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Comparison of Methods Needed to Estimate Population Size of Round Gobies (*Neogobius melanostomus*) in Western Lake Erie

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ABSTRACT. *The round goby* (Neogobius melanostomus) *is a small, demersal fish that was introduced into the Great Lakes basin in 1990. Since their arrival, the round goby has been implicated in many ecological changes—most notably changes in the flow of energy from the benthic to the pelagic food web through their consumption of dreissenid mussels. However, methods for evaluating the density and size of round gobies across different substrates are lacking, preventing the true quantification of the effects of round gobies on invaded ecosystems. In our study, we evaluated catch efficiency of numerous passive and active sampling methods for capturing round gobies. We then applied the best techniques to estimate the distribution, density, and biomass of round gobies in western Lake Erie. Visual census (underwater video transects) proved the best technique for assessing round goby size and density across a wide range of substrates. A combination of angling and bottom trawling proved most effective for obtaining biological samples. We estimated 9.9 billion round gobies in western Lake Erie in 2002. Continued efforts to describe abundance and demographics of round gobies in invaded ecosystems will enable scientists and managers to fully understand the impacts of this invading species.*

INDEX WORDS: *Round goby,* Neogobius melanostomus, *density, biomass, Lake Erie, substrate.*

INTRODUCTION

The round goby (*Neogobius melanostomus)*, native to the Ponto-Caspian region of eastern Europe, was first observed in the Great Lakes basin in 1990, and had spread to all five of the Laurentian Great Lakes within 5 years (Jude *et al.* 1992, Charlebois *et al.* 1997). In these novel habitats, populations quickly grew owing to the round gobies wide tolerance of environmental conditions, diverse diet, aggressive behavior, repeated spawning, and parental care (Charlebois *et al.* 1997, MacInnis and Corkum 2000a, Jude 2001). Impacts of these rapidly expanding populations included competition with native fishes for food and habitat (Jude *et al.* 1995, Dubs and Corkum 1996, Janssen and Jude 2001), consumption of eggs and young native fishes (Chotkowski and Marsden 1999, French and Jude 2001, Nichols *et al.* 2003), and altered ecological function including changing energy and contaminant pathways (Jude *et al.* 1995, Kuhns and Berg 1999, Morrison *et al.* 2000). While these impacts have been documented at a local scale, the true impact of round gobies on these ecosystems is not possible without an assessment of absolute density and biomass.

In this study, we compare the effectiveness of several techniques for capturing round gobies, and then apply this knowledge to estimate the absolute density and biomass of round gobies in the west basin of Lake Erie. Lacking a swim bladder, round gobies are demersal throughout their lives. In both their native range and in the Great Lakes, round gobies have been observed on substrates ranging from

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dense macrophyte regions to silty and rocky substrates in both lakes and rivers (Jude *et al.* 1995, Charlebois *et al.* 1997). They show a preference for complex structure that provides nesting habitat, although juveniles are often observed on sand (Chotkowski and Marsden 1999, Ray and Corkum 2001). Round gobies migrate offshore in the fall and return to nearshore habitats the following spring (Smirnov 1986; C. Knight, Ohio Division of Wildlife, Fairport Fisheries Research Station, pers. comm.). Given these complex behaviors, we evaluated density distribution on natural substrates throughout the openwater season to facilitate our predictions of lakewide population extrapolations. Specifically, our objectives are 1) to identify the most appropriate method for estimating round goby density and biomass, 2) to describe seasonal differences in habitat preference on the basis of round goby size, and 3) to generate a defensible, basin-wide estimate of round goby population size and biomass for western Lake Erie in 2002.

METHODS

We used a variety of active and passive sampling techniques to estimate the abundance of round gobies. In 1999, a series of traps were designed and evaluated (Table 1). On the basis of these results, only angling, bottom trawling, and underwater video were used in 2002.

In June 1999, 586 round gobies (37 to 141 mm TL) were captured using bottom trawl sampling in western Lake Erie and marked in the left cheek with an elastomer (injectible latex) tag (Northwest Marine Technology, Inc., Shaw Island, WA). The fish were kept in well-aerated lake water on board the vessel for a maximum of 4 h before being released in a single batch at the trap site near Grubb's Reef (41.54°N, 82.54°W) in western Lake Erie. At the point of entry (water depth about 5-m), the area of the introduction was less than 1-m^2. Just prior to release, six different traps of different designs (Table 1) were lowered to the reef within a 5-m radius, and their location documented with digital GPS. The traps were left undisturbed for 19 h (1600 to 1100) before being recovered. Fish from the catch were evaluated for the presence of tags, fish length, and sex.

During July 1999, the capture and retention efficiency of each of the traps was tested in the laboratory. Round gobies were placed in 574-L, fiberglass tanks containing well-oxygenated water held at ambient conditions (19–23°C). Bottom area of the tanks measured 0.9 m by 1.2 m. Six large limestone rocks (20 to 30-cm diameter) collected from Lake Erie, cleaned to remove any potential prey items, and placed haphazardly on the bottom of the tank. Twenty round gobies (52 to 126 mm TL) were placed in each tank and allowed to acclimate for a period of 4 d before experiments began. The round gobies were not fed for the duration of the experiment (10 d). A single trap was placed in the tank for a period of 24 h. Each trap was tested three times (randomly assigned) with and without food. Food consisted of Purina Cat Chow® kibble within perforated 35-mm film canisters placed within the traps. At the end of each trial the trap was removed and checked for the presence of round gobies.

To test trap retention efficiency, two equal-sized round gobies were placed in each trap and observed approximately hourly until they left the traps. Because of the difficulty of observing retention by the tire sampler, each trap was checked after 8 and 24 h. Three trials were conducted with each trap.

On the basis of these results (outlined below) we abandoned the use of passive traps as a means for assessing the abundance of round gobies, and relied on visual census. Due to the labour regulations restricting the use of SCUBA divers in Ontario (Ontario Ministry of Labour 2003), we opted to use a SeaClops™ remote underwater video system to visually census (density and size) the round goby population on all substrates.

Using Coakley *et al.*'s (1997) substrate map for western Lake Erie, we selected two sites (Colchester and Pelee Island) (Fig. 1) where the four dominant substrates were all found within close proximity. Digital GPS was used to verify the location of each site after the initial substrate verification cruise. To estimate density, a highly visible lead line, 10-m long and marked at 1-m intervals with 10-cm floats, was stretched in a straight line across the substrate. The SeaClops was deployed to the line, and operated for a total of six passes, three to the left, and three to the right of the line. The SeaClops operated about 0.25 m above the lake bottom, ensuring the bottom was clearly visible at all times. All observations were recorded on VHS.

At a later date, VHS tapes were examined using a high-resolution monitor and editing VCR that permitted precise control of tape speed and direction during image processing. Within each 1-m segment of line, the total number of round gobies and width of field of view were determined to provide areal estimates of goby density (no./m^2). Mean density was estimated by averaging the density in each of the ten,

TABLE 1. Description of gears (ranked in order of efficiency) used to sample round gobies in Lake Erie. Traps marked with an asterisk were not used in tank experiments due to their large size. Cost is given in approximate 2002 Canadian dollars.

Name	Description	Efficiency	Comments	Cost
Minnow trap	conventional wire mesh minnow trap	Extremely low	inexpensive and readily available	\$10
Minnow trap with habitat	as above but fitted with six pieces of 15-cm long × 3.8-cm diameter black PVC tube	Extremely low	added cost with no improvement in efficiency	\$12
Covered minnow trap	conventional minnow trap covered with opaque black plastic	Extremely low	added cost with no improvement in efficiency	\$11
Tire sampler	four 4.45-cm diameter holes cut into the tread wall of a 38.1-cm automobile tire mounted on a steel rim	Extremely low	low cost but labour intensive to cut holes	\$5
Torpedo sampler	1.2-m long 15-cm white ABS tube fitted with conical wire mesh guards (2-cm opening)	Extremely low	moderate cost	\$30
Tube sampler*	three pieces of 10-cm diameter × 40-cm long gray PVC tube (joined side-by-side) and fitted with conical wire mesh guards (2-cm opening in cone)	Low	relatively low cost but easy to customise	\$20
Windermere trap*	0.6-m by 0.8-m Windermere traps (0.6-cm wire mesh)	Low	limited availability	\$100
Windermere trap with habitat*	as above but fitted with 20 pieces of 15-cm long × 3.8-cm diameter black PVC tube	Low	added cost with no improvement in efficiency	\$110
Bottom trawl	10-m Biloxi bottom trawl fitted with 13-mm cod-end, mesh liner	Moderate	limited to smooth / soft bottoms; requires vessel (larger trawls, larger vessels)	\$1,500
Angling	dew worms *Lumbricus terrestris* on #8 to #12 hooks	Good	size selective (biased to larger round gobies) but relatively inexpensive and suitable for all habitats	\$50
Direct observation (SCUBA)	certified SCUBA divers sitting on bottom making visual census (180° field of view) for 2 min, after initial 2 min acclimation period	Good	specialised procedure (requires certification) currently regulated in Ontario; labour intensive; limited to census (no biological samples)	\$2,000
Underwater video	Remote-operated, underwater colour video system (www.hydrobotic.com/products/seaclops/seaclops.html)	Good	expensive, limited to census (no biological samples)	\$40,000

1-m segments for each of the six passes of the Sea-Clops per substrate and month. The size (total length, mm) of each round goby also was estimated, using fixed (diameter of compass mounted on front of Sea-Clops, and known dimension of lead line and floats) and natural (expected size range of dreissenids visible on substrate) points of reference. Length was converted to mass using length-weight regressions developed using samples from bottom trawls:

$$\log W = 3.2535 \log TL - 5.3430$$
$$n = 1{,}550,\ R^2 = 0.98$$

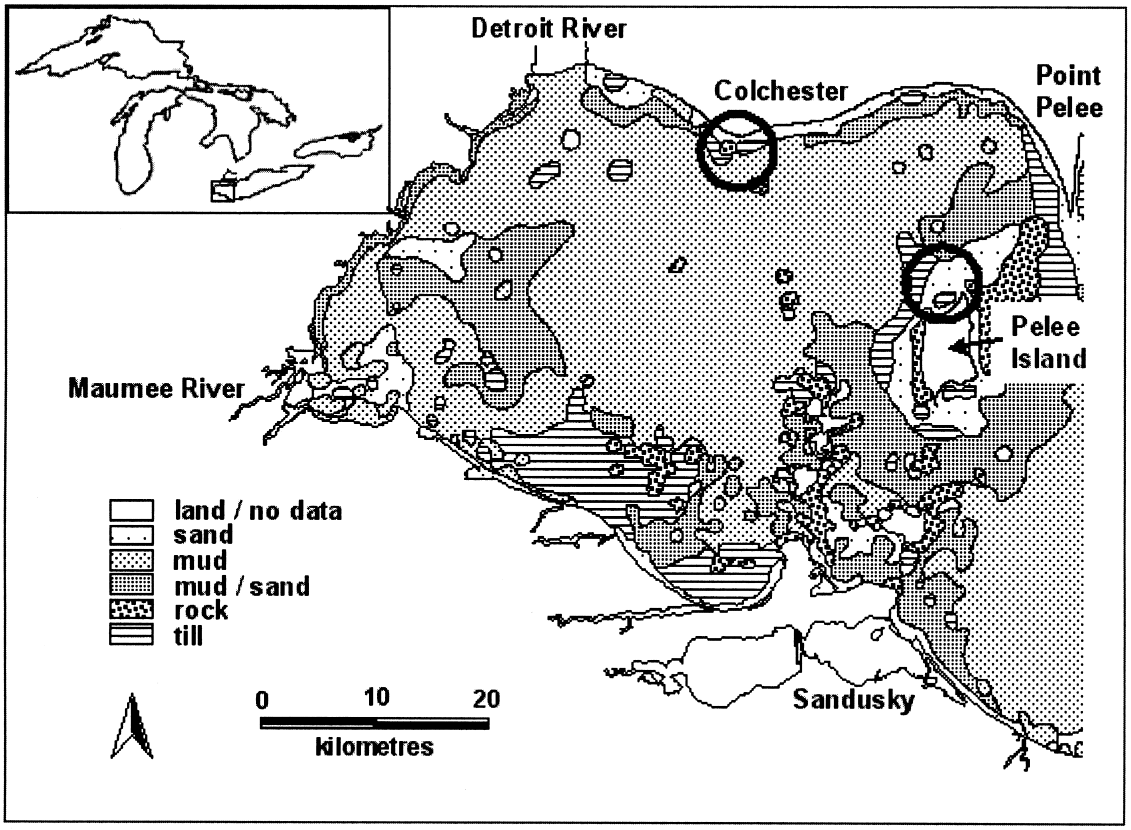

FIG. 1. Location of sampling sites and distribution of dominant substrate types in western Lake Erie. Substrate map redrawn from Coakley* et al. *(1997).

where W is body mass in g and TL is total length in mm.

The density of round gobies was estimated for the western basin using the seasonal mean density by substrate type, the total area of the basin, and the proportional substrate coverage within the basin. Basin area and substrate coverage were obtained from Coakley *et al.* (1997) and Haltuch *et al.* (2000).

Prior to analyses, all data were transformed to ensure normality. We performed a 3-way ANOVA to test for significant differences among sites, substrates, and months of collection. We used Scheffe's post-hoc test to detect where significant differences ($p < 0.05$) occurred.

RESULTS

Evaluation of Traps

Of the 586 marked round gobies released on top of the traps at Grubb's Reef in western Lake Erie, only one was recaptured in the tube sampler. One additional unmarked round goby was captured in a Windermere trap. No other round gobies were captured in any of the remaining passive sampling gears.

At the lab, all passive traps performed poorly. A total of four round gobies were captured in 30 independent trials: one round goby (82-mm male) in the tire sampler (no food); one round goby (68-mm male) in the tube sampler (food provided), and two round gobies (74-mm female, 67-mm male) in a single trial in the tube sampler (no food). Although round gobies consumed cat food when provided, its presence had no effect on trap efficiency.

All passive traps exhibited low retention of round gobies. Of the nine minnow trap trials, both round gobies had exited the traps within 1 h except one of two gobies in the conventional trap (escaped within 3 h) and one of two gobies in the covered minnow trap (< 8 h). The tire sampler retained one round goby after 24 h (the other trials failed to retain either goby for more than 8 h). The tube sampler retained one round goby for 2 hours and one round goby for 8 hours (separate trials); all others escaped within 1 hour.

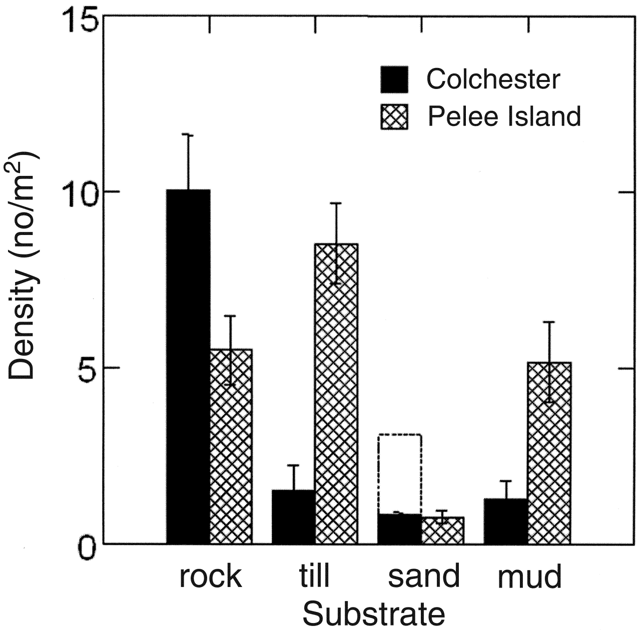

FIG. 2. Mean density (± 1 S.E.) of round gobies **Neogobius melanostomus** *on dominant substrate types at two sites in western Lake Erie in 2002. Dotted line above Colchester sand site includes unusually high density observed at this site in September.*

Estimation of Round Goby Density and Biomass

We enumerated 3,951 round gobies with the ROV, ranging in size from 13 to 108 mm. On average, 50.4 m^2 of bottom was surveyed on each substrate in each month (range 21 to 60 m^2). Visibility was too poor to permit sampling on mud sites in October. Significant interaction occurred among all three factors in the ANOVA, limiting us to descriptive narrative with respect to differences in site, substrate, and month of collection. In September, the Colchester sand site abutted several large boulders and many large round gobies were observed. We feel the presence of these boulders (ideal habitat for nesting round gobies) biased our "sand" substrate estimate high in this month. We have plotted all results, with (dotted bar) and without (solid bar) this uncharacteristic result. In general, density was highest at the Colchester rock and Pelee Island till site and lowest on sand substrate at both sites (Fig. 2). Density estimates on all but the rock substrate were similar at Colchester, while density estimates were more similar on all but the sand site at Pelee Island. When comparing round goby density across months, density increased marginally from June to August on all substrates before declining in October (Fig. 3a).

Mean round goby size was highest on rock and till substrates, lower on mud (except July, where the largest round gobies occurred), and significantly lower on sand (Fig. 3b). There was little evidence of seasonal changes in the mean size across months.

When density and length results were combined seasonal changes in biomass among substrates appeared linked to life history traits (Fig. 4). In June, biomass was highest in areas dominated by rock and till substrate. In July and August, biomass increased at the rock sites as both density and mean size increased. At sites dominated by till, biomass of gobies increased in August, and was largely a consequence of increased density alone. In September, biomass increased markedly over mud substrates as round goby density increased there. Sand sites exhibited low biomass throughout the year, and contained low densities and only very small (< 25 mm) round gobies. Biomass also fell to very low levels on till by September as both round goby density and size declined in the fall.

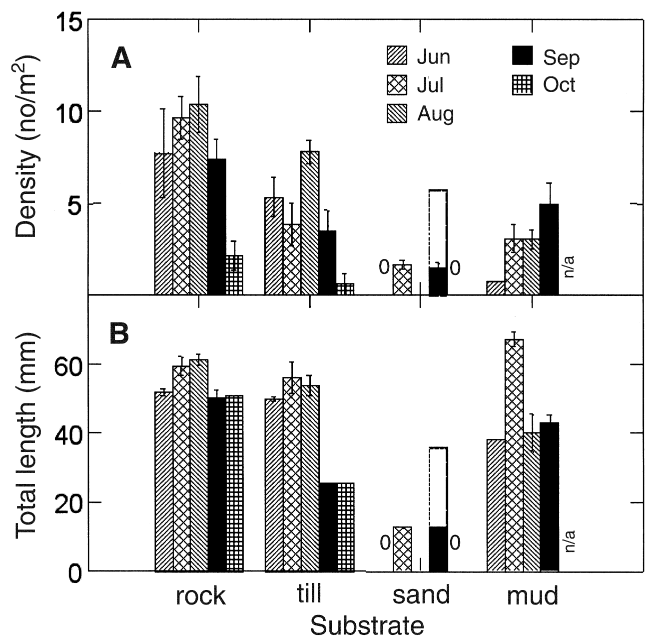

FIG. 3. Mean (a) density and (b) length (± 1 S.E.) of round gobies **Neogobius melanostomus** *on dominant substrate types in western Lake Erie between June and October 2002. Dotted bar above Colchester sand site includes unusually high density observed at this site in September. n/a = no data due to poor visibility at site, 0 = no round gobies observed.*

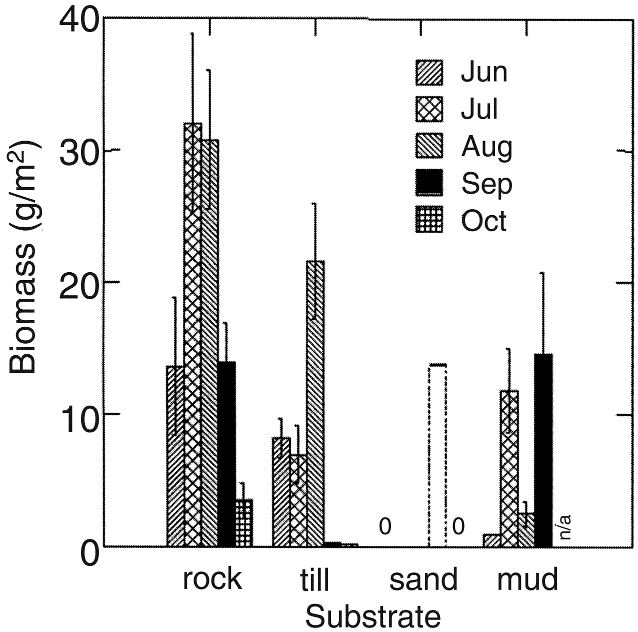

FIG. 4. Mean biomass (± 1 S.E.) of round gobies **Neogobius melanostomus** *on dominant substrate types in western Lake Erie between June and October 2002. Dotted bar above Colchester sand site includes unusually high density observed at this site in September. n/a = no data due to poor visibility at site, 0 = no round gobies observed.*

Our estimate of the average round goby population size in western Lake Erie between June and October 2002 is 9.9 billion round gobies (Table 2). Relative population size was highest on mud because this substrate type dominates the western basin. Basin-wide biomass also was estimated to be highest on mud, but became almost insignificant on sand because of the very small individual biomass of round gobies found on this substrate. Although rock had the highest individual biomass and density, the low incidence of this substrate limited the overall contribution to the basin-wide estimate.

DISCUSSION

At 9.9 billion individuals, the round goby population of western Lake Erie is a large component of the ecosystem. Estimated August age-0 production of percids in western Lake Erie has ranged from 5.08 to 736 million individuals since 1987 (Forage Task Group 2004). Percids form the basis of the billion dollar sport and commercial fisheries in Lake Erie owing to their high abundance and rapid growth. Basin-wide estimates for other species are less precise owing to biases associated with gear avoidance, habitat preference, and substrates upon which the bottom trawls can be effectively used. In the Sea of Azov, the round goby population ranged between 2.3 and 10.1 billion individuals between 1956 and 1973 (Kovtun *et al.* 1976), however the Sea of Azov is also nearly eight times larger than western Lake Erie. Annual average round goby density in the Sea of Azov ranged between 0.06 and 0.28 individuals/m^2. This is well below our density estimates in western Lake Erie (0.80 to 7.76 individuals/m^2), and many of those reported elsewhere in the Great Lakes basin (Charlebois *et al.* 1997, MacInnis and Corkum 2000a, Jude 2001, Ray and Corkum 2001). While the 133 individuals/m^2 reported by Chotkowski and Marsden (1999) for Calumet Harbor, southern Lake Michigan in 1997 is the highest density reported in the literature, the Sea of Azov density is conservative as no age-0 fish were included in their estimate. While methods of population assessment are lacking in Kovtun *et al.* (1976), assessments made with non-visual techniques (i.e., trawls, seines, angling) tend to be conservative. Ray and Corkum (2001) estimate that up to 60 times more round gobies were present than

TABLE 2. Estimated mean population size and total biomass (mean ± 1 S.E.) of round gobies in the western basin of Lake Erie between June and October 2002. Estimated total area of the western basin is 3,473 km^2. Lake area and substrate data estimated from Coakley et al. *(1997) and Haltuch* et al. *(2000).*

Substrate	Density (no. m^{-2})	Biomass (g m^{-2})	Substrate type (%)	Total abundance (billions)	Total biomass (tonnes)
Rock	6.94 ± 1.82	17.16 ± 6.04	5.1	1.23 ± 0.32	3,040 ± 1,069
Till	4.63 ± 1.40	8.27 ± 4.25	11.0	1.77 ± 0.54	3,159 ± 1,623
Sand	0.62 ± 0.33	0.029 ± 0.006	19.5	0.42 ± 0.22	19 ± 3
Mud	2.95 ± 1.21	9.38 ± 4.65	64.4	6.59 ± 2.72	20,975 ± 10,407
Grand total				9.89	25,048

detected during transect surveys, due to their cryptic behavior of hiding under rocks or burrowing into soft sediments.

Our observations confirmed the preference of round gobies for complex substrates (Moskal'kova 1996, Jude 2001, Ray and Corkum 2001). Density was highest on rock, followed by till and mud. Sand had the lowest density of round gobies. However, many of the smallest juveniles were observed on sand (Charlebois *et al.* 1997, Chotkowski and Marsden 1999, Ray and Corkum 2001), which may be a dispersal response related to cannibalism or aggressive behaviors from larger round gobies on the preferred rocky substrate (Ray and Corkum 2001). Our study provides direct evidence to support the dispersal hypothesis proposed by Ray and Corkum (2001).

Given the results of this study, we anticipate that different ages and sexes of round gobies shift habitats throughout the year. During the spring and early summer, mature round gobies spawn on complex habitats (rocks, shipwrecks, etc.) where ideal nesting habitat exists (Ray and Corkum 2001, Charlebois *et al.* 2001). Our visual estimates of density and biomass on these substrates are conservative as we could not detect the largest, nest-guarding males (Ray and Corkum 2001). As the summer progressed and new recruits are added to the population, aggressive behaviour (risk of cannibalism) apparently drives the small individuals to alternate habitats. Shortly after hatching, the smallest individuals quickly disperse to sand, in part because of lowest densities of aggressive adults on sand, and because their diet does not rely on molluscs (Jude *et al.* 1995, Charlebois *et al.* 2001) that are found predominantly on hard substrates. As these individuals grow, they move across the dominant substrate (mud) in search of better habitat supporting benthic prey and eventually nesting habitat. As a result, density increases on the mud substrate through the year, with little change in total biomass. As reproductive activity begins to slow in late July and August (MacInnis and Corkum 2000b), smaller females and males move onto till, a substrate that supports moderate densities of molluscs and benthic prey but limited habitat for nesting and predator avoidance. As a result, density and size declines on till substrate by late summer. By autumn, density declines on all substrates, as round gobies migrate to deeper waters (i.e., central basin) to overwinter (Smirnov 1986, Knight 1997).

Our insights into the density and seasonal behavior of the round goby population would not have been possible without first evaluating suitable methods for censusing their abundance. Steingraeber *et al.* (1996) evaluated several traditional fish sampling gears and found bottom trawls to provide the highest catch-per-unit-effort in the Illinois waterway system. Bottom trawls are an effective tool for sampling demersal fish like round gobies, but are limited to relatively smooth bottoms (sand, mud) and are selective in the size of fish captured. The interagency western basin bottom trawling program (Forage Task Group 2004) provides an estimate of 40.7 million round gobies in the western basin in 2002, but this program does not sample rock or till areas where we found the round goby density to be highest, and 27.5 mm is the smallest round goby fully vulnerable to the gear. Angling has proven effective for capturing round gobies in many habitats, but catches are biased to large individuals (MacInnis and Corkum 2000a). Electrofishing is ineffective because round gobies lack a swim bladder and therefore remain on or close to the bottom even when shocked. Shoreline seining is a popular technique, but is limited to shallow water and smooth bottom habitats, and is hard to employ in a quantitative way. Most passive gears (minnow traps, Windermere traps, fyke nets) appear limited for quantitative assessment of round goby populations because the fish have small home ranges (Moskal'kova 1996, Wolfe and Marsden 1998, Ray and Corkum 2001), and even when captured, the hopping behavior of round gobies seems to afford high escapement (Table 1).

When biological samples are not required, visual census is the preferred technique for population assessment (Sale 1997, Wickett and Corkum 1998b). Direct observation by snorkelling or SCUBA, or remote observation with a towed camera or ROV allows assessment of density and size with minimal disturbance of the round goby in its native habitat. Round gobies are naturally curious fish, and are often attracted to the presence of divers (Corkum, personal observation). We saw no evidence of this attraction to the ROV, as counts on the first pass were comparable to counts on the last pass. If the ROV came in contact with, and disturbed, the substrate round gobies quickly moved into the area, and it may be this physical disturbance of substrate that attracts round gobies to the SCUBA divers. Recording of the census on video permits reviewing the data repeatedly, permitting many facets of round goby behaviour and ecology to be analysed (Wickett and Corkum 1998a, b). While injectible dyes appear to be the best method for tagging round gobies

(Wolfe and Marsden 1998, Ray and Corkum 2001), high population sizes, rapid recruitment, and dynamic behaviours (seasonal movements, nest guarding, etc.) make the application of a mark-recapture study for mortality and population assessment logistically challenging.

Charlebois *et al.* (1997) and Jude (2001) called for enhanced effort to identify methods useful for collecting round gobies, describing their habitat preference and noting changes in distribution with respect to age, and projecting the standing stock of round gobies to enable the quantification of the ecological impact of round gobies in invaded ecosystems. Our study has gone a long way to address each of these research needs. On-going efforts to describe trends in abundance and changes in demographics will aid in our understanding of the population dynamics of this invading species.

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