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Diets and Diet Overlap of Nonindigenous Gobies and Small Benthic Native Fishes Co-inhabiting the St. Clair River, Michigan

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ABSTRACT. *Round gobies* (Neogobius melanostomus), *after successfully reproducing in the early 1990s, decimated populations of mottled sculpins* (Cottus bairdi) *and possibly logperch* (Percina caprodes) *in the St. Clair River. Studies were conducted during 1994 to determine whether diets of round and tubenose* (Proterorhinus marmoratus) *gobies overlapped with those of native forage fishes. In the nearshore zone (depth ≤ 1 m), round and tubenose gobies, logperch, and rainbow darters* (Etheostoma caeruleum) *of similar sizes (total lengths < 75 mm) consumed mainly small-sized macroinvertebrates (dipterans,* Caenis, *and amphipods) during June 1994. Logperch and rainbow darters were present in the nearshore zone only during this month. At the crest of the channel slope (depth = 3 m), round gobies and northern madtoms* (Noturus stigmosus) *ate mostly ephemeropteran nymphs* (Hexagenia *and* Baetisca), *while predation on zebra mussels* (Dreissena polymorpha) *and other mollusks by round gobies was minimal. Northern madtoms did not feed on mollusks. Diet overlap between round gobies and native fishes was not observed at the channel slope (depth = 5 m and 7 m) due to heavy predation on mollusks by round gobies. Young-of-the-year (YOY) round gobies migrated to deeper water in autumn and became prey of mottled sculpins and northern madtoms. Eggs and YOY of mottled sculpins may have become vulnerable to predation by both round gobies and native fishes in deeper water, since adult mottled sculpins were apparently confined to the channel with limited home range because aggressive round gobies occupied preferred shallow habitat, including spawning sites.*

INDEX WORDS: *Round goby, tubenose goby, diet, diet overlap, predation, St. Clair River, northern madtom, mottled sculpin,* Hexagenia*, logperch.*

INTRODUCTION

Populations of native forage fishes (TL < 30 cm) in the Great Lakes have declined during the 20th century after nonindigenous fishes of similar size were accidentally introduced into their habitats (Crowder 1980, Mills *et al*. 1994, Bronte *et al*. 1998). Predation on eggs and larvae and competition for food by nonindigenous fishes are factors advanced to explain declines in some Great Lakes forage fish populations. Predation on coregonine eggs and larvae by rainbow smelt (*Osmerus mordax*) and yellow perch (*Perca flavescens*) larvae by alewives (*Alosa pseudoharengus*) has been documented in the Great Lakes (Crowder 1980, Brandt *et al*. 1987); alewife predation on larval stages in winter may have decimated the population of deepwater sculpins (*Myoxocephalus thompsoni*) in Lake Michigan. Competition with alewives for zooplankton may have reduced recruitment of coregonines (Wells and McLain 1973). Bloaters (*Coregonus hoyi*), however, can avoid this competition with alewives by feeding on large zooplankters or ben-

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thic prey that are inaccessible to alewives (Crowder and Binkowski 1983).

Another recently introduced, nonindigenous fish species, the ruffe (*Gymnocephalus cernuus*), was first suspected to cause some declines in native forage fishes in Duluth Harbor, Lake Superior through egg predation and competition for food (Ogle 1995, Selgeby 1998). Preference for soft-bodied benthos was similar in both ruffe and yellow perch in experimental aquaria (Fullerton *et al*. 1998). However, early available evidence suggests the ruffe so far has had little impact. Bronte *et al*. (1998) suggested that declines in some native forage fishes in western Lake Superior might be due to natural population dynamics rather than interactions with ruffe. Ruffe and Eurasian perch (*Perca fluviatilis*) coexist in some lakes in Europe (Winfield *et al*. 1998), and Adams and Maitland (1998) found no significant diet overlap between ruffe and native fishes in Loch Lomond in Scotland.

The round (*Neogobius melanostomus*) and tubenose (*Proterorhinus marmoratus*) gobies are freshwater Eurasian gobiids that were first found in North America during 1990 in the St. Clair River, the interconnecting channel between Lakes Huron and St. Clair (Jude *et al*. 1992). These nonindigenous species are benthic with fused pelvic fins, which can be used as a suctorial disk for anchoring in fast-flowing water. Populations of mottled sculpin (*Cottus bairdi*), and possibly other small benthic fishes such as logperch (*Percina caprodes*), may have decreased in the St. Clair River after round gobies successfully reproduced (Jude *et al*. 1995). A similar mottled sculpin decline caused by round gobies was also documented in southern Lake Michigan by Janssen and Jude (2001). These authors suggested that round gobies competed with mottled sculpin and other native species for food resources at small sizes, for space at intermediate sizes, and for spawning habitat at large sizes. Therefore, competition for food may be a mechanism contributing to the decimation of mottled sculpin and logperch in the St. Clair River (Jude *et al*. 1995, Jude and DeBoe 1996).

Round gobies eat a wide variety of benthic invertebrates and small fishes (Charlebois *et al*. 1997). Molariform teeth enable the round goby to crush shells, and adults feed primarily on bivalves (French 1993, Ghedotti *et al*. 1995, Ray and Corkum 1997). Resource partitioning (Werner *et al*. 1977, Laughlin and Werner 1980, French 1988) may allow round gobies and some native forage fishes to co-exist in the St. Clair River after round gobies ontogenetically shift their diet mainly to mollusks. Jude *et al*. (1995) observed that the importance of mollusks in diets of round goby collected from the St. Clair River in August 1993 increased directly with round goby length; dipterans were common in small round gobies (TL = 47–59 mm). Data from this study will be useful to document potential impact on native species not previously studied in this river. These findings then can be used to make predictions for other ecosystems across the Great Lakes. Therefore, the objectives of this research were to 1) document the diet of round and tubenose gobies and small, benthic, co-occurring forage fishes collected along a transect at several depths in the St. Clair River in 1994, and 2) determine whether diets of round and tubenose gobies overlapped with those of selected native fishes.

STUDY SITE AND METHODS

Round and tubenose gobies and native forage fishes were sampled along a transect perpendicular to the shoreline in the St. Clair River adjacent to Algonac State Park, Algonac, Michigan at depths of 1 m, 3 m, 5 m, and 7 m during the day and night from May to December 1994. This part of the 63-km-long strait, which connects Lake Huron with Lake St. Clair, is near the outflow to Lake St. Clair, features considerable freighter traffic, a maximum depth in that area of 11 m, velocities up to 1.8 m/s (Derecki 1984), and a mean annual discharge rate of 5,182 m^3/s (USACOE 1990). Fishes were sampled from the riprapped shoreline by kicking the substrate and collecting all disturbed fishes in a small 4.7-m, specially designed seine (Jude and DeBoe 1996). Here a larger seine (15.2 m × 1.2 m) was used to catch fish in a shoal area (< 1 m deep) 4 to 8 m from the shore (Jude *et al*. 1995). Both shoreline sites were directly adjacent to trawling sites. Tows with a bottom, semi-balloon otter trawl with a 4.9-m headrope and 5.8-m wide footrope (Jude *et al*. 1995) were made at 3-, 5-, and 7-m depths for approximately 10 min. The 3-m-deep site was located near the crest of the shipping channel, and the deeper sites were on the sloping side (Hudson *et al*. 1986). Fishes were removed from the catch and injected with and stored in ethanol for future stomach content analyses. Gear bias is an obvious concern, both in comparing seine with trawl catches and comparing day with night catches. However, specimens were used only for determination of diets, so differential catch rates should not be a problem. Mass movements of fishes from one depth during the day to another at night would also bias diet comparisons. Undoubtedly, some migrations occurred, but these appeared to be minimal; fish such as round gobies at 1 m, 3 m, and 5 to 7 m depth were eating substantially different food items at each depth, which would not transpire if substantial migrations were occurring.

In the laboratory, fishes were identified to species, measured to the nearest mm total length, and weighed to the nearest 0.1 g. Round gobies, northern madtoms (*Noturus stigmosus*), logperch, and mottled sculpins were divided into two size classes (35 to 74 mm and ≥ 75 mm). Tubenose gobies and rainbow darters (*Etheostoma caeruleum*) only occurred in small size classes. Up to 20 fish per species, depth, date, and diel period were removed from collections for diet analyses; only those with measurable stomach contents were included in analyses. Total volume of all prey items in each individual fish was measured to the nearest 0.1 mL using a graduated burette to obtain a volumetric estimate (Jude *et al*. 1995). Stomach content items were identified to genus when possible, and counted. For each major group (ephemeropterans, crustaceans, etc.), percent contribution by volume to the total measured volume was visually estimated. Percentages for each group were then used to calculate a volume estimate (in mL) for each major prey group. Diets were then summarized by averaging the volume consumed of each major prey group and reporting this number as the percent contribution to the total stomach content volume for each date and depth. Mean volume of total contents consumed was also reported. The Schoener (1970) method was used to analyze diet overlaps between round and tubenose gobies and native fishes. Some bias may be introduced in the diet determinations from retention of organisms with hard structures such as zebra mussels (*Dreissena polymorpha*); however, Ghedotti *et al.* (1995) indicated that round gobies sometimes ingested zebra mussels, removed the flesh, then ejested the shells through their mouths.

RESULTS

Diets in the Nearshore Zone

There were 304 round gobies analyzed from the nearshore zone (≤ 1 m) throughout the collection season (Table 1); 17 had empty stomachs. Individual variations in the mean volume consumed of major prey items in diets of both small and large round gobies over time in the nearshore zone were large, with SD ranging from 25% to 46%. Diets of small round gobies changed throughout the sampling season, and were mainly composed of dipterans and mollusks (36% and 32% of mean total stomach volume, respectively; Table 1). In late June, dipterans consumed by small round gobies were so numerous (40 ± 24 SD; range = 0 to 101) that they dominated diets. Consumption of mollusks by small round gobies peaked in September. Zebra mussels and native mollusks (*Amnicola*, *Physa*, and *Gyraulus*) composed 51% of large round goby diets on average over the year. In late June, the diet was primarily dipterans (Chironomidae) and ephemeropterans (chiefly *Hexagenia* and *Caenis*); mollusks (fingernail clams and *Amnicola*) and zebra mussels composed 22% and 12% of the diet, respectively. Round gobies from both size groups ate two young-of-the-year (YOY) round gobies and one unidentified fish (unmeasurable due to heavy digestion). In addition, one large (139 mm) round goby ate a 41-mm trout-perch (*Percopsis omiscomaycus*), the only evidence of predation on an adult native fish.

Dipterans, small-bodied insects such as *Caenis* and trichopterans (*Cheumatopsyche*), and crustaceans (isopods and the amphipod *Gammarus*) were common food of tubenose gobies (Table 1) from May through late June and in December. Like small round gobies, tubenose gobies, rainbow darters, and small logperch consumed numerous dipterans. Significant diet overlap was observed between 1) tubenose gobies and rainbow darters (Schoener index = 0.74) on 2 June, 2) small round gobies and rainbow darters (Schoener index = 0.83) on 27 June, and 3) small round gobies and small logperch (Schoener index = 0.83) on 27 June. Three of nine tubenose gobies consumed round goby eggs during the day on 27 June. Diet overlap between large round gobies and logperch was moderate in late June (Schoener index = 0.54) when mollusks (gastropods), ephemeropterans, and trichopterans were common in both diets. Tubenose gobies and rainbow darters showed significant diet overlap for amphipods (Schoener index = 0.79) in December.

Diets at the Crest of the Slope

All 90 northern madtoms, 53 of 57 logperch, and 178 of 339 round gobies were captured from the crest of the channel slope (3 m) at night (Table 2). At this site, empty stomachs were found in 20 northern madtoms, 25 logperch, and 25 round gobies captured at night and 21 round gobies and 1 log-

TABLE 1. Mean percent composition of food items by volume (SD) in stomachs of fishes collected from the St. Clair River nearshore zone (depth ≤ 1 m) during 1994. No. Stom. (E) = total number of stomachs examined (number of stomachs examined that were empty), D/N = number of fish captured during day/number of fish captured during night, Mean Volume = mean volume of food in fish stomachs in mL, t = trace, sm. = small, lg. = large. Mollusks include only native species.

					Food item							
Date	Fish Category	No. Stom.(E)	D/N	Mean Volume	*Dreissena polymorpha*	Mollusks	Ephemeropterans	Trichopterans	Dipterans	Crustaceans	Fishes	Miscellania
9 May	Sm. round goby	22(0)	2/20	0.08	5(20)	12(17)	10(21)	28(32)	37(38)	8(22)	—	—
	Lg. round goby	19(1)	0/19	0.37	33(37)	14(22)	9(21)	27(27)	9(15)	8(17)	—	—
	Tubenose goby	21(0)	1/20	0.04	—	—	9(20)	2(7)	63(40)	18(28)	—	8(19)
2 Jun	Sm. round goby	40(5)	20/20	0.07	10(26)	25(38)	11(26)	11(26)	27(38)	12(29)	—	5(20)
	Lg. round goby	24(0)	4/20	0.36	50(39)	12(25)	15(25)	6(13)	14(27)	2(8)	1(3)	—
	Tubenose goby	17(0)	5/12	0.02	—	—	13(21)	8(18)	48(33)	26(36)	—	5(22)
	Sm. logperch	5(3)	0/5	0.09	—	—	50(71)	50(71)	—	—	—	—
	Lg. logperch	7(1)	0/7	0.12	—	—	2(4)	78(39)	20(40)	—	—	—
	Rainbow darter	24(1)	9/15	0.07	—	—	5(20)	16(31)	64(36)	14(23)	—	t(1)
27 Jun	Sm. round goby	40(1)	20/20	0.09	9(14)	6(10)	11(15)	4(11)	67(23)	4(6)	—	t(1)
	Lg. round goby	40(4)	20/20	0.26	12(23)	22(21)	20(23)	8(14)	37(29)	1(2)	—	t(2)
	Tubenose goby	14(1)	9/5	0.02	—	—	39(38)	—	23(32)	24(37)	13(30)	—
	Sm. logperch	14(0)	12/2	0.05	—	—	7(27)	4(13)	89(29)	t(1)	—	—
	Lg. logperch	5(0)	0/5	0.13	—	20(45)	12(27)	2(4)	26(43)	40(55)	—	—
	Rainbow darter	14(0)	12/2	0.05	—	t(t)	4(11)	t(1)	93(11)	2(5)	—	t(1)
15 Aug	Sm. round goby	23(0)	17/6	0.05	16(20)	20(15)	8(22)	9(12)	43(29)	3(7)	—	t(t)
	Lg. round goby	14(0)	11/3	0.79	49(42)	22(23)	t(1)	14(23)	7(10)	4(11)	3(12)	1(5)
	Lg. logperch	1(0)	1/0	0.30	—	—	—	99	—	1	—	—
	Rainbow darter	1(0)	1/0	0.05	—	—	5	95	—	t	—	—
14 Sep	Sm. round goby	20(0)	20/0	0.07	22(25)	38(25)	7(22)	1(2)	16(15)	3(12)	10(23)	4(14)
	Lg. round goby	13(3)	6/7	0.11	26(34)	31(33)	20(27)	7(13)	9(11)	5(12)	—	—
	Tubenose goby	2(0)	2/0	0.07	—	—	—	—	17(25)	33(46)	50(71)	—
27 Oct	Sm. round goby	20(1)	0/20	0.06	18(32)	19(23)	6(11)	15(27)	21(23)	21(32)	—	t(1)
	Lg. round goby	5(0)	0/5	0.16	29(40)	32(34)	1(2)	1(2)	3(4)	14(23)	20(45)	—
	Tubenose goby	2(0)	0/2	0.01	—	—	15(21)	—	25(7)	60(14)	—	—
5 Dec	Sm. round goby	21(2)	1/20	0.04	15(29)	7(15)	t(t)	8(15)	50(37)	17(33)	3(11)	—
	Lg. round goby	3(0)	0/3	0.30	27(40)	3(6)	60(28)	10(10)	—	—	—	—
	Tubenose goby	18(0)	15/3	0.14	—	—	—	—	19(30)	76(33)	—	5(19)
	Sm. logperch	1(0)	1/0	0.01	—	—	—	—	70	30	—	—
	Rainbow darter	24(0)	20/4	0.11	—	t(2)	1(5)	7(14)	32(32)	60(32)	—	—

TABLE 2. *Mean percent composition of food items by volume (SD) in stomachs of fishes collected from the St. Clair River channel crest (depth = 3 m) during 1994. No. Stom. (E) = total number of stomachs examined (number of stomachs examined that were empty), D/N = number of fish captured during day/number of fish captured during night, Mean Volume = mean volume of food in fish stomachs in mL, t = trace, sm. = small, lg. = large, n = northern. Mollusks include only native species.*

					Food item							
Date	Fish Category	No. Stom.(E)	D/N	Mean Volume	*Dreissena polymorpha*	Mollusks	Ephemeropterans	Trichopterans	Dipterans	Crustaceans	Fishes	Miscellania
9 May	Sm. round goby	38(1)	20/18	0.10	3(12)	10(18)	23(33)	22(38)	39(38)	1(2)	2(12)	—
	Lg. round goby	34(3)	14/20	0.21	43(45)	9(16)	25(32)	10(19)	11(20)	1(5)	—	—
	Sm. n. madtom	11(4)	0/11	0.02	—	—	21(39)	—	79(39)	—	—	—
	Lg. n. madtom	20(10)	0/20	0.37	—	—	72(27)	27(27)	1(2)	—	—	—
	Sm. logperch	8(2)	0/8	0.03	—	—	—	—	91(22)	9(22)	—	—
2 Jun	Sm. round goby	12(2)	12/0	0.14	—	4(6)	64(48)	32(39)	—	—	—	—
	Lg. round goby	3(1)	3/0	0.10	—	10(11)	48(55)	10(11)	32(33)	—	—	—
	Lg. n. madtom	8(4)	0/8	0.15	—	—	59(48)	3(5)	17(35)	21(43)	—	—
27 Jun	Sm. round goby	10(5)	0/10	0.07	5(8)	11(17)	57(46)	8(9)	19(20)	—	—	—
	Lg. round goby	10(3)	0/10	0.39	29(36)	—	69(45)	1(3)	—	—	—	—
	Lg. n. madtom	5(0)	0/5	0.40	—	—	91(10)	6(9)	3(4)	—	—	—
	Sm. logperch	3(2)	0/3	0.03	—	—	—	100	—	—	—	—
15 Aug	Sm. round goby	30(5)	10/20	0.10	3(16)	11(23)	46(40)	11(24)	17(26)	11(24)	1(5)	t(t)
	Lg. round goby	39(10)	19/20	0.15	17(37)	12(24)	51(42)	11(26)	5(12)	5(19)	t(1)	—
	Lg. n. madtom	7(1)	0/7	0.08	—	—	40(38)	19(40)	37(36)	—	4(10)	—
	Lg. logperch	3(1)	0/3	0.10	—	—	—	100	—	—	—	—
14 Sep	Sm. round goby	29(2)	9/20	0.07	4(19)	13(22)	56(41)	8(16)	18(25)	1(2)	—	t(1)
	Lg. round goby	40(2)	20/20	0.13	8(26)	14(23)	52(44)	19(30)	5(17)	3(16)	—	1(3)
	Sm. n. madtom	4(0)	0/4	0.06	—	—	82(25)	15(24)	2(2)	1(3)	—	—
	Lg. n. madtom	20(0)	0/20	0.27	—	—	95(5)	2(3)	2(3)	t(1)	1(4)	—
	Sm. logperch	3(3)	0/3	0.00	—	—	—	—	—	—	—	—
	Lg. logperch	5(1)	0/5	0.16	—	—	25(50)	67(47)	—	8(17)	—	—
27 Oct	Sm. round goby	20(1)	20/0	0.07	—	6(16)	17(31)	44(45)	29(40)	4(11)	—	—
	Lg. round goby	20(6)	20/0	0.17	—	8(18)	40(39)	49(40)	3(6)	—	—	—
	Lg. n. madtom	15(1)	0/15	0.25	—	—	90(16)	8(15)	2(3)	—	—	—
	Sm. logperch	9(6)	0/9	0.01	—	—	—	33(58)	—	67(58)	—	—
	Lg. logperch	18(7)	2/16	0.06	—	t(t)	9(30)	76(41)	8(27)	6(21)	—	—
5 Dec	Sm. round goby	28(2)	8/20	0.05	—	—	7(25)	50(43)	42(42)	1(2)	—	—
	Lg. round goby	26(3)	6/20	0.17	—	5(16)	15(30)	47(41)	23(39)	3(17)	7(23)	t(1)
	Lg. logperch	8(4)	2/6	0.07	—	—	9(17)	66(47)	25(50)	—	—	—

perch captured during the day. Ephemeropterans (*Hexagenia* and *Baetisca*) dominated diets of small round gobies from June to September; trichopterans (*Brachycentrus*) were eaten in fall. An unidentified 23-mm-long fish larvae was found in the stomach of a 74-mm round goby captured in May; two fish eggs were found in one small round goby in August. Predation on zebra mussels and native mollusks by large round gobies decreased considerably throughout the sampling season at the crest. Ephemeropteran nymphs (chiefly *Hexagenia* and *Baetisca*) were the most important food of round gobies in summer. In fall, round gobies shifted their diet to trichopteran larvae (*Brachycentrus*). In December, three large round gobies ate YOY round gobies. The greatest individual variations in diets of round gobies occurred at the crest (range of SD = 34 to 55% for mean volume of food items eaten).

Both sizes of round gobies showed significant diet overlap with small northern madtoms for *Hexagenia* in September (Schoener's Index = 0.67 for small gobies, 0.70 for large ones). Large northern madtoms fed mainly on *Hexagenia* and *Baetisca* throughout the collection season (Table 2). From June to August, diet overlap of large madtoms with small round gobies was greater than diet overlap with large round gobies. Four YOY round gobies and one unidentified larval fish were found in stomachs of four large northern madtoms collected in August (n = 2) and September.

Small logperch ate dipterans in May and trichopterans in June and October. Large logperch fed mainly on trichopterans (> 67% of the diet) in September and October. In October, diet overlaps between logperch and both size groups of round gobies were not significant (Schoener's Index = 0.58, 0.59). Logperch, however, ate only *Cheumatopsyche*, while *Brachycentrus* on average composed 93% of trichopterans in round goby diets. Schoener's Indices were 0.21 (logperch vs. small round gobies) and 0.13 (logperch vs. large round gobies) in September and October, respectively.

Diets at the Channel Slope

At 5 m and 7 m, 31 round gobies had empty stomachs during the sampling season, while 10 of 55 madtoms had empty stomachs, mostly in spring (Tables 3, 4) Predation on mollusks by round gobies increased with water depth. Zebra mussels on average composed 50% and 74% of the diet of large round gobies at 5 m and 7 m, respectively, while native mollusks (fingernail clams, snails) composed 12% and 13% of the diets, respectively, at these depths. Predation on zebra mussels by round gobies at 7 m was more consistent than at all other depths, except for in December (range of SD = 5 to 37%). Small round gobies ate a wide variety of prey at both depths. At 5 m, the diet on average was composed of 20% zebra mussels, 13% native mollusks, 21% trichopterans (*Brachycentrus* and *Cheumatopsyche*), and 26% dipterans. At 7 m, zebra mussels and native mollusks formed a little over half of the small round goby diet (30% and 23%, respectively). Trichopterans (24%) and amphipods (11%) were also important diet constituents for small round gobies. Also found was a round goby that was cut off behind the pelvic and anterior dorsal fins in the stomach of a 60-mm round goby; the length of the victim was estimated to be 30 mm.

The diet of large northern madtoms on the slope (5 to 7 m) was composed of 48% *Hexagenia* and *Baetisca*, 21% trichopterans (mostly *Brachycentrus*), 14% crustaceans (amphipods), and 11% fish on average (Tables 3, 4). Fishes (round gobies, northern madtoms, and unidentified) composed an average of 16% of the northern madtom diet at 5 m in May and August and 22% of the diet at 7 m in December.

The logperch diet (both size groups) on average was composed of 47% trichopterans, 11% ephemeropterans, 6% dipterans, 30% crustaceans, and 5% fish eggs by volume (Tables 3, 4). Four logperch ate 69 fish eggs at 7 m in May. To determine their identity, 20 eggs were measured that had been removed from gravid females (three round gobies, three logperch, and one mottled sculpin) that were captured on the same date. Eggs in the logperch stomachs (1.03 ± 0.13 mm SD) resembled mottled sculpin eggs (1.14 ± 0.07 mm SD) more than logperch (0.45 ± 0.07 mm SD) or round goby (0.76 ± 0.09 mm SD) eggs.

Mottled sculpins were collected only at 7 m. Diets of small mottled sculpins were dominated by caddisflies and crustaceans in June, September, and December, with fish (21%) being eaten in December. Large mottled sculpins ate mayflies (52%) and fish (45%) in May. During December, fish composed 93% of the large mottled sculpin diet; 11 of 18 large mottled sculpins ate 11 YOY round gobies, 1 mottled sculpin, and 3 unidentified fish.

DISCUSSION

In the nearshore zone, diet overlap occurred in June when an abundance of newly hatched dipter-

TABLE 3. Mean percent composition of food items by volume (SD) in stomachs of fishes collected from the St. Clair River channel slope (depth = 5 m) during 1994. No. Stom. (E) = total number of stomachs examined (number of stomachs examined that were empty), D/N = number of fish captured during day/number of fish captured during night, Mean Volume = mean volume of food in fish stomachs in mL, t = trace, sm. = small, lg. = large, n = northern. Mollusks include only native species.

					Food item							
Date	Fish Category	No. Stom.(E)	D/N	Mean Volume	*Dreissena polymorpha*	Mollusks	Ephemeropterans	Trichopterans	Dipterans	Crustaceans	Fishes	Miscellania
9 May	Sm. round goby	7(2)	4/3	0.05	—	1(2)	4(9)	17(35)	52(30)	4(4)	—	22(32)
	Lg. round goby	5(0)	0/5	0.32	82(21)	8(18)	5(11)	4(5)	1(2)	—	—	—
	Lg. n. madtom	21(6)	7/14	0.48	—	—	59(27)	33(21)	t(t)	1(2)	7(18)	—
	Sm. logperch	3(0)	0/3	0.01	—	—	—	65(41)	35(41)	—	—	—
2 Jun	Sm. round goby	5(0)	0/5	0.05	3(5)	11(25)	4(7)	53(34)	26(23)	3(7)	—	—
	Lg. round goby	6(0)	2/4	0.32	77(39)	—	2(3)	20(39)	1(1)	—	—	—
	Lg. n. madtom	2(1)	0/2	0.15	—	—	65	—	15	20	—	—
	Sm. logperch	2(0)	2/0	0.05	—	—	—	92(4)	8(4)	—	—	—
15 Aug	Sm. round goby	14(0)	0/14	0.03	40(34)	12(12)	1(5)	18(19)	4(6)	24(28)	—	t(1)
	Lg. round goby	7(1)	0/7	0.29	49(49)	4(9)	32(41)	8(12)	1(2)	6(10)	—	—
	Lg. n. madtom	7(0)	0/7	0.16	—	—	38(33)	6(6)	2(3)	13(12)	26(34)	15(16)
	Lg. logperch	1(0)	0/1	1.00	—	—	—	75	15	10	—	—
14 Sep	Sm. round goby	19(1)	19/0	0.06	53(44)	9(25)	25(42)	9(27)	2(8)	2(9)	—	—
	Lg. round goby	20(1)	20/0	0.22	27(44)	13(23)	31(37)	16(21)	2(8)	12(31)	—	—
	Lg. logperch	5(0)	5/0	0.82	—	—	21(41)	59(35)	1(2)	19(22)	—	—
27 Oct	Sm. round goby	14(0)	14/0	0.11	9(21)	3(5)	24(35)	32(29)	26(24)	6(15)	—	—
	Lg. round goby	19(3)	19/0	0.10	15(32)	20(30)	7(17)	45(47)	7(19)	5(13)	—	1(2)
	Lg. logperch	5(0)	5/0	0.10	—	—	2(3)	27(42)	—	71(41)	—	—
5 Dec	Sm. round goby	4(2)	2/2	<0.01	—	45(64)	—	5(7)	50(57)	—	—	—
	Lg. round goby	3(1)	0/3	0.27	22(33)	48(38)	3(9)	8(18)	t(1)	19(29)	—	—

TABLE 4. Mean percent composition of food items by volume (SD) in stomachs of fishes collected from the St. Clair River channel slope (depth = 7 m) during 1994. No. Stom. (E) = total number of stomachs examined (number of stomachs examined that were empty), D/N = number of fish captured during day/number of fish captured during night, Mean Volume = mean volume of food in fish stomachs in mL, t = trace, sm. = small, lg. = large, n = northern, mot. = mottled. Mollusks include only native species.

					Food item							
Date	Fish Category	No. Stom.(E)	D/N	Mean Volume	*Dreissena polymorpha*	Mollusks	Ephemeropterans	Trichopterans	Dipterans	Crustaceans	Fishes	Miscellania
9 May	Sm. round goby	20(1)	0/20	0.08	58(41)	1(2)	—	25(29)	6(11)	11(31)	—	—
	Lg. round goby	8(0)	0/8	0.50	95(5)	1(4)	—	2(4)	1(2)	1(4)	—	—
	Sm. logperch	2(0)	0/2	0.10	—	—	—	35(5)	43(22)	—	22(18)	—
	Lg. logperch	2(0)	0/2	0.20	—	—	—	3(4)	—	—	97(4)	—
	Lg. mot. sculpin	2(0)	0/2	0.15	—	—	52(67)	3(4)	—	—	45(64)	—
2 Jun	Sm. round goby	20(2)	0/20	0.08	27(36)	1(3)	7(12)	61(42)	1(2)	4(12)	—	t(t)
	Lg. round goby	11(0)	0/11	0.26	83(31)	t(1)	1(5)	15(30)	t(1)	—	—	—
	Lg. n. madtom	1(0)	0/1	0.30	—	—	40	10	—	50	—	—
	Sm. logperch	2(0)	0/2	0.03	—	—	55(35)	40(40)	—	5(5)	—	—
	Lg. logperch	2(0)	0/2	0.10	—	—	65(35)	35(35)	—	—	—	—
	Sm. mot. sculpin	2(0)	0/2	0.01	—	—	15(21)	70(42)	—	15(21)	—	—
15 Aug	Sm. round goby	39(1)	20/19	0.05	37(34)	19(23)	—	20(27)	4(8)	20(27)	t(1)	t(1)
	Lg. round goby	36(1)	20/16	0.34	71(35)	11(21)	1(4)	5(10)	t(1)	12(20)	—	t(t)
	Sm. logperch	1(0)	1/0	0.01	—	—	—	50	5	45	—	—
	Lg. logperch	1(0)	1/0	0.05	—	—	—	90	—	10	—	—
14 Sep	Sm. round goby	40(5)	20/20	0.05	23(33)	49(41)	4(14)	13(25)	2(7)	9(21)	—	—
	Lg. round goby	40(1)	20/20	0.55	86(32)	4(13)	2(12)	5(15)	—	3(16)	—	—
	Lg. n. madtom	5(1)	0/5	0.13	—	—	30(22)	2(3)	—	68(21)	—	—
	Lg. logperch	7(0)	0/7	0.16	—	—	12(32)	77(38)	—	11(26)	—	—
	Sm. mot. sculpin	4(0)	0/4	0.01	—	—	—	75(50)	—	25(50)	—	—
27 Oct	Sm. round goby	26(2)	20/6	0.03	19(35)	46(44)	—	9(19)	17(36)	5(13)	4(20)	—
	Lg. round goby	21(0)	20/1	0.28	87(29)	12(30)	—	1(4)	—	t(1)	—	—
	Lg. n. madtom	15(1)	0/15	0.27	—	—	90(16)	8(15)	2(3)	t(t)	—	—
	Lg. logperch	1(0)	1/0	0.20	—	5	30	5	5	55	—	—
5 Dec	Sm. round goby	20(2)	0/20	0.01	13(30)	22(31)	5(21)	15(27)	6(15)	39(38)	—	t(1)
	Lg. round goby	20(5)	0/20	0.08	22(33)	48(38)	3(9)	8(18)	t(1)	19(29)	—	—
	Sm. n. madtom	1(1)	0/1	0.00	—	—	—	—	—	—	—	—
	Lg. n. madtom	3(0)	0/3	0.50	—	—	42(49)	23(32)	13(23)	—	22(37)	—
	Sm. logperch	1(1)	0/1	0.00	—	—	—	—	—	—	—	—
	Lg. logperch	9(1)	0/9	0.10	—	—	1(2)	29(33)	2(7)	68(33)	—	—
	Sm. mot. sculpin	19(0)	0/19	0.13	—	2(5)	1(3)	7(23)	t(t)	69(41)	21(37)	—
	Lg. mot. sculpin	6(0)	0/6	0.33	—	—	1(2)	1(2)	5(8)	—	93(10)	—

ans was available for small fishes (TL < 75 mm). Rainbow darters and tubenose gobies were two species that sought food and refuge in the more diverse, rocky habitats near shore. Tubenose gobies avoided predation by round gobies and other predators by hiding in small crevices in rocky substrates and macrophytes (Jude *et al*. 1995, Jude and DeBoe 1996). Rainbow darters apparently preferred shallow waters where populations of small-sized prey were dense and they could avoid predation by large fishes in deeper water (Fisher and Pearson 1987, Greenberg 1991, Stauffer *et al*. 1996, Gray *et al*. 1997). However, logperch tended to spend most of their time in deepwater habitats (Greenberg 1991), where food items such as trichopterans were eaten.

At the slope crest (3 m), the significant diet overlap between northern madtoms, listed as an endangered species in Michigan (Evers 1994), and round gobies may not portend real competition for food resources. As active nocturnal feeders, northern madtoms successfully use their barbels to detect, then capture *Hexagenia* and *Baetisca* nymphs burrowing in soft sediments (Bardach *et al*. 1967, Scott and Crossman 1973, Edmunds *et al*. 1976); *Hexagenia* was more abundant at the crest (3 m) than on the slope (≥ 5 m) (Hudson *et al*. 1986). Northern madtom foraging behavior might cause nymphs to emerge from sediments and drift in currents. Waiting on the bottom, round gobies probably captured drifting ephemeropterans or detected them in or near their burrows in the dark (Jude *et al*. 1995; S. Carman, personal communication, Loyola University, Chicago, IL). The low predation on mollusks by round gobies was attributed to their feeding on the apparently more available ephemeropterans in 3-m depths.

Logperch were easily captured at the slope crest with the trawl at night when they were inactive and hid on the bottom (Greenberg 1991). Resource partitioning between logperch and small round gobies occurred in autumn when logperch skillfully snatched *Cheumatopsyche* from top surfaces of rocks (Smart and Gee 1979), while round gobies were eating ephemeropterans, dipterans, and *Brachycentrus* that are generally associated with water currents (Wiggins 1996). The interesting dichotomy among these three fish species, round gobies and northern madtoms eating *Brachycentrus* and logperch eating *Cheumatophyche*, might be explained by logperch being less benthic oriented and able to feed off the rocks, while round gobies and northern madtoms may have fed on *Brachycentrus* at night after this trichopteran left cryptic daytime hiding places.

Jude *et al.* (1995) found that mottled sculpins in the St. Clair River were apparently decimated by round gobies in shallow water, while mottled sculpins apparently found a refugium in deeper waters (7 m) that exposed them to stronger currents. As active nocturnal feeders, mottled sculpins feed mainly on aquatic insects, crustaceans, annelids, fishes, and fish eggs (Scott and Crossman 1973, Hoekstra and Janssen 1985). Harding *et al*. (1998) and Welsh and Perry (1998) found that rainbow darters preferred to seek refugia in spaces between rocks with current velocities that were substantially lower than adjacent velocities. This suggests that strong currents in the main channel of the St. Clair River may confine rainbow darters to the nearshore area. Logperch were the only small native benthic fish that displayed movements between nearshore and offshore waters.

There was evidence of predation on YOY fishes by both round gobies and native fishes in deeper waters. Round goby YOY migrated from nearshore to the slope in autumn and became easy prey of mottled sculpins and northern madtoms at the slope and bottom of the channel. Round gobies in their native habitat fed on young fishes in fall (Miller 1986) when they migrated to deep water (< 70 m) and in winter in the Sea of Azov (Skaskina and Kostyuchenko 1968). The poisonous, serrated spines in pectoral fins may protect northern madtoms from predation by round gobies (Birkhead 1967, Taylor 1969). Mottled sculpins might not move more than 15 m from their home sites (Brown and Downhower 1982, Hill and Grossman 1987, Greenberg 1991). Mottled sculpin eggs, therefore, may have been vulnerable to predation by highly mobile logperch in spring (Smart and Gee 1979, Gray *et al*. 1997) because adult mottled sculpins were confined to the channel bottom with limited movement from home sites. Mottled sculpins, like round gobies, nest in shallow water with rocks and slow currents (Greenberg 1991). Round gobies may have forced mottled sculpins deeper, exposing eggs and YOY to predation by native fishes and round gobies, which may be an important factor in the decline of mottled sculpin populations in the St. Clair River (Baltz and Moyle 1993). No evidence was found of substantial diet overlap between round gobies and native fishes (logperch, northern madtoms, and mottled sculpins) at the slope due to heavy predation on mollusks by round gobies.

Round gobies have the potential to detrimentally impact native fishes through competition for food resources and predation on young. Round gobies were found to be cannibalistic in this study, but they also ate a large adult trout-perch and other unidentified fishes. Some fish were also eaten by round gobies in the Detroit River (L. Corkum, personal communication, University of Windsor, Windsor, Ontario, Canada), and Weimer and Sowinski (1999) found white perch (*Morone americana*) larvae in stomachs of four round gobies trawled from the bottom of dredged harbors (depths = 8 to 10 m) in Lake Erie during summer 1998. Round gobies may also feed on eggs of native fish species as recorded here and may reduce lake trout survival by feeding on eggs (Chotkowski and Marsden 1999) or larvae on spawning reefs where these two species co-occur. Round gobies have recently been found in deep water (> 30 m) in Lake Michigan (Jude, unpublished data) and Lake Huron (G. Curtis, personal communication, USGS, Great Lakes Science Center, Ann Arbor, MI), setting up the potential to negatively impact populations of deepwater (see Vass *et al*. 1975), spoonhead (*Cottus ricei*), and slimy (*C. cognatus*) sculpins in the oligotrophic upper Great Lakes.

CONCLUSIONS

Previous studies have documented that mottled sculpin populations have declined precipitously concurrent with the arrival and expansion of the nonindigenous round and tubenose gobies (Jude *et al*. 1995, Janssen and Jude 2001). To determine what mechanisms might be responsible, the stomachs of round and tubenose gobies and those of common native species that co-inhabited several areas were examined to determine temporal and spatial overlap in diets. Nearshore (≤ 1 m) in June, fish < 75 mm of both species of gobies, logperch, and rainbow darters consumed common resources, mainly macroinvertebrates. At 3 m, round gobies and northern madtom diets overlapped significantly; mainly ephemeropteran nymphs were eaten. Few zebra mussels were consumed by round gobies at 3 m. However, at 5 to 7 m, round gobies ate large quantities of zebra mussels, which may have buffered their predation on other organisms, resulting in no diet overlap at these depths with native species that co-occurred with them. Round gobies may have forced some species (mottled sculpin) to deeper water where they established a refugium in the faster current of the St. Clair River because of their superior ability over round gobies to detect prey with their neuromasts (Jude *et al*. 1995, Janssen 1997). However, mottled sculpins may have experienced higher mortality because of suboptimal spawning substrate and higher predation rates. Eggs, fish larvae, and adult fish were found in the stomachs of round gobies, and cannibalism was documented, suggesting that predation could have an important impact when susceptible YOY or larvae of native species co-occur with round gobies. Round gobies could adversely affect lake trout recruitment (Chotkowski and Marsden 1999), and the recent dispersal of round gobies to deep water > 30 m in Lakes Michigan and Huron could portend dire consequences for slimy and deepwater sculpins, where they might compete for similar food resources or disrupt spawning.

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