
	Food items	Smolts, fish parts	0		Smolts	0	0
	# stomachs with goby (%)	0	0		0	0	0
2008 - Spring	# caught	21	6	7	35	34	1
	# full stomach	9	1	0	5	13	0
	Food items	Alewife, goby	Goby	0	Goby	Goby	0
	# stomachs with goby (%)	1 (11%)	1 (100%)	0	2 (40%)	8 (62%)	0
2008 - Fall	# caught	7	1	1	4	21	0
	# full stomach	4	1	0	3	2	0
	Food items	Alewife, goby	Fish parts	0	Goby	Goby	0
	# stomachs with goby (%)	2 (50%)	0	0	3 (100%)	2 (100%)	0
2009 - Spring	# caught	8	0	0	4	17	15
	# full stomach	3	0	0	0	4	0
	Food items	Goby, smolts	0	0	0	Goby	0
	# stomachs with goby (%)	1 (33%)	0	0	0	3 (75%)	0

Note: number in the parenthesis indicate percentage of fish with full stomachs containing one or more round gobies.

Table 4. Number of full stomach samples of predatory fish examined, and percent of full stomachs containing round goby in the Milwaukee harbor, 1999-2009 (spring and fall data were combined). Full stomach means the stomach contained some identifiable food item.

Species/Year	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009
Northern pike	5	3	1	2	1	12 (33%)	10 (40%)	3 (33%)	2 (50%)	
Rainbow trout						2 (50%)	5 (40%)	1		
Brook trout	1			1						
Brown trout	6	9	1		1	21 (57%)	42 (88%)	40 (83%)	15 (67%)	4 (75%)
Rock bass						1				
Smallmouth bass	15	35		2	2 (50%)	17 (29%)	13 (85%)	3 (67%)		
Largemouth bass	1	22	7	2	2	44 (48)	7 (100%)	6 (33%)	8 (63%)	
Walleye	6	5			1	15	34 (12%)	13 (8%)	13 (23%)	3 (33%)

No sampling was conducted in 2002

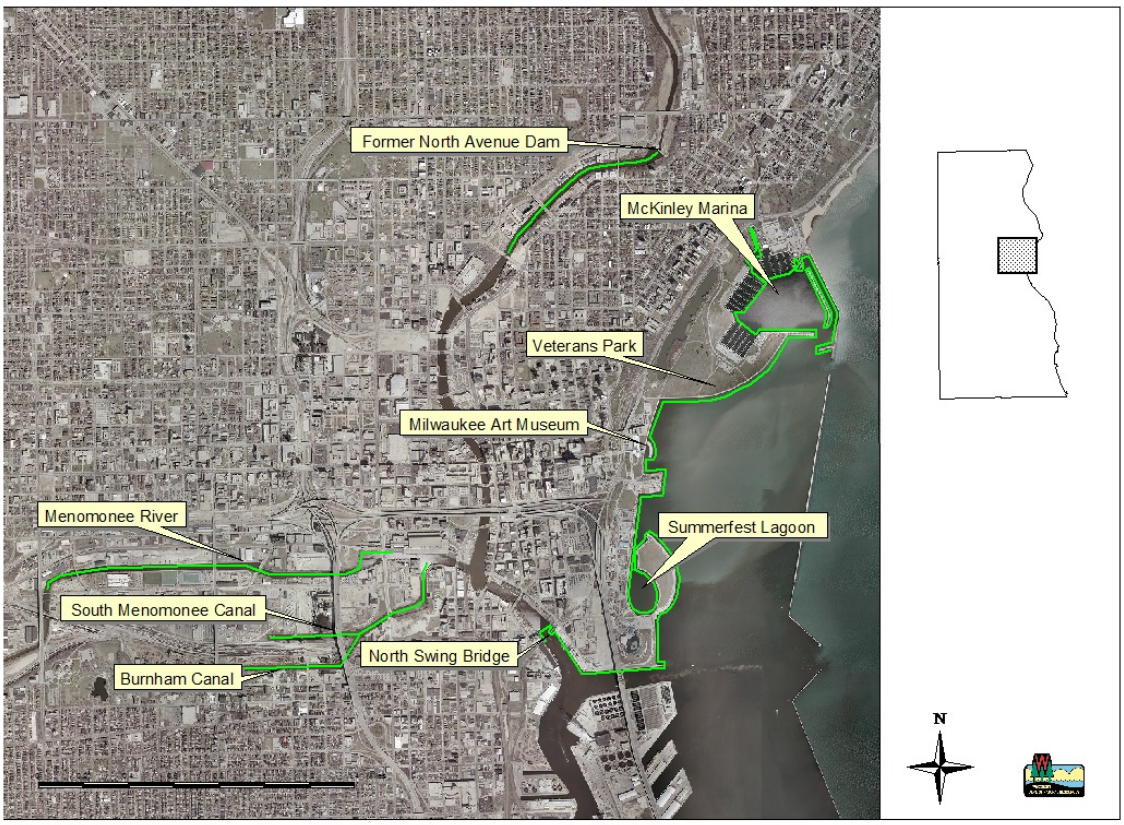

Figure 1. Study area indicating general sampling area for predatory fish collection using a Boomshocker in the Milwaukee estuary, and the lower Milwaukee River.