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Habitat and site affinity of the round goby, Neogobius melanostomus (Pisces: Gobiidae), in the Great Lakes.

William J. Ray
University of Windsor

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by

William J. Ray

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Abstract

This study was designed to explore the habitat characteristics and dispersal of the round goby (*Neogobius melanostomus*), an exotic fish in the Great Lakes.

Three surveys using SCUBA, trawls and seines were conducted in the western basin of Lake Erie to identify assemblages of fishes before and after the appearance of round gobies. Round gobies were not present in the surveys conducted during 1995, however 54 round gobies were caught in trawls in 1996, and were visible at Colchester Reef and Middle Sister Island during the SCUBA survey. There was no difference ($T^2 = 10.98$, $p = 0.477$) between the abundance of fish caught during the day and night in trawls. In 1996, round gobies were found at six sites in the western basin but were abundant where the Detroit River entered the basin. Round gobies were separated in space from an assemblage of pelagic fishes.

Line transects with use of SCUBA were conducted at 3 sites along the Huron/Erie corridor to examine habitat preference in day and night by round gobies. Results showed that round gobies prefer rocky habitat compared with sandy habitat ($p < 0.001$), but are capable of surviving and reproducing in both. Round gobies are more active during the day than night ($p < 0.001$) likely due to risk from predation. Round gobies densities ranged from 5 to 9 gobies/m^2 (St. Clair River), 0.5 to 3 gobies/m^2 (Lake St. Clair) and from 0.3 to 3 gobies/m^2 (Detroit River). However, round gobies have been observed to aggregate at up to 90 gobies/m^2 in the St. Clair River.

Mark-recapture (dye injection) and observational SCUBA studies were used to determine site affinity and home range of the round goby in the Detroit River. Round gobies are highly site specific (58% total recapture) with no differences between male (61% recaptured) and female (53 % recaptured) site fidelity. There was a large difference between site fidelity of small (gobies < 9.5 cm, 54% recaptured) and large size (gobies > 9.5 cm, 80% recaptured) gobies reflecting possible interactions between different size classes. I anticipate that round gobies will disperse throughout the Great Lakes.

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GENERAL INTRODUCTION

Few, if any aquatic ecosystems have been altered as dramatically through the invasion of species as the Laurentian Great Lakes (Moyle et al. 1986). A non-indigenous species is "a successfully reproducing organism that is transported into an area where they did not previously exist" (Mills et al. 1993). One hundred and thirty nine non-indigenous aquatic species have been identified in the Great Lakes (Mills et al. 1993). Results of some of these invasions [e.g., sea lambrey (*Petromyzon marinus*), zebra mussels (*Dreissena polymorpha*)] have been devastating with respect to economic losses (Mills et al. 1993). Exotic species have been known to alter the species structure in fish communities, initiating declines or even extinctions of fish stocks (Moyle et al. 1986). Several examples of recent exotics that have been able to establish in the Great Lakes are zebra mussels, spiny water flea (*Bythotrephes cederstroemi*), ruffe (*Gymnocephalus cernus*), tubenose goby (*Proterorhinus marmoratus*) and round goby (*Neogobius melanostomus*).

There are several characteristics shared among non-indigenous species that have facilitated their colonization of new areas. New areas must have similar climate, and suitable habitat. While invading species exhibit characteristics of high fecundity, short generation time, rapid dispersal and the ability to outcompete native species (Leach 1995), these factors enable an exotic species to successfully inhabit a new area.

Several recent invaders have been predicted to have originated in Eurasia and have been transported into the Great Lakes by ships' ballast (Mills et al.

1993). In the 1880's, new technologically advanced ships began using ballast water for stabilization (Mills et al. 1994). Since 1959, most Great Lakes exotic species entries have been related to shipping activities and this surge in ship-related introductions has coincided with the opening of the St. Lawrence Seaway (Mills et al. 1993). Of the 139 exotic species in the Great Lakes, 41 species are believed to have entered via ships' ballast or fouling. In 1990, due to severe problems with these recent invaders, the Great Lakes Fishery Commission and the International Joint Commission recommended that the governments of Canada and the United States require all ocean-going ships to exchange ballast water in mid-ocean before entering the Great Lakes (Leach and Lewis 1991; Locke et al. 1993; and Mills et al. 1994). Unfortunately, these guidelines were not enacted soon enough to prevent the introduction of recent exotic species.

The round (*Neogobius melanostomus*) and tubenose (*Proterorhinus marmoratus*) goby, two exotic fishes, were first observed in the St. Clair River in 1990 (Jude et al. 1992; Crossman et al. 1992). These fishes probably arrived in ballast water discharged from ocean-going vessels from the Black-Caspian Sea area (Crossman 1992; Mills et al. 1993). The Gobiidae are small, benthic, marine fish, although freshwater species occur including the round and tubenose gobies (Magnhagen et al. 1993).

Tubenose gobies are less aggressive than the round goby and are associated with aquatic macrophytes. The tubenose goby has been able to disperse throughout the St.Clair River, Lake St.Clair, the Detroit River and at sites along the north shore of western Lake Erie (Muzzall et al. 1995; Thomas and Haas 1996, personal observations). At the present time, the tubenose goby is endangered in its native range due to habitat destruction (Jude et al 1992); however, it is prospering well in the Huron/Erie corridor.

In 1990, the round goby also successfully invaded the Gulf of Gdansk in the southern Baltic Sea (Skora and Stolarski 1993). Since, its initial entry into the St.Clair River, round gobies have been reported in each of the Great Lakes (Charlebois et al. 1997). These isolated populations in the different lakes are likely the result of intrabasin transfer by ship ballast waters. However, both adult and young-of-the-year individuals are found in the St. Clair River, Detroit River, Lake Michigan and in the west and central basins of Lake Erie (Jude et al. 1992; personal observation), suggesting that round gobies have successfully invaded the Great Lakes and are capable of dispersing throughout the system. In the St. Clair River, the round goby has quickly become one of the most abundant species of benthic fish. Densities of round goby of 40 / m^2 have been reported from Grand Calumet Harbour, Lake Michigan and of 1 - 17 /m^2 in the central basin of Lake Erie, Ohio (Charlebois et al. 1997).

The round goby is robust and is able to survive under degraded water quality conditions (Jude et al. 1995). Jude et al. (1995) showed that the round goby is able to survive at low oxygen concentrations, enabling the fish to survive in the ballast waters of ships.

Round gobies occur in rocky, shell and sandy inshore areas to depths of 20 m in the Black Sea (Miller 1986). In the Great Lakes, round gobies have been observed in rocky, sandy and macrophytic areas to depths of 15 m (Jude et al.

1995; personal observation). Round gobies are multiple spawners and are capable of reproducing every few weeks from April to August (Charlebois et al. 1997). The prolific spawning habits of round gobies allow them to increase quickly and to disperse faster than most fish species. A single nest of a round goby may contain up to 10,000 eggs from 4 to 6 females. Where fertilization is typically high, hatching success may reach 95 % (Charlebois et al. 1997).

Another factor that enables the round goby to be a successful invader is its ability to use zebra mussels as a food resource. The round goby is a benthic feeder whose diet is composed primarily of crustaceans and molluscs (Ray and Corkum 1997; Ghedotti et al. 1995). The ability of the round goby to consume a resource that is widely available in the Great Lakes will enable it to easily become established throughout the Great Lakes.

This study was designed to explore the habitat characteristics of the round goby in the Huron/Erie corridor of the Great Lakes. Chapter I describes dispersal of the round goby into the western basin of Lake Erie and the possible effects it may have on the native food web. Round goby habitat preference is addressed in chapter II. A mark-recapture and visual observation study to determine site affinity and home range of round gobies are presented in Chapter III.

CHAPTER I. ROUND GOBY DISPERSAL AND POSSIBLE ITERACTIONS AMONG FISH SPECIES IN THE WESTERN BASIN OF LAKE ERIE.

Introduction

In the Great Lakes, fish populations can be affected by several factors including fish harvests, toxic contaminant loads, climatic changes, evolutionary changes of existing species and exotic species invasions (Fontaine and Stewart 1992). Fisheries-based revenues from the Great Lakes region alone is very large with 2.3 - 4.3 billion dollars annually (OMNR 1998).

The shallowest and warmest areas of the Great Lakes are in western Lake Erie. Lake Erie has three distinctive basins and receives the highest contaminant loadings of any of the Great Lakes (Bolsenga and Herdendorf 1993). Moreover, it supports the most valuable freshwater fishery in the world. Commercial and sport fisheries also play a major role in the economics of the Great Lakes. The total landed value of the commercial and sport catch in 1997 for Lake Erie was 33.6 million dollars, which was 2.2 million dollars greater than in 1996 (OMNR 1998). Lake Erie is responsible for 50% of the commercial fish catch in the Great Lakes, with the western basin is responsible for approximately 50% of the commercial catch in the lake (Bolsenga and Herdendorf 1993).

Lake Erie has changed from a eutrophic to an oligotrophic system in a short period of time (Haffner 1994). Reasons for this change have been attributed to phosphorus reduction loads and to the filtering capacity of zebra mussels within the lake. With the invasion of zebra mussels, Lake Erie has become a more benthic rather than pelagic-driven system (Leach 1993). Zebra mussels have the potential to transfer organochlorine through the benthic food web (Haffner 1994).

The round goby is a robust, bottom-dwelling species (Jude 1992). Gobies have fused pelvic (bottom) fins (suctorial disk) and long dorsal and anal fins (French 1993). Round gobies have large moliform, conical, pharangeal teeth, which are well suited for crushing shell of prey. In its native range, the round goby grows to 30 cm long, but the largest gobies in the Great Lakes reported from the central basin of Lake Erie are about 25 cm in length (Charlebois et al. 1997).

Studies from Lake Erie, Lake Michigan, Lake St. Clair and the Detroit River have shown that in all areas the dominant prey of round gobies is the zebra mussel (Gehdotti et al. 1995; Ray and Corkum 1997). Given the high densities of zebra mussels (up to 3.4×10^5 mussels per m^2) in the western basin of Lake Erie (Leach 1993) and their extensive distribution in North America (Strayer 1991), abundant food resources exist for the round goby to expand its current distribution.

We have observed *Neogobius* feeding voraciously on mussels in the laboratory. Round gobies have also been shown to be an effective predator of lake trout eggs and fry which may threaten lake trout rehabilitation efforts in the Great Lakes (Chotkowski and Marsden 1996). Since the invasion of round goby into western Lake Erie in 1996, *Neogobius* may become the major predator of mussels. Moreover, *Neogobius* (along with freshwater drum, *Aplodinotus grunniens*, French and Bur 1992) likely transfer contaminants to top predators important in the sport and commercial fishery of Lake Erie.

The numbers of native species are declining in areas where the goby has become abundant (Crossman et al. 1992). The round goby has the possibility of also reducing species diversity in the western basin of Lake Erie by competing with the mottled sculpin (*Cottus bairdi*), darters (*Etheostoma spp.*), and the log perch (*Percina caprodes*) (Jude et al. 1995).

Several piscivores fish that are found in the western basin of Lake Erie may switch to feeding preferentially on the round goby because of its increasing abundance. Currently, the extent to which native piscivores prey on round gobies is unknown. Some species including smallmouth bass (*Micropterus dolomieu*), walleye (*Stizostedion vitreum*), yellow perch (*Perca flavescens*), and rock bass (*Ambloplites rupestris*) have been reported to prey on round gobies (Jude et al. 1995). Jude et al (1995) predicts that smallmouth bass will be one of the major predators of round gobies.

This study was designed to determine if the round goby will be able to disperse from its present population in the Detroit River and central basin of Lake Erie to the western basin of Lake Erie. Given the ability of the round goby to reproduce successfully and to disperse, I wanted to compare fish assemblages before and after introduction of the round goby into western Lake Erie. Fish assemblages were monitored using seines, trawls and SCUBA.

Methods

In 1995, a field survey of the western basin of Lake Erie was conducted during June, July and August. This survey was divided into three studies. Study I consisted of visual surveys using SCUBA around islands in the middle of western Lake Erie. Study II consisted of day and night trawls at different shoreline locations on the American and Canadian side of western basin of Lake Erie. Study III was a seining survey conducted at each of the trawling sites.

In study I, a visual search of rocky habitat around several islands in the western basin of Lake Erie was undertaken. These sites were located around East Sister Island, North Bass Island, Middle Bass Island, and South Bass Island (Fig 1.1). At each location, two SCUBA divers would search for round gobies in the area around the islands. Rocks and cobble stones were disturbed to see if any fish were hiding underneath and in the cracks between rocks. Diving was conducted from inshore to approximately 50 m offshore ranging in depth from 1 to 5 m. Each dive was approximately 45 minutes in duration. Dives were conducted during the months of June and July in 1995 and 1996.

Study II (a trawl survey) was conducted in shoreline areas approximately between 200 - 600 m offshore. Sites in the western basin of Lake Erie were selected along shorelines where rivers flowed into the lake. There were ten trawling sites along the American shoreline and four sites in Canadian waters (Fig 1.1) (Table1.1). In summer 1996, I trawled at eight sites that corresponded to sites 1 to 4 and sites 11 to 14 sampled in 1995.

At each site an otter trawling net (5 m in length) was used with a 2 m x 1

Table 1.1 Description of sites used in the trawling survey conducted in the western basin of Lake Erie in 1995 and 1996.

SITE	Date SAMPLED 1995	DATE SAMPLED 1996	NAME OF SITE	TIME (EDT)	# of DAY TRAWLS 1995/1996	TIME (EDT)	# of NIGHT TRAWLS	LATITUDE (N)	LONGITUDE (W)	DEPTH (m) of TRAWLS
1	Jul-12/Aug-1	Oct-01	Brest Bay	11:00	(3) (3)	22:00	3	41. 56' 10"	83. 17' 44"	1-2
2	Jul-12/Aug-2	Oct-08	River Raisin	13:30	(3) (3)	1:00	3	41. 53' 18"	83. 20' 0"	2-4
3	Jul-13/Jul 19	Oct-08	Toledo Beach	17:00	(3) (3)	23:25	3	41. 47' 47"	83. 26' 34"	1-4
4	Jul-13/Jul-12	Oct-08	Maumee Bay	13:30	(3) (3)	23:00	3	41. 41' 10"	83. 28' 23"	2-6
5	Jul-13		Crane Creek	11:00	3	1:30	3	41. 40' 50"	83. 14' 14"	3-4
6	Jul-13		Toussaint R.	9:15	3		0	41. 35' 53"	83. 03' 48"	2-4
7	Aug-11		Port Clinton	7:00	3		0	41. 31' 39"	82. 56' 42"	2-6
8	Aug-11		Sandusky Bay		0	3:00	3	41. 28' 54"	82. 42' 34"	2-5
9	Aug-11		Huron, Ohio		0	1:00	3	41. 24' 16"	82. 32' 17"	2-5
10	Aug-10		Vermilion		0	23:30	3	41. 25' 57"	82. 22' 28"	3-4
11	Jul-20	Sep-23	Big Creek	9:00	(3) (3)		0	41. 52' 34"	83. 20' 27"	2-8
12	Jul-20	Sep-23	Colchester	11:00	(3) (3)		0	41. 55' 39"	83. 18' 32"	2-8
13	Aug-21	Sep-25	Kingsville	14:45	(3) (3)		0			2-8
14	Aug-21	Sep-25	Leamington	17:00	(3) (3)		0			2-8

Table 1.2 **Fish species found in the study area**

ABBREVIATION	COMMON NAME	SPECIES
AW	Alewife	*Alosa pseudoharengus*
RB	Rockbass	*Ambloplites rupestris*
SS	Silverside	*Antherinidae*
FD	Drum	*Aplodinotus grunniens*
WS	White Sucker	*Catostomus commersoni*
WF	White Fish	*Coregonus clupeaformis*
CP	Carp	*Cyprinus carpio*
GS	Gizzard Shad	*Dorosoma cepedianum*
JD	Johnny Darter	*Etheostoma nigrum*
CC	Channel Catfish	*Ictalurus punctatus*
SF	Sunfish	*Lepomis sp.*
PK	Pumpkinseed	*Lepomis gibbosus*
BG	Blue Gill	*Lepomis macrochirus*
SM	Smallmouth Bass	*Micropterus dolomieu*
LM	Largemouth Bass	*Micropterus salmoides*
WP	White Perch	*Morone americana*
WB	White Bass	*Morone chrysops*
RG	Round Goby	*Neogobius melanostomus*
ES	Emerald Shiner	*Notropis atherinoides*
ST	Spottail Shiner	*Notropis hudsonius*
SH	Shiner	*Notropis sp.*
YP	Yellow Perch	*Perca flavescens*
LP	Logperch	*Percina caprodes*
TP	Troutperch	*Percopsis omiscomaycus*
BN	Bluntnose Minnow	*Pimephales notatus*
CH	Chub	*Semotilus sp.*
WA	Walleye	*Stizostedion vitreum*

m mouth. The trawling net was pulled behind the boat that was travelling about 5 km/h for 10 minutes. Occasionally, snags caused the trawl to be interrupted. Trawls were conducted at various depths ranging from 1.5 m to 8 m.

I conducted three trawls at each site. Trawls were conducted in day and night at several sites to determine if there was a significant difference in fish caught during each light regime.

In each trawl, all fish were identified and measured (standard length) before being released into the water. If a fish could not be identified in the field, a voucher specimen was retained for identification. If fish were not collected in a given trawl, an additional trawl was conducted to eliminate possible errors in running the trawl. Most trawls were conducted between 1.5 m and 5 m where optimal fish habitats were found for round gobies.

In Study III, I determined if gobies were present along the nearshore areas of the western basin of Lake Erie. Shoreline seines using a 5 cm mesh and a 6 m seine with pocket were used at sites where trawls were taken. Nine sites along the American shore were seined (one site was inaccessible) and three sites along the Canadian shore were seined (one site was inaccessible) to determine if round gobies were utilizing habitats in water depths between 0 m and 1 m (Fig. 1.1). Seining consisted of two people wading through the water for 5-10 minutes (depending on substrate) pulling the net against the current. Fish that were caught in the seine were identified and measured for standard length. At some sites, the number of fish caught was tremendous (site 2, n=1433 fish) and so the catch was subsampled; these specimens were identified and measured. Voucher specimens were collected for those fish that could not be identified in the field.

Species assemblages were identified using principal component analysis (PCA). This analysis permits species groups to be combined that are linearly dependent into one group so that data can be presented in fewer dimensions. The 1995 and 1996 data obtained from trawling at sites throughout western Lake Erie were analyzed using fish species that dominated the catches (i.e, the dominant species that represented at least 80% of all fish caught were used in analyses). PCA also was used to identify assemblages of fish caught using seines in 1995. A Hotelling's T^2 test was used to determine if differences occurred in the abundance of fish species caught between night and day.

Results

SCUBA surveys that were conducted in 1995 showed that gobies were not present at any of the four sites. There was no confirmation of any goby being caught in the western basin of Lake Erie in 1995. However, in 1996 round gobies were seen at two (Colchester Reef and Middle Sister Island) of the four sites (Figure 1.2). Round gobies were not present at either North Bass or Middle Bass islands. About 35 round gobies were observed throughout the dive at Middle Sister Island with a size range from YOY (30 mm) to about 100 mm in length (total length). More than 100 round gobies ranging in size from YOY to 90 mm in length (total length) were observed at Colchester Reef. Results from the SCUBA survey indicated that the round goby likely dispersed from the Detroit River into the western basin of Lake Erie.

During the SCUBA survey in 1995, I also searched for mottled sculpins at

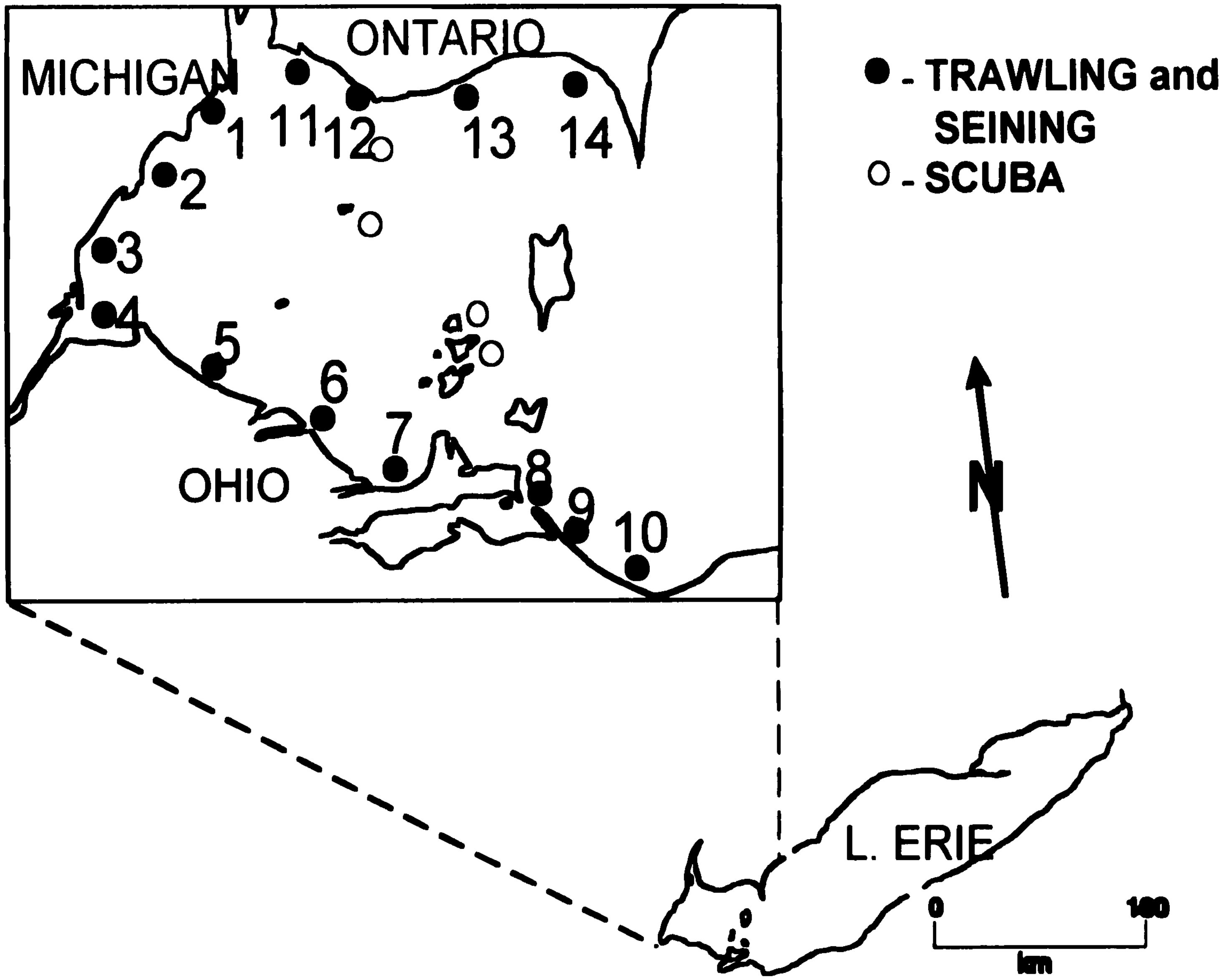


Figure 1.1 Map of study area (1995). Sample sites along the lake are indicated by closed circles (trawling and seining) and open circles (SCUBA).

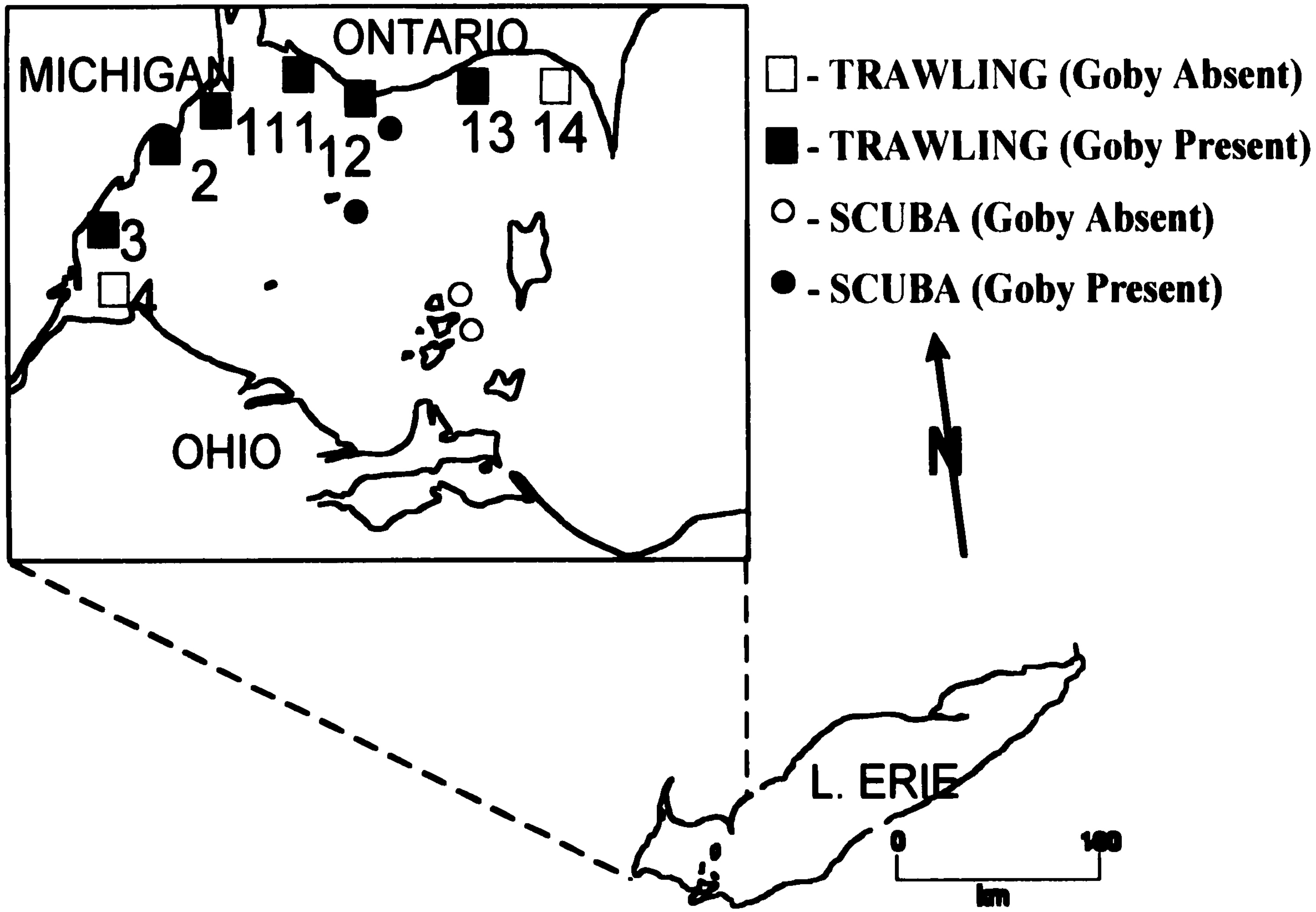


Figure 1.2 Map of study area (1996). Sample sites along the lake are indicated by open/closed squares (trawling) and open/closed circles (SCUBA).

Middle Sister Island. In years 1992-1994, mottled sculpins were abundant around the island (Todd Leadly, University of Windsor, personal communication); however, no mottled sculpins were observed in 1995 or 1996.

In 1995 trawling was conducted at 14 sites along the shoreline in the western basin of Lake Erie (Figure 1.1). No round gobies were caught in the western basin of Lake Erie during the trawls. A total of 20 different fish species was caught in the trawls during the day and night. A total of 2016 fish was captured and identified (Table1.3). Some of the fish species included walleye (*Stizostedion vitreum*), smallmouth bass (*Micropterus dolomieu*), yellow perch (*Perca flavescens*), logperch (*Percina caprodes*) and johnny darter (*Etheostoma cepedianum*). Most fish that were caught were from sites 1 to 10 along the American shoreline.

In 1996, trawling was again conducted at eight sites. Round gobies were caught at sites 1, 2, 3, 11, 12, and 13 in the western basin of Lake Erie (Figure 1.2). Round gobies were not collected at sites 4 or 14. Nineteen different fish species were caught at the eight sites in 1996. A total of 2689 fish was caught by trawling at the eight sites. A total of 59 roun d gobies was caught during the summer of 1996 in the western basin of Lake Erie by trawling. Round gobies caught at each site were as follows: site 1 (4 gobies), site 2 (2 gobies), site 3 (1 goby), site 11 (50 gobies), site 12 (1 goby) and site 13 (1 goby) (Table 1.4).

To determine if there was a difference in the relative abundance of fishes caught in trawls between day and night, Hotelling's T^2 test was conducted on the 1995 data for sites 1-5. The five most abundant species (alewife, freshwater

Table 1.3 Number of fish collected in the study area by trawling (Jul. and Aug., 1995). Abbreviated names are presented in Table1.2 Site numbers correspond to those in Figure 1.1 (n=night, d=day).

		SPECIES																									TOTAL
TIME	SITE	AW	RB	SS	FD	WS	WF	CP	GS	JD	CC	SF	PK	BG	SM	WP	WB	RG	ES	ST	SH	YP	LP	TP	BN	CH	WA	
D	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	4	0	2	0	0	0	0	0	9
N	1	10	1	0	1	0	0	0	0	0	1	0	0	0	0	2	1	0	0	1	0	0	0	0	0	0	0	17
D	2	178	0	0	0	1	0	1	0	0	1	2	0	0	0	40	41	0	0	26	0	12	4	4	0	0	1	311
N	2	6	1	0	11	0	2	0	9	0	4	0	0	6	0	48	49	0	0	44	0	1	1	3	0	0	1	186
D	3	1	2	0	3	0	0	0	0	0	2	0	0	0	0	0	10	0	0	4	0	2	0	0	0	0	0	24
N	3	5	1	0	42	0	2	0	1	0	0	0	0	0	0	81	52	0	2	0	0	20	0	14	0	0	10	230
D	4	0	0	0	98	0	0	4	0	0	37	0	0	0	0	41	25	0	0	19	0	2	1	12	0	0	1	240
N	4	46	0	0	10	0	0	0	0	0	3	0	0	0	0	2	10	0	1	2	0	1	0	0	0	5	0	80
D	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	4	0	0	0	0	0	0	0	26
N	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	16	0	3	1	0	0	0	0	0	0	0	25
D	6	0	0	0	20	0	0	0	1	0	0	0	0	0	0	30	0	0	0	23	0	10	0	1	0	0	0	85
D	7	3	0	0	149	0	0	3	2	0	43	0	0	0	0	16	5	0	0	0	1	0	0	0	0	0	0	222
N	8	1	0	0	75	0	0	1	0	0	2	0	0	0	0	155	1	0	2	33	0	38	0	0	0	0	3	311
N	9	0	0	0	29	1	0	0	0	0	0	0	0	0	0	120	6	0	0	12	0	9	0	0	0	0	4	181
N	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	11	2	0	0	2	0	0	0	0	0	0	0	0	0	0	7	2	0	0	1	0	2	0	0	0	0	0	16
D	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	6	0	1	2	0	2	0	0	0	0	0	15
D	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	8	0	0	4	0	1	0	0	0	0	0	16
D	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	1	0	0	0	0	13	22
	TOTAL	253	5	0	440	2	5	9	13	0	93	2	0	6	1	584	232	0	9	180	1	103	6	34	0	5	33	2016

Table 1.4 Number of fish collected in the study area by trawling (Sep. and Oct. 1996). Abbreviated names are presented in Table 1.2 Site numbers correspond to those in Figure 1.2 (d = day).

		SPECIES																										TOTAL
TIME	SITE	AW	RB	SS	FD	WS	WF	CP	GS	JD	CC	SF	PK	BG	SM	WP	WB	RG	ES	ST	SH	YP	LP	TP	BN	CH	WA	
d	1	0	3	0	2	0	0	0	0	1	0	0	0	0	0	77	0	4	0	5	0	30	3	6	4	0	4	139
d	2	0	0	0	1	1	0	2	0	0	0	0	0	0	0	53	6	2	0	3	0	1	0	0	2	0	0	71
d	3	0	0	0	183	2	0	0	0	1	6	0	0	0	0	57	2	1	0	13	7	42	0	23	16	0	0	353
d	4	0	0	0	68	1	0	0	0	0	23	0	0	0	1	32	0	0	0	2	0	92	5	7	7	0	3	241
d	11	0	2	0	0	0	0	0	0	4	0	0	0	0	28	0	0	50	0	0	0	23	31	0	1	0	0	139
d	12	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	20	1	1	0	0	0	1	16	0	0	0	44
d	13	4	0	0	1	0	0	0	0	0	0	0	0	0	2	213	0	1	0	59	0	136	4	65	0	0	2	487
d	14	64	0	0	1	0	0	0	0	0	0	0	0	0	2	380	2	0	0	50	0	552	10	148	2	0	4	1216
	TOTAL	68	5	0	257	4	0	2	0	6	29	0	0	0	37	812	30	59	1	132	7	876	54	265	32	0	13	2689

drum, white perch, white bass and spottail shiner), which represented 83.8% of all fish caught, were examined to determine if there were differences in abundance of taxa between day and night. Overall, there was no significant difference in abundance of taxa collected in day versus night for the 1995 trawls (T^2=10.98, p = 0.477). Therefore, all trawls (either day or night) were included in subsequent analyse.

In 1995, the most abundant fish caught in trawls in decreasing order were white perch, freshwater drum, alewife, white bass, spottail shiner, yellow perch, and catfish (Figure 1.3). Principal component analysis (PCA) showed that 80.31% of the variance was explained by the first three axes (Table 1.6) The first axis (Factor 1) accounted for 39.4% of the total variance and had high positive loadings with catfish and freshwater drum and negative loadings with white perch. The second and third axes extracted 22.7% and 18.3% of the variance, respectively. White bass and freshwater drum were separated from other species along PCA 2. Yellow perch and catfish were separated along PCA 3. Overall, the bottom-dwelling channel catfish and freshwater drum were associated with one another and were separated from the group of fish that co-occurred within the water column (e.g. alewife, yellow perch).

In 1996, the most abundant fish that were caught in trawls in decreasing order were white perch, yellow perch, freshwater drum, trout perch, spottail shiner, alewife, and round goby (Figure 1.3). A second PCA was conducted to determine the fish assemblages in 1996 (Table 1.7). PCA showed that 87.6% of the variance was explained by the first three axes (Table 1.7) The first axis

Table 1.5 Summary of the Hotelling's T(2) to examine differences in dominant fish caught in trawls between day and night.

Variable	F-ratio	p
AW	1.414	0.75
FD	2.449	0.41
WP	4.151	0.2
WB	3.909	0.22
ST	2.976	0.32

T(2) = 10.9831
F (5,4) = 1.0893
p = 0.47712

Table 1.6 Summary of principal component analysis for dominant fish captured in trawls throughout western Lake Erie, 1995. See Table 1.2 for description of fish codes.

Variable	Factor 1	Factor 2	Factor 3
AW	* 0.649	0.553	-0.028
FD	0.084	* -0.356	0.175
CC	* 0.878	0.112	* -0.38
WP	* -0.576	-0.289	0.519
WB	-0.047	* 0.927	0.015
ST	-0.057	0.445	0.789
YP	-0.114	-0.232	* 0.815
Eigenvalues	2.757	1.586	1.278
% Total Var.	39.38	22.66	18.27

Cumulative % for 3 factors = 80.31 %

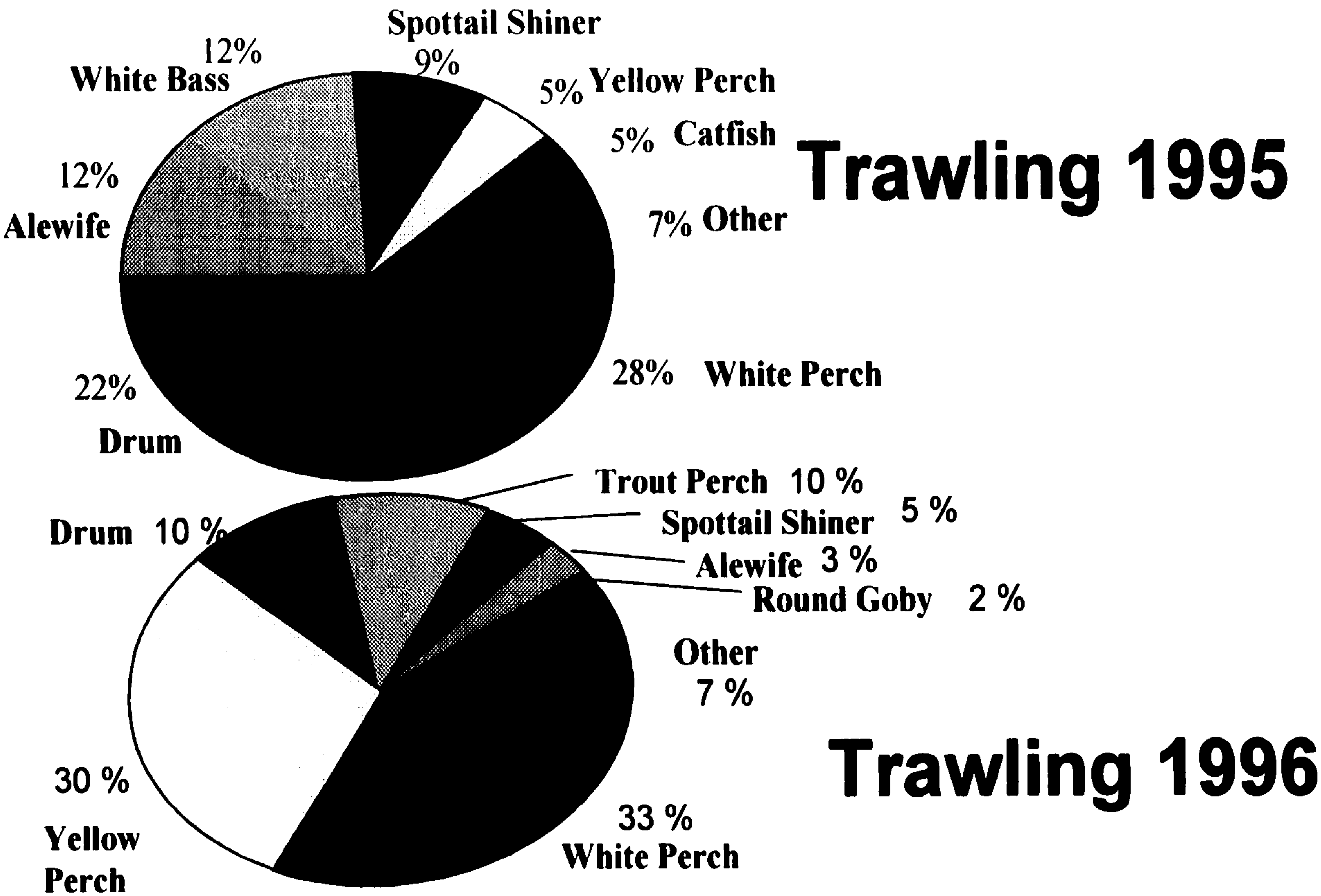


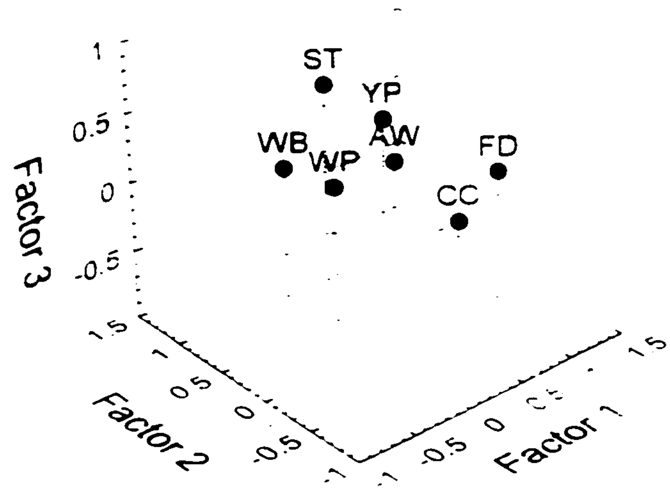
Figure 1.3 Frequency of occurrence of the most abundant species collected by trawling.

Table 1.7 Summary of principal component analysis for dominant fish in trawls throughout western Lake Erie, 1996. See Table 1.2 for description of fish codes

Variable	Factor 1	Factor 2	Factor 3
AW	0.357	-0.803	0.434
FD	0.172	* 0.915	0.271
WP	* 0.956	0.023	-0.033
RG	* -0.752	-0.009	* -0.583
ST	* 0.928	-0.097	0.059
YP	0.598	* -0.412	-0.286
TP	-0.028	0.044	* 0.959
Eigenvalues	3.117	1.698	1.31
% Total Var.	44.53	24.26	18.77

Cumulative % for 3 factors = 87.6%

Trawl. 1995



Trawl, 1996

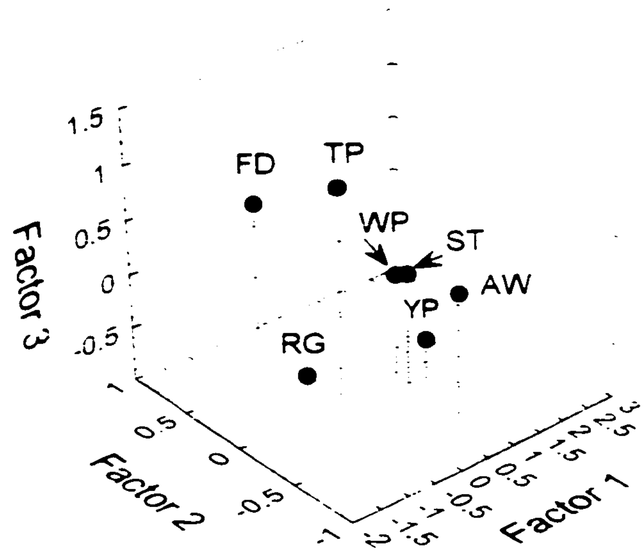


Figure 1.4 Principal component analysis of the most abundant fishes collected by trawling in 1995 and 1996.

(Factor 1) accounted for 44.53% of the total variance and had high positive loadings with white perch and spottail shiner and negative loadings with round goby. The second and third axes extracted 24.3% and 18.8% of the variance, respectively. Yellow perch and freshwater drum were separated from other species along PCA 2. Trout perch and round goby were separated along PCA 3.

Overall, there was a tight grouping of fishes found within the water column (alewife, yellow perch, and white perch) and sandy, rocky shores of the lake (spottail shiner). Round gobies, freshwater drum and trout perch were separated in space. Freshwater drum occurred mainly at sites 3 (Toledo Beach) and 4 (Maumee Bay); trout perch were most abundant at sites 13 (Kingsville) and 14(Leamington); and round gobies were most abundant at site 11 (Big Creek), where the Detroit River enters the western basin of Lake Erie. Although round gobies occurred at six sampling sites, it appears that they colonized the western basin from the Detroit River.

Eighteen fish species representing 4, 972 fish were caught in seines throughout the western basin of Lake Erie (Table 1.8). Alewife was the most abundant fish, representing 38% of all fish caught in seines. Other abundant species included spottail shiner (23%), emerald shiner (15%), shiners (8%), white perch (7%) and white bass (3%) (Table 1.8). Round gobies were absent from all sampling sites.

Results of the PCA on the dominant six species caught in seines showed that 81% of the variance was explained by the first two axes (Table 1.9). The first axis accounted for 55% of the total variance. Shiners were separated from a

Table 1.8 Number of fish collected in the study area by seining (Jul. and Aug., 1995). Abbreviated names are presented in Table 1.2. Site numbers correspond to those in Figure 1.1 (n = night, d = day).

		SPECIES																										TOTAL
TIME	SITE	AW	RB	SS	FD	WS	WF	CP	JD	GS	CC	SF	PK	BG	SM	WP	WB	RG	ES	ST	SH	YP	LP	TP	BN	CH	WA	
n	1	106	1	0	0	0	0	0	0	0	0	5	7	1	0	0	7	0	20	782	113	2	6	0	0	0	0	1050
n	2	1321	0	0	2	0	0	0	0	0	0	0	0	0	0	18	71	0	2	17	0	1	1	0	0	0	0	1433
n	3	2	0	12	2	0	0	0	0	4	3	0	0	0	0	2	2	0	42	0	4	0	0	0	0	0	0	73
d	4	145	0	3	1	0	0	0	0	0	5	0	0	0	0	60	33	0	170	3	5	0	8	0	0	0	0	433
d	5	34	0	0	0	0	0	0	0	0	0	0	0	0	0	80	36	0	117	209	2	0	1	0	0	0	0	479
d	7	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	6
n	8	0	2	0	0	0	0	0	0	0	0	155	0	0	41	1	0	0	2	41	0	1	0	0	0	0	0	243
n	9	264	0	0	1	0	0	0	0	0	0	0	0	0	0	200	0	0	10	15	0	4	0	0	0	0	0	494
n	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	12	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	56	12	0	0	0	0	0	0	0	71
d	13	11	0	0	0	1	0	0	0	0	0	0	0	0	5	0	0	0	280	81	252	6	6	0	0	0	0	642
d	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	1	8	0	0	0	0	0	0	48
	TOTAL	1883	3	15	7	1	0	0	0	4	8	160	7	1	54	361	149	0	738	1161	384	14	22	0	0	0	0	4972

Table 1.9 Principal component analysis of the 6 most abundant fishes collected by seining in 1995.

Variable	Factor 1	Factor2
AW	0.531	* 0.767
WP	* 0.971	0.154
WB	* 0.843	0.505
ES	0.067	* -0.954
ST	* -0.903	0.224
SH	-0.151	-0.513
Eigenvalues	3.297	1.569
% Total Var.	54.93%	26.14%

Cumulative % for 2 factors = 81.07%

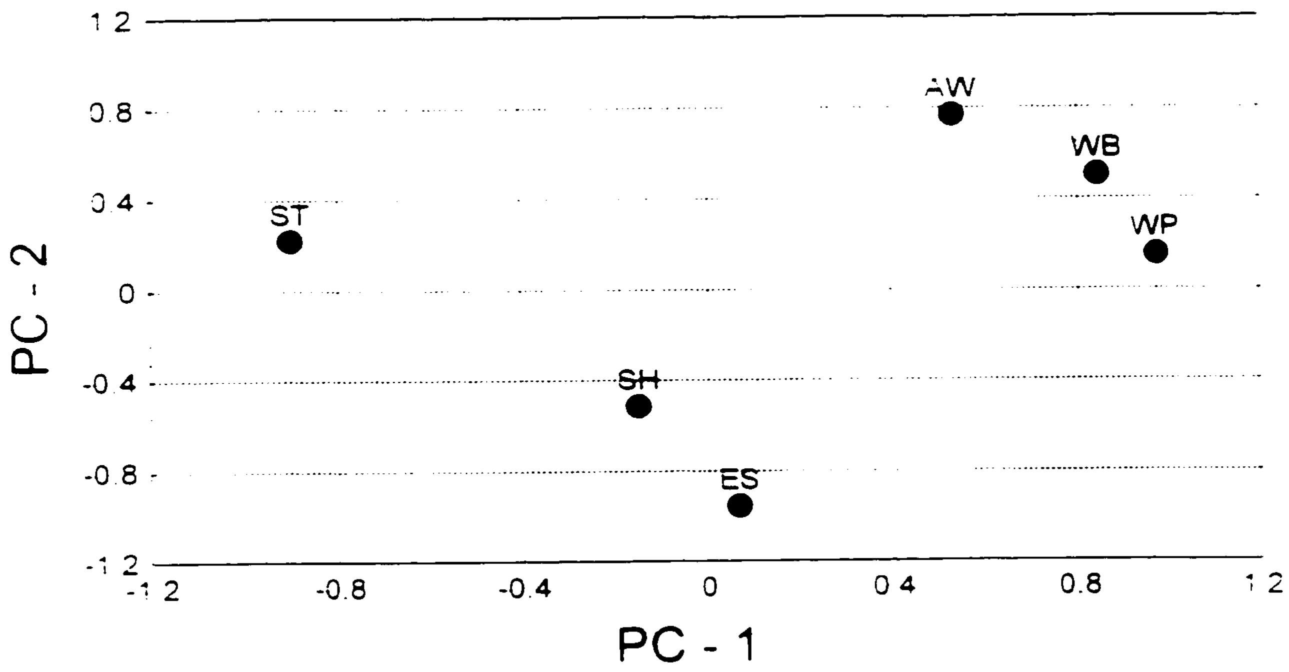


Figure 1.5 Principal component analysis of the most abundant fishes collected by seining in 1995.

second group consisting of alewife, white bass and white perch. Along the second PCA, which accounted for 26% of the total variance, emerald shiners and other shiners were separated from other fishes.

Discussion

Usually introductions accompany major environmental changes or other stresses on the native fish community, so it is uncertain whether the declines are caused by the environmental changes, introduced species, or both. Aspects of fish biology such as spawning habits, degree of parental care, adult size and feeding habits seem to have little bearing on whether or not a species can be successfully introduced. However, introduced fishes seem to have a fairly broad range of environmental conditions under which they survive, have the ability to disperse rapidly, and the ability to interact successfully with other fishes and become integrated into local fish communities (Moyle 1986). The round goby is an example of an invader that has been able to successfully establish in the western basin of Lake Erie. The round goby has been in the Great Lakes system since 1990 (Jude et al. 1992) and, within a few years, has dispersed throughout all five Great Lakes (Figure 1.6).

Using a variety of sampling techniques (trawling, seining, and SCUBA) I was unable to find any round gobies in western Lake Erie in 1995. These observations were confirmed by the 1995 monitoring program conducted by the OMNR (OMNR 1996). However, the round goby became established in the western basin in 1996 (Fig. 1.3). The unique spawning habits of round gobies (Corkum et al. 1998), use of zebra mussel as prey (Ray and Corkum 1997), and its ability to survive under low oxygen conditions (Jude et al. 1995) may have helped to establish round goby populations in the western basin of Lake Erie.

Throughout North America, fish faunas have been altered through the

Figure 1. 6 Map of the current distribution of round gobies.

introduction of new species. Most of the introductions have been of North American species into North American waters from which they were absent, although some of the more spectacular introductions (common carp, and zebra mussels) have been non-indigenous species (Moyle 1986).

Round and tubenose gobies were both established in the western basin of Lake Erie in 1998. The effects that they will have on native fish fauna is yet to be determined. However, the decline and extirpation of native fish populations as a result of direct interaction with introduced fishes has been documented throughout North America. In streams in North Carolina, green sunfish (*Lepomis cyanelus*) replaced various *cyprinids* as the dominant species (Lemly, 1985). In the Great Lakes, lake trout (*Salvelinus namaycush*) was driven to near extinction by sea lamprey (*Petromyzon marinus*) (Crowder 1980). The exotic alewife *(Alosa pseudoharengus*), may be responsible in part for the extinction or reduction of several native fish species in the Great Lakes through food competition and larval predation (Krueger et al. 1995). Lastly, cutthroat trout (*Salmo clarki*) have been replaced by the ecologically similar but more aggressive rainbow trout (*S. gairdneri*) in the Great Lakes (Moyle and Vondracek 1985). Introduced fishes have displaced native species through competition, predation, inhibition of reproduction, environmental modification, transfer of new parasites and diseases, contaminants, and hybridization (Moyle et al. 1986).

The round goby may cause dramatic change to Lake Erie native fish assemblages. The similarity in benthic habitat, substrate preference (rocky nearshore areas) and prey (soft bodied invertebrates and zebra mussels) suggest that competitive interactions exists between gobies and native fauna. Early evidence from Lake Michigan indicates that the round goby is displacing the mottled sculpin (Jude et al. 1995, Jude and Deboe 1996). Both are benthic species with similar ecological requirements for nesting, feeding, and shelter. Both species are nocturnaly active (Jude et al. 1995), however, round gobies seem to be more active during the day (personal observations). Because both the round goby and mottled sculpin deposit eggs on the underside of rocks defended by males, the spawning failure in sculpins may be due to competition for nest sites, egg predation by gobies, or both. However, gobies may not be the sole factor responsible for the decline of sculpins in the Great Lakes. During the SCUBA surveys in 1995, the year before round gobies were detected in western basin of Lake Erie, mottled sculpins also were absent. Mottled sculpins were abundant in 1992 and 1993. Therefore, factors other than round gobies may be responsible for the decline of the mottled sculpin.

The extent to which high goby densities might alter the structure of invaded communities remains uncertain. Round gobies have been observed at densities of 1 to 40 individual/m^2 throughout the Great Lakes (Charelbois et al. 1997, personal observations).

In the PCA for trawls in 1996, round goby, trout perch and freshwater drum were grouped together and separated from other fish species. Freshwater drum, like the round goby, is a bottom-feeding fish that spawns from July to September (Scott and Crossman 1973). The trout perch is an important forage fish and feeds during the evening. The round goby has the ability to feed at night with its lateral line system and also may become an important forage fish in the Great Lakes. The other group of fish consisted of white perch, yellow perch, alewife and spottail shiner all showed similarities in the PCA. Yellow and white perch are very similar in that they both spawn during early spring and feed (depending on age) on zooplankton, macroinvertebrates and other forage fish. The yellow perch is inactive at night compared to the white perch, alewife and spottail shiner which feed primarily at night. The yellow and white perch and alewife all exhibit movement either inshore during night and offshore during day (alewife) or vertical movements in the water column (yellow and white perch). There seems to be no movement of round gobies during the day and night between areas.

Other fishes that the round goby may potentially compete with are the logperch, johnny and rainbow darters, and slimy sculpins. The smaller and diurnaly active darters (*Etheostoma spp.)* (Greenberg 1991), which are also benthic, appear to be unaffected by the round goby (Jude et al. 1995). I observed darters together with round gobies along transects during the day. Darters also were collected in trawls in 1995 and 1996. There seems to be no difference in the population of darters that were caught before and after the introduction of round gobies into the western basin.

Decline of logperch populations in the St. Clair River may be due to predation of round gobies on logperch eggs (Jude et al. 1995), however, the data gave no indication whether the round goby is having an effect on the logperch populations in the western basin of Lake Erie.

Round gobies also may interact with commercially harvested fish such as the white and yellow perch, and walleye. Interactions with other fish species could affect the relationship between walleye and perch growth rates. Perch growth may be reduced due to both inter and intra-specific competition with white perch and also round gobies. There is a negative correlation between growth rates of walleye and yellow perch, indicating the importance of predator-prey interactions in determining the growth of the two species (Rudstam 1996). If YOY (young of the year) gobies are competing with yellow perch for food resources, then walleye populations may be indirectly affected. Danehy et al. (1991) found that differences in growth patterns between cobble/rubble shoals and sand sites illustrate a subtle effect of habitat for yellow and white perch. Since the round goby prefers rocky habitat (personal observation), they may push yellow and white perch into suboptimal habitat which will affect their growth rate. However, on the basis of the trawling surveys, there is no evidence that round gobies affect either white perch or yellow perch. In fact, results from the PCA (Fig. 1.4) indicate that round gobies are separated in space from white perch and yellow perch.

Just as the round goby may have an indirect effect on walleye populations through their interactions with yellow perch, the spawning success of walleye may be hampered directly by gobies. The loss of walleye eggs to fish predation appeared to be important only when the reproductive periods of fishes overlap. (Roseman et al. 1996). Walleye spawning takes place in April and studies have shown that walleye eggs appeared in 86% of white perch stomachs, with each white perch stomach containing an average of 349 walleye eggs from Toussaint and Niagara reefs in western basin of L. Erie (Roseman et al. 1996). White perch likely do not affect walleye populations because there is minimal overlap in their reproductive periods. However, the reproductive periods of round gobies and walleye do overlap. The round goby is able to reproduce from April to September (Jude et al. 1995). Additionally, walleye lay their eggs in the preferred habitat of round gobies. Walleye spawn randomly over substrates and do not provide any parental protection for eggs or juveniles (Malison and Held 1996). Since, gobies can reach very high densities (Charlebois et al. 1997; see Chapter 2), the round goby may affect walleye populations by consuming walleye eggs.

During the SCUBA survey in 1996 at Colchester Reef, I saw smallmouth bass eating round gobies. The possible relationship between smallmouth bass and round gobies is of special interest because of the economic and recreational importance of the bass. Bass may be attracted to areas of high goby density. On the other hand, goby predation or other interference with bass breeding activities in the shallow cobble areas adjacent to islands in the western basin of Lake Erie could reduce bass numbers or result in smallmouth bass shifting to suboptimal habitat for spawning. For sport caught smallmouth bass, crayfish was the most frequent prey (Ross et al. 1995). The round goby has been shown to share refuge with crayfish in Lake St. Clair and utilize crayfish burrows for reproduction. Therefore, the round goby may become the major prey item of the smallmouth bass.

The western basin of Lake Erie appears to have the highest concentration of selected toxic chemicals in Lake Erie (Wang and Xie 1994). With the high density of zebra mussels, ecosystems changes have been extensive in the Great Lakes. Although the trophic state of lakes other than Lake Erie have not changed, Lake Erie has shifted from pelagic-dominated systems to benthic/pelagic systems with strong nutrient links between the benthos and pelagic communities. However, these systems are now exposed to a new invader (round gobies) that may be able to regulate the abundance of zebra mussels, and thus alter nutrient and energy pathways again. Since round gobies feed predominantly on zebra mussels (Ghedotti et al 1995; Ray and Corkum 1997), there is also a possibility that contaminant transfer may occur and through bioaccumulation, round gobies will have high levels of contaminants in its lipid. Smallmouth bass that consume round gobies will bioaccumulate the contaminants and therefore the commercial and sport fisheries may be eventually affected.

Exotic species become environmental pests when they attack and threaten the continued existence of particular native species, or alter ecosystems in ways that threaten the continued existence of whole biological communities. In many cases, exotic species do not directly attack native forms but rather outcompete them for resources by various broad effects that alter the ecosystem or preempts their living space (Moyle 1986). The round goby has the potential to become an environmental pest through interactions with native fish assemblages. Currently, research is being conducted to try and prevent the further dispersal of the round goby into the Mississippi River basin. An electrical field will be implemented in the Chicago River drainage to try and prevent the round gobies from dispersing from the Great Lakes basin to the Mississippi basin. Unfortunately, the barrier is not 100% effective and it is believed that the round goby has already passed beyond the location of the proposed barrier that is under construction.

One of the most common effects of introduced environmental pests is the formation of dense areas of single species that cover a high percentage of the available habitat (Moyle 1986). This is especially true for the round goby with densities up to 90 gobies/m^2 (personal observation).

In summary, the round goby was able to successfully establish in the western basin of Lake Erie. Trawling is an excellent technique to monitor and catch round gobies in nearshore areas. The effects that the round goby will have on native fish assemblages is yet to be fully understood. However, it is likely that the round goby will cause decreases in populations of logperch and darters through competition for refugia. The round goby may also affect populations of yellow perch, walleye, white perch and smallmouth bass, through predation of eggs. In turn, round gobies may be preyed upon by these fishes. Additional studies are needed to determine the effect of the round goby on the Lake Erie food web.

CHAPTER II DENSITY OF THE EXOTIC ROUND GOBY IN DIFFERENT HABITATS IN DAY AND NIGHT.

Introduction

Populations of fish may be restricted to habitats that create spatial refugia through differential mortality or through active habitat selection (Taylor 1984; Sih 1987). Structurally complex habitats, the intertidal zone, and perhaps even deep water below the photic zone, may represent spatial refugia where predation pressure is reduced. Behavioral preferences for such refugia are a predictable outcome of strong selection against occupying open habitats (Wahle 1992). Availability of ideal habitat is also a very crucial factor which determines population density. Behaviour and habitat use can vary among introduced species and may influence predation risk (Werner et al. 1983).

When introduced into a new and different community, species may change their niche utilization and life history traits (Reznick et al. 1990). These changes are the result of both biotic and abiotic factors affecting the species (Connell 1975). Competition and predation have been shown to have particular importance in changing the niche of an individual (Reznick et al 1990). The non-indegenous round goby has an advantage over many native species because of its multiple spawning habits. Separate spawning events occur every 3 to 4 weeks depending on water temperature (28 days in water temperature of 15 - 17 °C, and 15 - 17 days at temperatures above 20 °C)(Charlebois et al. 1997). The spawning period for the round goby lasts from April to August (Jude et al. 1992). Round goby nests are built under hard substrate and eggs are laid in a single layer underneath surfaces. Male gobies guard nests and are very territorial during the breeding season (Jude et al 1995, Corkum et al. 1998). Similarly, the unique canal and superficial neoromasts of the lateral line system have contributed greatly to the success of gobiidae (Jude et al 1992) compared with the lateral lines of other fishes in the Great Lakes. The lateral line system of the round goby enables it to feed effectively on prey at night.

In its native range of the Black and Caspian Seas and in the Sea of Azov, round gobies occupy coarse gravel, shell and sandy inshore areas to a depth of about 20 m. The round goby prefers littoral areas in its native range where the wave action maintains high DO and reduces the amount of decaying material (Charlebois et al. 1997). Round gobies are capable of surviving under a wide range of temperatures from 0.5 - 9.0 °C in the winter and as high as 25 °C in the summer (Charlebois et al. 1997). They have also been known to appear in lower and middle reaches of rivers (Miller 1986). From spring to autumn, round gobies are found up to depth of 20 m in slow rivers, lagoons, and brackish water in the Black Sea (Jude and Deboe 1996). In winter, the goby seeks the warmth of the deeper waters often in the range of 50-60 m (Miller 1986).

Round gobies prefer and flourish in areas of rock cobble, riprap, and vegetation in the nearshore margins of rivers. Macrophytes and cobble provide large interstices for refuge and spawning (Jude and Deboe 1996); however, round gobies apparently are not restricted to these habitats (Jude et al. 1992). In Lake Michigan, round gobies are abundant on cobble and sandy substrates, although adults were less abundant on sand than juveniles (Jude et al. 1992).

Knowledge of the area normally used by a species during its feeding activities, the habitat types used most often by a species and the times when a species is most active are all valuable data for the fisheries manager. Accurate estimates of these three biological attributes are almost impossible without some direct measure of fish movement, such as that obtained by underwater observations (Helfman 1986).

A common application of underwater SCUBA methods is in estimating population abundance (Russell et al. 1978). Counts made by divers can be used as estimates in or as an aid in planning or verifying counts made in an indirect manner (Barans 1982). An initial qualitative survey by divers can help determine if a target species occurs in schools or individually. This is important with respect to the assumption of random distribution of marked fish in a mark-recapture program. Differences in species' locales by day and night can be rapidly assessed after a few short dives. This can prevent over or underestimation of population size if only depth range or time period is sampled by an indirect method (Loesch et al. 1982). Use of underwater observation for surveys of benthic species has been limited and information on the precision and reliability of estimates is lacking. The fact that underwater observation is not a common technique for assessing benthic species abundance may be due to the assumption associated with its more unusual application to large, highly visible species in waters of good clarity (Ensign et al. 1995).

The accuracy of visual surveys has frequently been questioned, though rarely tested, because the bias has been difficult to measure. Several sources of bias have been identified such as the failure of an observer to notice individuals, the presence of the observer, observer experience, observer speed, and fish detectability (Sale and Sharp 1983). If there is an "against" component of movement of fish with respect to the diver, the visual counts will overestimate density. An underestimation of density occurs when there is a "with" component of fish movement with respect to the diver. This positive or negative bias increases with increasing speed of fish (Watson et al. 1995).

In the previous study (chapter I), I showed that the round goby was able to successfully invade the western basin of Lake Erie. Despite the status of the round goby, little is known about its behavior or habitat requirements. To understand the consequences in respect to the native species one must know more about the habitat preference and characteristics of the round goby. This study was undertaken specifically to determine: if there is a difference between the number of round gobies found in rocky habitat or sandy habitat, if there are any differences between the number of round gobies found during the day and night in a particular habitat, and the interaction between habitat and light. These questions were addresses by the use of underwater transect survey. Finally, the densities of round gobies were determined by the underwater transects, quadrats and visual observations.

Methods

Site Selection

Three areas were chosen where gobies were known to have occurred for at least two years prior to the study. The areas chosen were the St. Clair River (Sarnia), Lake St. Clair (Town of Belle River), and the Detroit River (Peche

Island). These areas were selected using the following criteria: (i) the presence of round gobies, (ii) the presence of both rocky and sandy habitat, (iii) sites had to be easily accessible, and (iv) all sites had to have similar depth. At each site two habitats were selected, one representing soft substrate (sandy) and the other having hard substrate (rocky). All sites were approximately 3 to 5 m in depth.

Transects

Three transects were surveyed in each habitat (sandy and rocky) during the day and night in June and July [Peche Island (June 12 and 13), Sarnia (June 28 and 29) and Belle River (July 8 and 9)], 1996. At each transect a 50 m tape was placed on the substrate. After an interval of 10 minutes to allow the fish in the area to return after disturbance from laying out the tape measure, a SCUBA diver swam along the transect. A one metre pole was held in front, perpendicular to tape meassure, of the diver so that fish could be tallied within an area 50 m^2. Ruled marks along the pole were used to estimate the size of the gobies observed. The diver recorded the information on an underwater notebook. Other fish species observed were also recorded. This procedure was used for day and night transects. Underwater lights were used at night to enhance observations. Two small underwater lights (high light intensity) were attached to the air tank and angled downward while a third larger light was held by the scuba diver. Preliminary observations indicated that the use of underwater lights at night would neither attract nor repel gobies.

Statistical Analysis

To detect if there was a significant difference between the mean number of gobies observed during the day/night, rocky/sandy habitat, and among the three sites, a three factor (Light x Habitat x Site) Analysis of Variance (ANOVA) was performed using SYSTAT.

Length - Weight relationships were determined for round gobies at the three sites using regression analysis. Analysis of variance was also used to determine if there were significant differences in mean number of round gobies and other fish species found in different habitats and photoperiods among the sites. Analysis of variance also was used to determine if there were significant differences between the sizes of gobies that were observed in the different transects.

Gobies collection

A minimum of 30 gobies were collected by using a benthic otter trawl (5 m with a 2 m x 1 m mouth and a 2 cm mesh cod end), at each of the three sites. All gobies were sexed, measured (total length), and weighed (gape height, and gape width also were determined).

Quadrat Study

In order to associate densities of round gobies found in the transect study one needs to determine the accuracy of the transect by use of quadrats. A quadrat study was conducted in Detroit River (Peche Island) to determine the density of round gobies during July, 1997. Quadrats were made of cement filled ABS pipes with dimensions of 1 m x 1 m. Twelve quadrats were placed on the bottom of the rocky habitat in 3 m of water. A SCUBA diver would count the number of gobies in the quadrat area including underneath rocks to determine the density.

Results

At all three locations round gobies were found in both sandy and rocky habitat. Results of the three factor ANOVA indicated that the light regime, habitat, and site significantly influenced the number of gobies seen in the 50 m^2 transect (Table 2.1). The interactions between light/habitat and light/site significantly influenced the number of gobies observed (Table 2.1). The highest F value (1292.54) was noted for differences among sites and the highest densities observed occurred at Sarnia, nearby where round gobies where first reported. The number of gobies seen in the 50 m^2 transect for the Sarnia site ranged from about 250 gobies to 450 gobies per transect. Round gobies densities were lower at the Peche Island (20 to 175 gobies/50 m^2 transect) and Belle River (30 to 175 gobies/50 m^2 transect) than at Sarnia (Figure 2.2).

Round gobies were more abundant in the rocky habitat than in sandy habitats. Similarly, round gobies were observed more often during the day than at night. Gobies were also more abundant on rocky substrate than sandy substrate during either the day or night.

Species

Species other than round gobies also were recorded during the transect survey. Results of the three factor ANOVA indicated that light, habitat, and site significantly influenced the mean number of species observed in the 50 m^2 transects (Table 2.2). Once again, largest differences were recorded among sites (F-value=73.92). The mean number of species observed ranged from

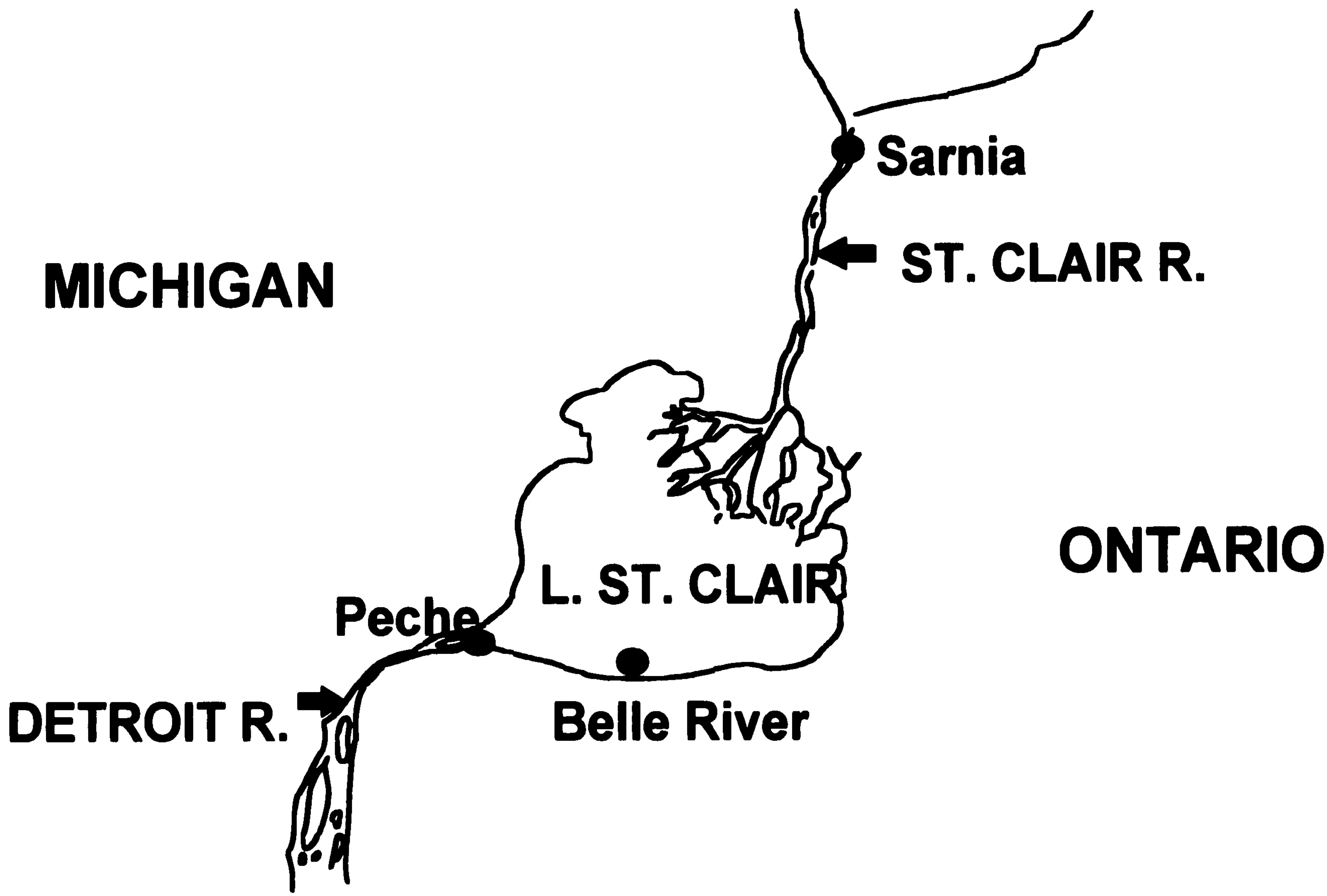


Figure 2.1 Map of study area indicating location of sampling sites (closed circles), 1996.

Table 2.1 Summary of the 3-way ANOVA to examine differences of the mean number of gobies in rocky/sandy habitat, during day/night, and at each of the three sites.

Dep Var: round gobies N: 36 Multiple R: 0.996 Squared multiple R: 0.993

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
LIGHT	69696.000	1	69696.000	296.93	0.000
HABITAT	49877.778	1	49877.778	212.50	0.000
SITE	606775.722	2	303387.861	1292.54	0.000
LIGHT*HABITAT	14802.778	1	14802.778	63.07	0.000
LIGHT*SITE	857.167	2	1428.583	6.09	0.007
HABITAT*SITE	938.389	2	469.194	2.00	0.157
LIGHT*HABITAT*SITE	1007.389	2	503.694	2.15	0.139
Error	633.333	24	234.722		

Durbin-Watson D Statistic 2.549
First Order Autocorrelation -0.294

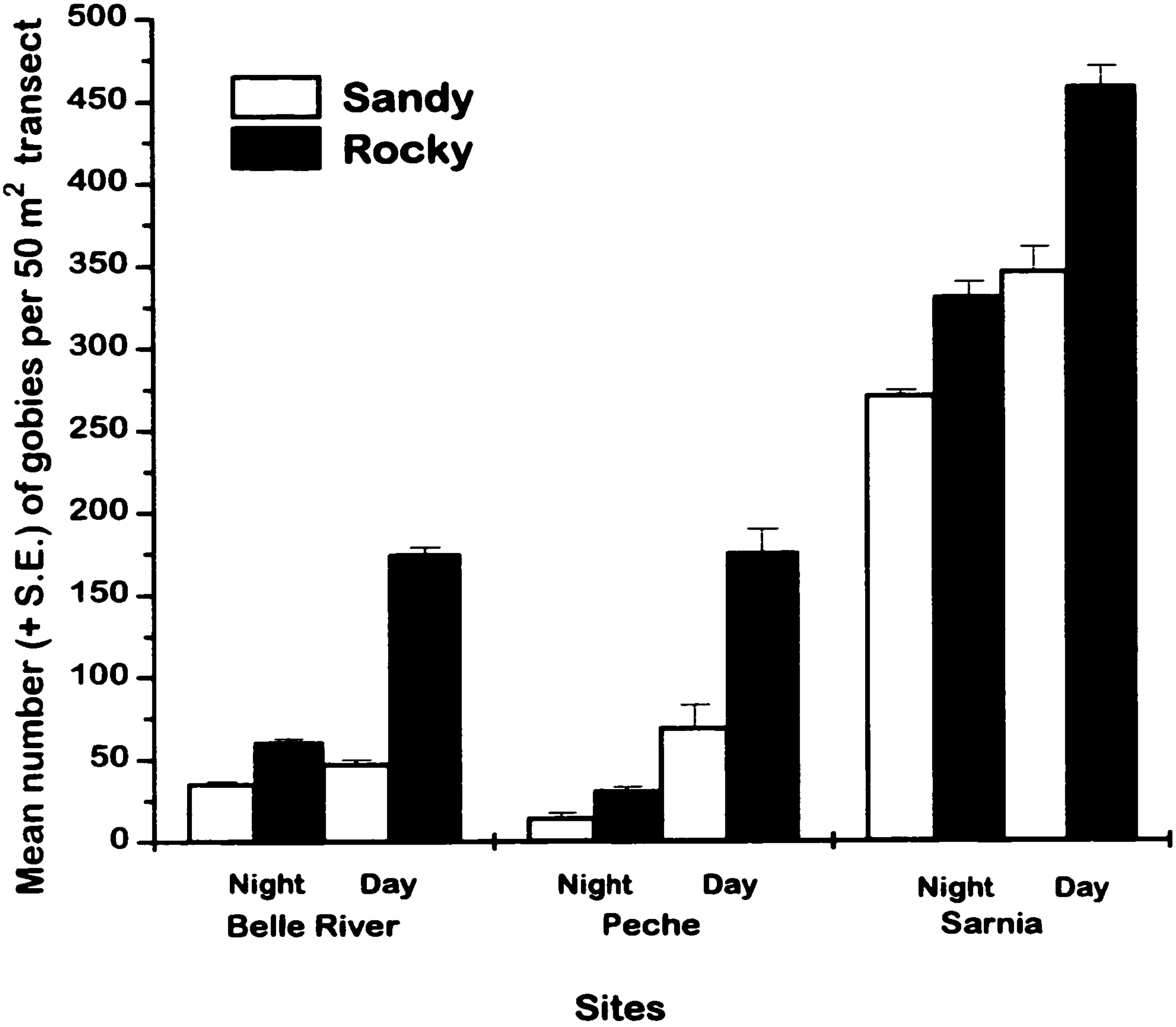


Figure 2.2 The mean number of round gobies observed in transects for rocky and sandy habitat in night and day at three sample sites.

Table 2.2 **Summary of the 3-way ANOVA to examine differences of light** regime (day/night), **habitat, sites and their interactions** (n = 36, R^2 = 0.85, different species).

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
LIGHT	26.694	1	26.694	73.92	0.000
HABITAT	10.028	1	10.028	27.77	0.000
SITE	2.667	2	1.333	3.69	0.040
LIGHT*HABITAT	3.361	1	3.361	9.31	0.005
LIGHT*SITE	0.889	2	0.444	1.23	0.310
HABITAT*SITE	4.222	2	2.111	5.85	0.009
LIGHT*HABITAT*SITE	0.222	2	0.111	0.31	0.738
Error	8.667	24	0.361		

Durbin-Watson D Statistic 2.410
First Order Autocorrelation -0.231

approximately 1 to 5 species per 50 m^2 transects for each of the three sites. More species were seen in rocky habitat during the night than at any other time or habitat (Figure 2.3).

The different species that were observed were yellow perch, white perch, log perch, northern madtom, tubenose goby, darters, shiner, white sucker, smallmouth bass and crayfish (Appendix 1.1). All fish were observed within the 50 m^2 transects, all other species observed outside of the area were not recorded.

Size of gobies

During the underwater transects, the round gobies were classified into two categories of size, small and large. Round gobies were determined to be either $<$ 5 cm (small) or $>$ 5 cm (large). Results of the 3-way ANOVA for the small size class of round gobies indicated that the light, habitat, and site significantly influenced the mean number of gobies observed in the 50 m^2 transect, with largest differences (F-value=47.83) among sites (Table 2.3). The mean number of small round gobies ranged from approximately 10 to 70 gobies for the Peche Island site, and approximately 5 to 20 gobies for Belle River and Sarnia Sites (Figure 2.4). More small round gobies were observed during the day in the sandy habitat at the Peche Island site than in any other habitat or site.

Results of the 3-way ANOVA for large round gobies ($>$ 5 cm) indicated that light regime, habitat, and site significantly influenced the mean number of gobies observed in the 50 m^2 transects (Table 2.4). The interactions between light/habitat, light/site and habitat/site also influenced the mean number of round

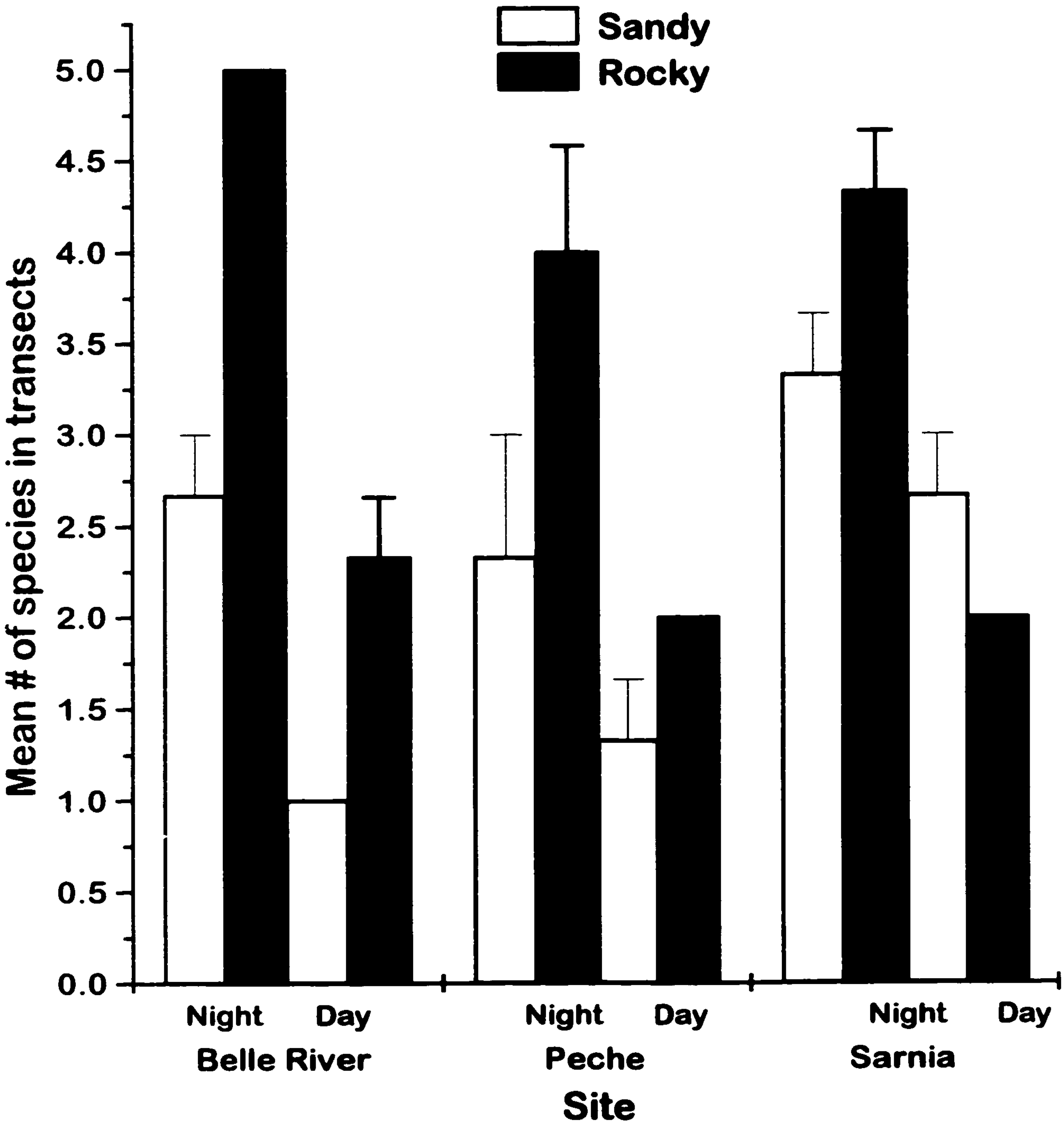


Figure 2.3 The mean number of fish species observed in transects for rocky and sandy habitat in night and day at three sample sites.

Table 2.3 Summary of the 3-way ANOVA to examine differences of light regime (day/night), habitat, sites and their interactions (n=36, R^2 = 0.85, goby < 5 cm).

Source of Var.	Sum-of-Squares	df	Mean-Square	F-ratio	P
LIGHT	1921.361	1	1921.361	34.07	0.000
HABITAT	1806.250	1	1806.250	32.03	0.000
SITE	5394.667	2	2697.333	47.83	0.000
LIGHT*HABITAT	66.694	1	66.694	1.18	0.288
LIGHT*SITE	3338.889	2	1669.444	29.61	0.000
HABITAT*SITE	120.667	2	60.333	1.07	0.359
LIGHT*HABITAT*SITE	32.889	2	16.444	0.29	0.750
Error	1353.333	24	56.389		

Durbin-Watson D Statistic 2.748
First Order Autocorrelation -0.380

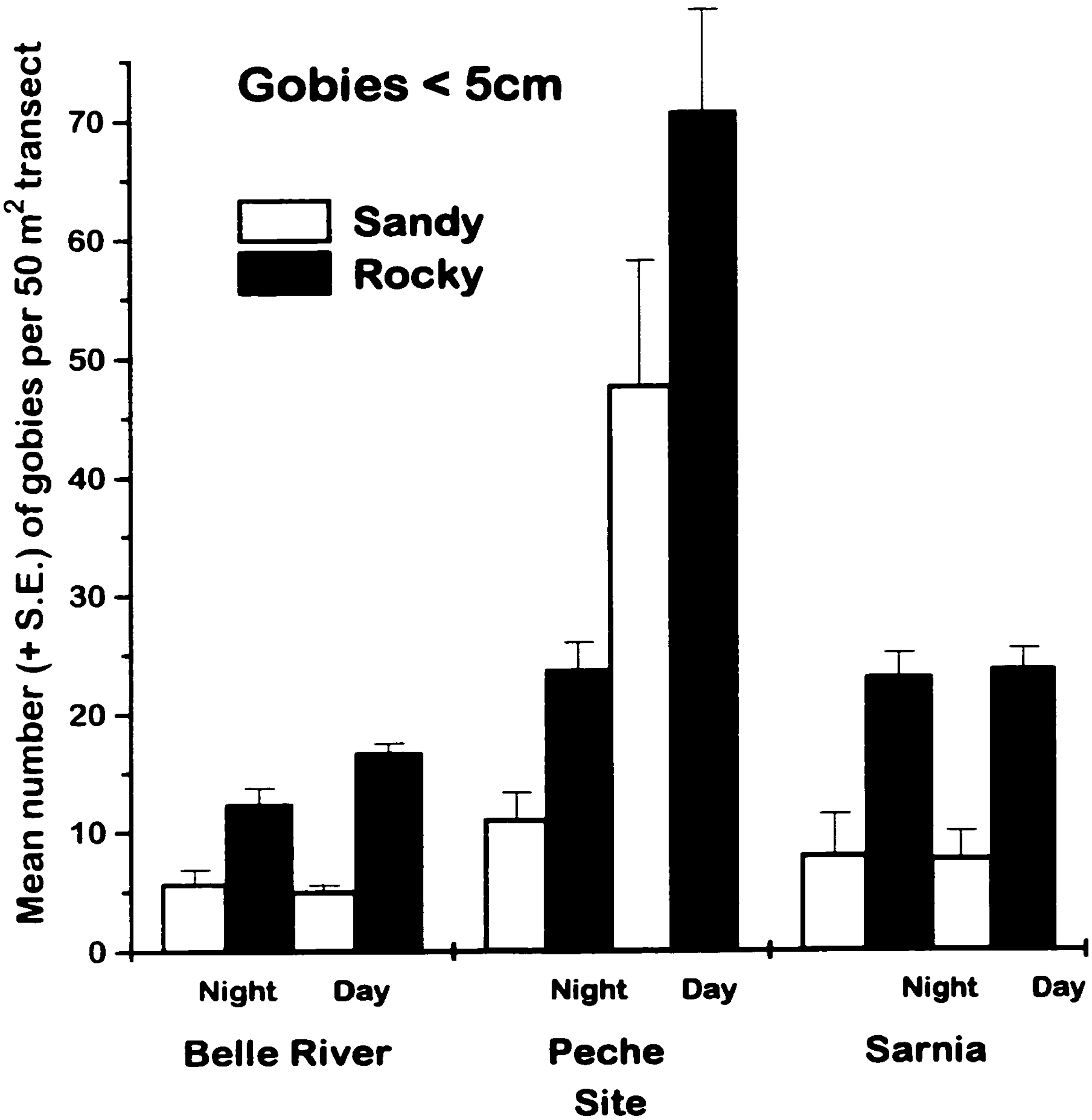


Figure 2.4 The mean number of round gobies < 5 cm observed in transects for rocky and sandy habitats in night and day at three sample sites.

Table 2.4 **Summary of the 3-way ANOVA to examine differences of light** regime (day/night), **habitat, sites and their interactions** (n = 36, **R** ^{2} = 0.994, **goby** > 5 cm).

Source of Var.	Sum-of-Squares	df	Mean-Square	F-ratio	P
LIGHT	48473.361	1	48473.361	274.55	0.000
HABITAT	32700.694	1	32700.694	185.22	0.000
SITE	652052.389	2	326026.194	1846.59	0.000
LIGHT*HABITAT	12882.250	1	12882.250	72.96	0.000
LIGHT*SITE	3572.722	2	1786.361	10.12	0.001
HABITAT*SITE	1310.389	2	655.194	3.71	0.039
LIGHT*HABITAT*SITE	797.167	2	398.583	2.26	0.126
Error	4237.333	24	176.556		

Durbin-Watson D Statistic 2.606
First Order Autocorrelation -0.343

gobies observed with largest differences (F-value=1846.59) among sites. For Sarnia, the mean number of round gobies observed ranged from 250 in sandy habitat at night to 425 during the day in rocky habitat. The mean number of round gobies observed for Belle River ranged from 25 gobies in sandy habitat at night to 150 gobies in rocky habitat during the day. Lastly, for Peche Island there was significantly fewer large round gobies (5 to 80 gobies per 50 m^2 transect) (Figure 2.5).

Densities of gobies

The densities of round gobies were examined for three different bodies of water (St. Clair River, Lake St. Clair and the Detroit River). The densities of round gobies ranged from 5 to 9 gobies/m^2 (St. Clair River), 0.5 to 3 gobies/m^2 (Lake St. Clair) and from 0.3 to 3 gobies/m^2 (Detroit River) (Figure 2.6). These densities were calculated from observations of the 50 m^2 transects. Observations in the St.Clair River, in rocky habitat, showed that round gobies were able to aggregate up to 90 gobies/m^2. This was observed between dives in approximately 4 m of water during the transect study.

Quadrat Study

The mean densities of round gobies were compared using two different techniques. When the densities of gobies were calculated by observational 50 m^2 transects the mean number of gobies seen was approximately 4 gobies/m^2 (n=3, S.E.= ± 14.88). When quadrats (July 29, 1997) were placed in the rocky habitat where the transects (June 19, 1996) were taken, the mean densities of gobies was observed to be approximately 19 gobies/m^2 (n=12, S.E.= ± 4.40). This value

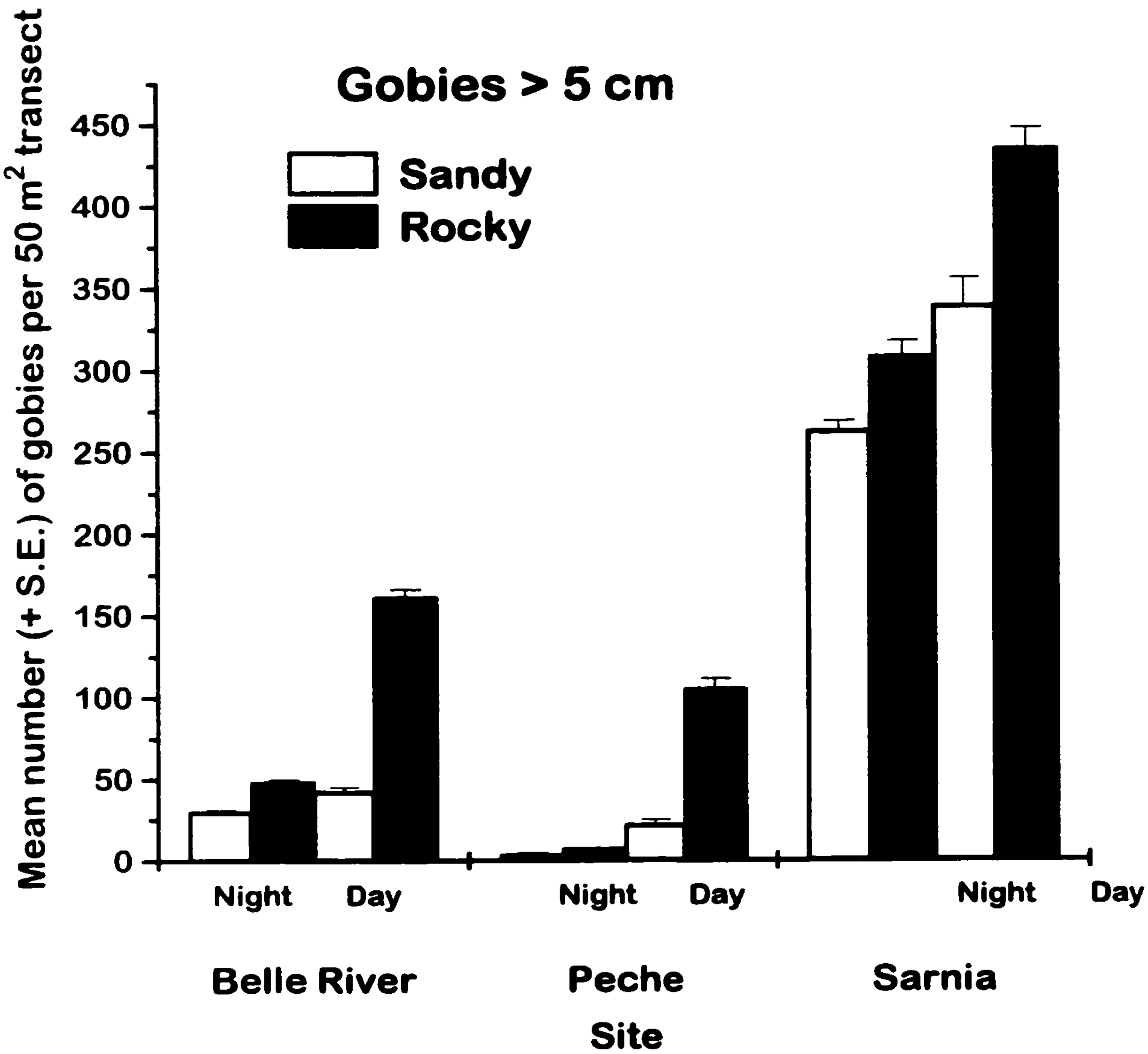


Figure 2.5 The mean number of round gobies > 5 cm observed in transects for rocky and /sandy habitats in night and day at three sample sites.

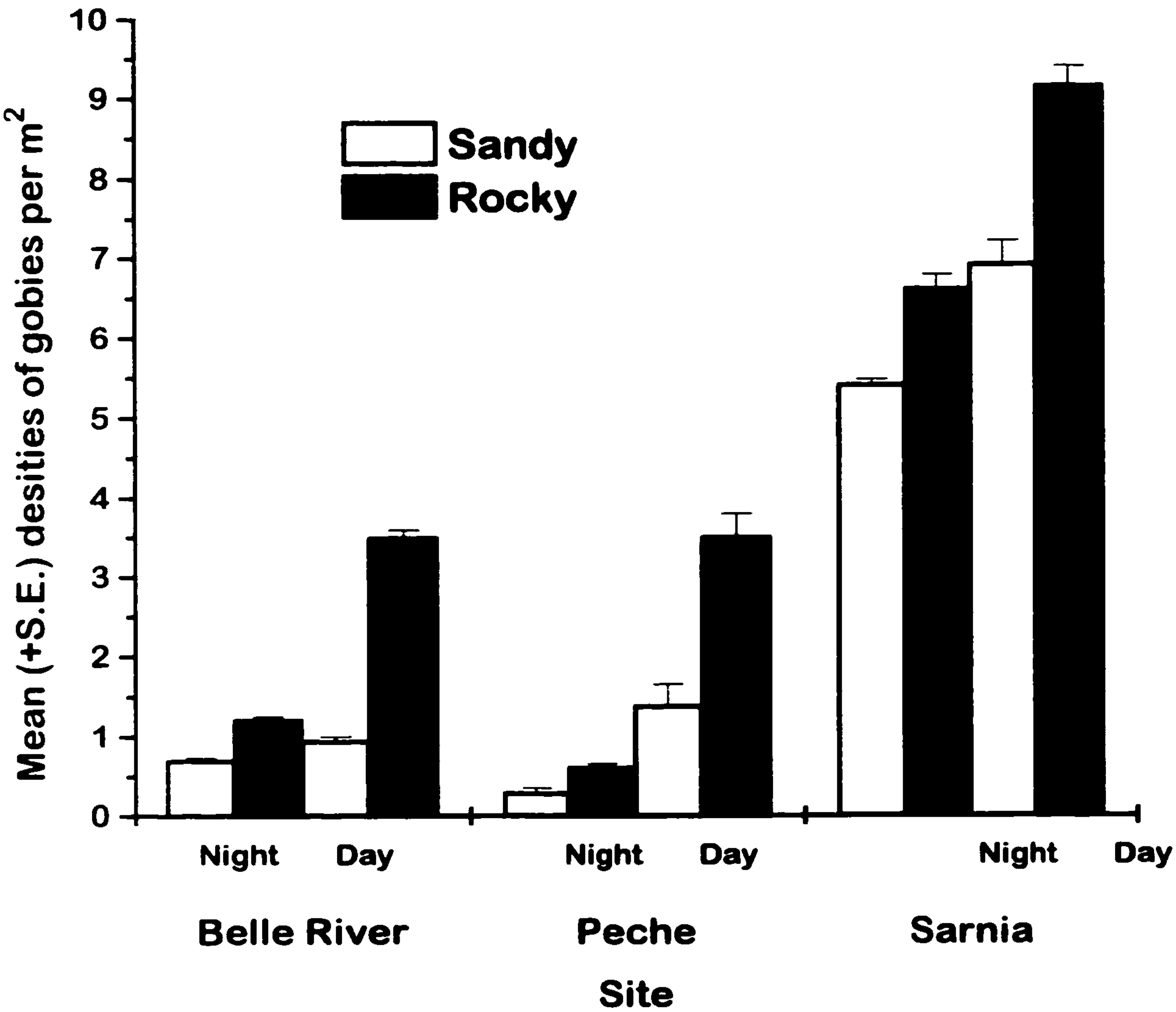


Figure 2.6 The mean densities (1 m ^{2}) of round gobies observed in transects for rocky and sandy habitats in night and day at three sample sites.

(not directly comparable) is considerably higher than the value found in the transect study which indicates that there may be an underestimation of round goby density in the transect study.

Reproduction

During different transects studies several nests of gobies were observed. Gobies' nests were observed at approximately 14 m in the middle (mid point across the river) of the St.Clair River on a shipwreck (Monarch), as well as, in rocky habitat at approximately 4 m. During transects in sandy habitat offshore from Belle River, I observed round gobies to have laid their nests in crayfish burrows. One nest was approximately 30 cm x 30 cm. The male goby was observed guarding the entrance to the burrow.

Discussion

A central goal of ecology is the identification of the roles that abiotic factors play in determining the distribution and abundance of species (Ensign et al. 1995). I used line transects to determine habitat preference of the round goby. Three basic assumptions underlie valid line transect estimations:(1) objects on the line of travel are detected with certainty, (2) objects are detected at their initial location, and (3) all measurements are exact. Without ancillary data (i.e., an alternative manner of determining if fish on the line of travel are being missed), it is difficult to assess whether the first assumption is violated. (Ensign et al. 1995). However, round gobies are not easily spooked when a diver passes over them. Divers were able to swim one metre above the fishes without disturbing them. Another aspect, is the reaction of fish to lights during night dives. Fortunately, round gobies did not exhibit any behavioural response to underwater lights at nighttime. Gobies did not approach or retreat when a flashlight was beamed directly at the fish.

In this study, round gobies used both rocky and sandy habitats. However, significantly more round gobies were observed at rocky than sandy habitats. The habitat complexity of rocky substrates and corresponding increase in refuges probably accounted for the higher density of fish. There was also a significant difference in the number of gobies that were found at the three different sites. Since round gobies were first recorded in the St. Clair River (Jude et al. 1992) one would expect the St. Clair River site to have a higher population density than other sites. One would expect also that the populations at the other two sites would continue to increase and eventually reach the densities that are found in the St. Clair River. Jude et al. 1995 stated that the round gobies are not expected to become abundant in nearshore areas of the Great Lakes, including Lakes Michigan and Huron, where sand bottoms predominate. However, round gobies occupy sandy habitat in all three study areas that I examined. Densities of round gobies are much lower in sandy habitat but when compared to densities of other fish species round gobies have a higher density per unit area.

Fish were generally uniformly distributed across the transect both day and night within sites. Occasionally, fish were clumped into dense, large aggregations on a small spatial scale during the day, but over a larger spatial scale, the distribution tended to be uniform from observations during the transect.

Differences in photoperiod activity of a species can be related to differences in environmental factors (e.g. risk of predation, competition, presence of food) (Helfman 1986). Several factors can affect variation in fish density (Maclennan and Simmonds 1992) and should be considered in sampling designs regardless of sampling equipment. Diel differences are mediated by fish behaviour which changes with light level and time of day. For example, gizzard shad demonstrate schooling behaviour during the day and disperse at night, similar to other fishes (Maclennan and Simmonds 1992). Also, diel patterns could be significantly affected by the vertical migration of fish in response to food availability (Baumann and Kitchell 1974) and predation (Carter and Goudie 1986), which generally follow cyclic patterns. Fish behaviour can also change throughout the day, switching between feeding, swimming, courtship or spawning. In my study, round gobies were significantly more active (movement and interactions with other fish) during the day then at night which was evident in the number of gobies that were seen during transects. The round goby is capable of feeding during the day and also at night owing to the well developed lateral line system. In another study (chapter 3), I showed that round gobies feed more during the day then at night. When fishing using hook and line it is very easy to catch gobies during the day, however, the number of gobies caught during the night is reduced. Jude et al. (1992) stated that they observed gobies moving onto sandy beaches to feed at night. However, in our study round gobies were very inactive at night. After transects were conducted, I observed that round gobies were nestled under rock and crevices in the sand at night. It was very common to overturn a rock and find 4 - 6 gobies resting underneath with crayfish. Since, the majority of prey items that round gobies consume are zebra mussels (Ghedotti et al 1995; Ray and Corkum 1997) it does not matter what time of day gobies feed because the food resource is always available and the competition for food is likely low. Therefore, one factor that may be controlling the diel movement of the round goby would be the risk of predation.

If growth potential and mortality differ among habitats, then fishes forced into sub-optimal habitats may be vulnerable to predation due to feeding habits. The mean number of different species that were found at the three sites during the line transects ranged from 1 to 5 species. There was a significant difference between the number of different species observed at night than during the day and also between rocky and sandy habitats. There, was no significant difference in the number of species found among the sites. Some potential predators of the round goby include smallmouth bass, walleye, rock bass, and yellow perch. Other fish exhibit similar behaviour of the round goby. For example, *Cottus* is a nocturnal feeder, whereas *Percina* and *Etheostoma* are, typically active during the day. All species seek cover at night, suggesting these fish may be particularly sensitive to predation at night. Thus, it is most likely that round gobies are inactive at night to avoid predation by smallmouth bass, a nighttime feeder. Throughout the study, I observed that smallmouth bass would swim down and consume a round goby when it was exposed from under a rock. This occurred at the Peche Island site during the night transects in rocky habitat. It has also been observed at Colchester reef (during the day) in July of 1996. I observed a large school of smallmouth and rock bass hovering over rocks under which gobies were hiding. When a rock was disturbed, round gobies would dart out and be consumed by the smallmouth bass. Approximately 10 gobies were consumed by different smallmouth bass over a period of 5 minutes. The behavioural data of the round goby are consistent with the notion that the benthic-invertebrate feeding guild is sensitive to predation, in terms of both behaviour and habitat use (Greeensburg 1991).

Round gobies were more abundant in rocky habitat than in sandy habitat and were more abundant in the day than the night. The densities of round gobies ranged from 1 to 9 gobies/m^2. However, the results of the transect studies are most likely underestimated. An additional study was conducted with quadrats at the Peche Island site. Results from the transect study indicated that round goby densities were 4 gobies/m^2. In contrast, results from the quadrat study indicated that the round goby densities were 19 gobies/m^2. The difference in time when the studies were conducted may explain some of the differences but also hidden fish were not scored in the transect survey. Additionally, round gobies aggregated in groups from 30 - 70 gobies/m^2 and the highest density of gobies observed was 90 gobies/m^2. The highest goby density in 1996 that were found in the central basin of Lake Erie ranged from 1.8 m^2 (Fairport Harbour) to 6.3 m^2 (Watterworks)(K. Baker, Heidelberg College, pers. comm.). K.Baker has observed round goby densities to be as high as 17 m^2 in 1995 at Fairport Harbour (Central basin of Lake Erie). Similarly, Marsden et al. (1996) reported densities of over 40 gobies/m^2 at Calumet Harbour, Illinois in 1995. Throughout the Great Lakes the round goby has been able to reproduce and attain high density that might alter the present community composition.

Throughout the study, several round goby nests were observed. The most interesting nest that was observed was at the Belle River Site where a large nest guarding goby (10 cm in total length) was seen sticking his head out of a crayfish burrow. I dug up the burrow and noticed a nest underneath the sand and clay. The nest measured approximately 30 cm x 30 cm with eggs covering the ceiling of the nest. Nests are generally under rocks, logs and cavities (Charlebois et al. 1997). The ability to lay nests in soft substrate indicates that round gobies may be able to use sandy habitat throughout the Great Lakes.

Generalist species, as a consequence of their ability to exploit a wide range of resources, become both widespread and abundant, or alternatively, the resources used by some species are more abundant and widespread than those of other species, resulting in a correlation between abundance and distribution (Meekan et al. 1995). The influences of habitat on species distribution may change when examined over different spatial scales (Norton 1991). The differences in resource availability and habitat use may result in different densities on different habitats for round gobies.

In summary, these studies have shown that round gobies prefer rocky habitat over sandy habitat but are capable of surviving and reproducing in both. Round gobies are more active during the day than at night likely due to risk from predation. Round gobies densities are underestimated for transect studies, but the transects are still capable of giving a estimate of the relative abundances of densities. Due to unlimited prey resources and its ability to reproduce in different environments, the round goby will most likely disperse throughout the Great Lakes.

CHAPTER III. SITE AFFINITY AND HOME RANGE OF THE ROUND GOBY IN THE DETROIT RIVER.

Introduction

Home range is the area over which an animal normally travels, in contrast to a territory which is any defended area (Grant and Kramer 1990). A territory is an actively defended area involving energy expenditure, and thus territory size might be expected to be functionally related to metabolic activity (Minns 1995). The larger home range can be influenced by a variety of factors including diet (Norman and Jones 1984), predators and intraspecific interactions (Schoener and Schoener 1982). Individuals of many species have limited home ranges even during the nonbreeding season (Gerking 1953). Home ranges have been documented in freshwater fish but ecological and behavioural determinants of home range size are poorly understood. Minns (1995) concluded that home range sizes in fishes might be expected to be smaller in rivers than in lakes due to differences in fish assemblages betwen riffles and pools. Home range size also may increase with body size of the fish (Grant and Kramer 1990).

Round gobies have been known to be very aggressive when defending their nests (Wickett and Corkum 1998). Males defend their nests by spitting, flaring their gills, lunging, biting, and producing a growling sound for 1-1.5 s (Protasov et al. 1965). However, there is no evidence indicating that round gobies in the Great Lakes, Black and Caspien Seas are territorial although they might have a limited home range.

When examining the home range of a species it is necessary to consider the resources needed by the organism to survive. Habitats with higher productivity should result in smaller home ranges for an individual. This is simply a consequence of a smaller area being able to meet the metabolic needs of the consumer (Harestad and Brunnell 1979). Gobies are benthic feeders, and their diet is primarily composed of crustaceans and molluscs, including zebra mussels. The diet of round gobies in the Sea of Azov consisted of 78% molluscs, 10% crustaceans, 6% worms and 3% fish (Kovtun 1978). In the Great Lakes, the round goby diet consists of zebra mussels (39%-82%), *Gammarus*, *Ephemeroptera*, *Oligochaeta, Ostracoda,* and *Decapoda* (Jude et al. 1995, Ghedotti et al. 1995, Ray and Corkum 1997). Gobies can ingest zebra mussels whole and after digestion either spit the empty shell out or pass complete shells though the anus (Ray and Corkum 1997, Charlebois et al. 1997).

In lentic studies, radio- and ultrasonic telemetry methods, and mark-recapture methods are used to determine the home range of the species (Minns 1995). The cheaper mark-recapture method was used in this study.

Assumptions of the mark-recapture techniques include (1) constant effort being used, (2) no emigration, immigration, recruitment or mortality, (3) the probability of capture/recapture is the same for all individuals and remains constant with time and (4) marked individuals are easily and reliably identifiable (Naismith and Knights 1990).

Injection of chemical substances to form spots is a technique which offers greater individuality of marks (Hart and Pitcher 1969). Similarly, fin clipping has been a popular marking method used on many different types of organisms. Fin-clipping does not appear to affect the sustained swimming ability of fish (Radcliffe

1950). Partial fin-clips are often used in short-term mark-recapture experiments for estimating the numbers of fish in a particular body of water. Some tags or marks may increase mortality and affect the results of the study. Marks that change the behaviour of animals after release can affect the rate of tag recovery and can bias observations about the animals' habits (Wydoski and Emery 1983). Through the use of injection of acrylic paint for marking the round gobies the behaviour of the fishes will not change (personal obnservation).

A field study was conducted using mark-recapture methods (I) to examine whether the round goby has a low or high site fidelity; (II) to estimate population size of round gobies; (III) to determine whether male and female round gobies exhibit similar site fidelity; and (IV) to determine whether size of the round goby influences site fidelity. Also, an observational study using SCUBA was conducted to estimate the approximate home range of the round goby in the Detroit River.

Methods

Site selection

The Detroit River was selected for both the site affinity study (mark-recapture) and the home range studies (Observational SCUBA) because the site was nearby and selected locations were not frequently visited by others. I wanted an isolated area to avoid the problem of anglers catching marked fish. The mark-recapture study was conducted off a dock at the end of Lauzon road in Windsor, Ontario (Canadian side of the Detroit River) across from the eastern tip of Belle Isle in a depth of approximately 1.7 m. Both studies were conducted in September and October of 1996. The home range study (SCUBA) was conducted off the south shore of Peche Island 100 m off shore at a depth of 3 to 4 m.

Mark-recapture study

To determine site affinity of the round goby, a mark-recapture study was performed. Round gobies were caught using a hook and line using worms for bait. Round gobies that were caught were sexed (using papilla), measured (total length). The sex of the goby was determined by examining the external papillae. Male round gobies have a long, triangular-shaped papilla with a broad base and narrow tip. Female gobies have papilla that are shorter and rectangular in shape being broad at both the base and the tip, enabling eggs to be released. Each day, the numbers of round gobies that were caught were recorded. Each goby was then marked by injecting non-lethal acrylic paint into their cheeks by using a 3 cc needle and syringe. The color of dye indicated the day that the goby was captured. After gobies were marked, they were then returned to the water. A minimum delay of 48 hours before fishing was resumed to allow the fish to recover. After the first day, each fishing day consisted of fishing for several hours. Round gobies caught that had been previously marked were retained and frozen and returned to the lab. Round gobies that were not marked were marked using a different colour of dye to again indicate the specific day of capture. These fish were returned to the river. This process continued until 200 gobies were marked. Gobies were marked either on the left side or right side of the cheeks and with four different colours of acrylic paint (Blue, Red, Green, and White). There was no difference in the colour of paint remaining after recapture. A preliminary lab study that I conducted showed that round gobies were not affected by the injection of paint into their cheeks and that the dye could last for at least six weeks. McDonald (1969) found 12.5% mortality of 234 fish that were anesthetized with MS-222 (tricaine methanesulfonate), marked with Floy dart tags with nylon barbs, and then held in a net pen for 24 hours. When no anesthetic was used, McDonald recorded 9.1% mortality of 243 tagged fish that were held in a net pen for 48 hours. Thus, it was decided for this study that no anesthetics would be used to mark the fish. Round gobies were easily handled with not much stress being placed on them as they were injected with the paint. Repeated captures would suggest little effect on the behaviour of these fish from the repeated handling process or that they were repeatedly recaptured in refuge habitats (Heggenes 1988).

This study commenced on September 3, 1996 and was concluded on October 15, 1996. From September 3 to September 29th, 200 gobies were marked and this ended the marking period. An additional two weeks of fishing (Sept. 30 to Oct. 15) were conducted to recapture as many marked fish as possible. When the fish were returned to the laboratory, the sex and size was determined for each fish that was recaptured. Fishing was only conducted in a 1 m x 2 m area.

Population size of the round goby was estimated using the Peterson method (N=MC/R) where N is the population size, M is the number of gobies that were marked, C is the total number of fish recovered, and R is the number of marked fish that were recaptured (Diana 1995).

The habitat consisted of several large rocks covered with zebra mussels in approximately 1.7 m of water. Fishing was conducted during the day mostly when the gobies were most active (Chapter 2, personal observation).

Observational Technique to Determine Home Range

This study was conducted off Peche island in approximately 3 to 4 m of water in which the distance traveled by one round goby in one hour was delineated. This study took place between July 29 and August 12, 1996. Home ranges of round gobies were determined by following one round goby for 1 h (Eight round gobies were observed individually). The diver using SCUBA descended to the bottom where a goby in the size range of 5 - 10 cm was chosen. The diver then stayed as far away as possible to insure that the goby was not disturbed. As the round goby moved from area to area, the diver would drop coloured bolts (1 cm bolts painted with acrylic paint) where the goby was observed. The coloured bolts were used to represent different time intervals. For example, for the first five minutes the goby was observed and movement was noted by dropping red bolts. Orange bolts were used during the next five minutes of observation. At the end of one hour the area of the goby movements were measured by taking the furthest two distances that the goby traveled in an x, y co-ordinate plain. The area inhabited by the goby was determined by multiplying the two distances together to estimate home range size. The study was performed during the day when gobies were most active.

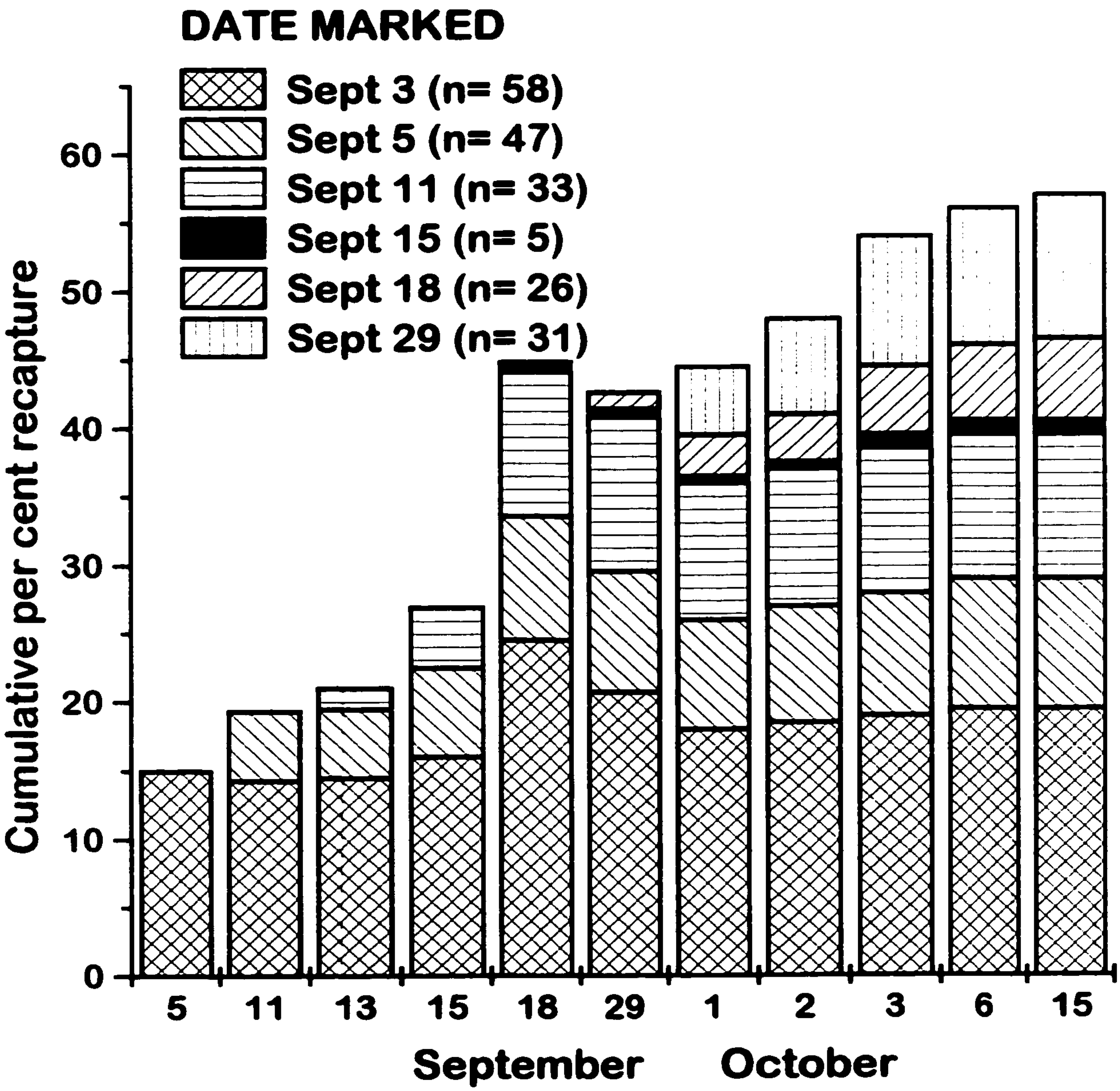


Figure 3.1 The cummulative per cent of round gobies recaptured in the Detroit River for sample date during 1996.

Results

Mark-recapture

During the period of September 3 to September 29, 200 round gobies were captured, marked and then returned to the water. Of the 200 gobies that were marked 108 were male and 92 were female. Figure 3.1, shows the cumulative per cent recapture of round gobies. A total of 58% of gobies was recaptured between September 5 to October 15. Round gobies that were marked on the beginning day (September 3) were still being recaptured 42 days later on October 15 (Figure 3.2). The high 58% recapture rate indicates that the round goby has very high site affinity. Between October 1 and October 15, 110 round gobies were caught that were not marked, indicating that round gobies can reach high densities in an optimal area (rocky substrate) or that round gobies were immigrating. The population size for the sampling area was calculated to be 396 round gobies.

Of the 115 gobies that were recaptured, 66 gobies were male and 49 gobies were female. The total per cent recapture for males was 61% and for females was 53%.

The total length of each goby was measured when marked and also when recaptured. The size of round gobies was divided into two arbitrarily size classes of < 9.5, and > 9.5 cm. Of the 145 small round gobies (< 9.5 cm) that were marked only 79 gobies (or 54%) were recaptured. In the larger size class of gobies (> 9.5 cm) only 45 gobies were marked and 36 (or 80%) of those were recaptured (Figure 3.3). Thus larger size gobies are more site specific then the

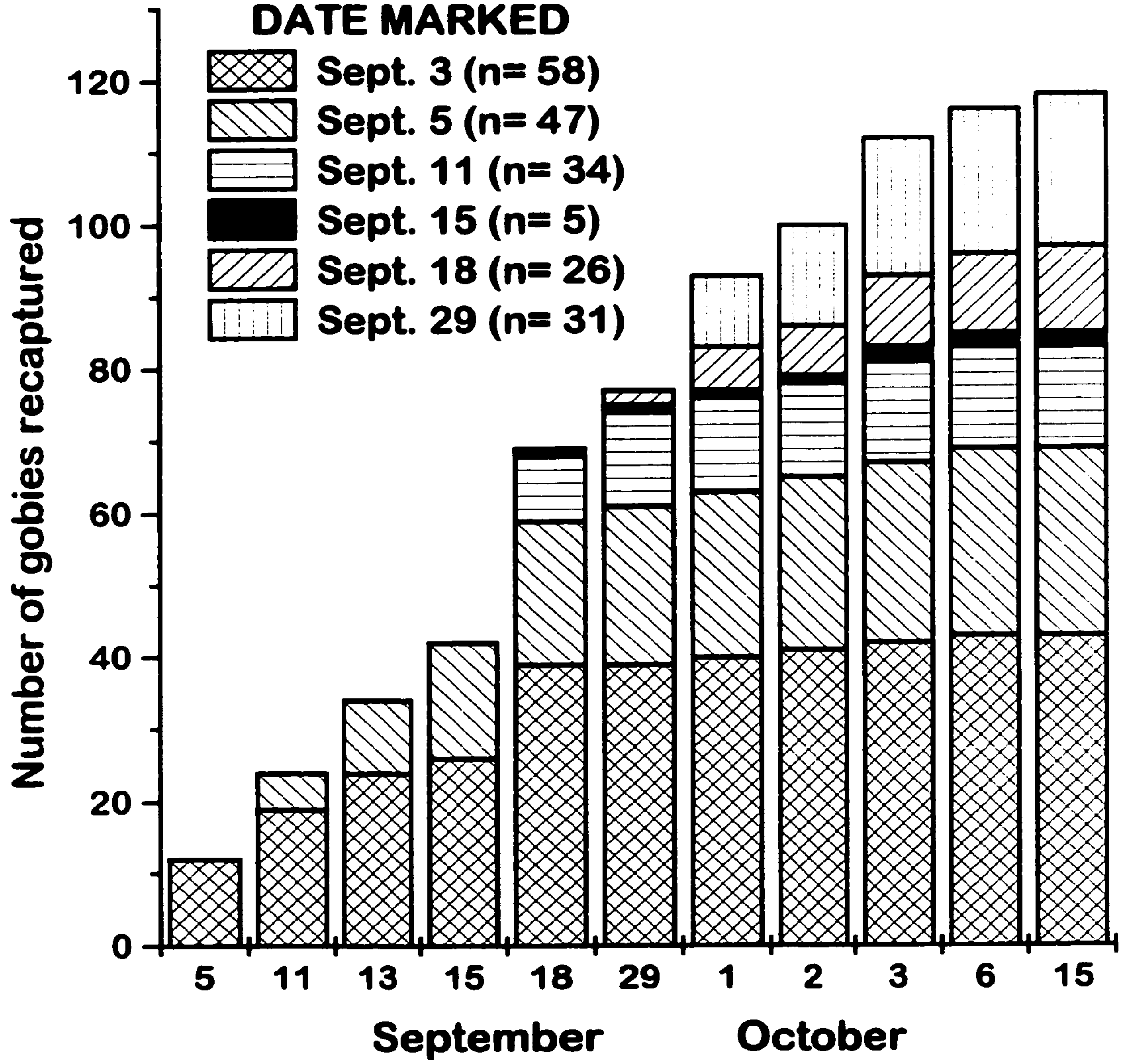


Figure 3.2 The number of round gobies recaptured in the Detroit River during 1996 (n=200).

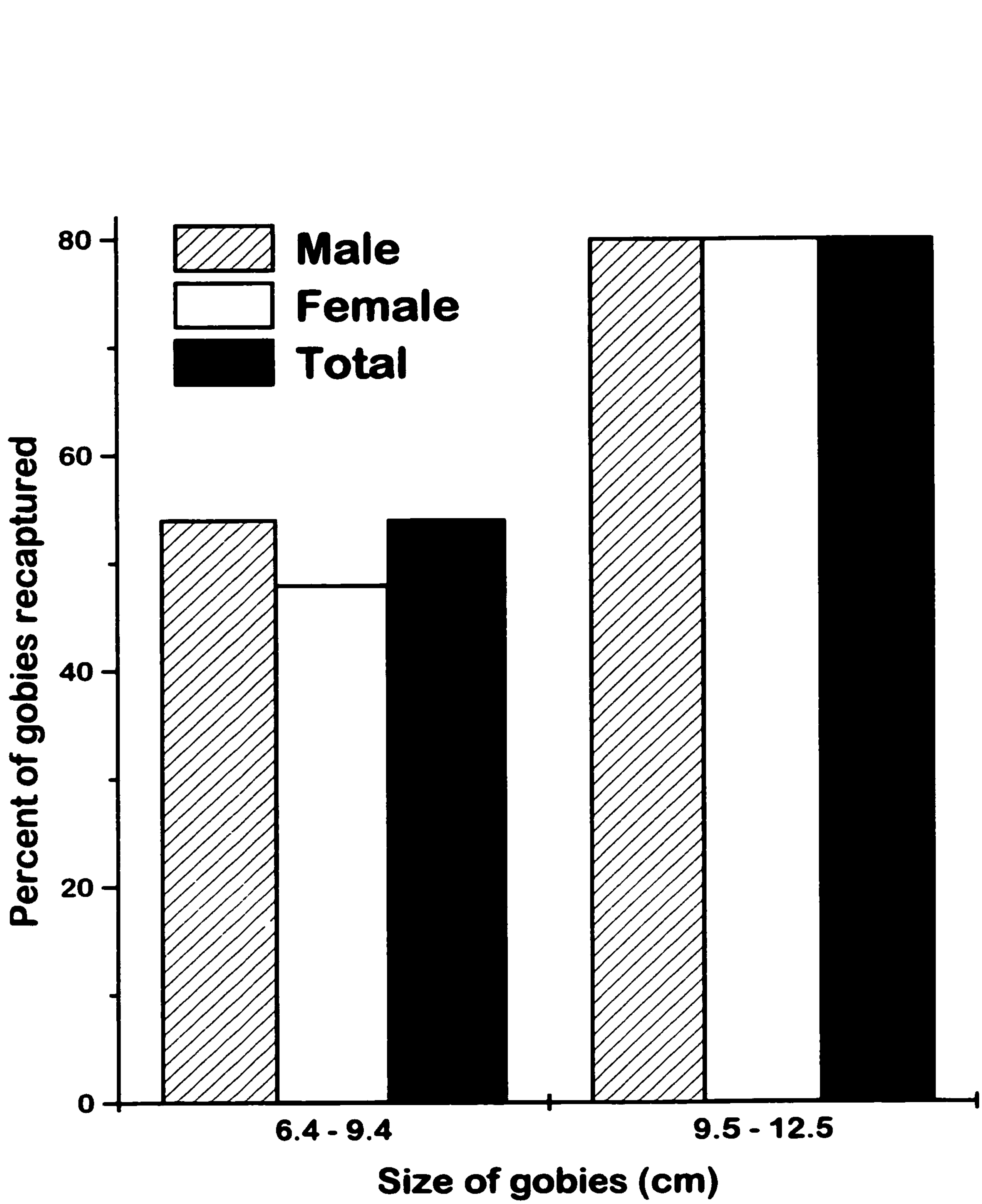


Figure 3.3 The percent of round gobies recaptured for different size classes of male and female gobies (n=200).

smaller size gobies or mortality is less for the larger size class.

All gobies that were recaptured still were easily identifiable by the acrylic paint that was injected into the cheek. This indicates that the injection of chemical substances to form spots is an excellent technique for the round goby for mark-recapture studies at least for the duration of this study, 1.5 months.

Observational Technique to Determine Home Range

Eight round gobies (TL: 7.0 - 10.0 cm) were observed using SCUBA for one hour each in the Detroit River off the Southwest shore of Peche Island. A total of 8 round gobies was observed individually and the home range area calculated for each. Figure 3.4 shows the mean home range area (m^2) of the round gobies for 60 minutes. The home range was estimated to be approximately 5 m^2 ($\pm$ 1.2 m^2) for the gobies in the Detroit River. During the observation period, numerous interactions were recorded. Some of these interactions included foraging for food, movement towards another goby, and movement away from approaching gobies. There were no other fish species observed during the observation period to indicate any predator-prey or interspecific competition. Some round gobies when observed for one hour reached the furthest distances in only 5 or ten minutes. However, the earliest mean time that gobies reached their maximum distance traveled (home range) in the study was after 30 minutes (Figure 3.4). Thus, at least 30 minutes of observation is required to estimate the home range of an individual round goby.

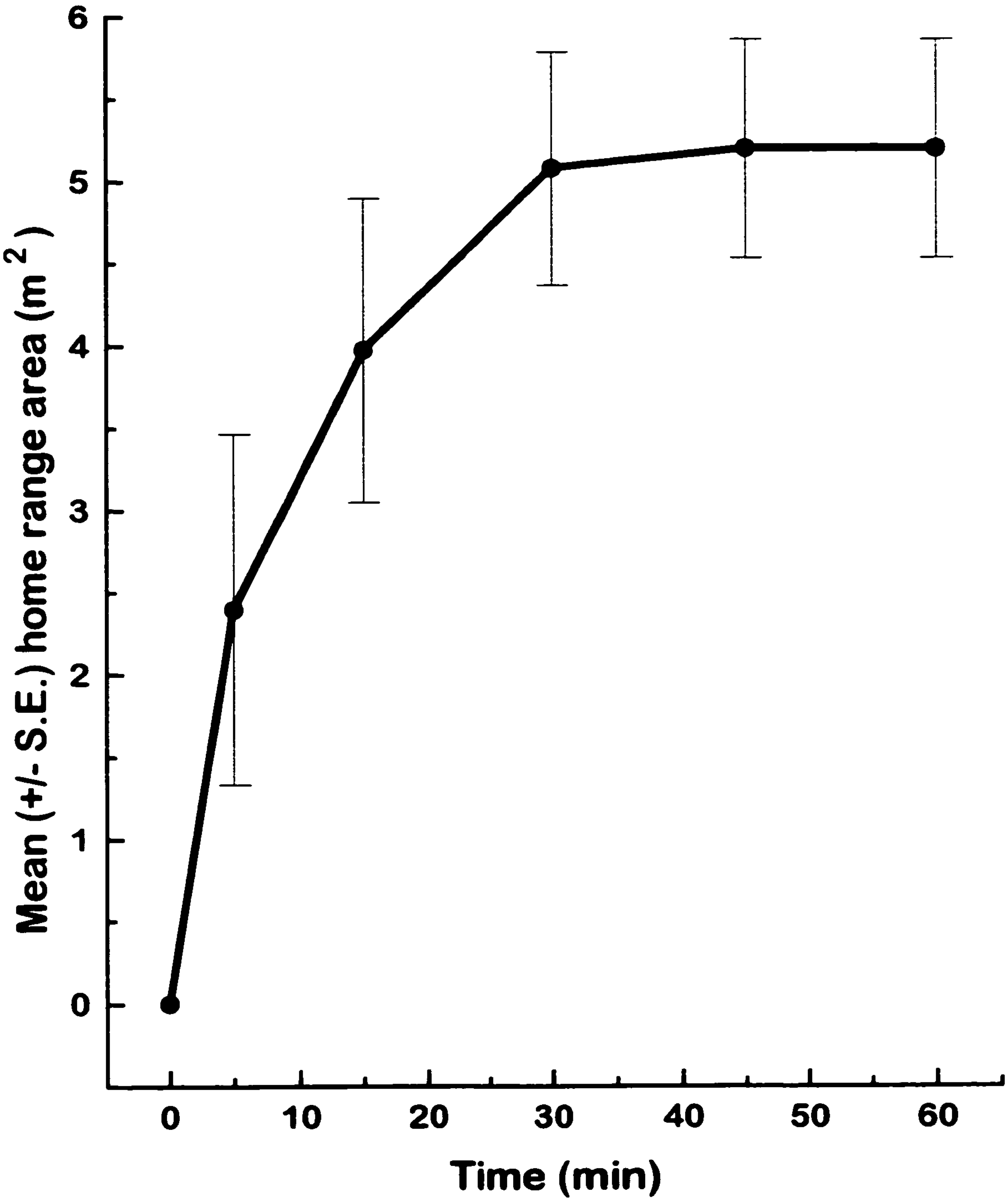


Figure 3.4 The mean (S.E.) home range area of round gobies for one hour observations in the Detroit River (n=8).

Discussion

Two assumptions of mark-recapture experiments are that marks are not lost and that mortality does not differ between marked and unmarked fish (Pierce and Tomcko 1993). Injections of acrylic paint in the cheek area of round gobies maintained in the laboratory lasts for several months (K. Wolfe, Illinois Natural History Survey, personal communication).

In Figure 3.1, the cumulative percent of round gobies that were recaptured was 58% out of a total of 200 fish that were marked. This indicates that round gobies have a high tendency for site fidelity. Since, movement of the round gobies were not followed, round gobies may be travelling a larger distance than indicated from the study. Round gobies tend to aggregate together (as high as 90 gobies/m^2, chapter 2) and stay in one area for the summer and early fall months. The longest time between marking a goby and recapturing that same goby was 42 days (Fig. 3.2). The majority (58%) of the fish that were marked were recaptured between 7 - 14 days (Fig. 3.2). This study shows that the round goby is site-specific and does not travel far considering that there was ample food resources (zebra mussels) available. Both biological (e.g. local density, food availability and fish size) and physical factors (e.g. habitat availability) have been suggested as being influential in fish movement and home range size (Hill and Grossman 1987 and Hestagen 1988). Since round gobies use various habitats (sand and rock areas) and food availability is abundant, the most likely factor that affects the round goby movement and home range would be local densities, fish size of round gobies and the influence of other fish species.

Among birds and mammals there are striking differences in the mobility of males and females (Downhower and Armitage 1981, Greenwood 1980, Wrangham 1981). Downhower et al. (1990) showed that there was no difference in male/female mobility in *Cottus gobio*. Similarly, this study showed that there were no differences between the number of round gobies males or females that were recaptured. A total of 108 male gobies was marked and 66 (61%) were recaptured, 92 females marked and 49 (53%) recaptured (Fig. 3.3), indicating that both males and females have similar site affinity.

Downhower et al. (1990) also showed that mobility of *Cottus gobio* was weakly associated with size of the fish in particular that larger fish were more mobile than smaller fish. In examining the differences among arbitrary size classes, there was a significant difference in the percent of gobies that were recaptured. Only 54% of small gobies (< 9.5 cm), and 80% of large gobies (> 9.5 cm) were recaptured. Figure 3.3 shows that the size of the goby played a crucial role in the site affinity of the round goby. Several factors may have attributed to the differences in the per cent recapture: (1) larger gobies may be displacing the smaller gobies to a different area outside of the sampling area; (2) smaller gobies may be more prone to predation from other fish; and, (3) stress from the injection of the paint might have been greater for the smaller gobies. Since, small round gobies were still recaptured several weeks after being marked, it is most likely that stress was not an important factor in explaining differences in recapture between small and large fish. Laboratory trials conducted indicate that mortality rate of round gobies from injections is low. The most likely factor in the difference between the size of gobies recaptured would be that as the population density grew in the small (1 m x 2 m) area, intraspecific competition was occurring for refuge space or that small fish emigrated. Food availability would not be a factor because small and large gobies utilize different prey items (Ghedotti et al. 1995; Ray and Corkum 1997). Smaller size gobies feed more on invertebrates than mussels whereas the large size gobies prey resource is almost entirely molluscs (Jude et al. 1995). Ray and Corkum (1997) showed that the size of zebra mussel consumed by a round goby presumably was limited by an individual's gape, which was positively related to body length. Two means of predator avoidance can be proximity of round goby to physical structure such as vegetation or rocks; and proximity round goby to other fish. The first is ambiguous because physical structure can serve as a feeding site in addition to a refuge from predators. The second is more satisfactory because there is little reason for juveniles to seek the presence of conspecifics, other than to avoid risk of predation. If individuals centered their home range on a refuge from predators, we would expect them to cluster with other fish at the edge of their home range. (Coleman and Wilson 1996). In this study, the mobility of round goby was strongly associated with size of the fish, indicating that round gobies may cluster to avoid predation. However, when the population size becomes too large the smaller round gobies may be pushed outside of their home range.

The home range of freshwater fish are smaller than those of terrestrial mammals, birds and lizards (Minns 1995). However, the home range size of different fishes vary. Some examples, from mark-recapture and radio-telemetry studies, are: *Cottus bairdi* (mottled sculpin) 83.9 m^2, *Micropterus dolomieu* (smallmouth bass) 2000 m^2, and *Salmo trutta*, (brown trout) 40-50 m^2 (Hesthagen 1990). The home range size that was calculated for round gobies (TL = 7.0 cm - 10.0 cm) was much smaller (5 ± 1.2 m^2) compared to the mottled sculpin (83.9 m^2). Due to the low number of fish (n=8) that were sampled, the home range size of round gobies may have been underestimated in my observational study. With the home range size of gobies being 5 m^2, this indicates that the round goby has very high site fidelity and tends to aggregate and may do so to prevent predation. Malinin (1969) stated that the location of a home range depends mainly on food resource availability. Since, my study was conducted in rocky habitat and the home range size was small (5 m^2) one might expect the home range of round gobies in sandy habitat to be larger. Round gobies can utilize a variety of resources and the necessary time and cost of searching for prey is greatly reduced.

Another possible explanation for small home ranges is that familiarity with the habitat increases foraging success (Coleman and Wilson 1996). The small home ranges observed are remarkable because they can be traversed in only a few minutes at a normal swimming speed and the fish are not restricted to their home ranges by either intraspecific aggression or by predators (Wilson et al 1993). Another common antipredator behaviour in fish is to seek the proximity of conspecifics (Pitcher 1986). Fish that were within three body lengths of each other were considered to be in an aggregation or cluster (Wilson et al. 1993). My observations showed that round gobies aggregate together and that no predators were observed. There is clearly something important about a home range that compels fish to choose and remain within a very small area, yet home ranges are not defended and overlap a great deal. (Coleman and Wilson 1996).

Feeding is often cited as an important determinant of home range size in other species. Fish and Savitz (1983) suggested that variation in the home range size of centrachid species within a lake may be due to variation in prey densities. However, with the ability to consume zebra mussels, the round goby can obtain prey easily even in sandy habitats with the increase in colonization of zebra mussels beds of soft substrates. Thus, it appears that shelter may be a more limiting resource than food.

In summary, round gobies are highly site specific with no differences between male and female site fidelity. There was large difference (26% difference in the number of gobies recaptured) between the site fidelity of small and large size gobies with the most probable factor being intraspecific competition. Lastly, home range area was calculated to be 5 m^2 for round gobies (TL 7.0 - 10.0 cm). The use of dye injections for mark recapture studies for round gobies are very cost and time efficient.

General Discussion

In its native range of the Black and Caspian Seas and in the Sea of Azov, round gobies occupy coarse gravel, shell and sandy inshore areas to a depth of about 20 m. The round goby prefers littoral areas in its native range where the wave action maintains high DO and reduces the amount of decaying material (Charlebois et al. 1997). From spring to autumn, round gobies are found up to depth of 20 m in slow rivers, lagoons, and brackish water in the Black Sea (Jude and Deboe 1996). In winter, the goby seeks the warmth of the deeper waters often in the range of 50-60 m (Miller 1986).

In this study, round gobies used both rocky and sandy habitats. However, significantly more round gobies were observed at rocky than sandy habitats. Jude et al. 1995 stated that the round gobies are not expected to become abundant in nearshore areas of the Great Lakes, including Lakes Michigan and Huron, where sand bottoms predominate. However, round gobies occupy sandy habitat in all three study areas that I examined. Densities of round gobies are much lower in sandy habitat but when compared to densities of other fish species round gobies have a high density per area.

Round gobies are multiple spawners and are capable of reproducing every few weeks from April to August (Charlebois et al. 1997). The prolific spawning habits of round gobies allow them to increase quickly and to disperse faster than most fish species. A single nest of the round goby may contain up to 10,000 eggs from 4 to 6 females. where fertilization is typically high, and hatching success may reach 95 % (Charlebois et al. 1997). Round gobies have been known to be very aggressive when defending their nests (Wickett and Corkum 1998). Males defend their nests by spitting, flaring their gills, lunging, biting, and producing a growling sound for 1-1.5 s (Protasov et al. 1965). Throughout the study several round goby nests were observed. Nests are generally under rocks, logs and cavities (Charlebois et al. 1997). However, a nest was observed in soft substrate indicating that round gobies are able to use sandy habitat throughout the Great Lakes to reproduce.

The densities of round gobies ranged from 1 to 9 gobies/m^2 in the transect study. Additionally, round gobies aggregated in groups from 30 - 70 gobies/m^2 and the highest density of gobies observed was 90 gobies/m^2. The highest goby density in 1996 that were found in the central basin of Lake Erie ranged from 1.8 m^2 (Fairport Harbour) to 6.3 m^2 (Watterworks)(K. Baker, Heidelberg College, pers. comm.). K. Baker has observed round goby densities to be as high as 17 m^2 in 1995 at Fairport Harbour (Central basin of Lake Erie). Similarly, Charlebois et al. (1997) reported densities of over 40 gobies/m^2 at Calumet Harbour, Illinois in 1995. Throughout the Great Lakes the round goby has been able to reproduce and attain high densities that might alter the present community composition.

The decline and extirpation of native fish population as a result of direct interaction with introduced fishes has been documented throughout North America. In streams in North Carolina, green sunfish (*Lepomis cyanelus*) have replaced various *cyprinids* as the dominant species (Lemly, 1985). In the Great Lakes, lake trout (*Salvelinus namaycush*) was driven to near extinction by sea lamprey (*Petromyzon marinus*) (Crowder 1980). Introduced fishes have displaced native species, through competition, predation, inhibition of reproduction, environmental modification, transfer of new parasites and diseases, contaminants, and hybridization (Moyle et al. 1986). The round goby may cause dramatic change to Lake Erie native fish assemblages. Since round gobies feed predominantly on zebra mussels (Ghedotti et al 1995; Ray and Corkum 1997), there is a possibility that contaminant transfer may occur and through bioaccumulation, round gobies will pass on the contaminants to smallmouth bass. Therefore the commercial and sport fisheries may be eventually affected.

In the principal component analysis for trawls in 1996, round goby, trout perch and freshwater drum were grouped together and separated from other pelagic fish species. Freshwater drum, like the round goby, is a bottom-feeding fish that spawns from July to September (Scott and Crossman 1973). The trout perch is a important forage fish and feeds during the evening. The round goby may become an important forage fish in the Great Lakes.

The similarity in benthic habitat, substrate preference (rocky nearshore areas) and prey (soft bodied invertebrates and zebra mussels) suggest that competitive interactions exists between gobies and native fauna. Early evidence indicates that the round goby is displacing the mottled sculpin (Jude et al. 1995, Jude and Deboe 1996). Both are benthic species with similar ecological requirements for nesting, feeding, and shelter. Both species are nocturnaly active (Jude et al. 1995), however, round gobies seem to be more active during the day (personal observations). On the other hand, the smaller and diurnaly active darters (*Etheostoma spp.)* (Greenberg 1991), which are also benthic, appear to be unaffected by the round goby (Jude et al. 1995, personal observation).

Home range size of different fishes vary. Some examples, from mark-recapture and radio-telemetry studies, are: *Cottus bairdi* (mottled sculpin) 83.9 m^2. *Micropterus dolomieu* (smallmouth bass) 2000 m^2, and *Salmo trutta*, (brown trout) 40-50 m^2 (Hesthagen 1990). The home range size that was calculated for round gobies (TL = 7.0 cm - 10.0 cm) was much smaller (5 ± 1.2 m^2) compared to the mottled sculpin (83.9 m^2).

Round gobies tend to be highly site specific (58% recapture of gobies). There seems to be no difference between male and female site affinity. However, 54% of small gobies (< 9.5 cm), and 80% of large gobies (> 9.5 cm) were recaptured indicating that the size of the goby plays a crucial role in site affinity.

Additional research is needed on the round goby to determine the impacts it will have on the native food web in the Great Lakes. Currently, projects are under way to try and prevent the round goby from entering the Mississippi River basin.

Future Research Need

This study presented results of habitat preference, home range, dispersal and possible interactions between round goby and other fishes in the Huron/Erie corridor of the Great Lakes. Some parts of the study are not conclusive and further research is needed to determine the exact impacts that round gobies will have on the native fish assemblages of the Great Lakes.

The use of line transects to determine the density of round goby in sandy and rocky habitat was quit effective. However, in future studies a combination between line transect and quadrat studies should be used at the same time to ensure that the line transects are not underestimating the number of gobies that occupy rocky and sandy habitats. Line transects would be a useful technique to determine if movements by round gobies varied with depths throughout the year. Charlebois et al. (1997) has suggested that round gobies move offshore in autumn. Since the round goby can reproduce in both rocky and sandy habitats studies could be conducted to determine the number of natural nests that occur in sandy areas by use of SCUBA.

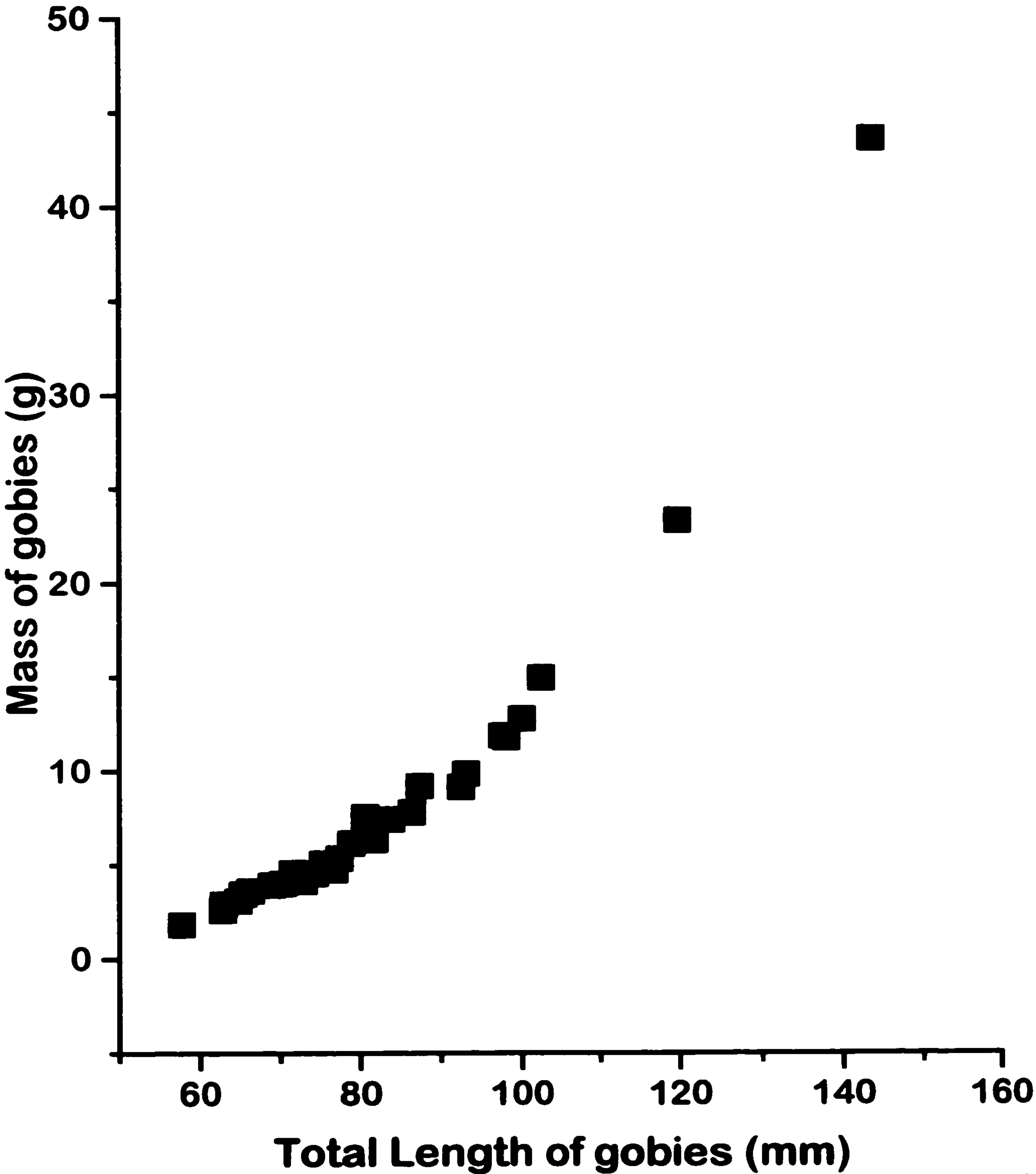
The use of injected dye proved to be very effective for a mark-recapture study. However, it would be useful to examine growth of individual round gobies by ensuring that each goby had a unique mark. The home range study using SCUBA was very effective, however, few fish were monitored. Since round gobies prefer rocky substrates compared to sandy areas, it would be useful to test if home range size differed between habitats. One might expect home range to be more restricted in populations occupying the preferred habitat. In addition further research is needed to determine if home range size of round gobies will change during the winter months after the fish move offshore.

Future studies are needed to quantify the effect of round gobies on native fish assemblages. In particular, studies should be designed to observe the interactions among logperch, darters, smallmouth bass, crayfish and sculpins with round gobies. Predation studies at Colchester Reef to determine the amount of round gobies consumed by the smallmouth bass would be very beneficial to the sport industry.

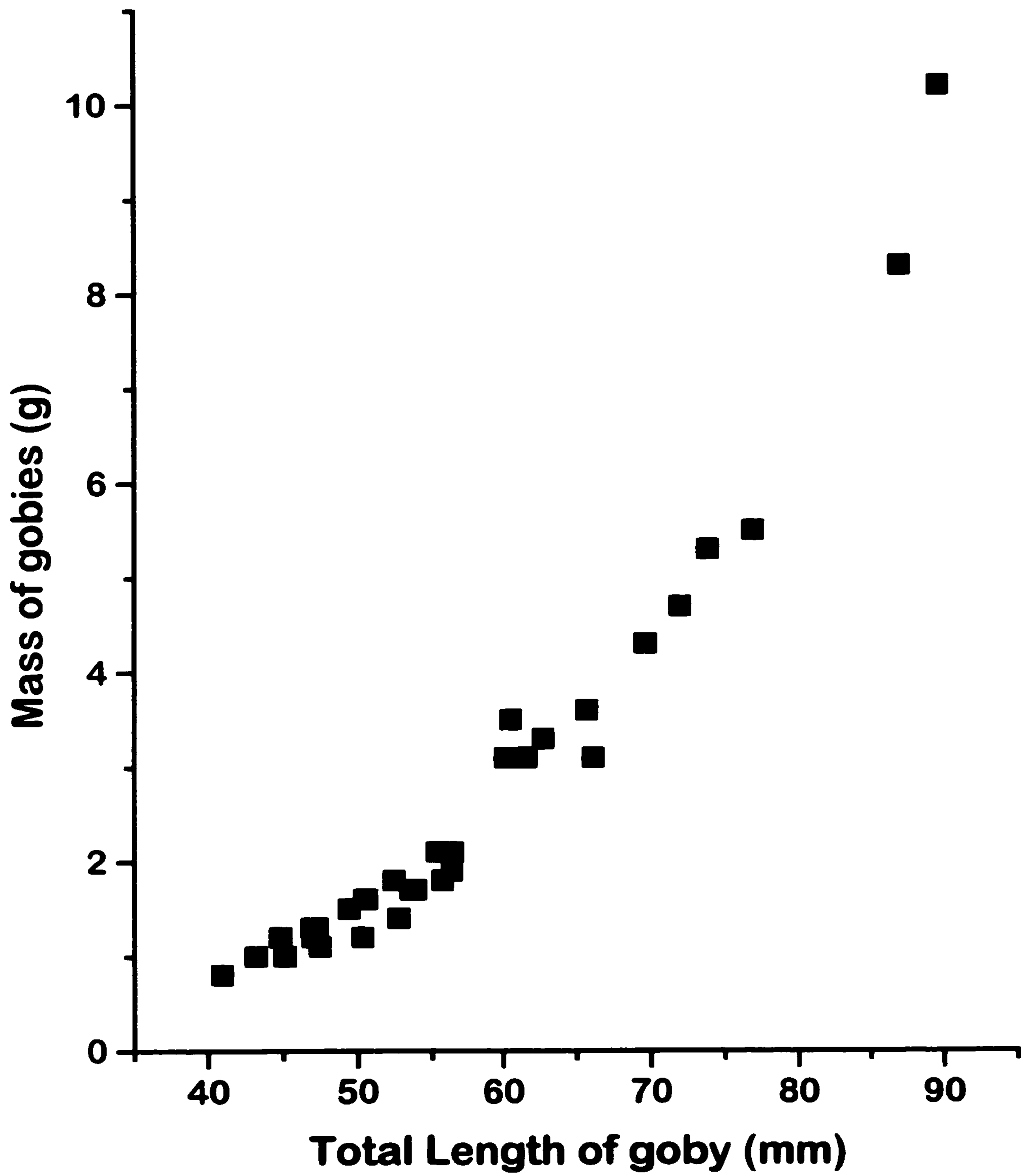
Also, studies are needed to quantify the effect of round gobies preying on eggs of walleye, smallmouth bass, lake sturgeon and lake trout. The round goby will most likely become a major part of the Great Lakes food web as the round gobies become more established in the Great Lakes basin.

Appendix 1.1 Raw data of number of round gobies and fish species observed in transects for rocky and sandy habitats in night and day at three sample sites (CF = crayfish, TN = tubenose goby). See Table 1.2 for codes.

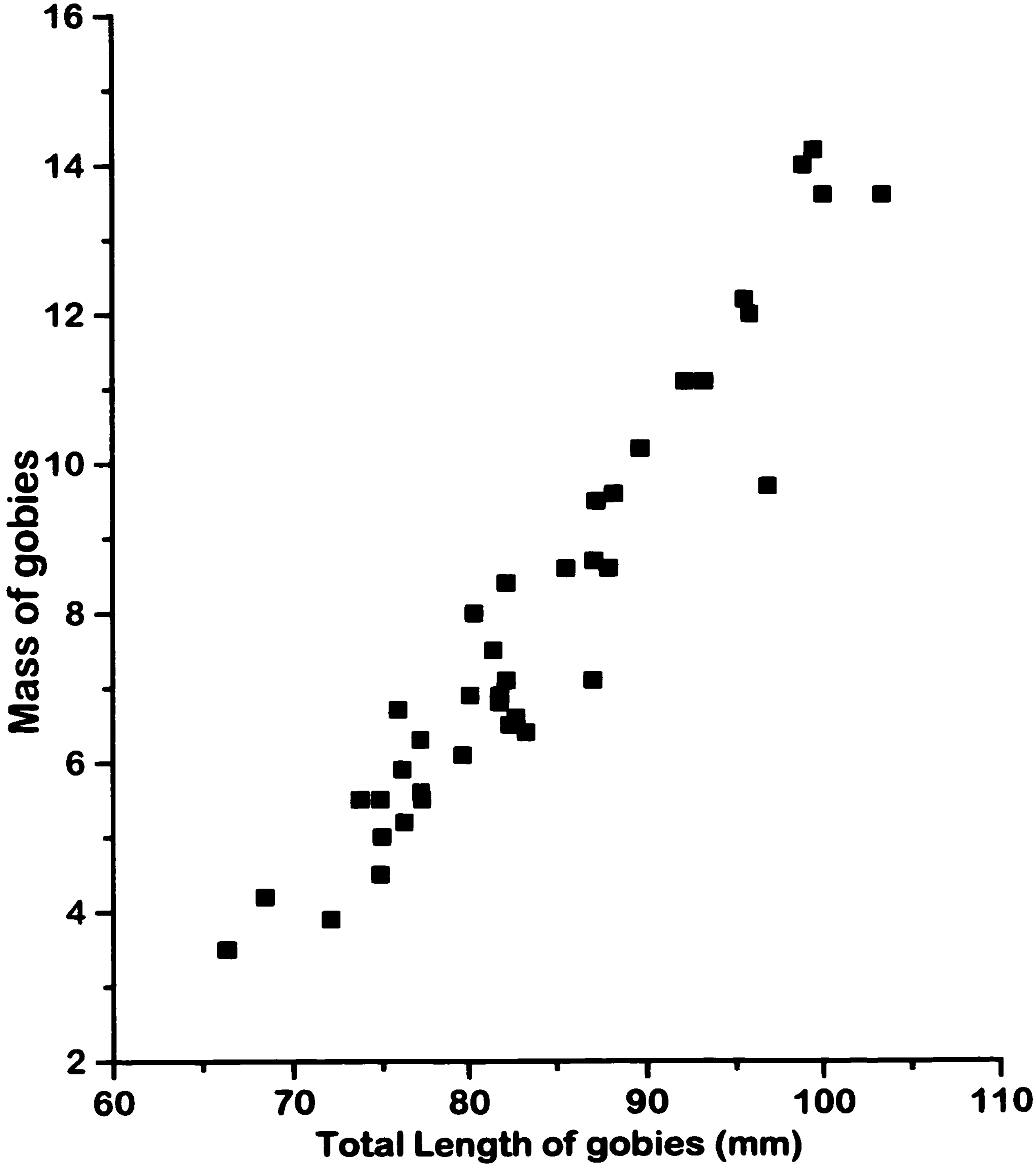
SITES	Habitat	Trawl #	Gobies < 5 cm	Gobies > 5 cm	LP	CF	SM	TN	CC	DA	SH	FD	YP	ST	WS
Peche Island															
	Rocky/Night	T#1	20	7	2	1			1						
	Rocky/Night	T #2	28	2	3	1	2		2						
	Rocky/Night	T#3	28	7		1			3						
	Rocky/Day	T #1	55	97	1										
	Rocky/Day	T #2	72	99	1										
	Rocky/Day	T #3	85	117	1										
	Sandy/Night	T #1	15	5	1										
	Sandy/Night	T #2	11	3	1										
	Sandy/Night	T #3	7	2	1								1		
	Sandy/Day	T #1	27	15											
	Sandy/Day	T #2	55	22				2							
	Sandy/Day	T #3	61	27											
Sarnia															
	Rocky/Night	T#1	2	325		1					1		2	1	
	Rocky/Night	T #2	27	306		2					3				
	Rocky/Night	T#3	22	291		3					1	1	1		
	Rocky/Day	T #1	23	460							1				
	Rocky/Day	T #2	21	428							1				
	Rocky/Day	T #3	27	414							1				
	Sandy/Night	T #1	2	275						1			1		
	Sandy/Night	T #2	14	255						1			1		
	Sandy/Night	T #3	8	257	1							1	1		
	Sandy/Day	T #1	10	320						3			1		
	Sandy/Day	T #2	3	373						1					
	Sandy/Day	T #3	10	342						3			2		
Belle River															
	Rocky/Night	T#1	12	51		1				1		1		3	
	Rocky/Night	T #2	10	47		1				1	3				2
	Rocky/Night	T#3	15	47	1	1				1	1				
	Rocky/Day	T #1	15	169			1								
	Rocky/Day	T #2	17	152			2								
	Rocky/Day	T #3	18	152	1		2								
	Sandy/Night	T #1	8	28							1				
	Sandy/Night	T #2	5	32							2		1		
	Sandy/Night	T #3	4	29	1						1				
	Sandy/Day	T #1	4	38											
	Sandy/Day	T #2	6	44											
	Sandy/Day	T #3	5	45											



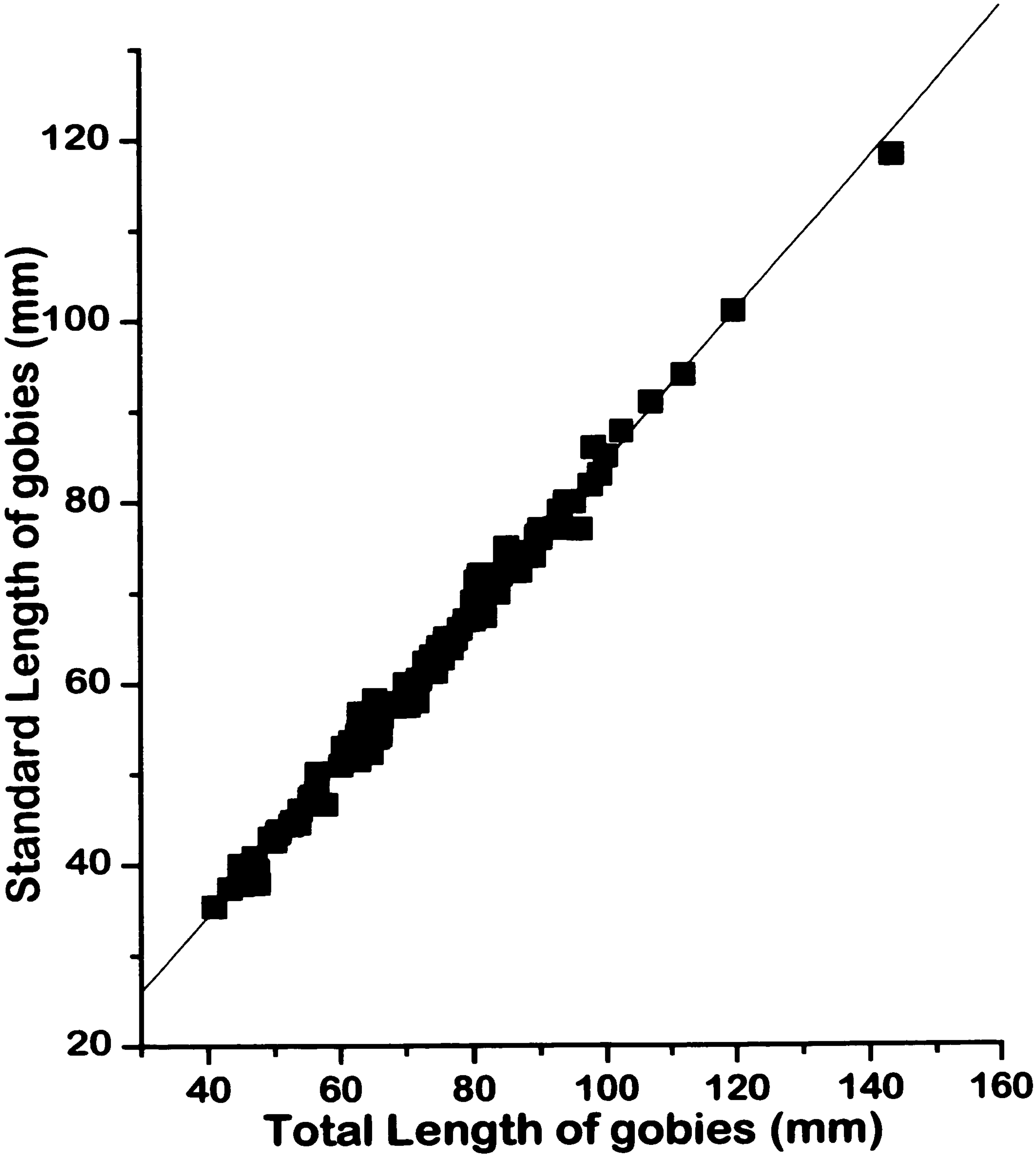
Appendix 1.2 The relationship between mass (g) and total length (mm) of the round goby at Belle River (n=30).



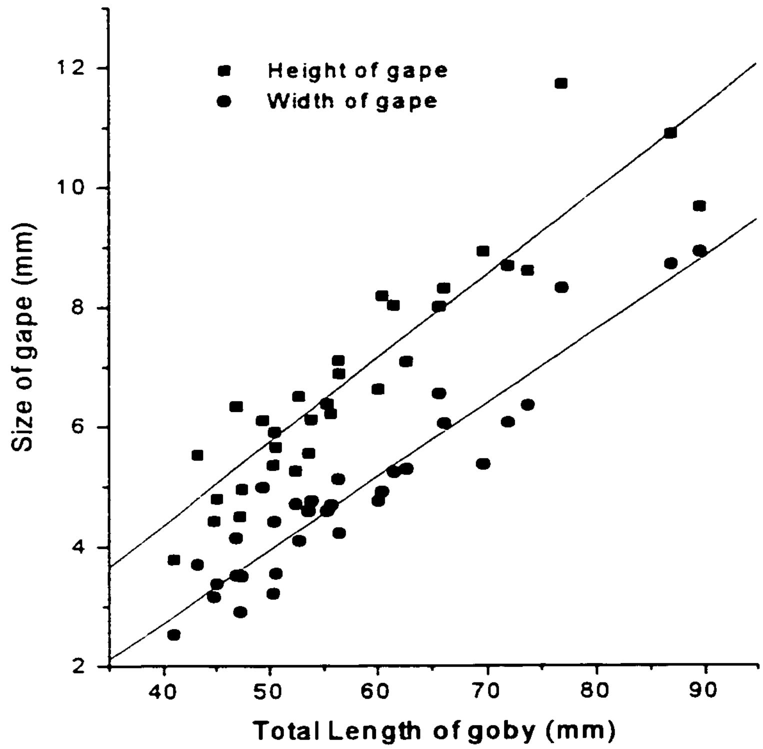
Appendix 1.3 The relationship between mass (g) and total length (mm) of the round goby at Peche Island (n=30).



Appendix 1.4 The relationship between mass (g) and total length (mm) of the round goby at Sarnia (n=30).



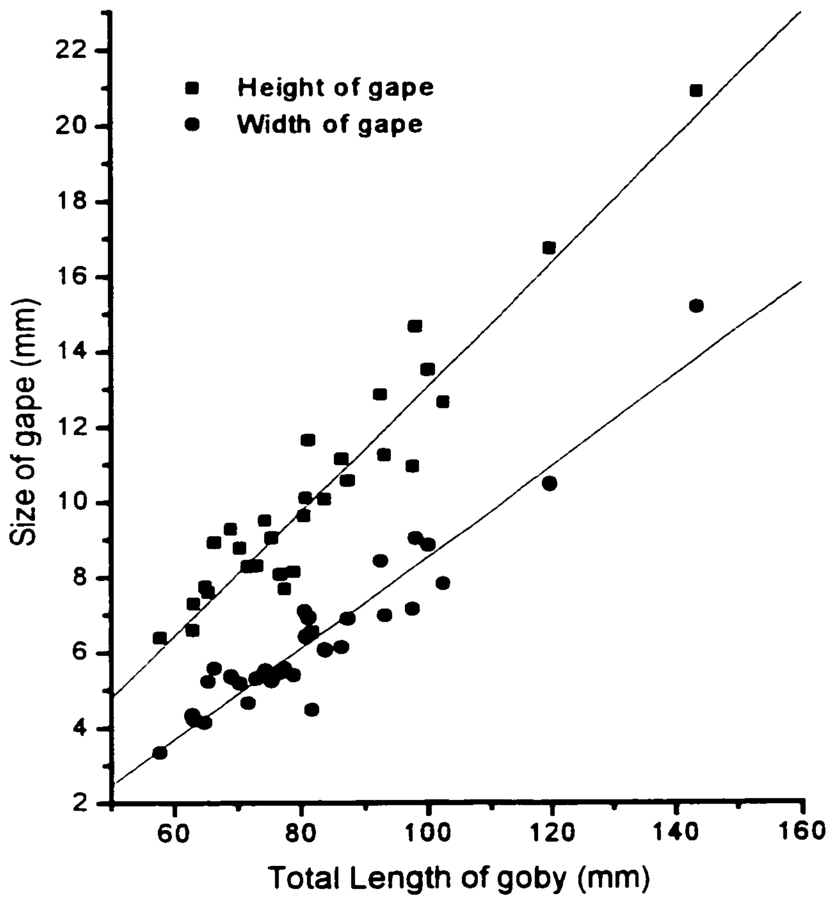
Appendix 1.5 The relationship between standard length and total length of the round goby in Lake St. Clair, Detroit and St. CLair Rivers.



Linear regression for Width of gape		
Y=A + B * X		
Param	Value	sd
A	-2.18	0.448
B	0.122	0.008
R=0.947		
SD= 0.516, N=30		
P= 2.55E-16		

Linear regression for Height of gape		
Y= A + B* X		
Param	Value	sd
A	-1.24	0.643
B	0.140	0.011
R=0.919		
SD= 0.741, N=30		
P= 1.08E-13		

Appendix 1.6 The relationship between size of gape and total length of the round goby at Peche Island (n=30).



Linear regression for Width of gape
Y=A + B * X

Param	Value	sd
A	-3.587	0.634
B	0.121	0.008

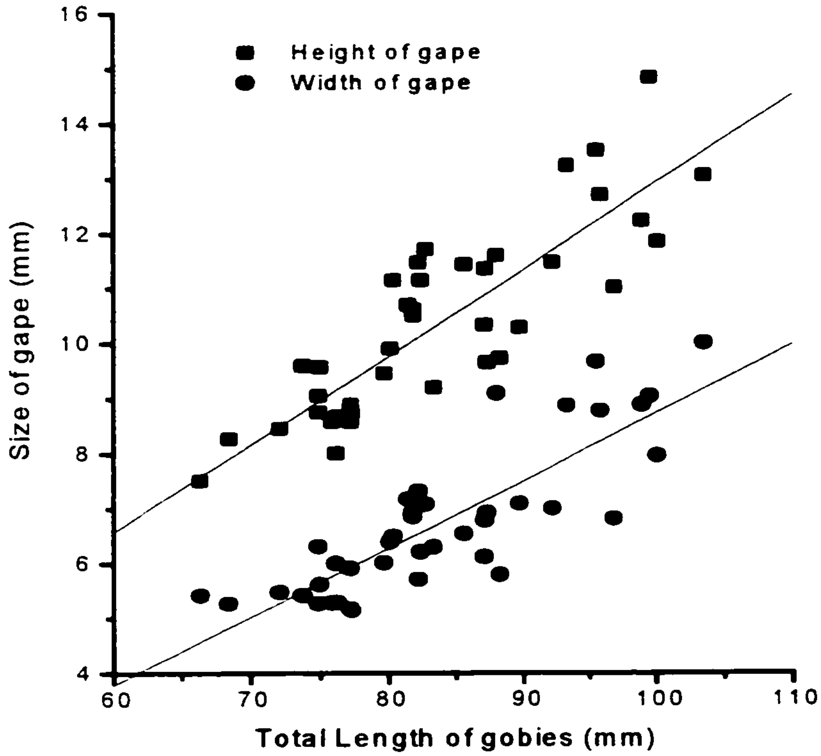
R=0.950
SD= 0.733, N=30
P= 1.03E-15

Linear regression for Height of gape
Y= A + B* X

Param	Value	sd
A	-3.463	0.989
B	0.165	0.012

R=0.950
SD= 1.14, N=30
P= 3.08E-14

Appendix 1.7 The relationship between size of gape and total length of the round goby at Belle River (n=30).



Linear regression for Width of gape		
Y=A + B * X		
Param	Value	sd
A	-3.64	1.10
B	0.124	0.013
R=0.838		
SD= 0.745, N=30		
P= 1.57E-11		

Linear regression for Height of gape		
Y= A + B* X		
Param	Value	sd
A	-3.78	1.21
B	0.160	0.015
R=0.822		
SD= 1.02, N=30		
P= 8.16E-11		

Appendix 1.8 The relationship between size of gape and total length of the round goby at Sarnia (n=30).

Appendix 1.9 Raw data for the number of gobies recaptured

Total Length	Sex	Date Marked	Total Length	Sex	Date Recaptured
90.9	F	Sep-03	92.2	F	Sep-05
121.1	M	Sep-03	106.9	M	Sep-05
83.8	M	Sep-03	87.6	M	Sep-05
92.9	F	Sep-03	83.5	M	Sep-05
84.5	F	Sep-03	92.5	F	Sep-05
84.3	M	Sep-03	95.1	M	Sep-05
98.2	M	Sep-03	83.5	M	Sep-05
101.6	M	Sep-03	97.7	F	Sep-05
91.9	F	Sep-03	102.5	M	Sep-11
80.4	M	Sep-03	99.8	M	Sep-11
88.5	F	Sep-03	95.5	F	Sep-11
98.6	M	Sep-03	103.7	F	Sep-11
91	F	Sep-03	109.7	M	Sep-11
85.5	F	Sep-03	94.4	F	Sep-11
89.1	M	Sep-03	82.2	F	Sep-11
92.8	M	Sep-03	121.7	M	Sep-11
97.2	M	Sep-03	93.9	M	Sep-11
86.6	F	Sep-03	84.5	M	Sep-11
84.3	M	Sep-03	94.9	F	Sep-11
95.6	M	Sep-03	104.1	F	Sep-11
97.7	M	Sep-03	87.9	F	Sep-13
99.7	F	Sep-03	86.5	M	Sep-13
84.6	F	Sep-03	88.9	M	Sep-13
91.5	M	Sep-03	93.1	F	Sep-13
79.3	F	Sep-03	87.5	F	Sep-13
84.6	F	Sep-03	79.7	M	Sep-13
84.9	M	Sep-03	74.8	F	Sep-13
83.3	F	Sep-03	77.4	M	Sep-13
101.1	M	Sep-03	99.9	M	Sep-13
86.2	F	Sep-03	84.5	M	Sep-13
81.4	M	Sep-03	117.5	M	Sep-15
91.8	F	Sep-03	86.5	F	Sep-15
93.7	F	Sep-03	86.6	F	Sep-15
81.6	F	Sep-03	89.6	M	Sep-15
94.5	F	Sep-03	113.3	M	Sep-15
90.5	M	Sep-03	81.8	M	Sep-15
86.8	M	Sep-03	85.4	F	Sep-15
92.1	F	Sep-03	89.6	F	Sep-15
85.9	F	Sep-03	98.4	F	Sep-18
85.4	M	Sep-03	90.9	F	Sep-18
70.6	M	Sep-03	94.4	F	Sep-18
90.2	F	Sep-03	92.3	F	Sep-18
90.2	F	Sep-03	85.5	M	Sep-18
80.4	M	Sep-03	100.9	M	Sep-18
93.5	F	Sep-03	85.3	F	Sep-18
87.5	F	Sep-03	85.6	F	Sep-18
86.1	M	Sep-03	89.6	M	Sep-18
105.2	M	Sep-03	86.6	F	Sep-18
105.5	M	Sep-03	81.1	M	Sep-18
74.3	M	Sep-03	86.5	M	Sep-18
80	F	Sep-03	77.1	F	Sep-18
83.8	F	Sep-03	86.7	M	Sep-18
76.9	M	Sep-03	95.1	F	Sep-18
79.2	M	Sep-03	82.4	F	Sep-18
76.6	F	Sep-03	78.2	F	Sep-18
85.9	M	Sep-03	78.9	M	Sep-18
79.36	F	Sep-03	74.5	M	Sep-18
88.8	F	Sep-03	87.5	M	Sep-18
77.7	F	Sep-05	96.7	M	Sep-18
89.7	M	Sep-05	93.7	M	Sep-18
84.6	M	Sep-05	113.2	M	Sep-18
94.3	M	Sep-05	83.7	F	Sep-18
95.4	F	Sep-05	65.6	F	Sep-18
89.3	F	Sep-05	93.7	M	Sep-18

83.2	F	Sep-05
93.6	M	Sep-05
92.9	M	Sep-05
88.7	F	Sep-05
84	F	Sep-05
72.4	M	Sep-05
95	F	Sep-05
80.3	M	Sep-05
80.6	F	Sep-05
88	M	Sep-05
87.6	M	Sep-05
93.3	M	Sep-05
85.5	F	Sep-05
97.3	M	Sep-05
80.9	F	Sep-05
74.5	F	Sep-05
104.1	M	Sep-05
73.7	M	Sep-05
96.3	M	Sep-05
80.6	M	Sep-05
78.7	F	Sep-05
93.2	M	Sep-05
77.3	M	Sep-05
103.9	F	Sep-05
74.7	M	Sep-05
81.7	F	Sep-05
81.7	M	Sep-05
81.1	M	Sep-05
80.3	F	Sep-05
90.9	F	Sep-05
95.5	M	Sep-05
74.8	F	Sep-05
122.1	M	Sep-05
84.8	M	Sep-05
99.9	F	Sep-05
75.1	M	Sep-05
77.8	F	Sep-05
72.1	M	Sep-05
83.1	M	Sep-05
81.8	F	Sep-05
75.6	F	Sep-05
89	F	Sep-11
88.7	M	Sep-11
95.7	F	Sep-11
112.4	M	Sep-11
86	F	Sep-11
83.5	F	Sep-11
92.6	M	Sep-11
101.9	F	Sep-11
104.8	M	Sep-11
96	F	Sep-11
112.6	M	Sep-11
90.3	M	Sep-11
90.8	F	Sep-11
80.7	M	Sep-11
86.7	F	Sep-11
91	M	Sep-11
80.1	M	Sep-11
80.7	M	Sep-11
88.5	M	Sep-11
87.9	F	Sep-11
81.8	M	Sep-11
98.8	M	Sep-11
86.2	F	Sep-11
96.9	M	Sep-11
70.2	M	Sep-11
93.8	M	Sep-11
77.6	M	Sep-11
87.5	M	Sep-11
83.1	F	Sep-18
98.8	M	Sep-29
75.3	M	Sep-29
93.2	M	Sep-29
93.3	M	Sep-29
92.3	F	Sep-29
93.1	M	Sep-29
91.4	M	Sep-29
100.3	F	Sep-29
77.8	M	Oct-01
84.7	M	Oct-01
90.5	M	Oct-01
85.9	F	Oct-01
66.9	M	Oct-01
71.3	M	Oct-01
73.6	M	Oct-01
99.3	M	Oct-01
96.3	F	Oct-01
119.2	M	Oct-01
101.3	M	Oct-01
101.9	M	Oct-01
91.7	F	Oct-01
97.5	F	Oct-01
108.2	M	Oct-01
89.6	M	Oct-01
90.8	M	Oct-01
111.8	M	Oct-02
87.1	F	Oct-02
82	F	Oct-02
82.4	M	Oct-02
88.1	F	Oct-02
81.7	F	Oct-02
97.6	M	Oct-02
81.5	M	Oct-03
80.6	F	Oct-03
95.4	M	Oct-03
86.5	F	Oct-03
80.5	M	Oct-03
87.9	F	Oct-03
72.2	M	Oct-03
84.1	M	Oct-03
104.8	F	Oct-03
103.1	F	Oct-03
112.2	M	Oct-03
84.5	M	Oct-03
101.9	M	Oct-06
78.8	F	Oct-06
73.6	M	Oct-06
96.9	M	Oct-06
75.2	F	Oct-15
110.9	M	Oct-15

87.4	M	Sep-11
80.1	F	Sep-11
92.2	F	Sep-11
93.7	M	Sep-11
75	F	Sep-11
86.7	M	Sep-15
94	M	Sep-15
75.9	M	Sep-15
81.2	F	Sep-15
75.7	M	Sep-15
93.3	F	Sep-18
99.9	F	Sep-18
82.2	M	Sep-18
69.4	M	Sep-18
88	M	Sep-18
79.4	F	Sep-18
73.6	M	Sep-18
80.9	F	Sep-18
88.9	M	Sep-18
68.9	F	Sep-18
79	F	Sep-18
93.9	F	Sep-18
98	M	Sep-18
70.8	M	Sep-18
76.7	F	Sep-18
78.6	F	Sep-18
72.6	F	Sep-18
74.6	M	Sep-18
86.6	F	Sep-18
67.9	M	Sep-18
86.9	F	Sep-18
87	M	Sep-18
84.2	F	Sep-18
73.1	M	Sep-18
86.8	F	Sep-18
66.7	F	Sep-18
73.9	M	Sep-29
96.1	M	Sep-29
86	M	Sep-29
98.9	M	Sep-29
92.7	M	Sep-29
111.2	M	Sep-29
86.4	F	Sep-29
113.5	M	Sep-29
87.9	F	Sep-29
106.1	F	Sep-29
87.8	F	Sep-29
112.7	M	Sep-29
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97.9	F	Sep-29
107.6	F	Sep-29
106.3	M	Sep-29
92.8	F	Sep-29
93.8	M	Sep-29
118.2	M	Sep-29
99.7	F	Sep-29
86.3	M	Sep-29
81.3	F	Sep-29
107.9	M	Sep-29
81.9	M	Sep-29
89.5	F	Sep-29
116.6	M	Sep-29
74.8	M	Sep-29
99	M	Sep-29
106.7	F	Sep-29
95.2	F	Sep-29
83.1	M	Sep-29

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VITA AUCTORIS

NAME:	William J. Ray
PLACE OF BIRTH:	Windsor, Ontario
DATE OF BIRTH:	November 7, 1971
EDUCATION:	Holy Names High School Windsor, Ontario 1985-1990
	University of Windsor Windsor, Ontario 1990-1994 B. Sc. (Honours)
	University of South Florida Tampa, Florida 1995-1996 B. Ed.
	University of Windsor Windsor, Ontario 1996-1998 M. Sc.