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Age and Growth of Round Goby *Neogobius melanostomus* in the Upper Detroit River

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Abstract.—The round goby *Neogobius melanostomus* has quickly become one of the most abundant benthic fishes in the Lake Huron–Lake Erie corridor of the Laurentian Great Lakes since it was first discovered in the St. Clair River in 1990. We describe the age, growth, and size structure of the round goby population from samples collected in the upper Detroit River. Round gobies were collected using an otter trawl about every 3 weeks during spring, summer, and autumn 1996. Age-1 fish were found to be the most abundant group in the population, and fish size within a given age-group was highly variable. Both males and females were found to be maturing younger and at smaller sizes than in their native range. Marginal increment analysis of otoliths revealed that annulus formation occurred in late May–early June. Although mean size of fish differed significantly with sample date ($P < 0.001$), there was little increase in mean size from May to October. Age-1 fish had a larger growth than age-2 fish. Mean annual growth for age-1 males (37 mm) was greater than for females (33 mm), but size ranges overlapped. Early maturity and rapid growth are two factors that may ensure the continued expansion of the round goby throughout the Great Lakes.

The round goby *Neogobius melanostomus* and the tubenose goby *Proterorhinus marmoratus,* two bottom-dwelling gobiid species native to the Ponto–Caspian region of Eurasia, were first discovered in 1990 in the St. Clair River of the Laurentian Great Lakes (Crossman et al. 1992; Jude et al.1992). The tubenose goby has expanded its range to include Lake St. Clair, the upper Detroit River (Thomas and Haas 1997; A. J. MacInnis, personal observation) and western Lake Erie (L. D. Corkum, personal observation). The larger, more aggressive, round goby has spread rapidly to the five Great Lakes (Charlebois et al. 1997). Densities of the round goby of 1.8–17/m^2 have been reported from the central basin of Lake Erie (Ohio) and up to 40/m^2 in Grand Calumet Harbor, Lake Michigan (Charlebois et al. 1997).

Introductions of gobiid fishes elsewhere in the world have disrupted native fish communities (California, Brittan et al. 1970; Matern and Fleming 1995; Netherlands, Vaas et al. 1975; Australia, Middleton 1982; Poland, Skora and Stolarski 1993), and the same can be expected of the round goby in the Great Lakes. In the St. Clair River and Grand Calumet Harbor, the round goby has been implicated as the cause of year-class failure in the mottled sculpin *Cottus bairdi* (Jude et al. 1995). Introduction of round goby also might have resulted in the population decline of logperch *Percina caprodes* in the St. Clair River (Jude et al. 1995). Round gobies have the potential to affect other benthic fishes throughout the Great Lakes including darters (*Etheostoma* spp., *Percina* spp.), sculpins (slimy sculpin *Cottus cognatus,* deepwater sculpin *Myoxocephalus thompsoni*), and madtoms (*Noturus* spp.). These native fishes are important prey to piscivores including lake trout *Salvelinus namaycush,* smallmouth bass *Micropterus dolomieu,* and walleyes *Stizostedion vitreum.*

Currently, little is known of the basic life history characteristics of the round goby in North America (Charlebois et al. 1997). In the Black and Caspian seas and associated waters, the round goby was an important component of the commercial gobiid catch (Miller 1986), fluctuating from 10.1 to 2.3 billion individuals (184×10^6–11×10^6 kg) in the Sea of Azov from 1956 to 1973 (Kovtun et al. 1976). There was a record catch of nearly 45,454 metric tons of round gobies in the Aral Sea in 1956 (Charlebois et al. 1997). However, round gobies have declined in their native range because of decreased food supply (mollusks), changes in salinity (Aral Sea), habitat loss from siltation, and low oxygen concentrations at the sediment surface (Charlebois et al. 1997).

The primary objective of our study was to describe the sex-specific age, growth, and size structure of the round goby population in the Detroit River.

Methods

Fish collections.—To determine age structure and growth of round gobies, we collected fish

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about every 3 weeks from the upper Detroit River (42°20′N, 83°00′W) during spring, summer, and fall 1996 using a small otter trawl. The trawl was equipped with ‘‘rockhopper’’ foot gear, and the dimensions of the net opening were 4 m wide × 1 m high. The netting consisted of 40-mm-stretch-measure mesh on the body of the net with 10-mm-stretch mesh in the cod end. The net was towed at an average speed of 3.5 km/h for 10 min/haul. We trawled for round gobies on 6 May, 29 May, 4 June, 17 June, 8 July, 19 September, and 22 October 1996 (10 trawls/date). Fish were not collected in August because a trawl was unavailable; however, we caught round gobies on 29 July 1996 using hook and line.

Captured round gobies were euthanatized with CO_2 and individually frozen to avoid damage to otoliths (Geffen 1987) and to eliminate change in body shape or weight (Butler 1992). Standard lengths were recorded to the nearest 1 mm and total weight to the nearest 0.1 g. Sex of round gobies was determined by examination of the genital papilla (Miller 1984) and fish were assigned to one of three categories: male, female, or immature. Mature individuals of both sexes can be distinguished by the length and thickness of the papilla with the papilla being larger in mature individuals. Male round gobies have a long, triangular-shaped papilla with a broad base and narrow tip. In females, the papilla is shorter and rectangular in shape, being broad at both the base and tip. Adult parental males can also be distinguished by their dark grey to black coloration and their enlarged cheek muscles (Miller 1984).

Aging.—Although both sagittae and lapilli pairs of otoliths were removed, lapilli were used for aging because they have the most distinct increments (Brothers 1987). Growth in the lapilli was much more uniform, regardless of fish age, with clear annual increments always present. Examination of whole and partially sectioned sagittae showed multiple growth zones and no clear annuli. Each lapillus was mounted on a glass slide, ground, and polished. Otoliths were examined using a compound microscope equipped with dual polarizing filters and connected to a black-and-white video camera and monitor. The image was captured and analyzed using computer-aided image analysis (Mocha System, Jandel, Inc.).

Ages were assigned by counting the number of annuli visible in the otolith. Fish without visible annuli were assigned an annual age of 0. The distance from the nucleus to each annulus and from the nucleus to the edge of the otolith was measured on the longest axis of the otolith using image analysis. The date of annulus formation was determined using marginal increment analysis, a technique that determines the date of annulus formation by following the increase in width of the newest increment (from the most recent annulus to the edge of the otolith) with time (Mgaya 1995). Only fish with a single annulus present were used for marginal increment analysis because these would be the fastest-growing fish in the population and would show the most visible increases in increment width.

Back-calculation of size at age.—One can obtain information on past growth of a fish based on the relationship between a hard part (e.g., scale or otolith) and fish length using regression analysis. Values for the slope and *y*-intercept of the relation were used in back calculating fish size at age. The degree of error in back-calculation was expressed as the difference between ‘‘scale’’ proportional (regression of otolith radius on fish length) and ‘‘body’’ proportional (regression of fish length on otolith radius) forms of linear and nonlinear models (Whitney and Carlander 1956; Francis 1990; Smedstad and Holm 1996). Size-at-age results were compared by inspection with the minimum size, maximum size, range, and mean size of fish collected in the field at the time of annulus formation to select the best back-calculation formula. Back-calculated sizes also were tested (*t*-test) to determine if the mean back-calculated size at age 1 differed significantly for age-1 and age-2 round gobies.

Growth.—Seasonal growth patterns were examined by plotting the mean standard length (SL) of age-1 and age-2 fish by sex and maturity on each sample date. The current year's growth for all fish was estimated by the difference in size from the back-calculated size at the most recent annulus and the size at capture. The mean size increase on each sample date was then determined for age-1 and age-2 fish, as well as for male, female, and immature fish separately.

Results

Fish Collections

Round gobies were collected in shallow water (<4 m depth, usually 2–3 m) and were rarely caught in water deeper than 5 m. No round gobies were captured on the earliest sample date, 6 May 1996. There was considerable variation in the numbers of fish caught on each sample date, ranging from 23 individuals on 19 September to 104 on 17 June (Figure 1). Fewer gobies were captured on 19 September because the trawl was clogged repeatedly with macrophytes. The mean size of gobies collected also varied significantly with collection date (one-way analysis of variance, ANOVA: $F = 12.79$; df = 5, 354; $P < 0.001$). The hook-and-line collections of 29 July would potentially be biased toward larger fish and were not included in the ANOVA. There was a significant log–log relation between standard length and weight of round gobies ($N = 435$; $r^2 = 0.99$; $P < 0.0001$). The slope of the line was 3.26, indicating that weight increases at a faster rate as length increases.

Aging

Marginal increment analysis showed annulus formation to occur between late May and early June (Figure 2). Examination of the otoliths from 29 May and 4 June samples showed the start of the current year-2 growth to be just forming at the margin, but often the increment was too narrow to be effectively measured on the computer.

Four age-groups were collected during the sampling period with age-1 fish being most common followed by age-2 fish (Figure 1). Age-1 fish exhibited considerable size range (25–90 mm) and overlapped in size with age-2 fish (55–100 mm) in June and July. Age-0 fish were present in samples from 29 July until 22 October. The sex ratio of females to males was 1.27:1 ($N = 295$); 168 individuals were immature and unable to be sexed. Mean sizes of males were larger than females for age-1 and−2 fish; only three age-3 fish (all females) were collected (Table 1).

Back-Calculation of Size at Age

The nonlinear proportional model of fish length on otolith radius was chosen as the best back-calculated formula based on the r^2 value ($y = -25.57 + 180.1x$; $r^2 = 0.738$, $N = 413$, $P < 0.0001$) and agreement of back-calculated size at age 1 (15.3–65.3 mm) with observed body length of age-1 round gobies (24.0–61.5 mm) collected in the Detroit River at the time of annulus formation (4 July). Lee's phenomenon (back-calculated lengths at age are smaller for older fish than for younger fish in the sample, Lee 1912) was observed in adult females and immature males (two-sample *t*-test; $t = 1.980$, $P < 0.05$; and $t = 1.989$, $P < 0.01$). Lee's phenomenon also was observed in adult males—mean back-calculated length at age 1 was 42.2 mm (age 1) and 33.9 (age 2)—but the sample size was low for both age-1 ($N = 6$) and age-2 ($N = 5$) males.

Seasonal Growth

Although the mean size of fish collected varied significantly with collection date ($P < 0.001$), there appeared to be little increase in the mean size throughout the sampling season (Figure 3). When the mean sizes were separated into age-groups, there was a significant increase in size during the sample period for age-1 fish ($P < 0.05$) but not for age-2 fish ($P > 0.05$; Figure 3). The mean annual growth for age-1 males was 36.9 mm (range, 24.6–46.0 mm) and for females was 32.8 (range, 21.0–43.0 mm). Attempts to fit a von Bertalanffy growth model to the size-at-age data were unsuccessful due to large standard errors in model parameters.

Discussion

Overall, sizes of round goby are smaller at a given age in the Detroit River than in Europe. In their native range, round goby males reach about 100–130 mm SL and females reach 80–110 mm in their first year (Berg 1949). Lengths of males and females at age-groups 1 and 2 in the 1996 Detroit River population are considerably smaller (Table 1) than sizes of round goby in their first year in Europe. In both regions, males are larger than females at a given age. In Europe, maximum lengths of males and females are 250 mm and 130–140, respectively (Berg 1949), and commercially caught fish weigh up to 30 g (Charlebois et al. 1997). In the Detroit River, the largest round goby male collected was 124 mm (total length) and weighed 28.5 g; the largest female collected was 112 mm (total length) and weighed 17.5 g. In Europe, round gobies typically live to 4–5 years (Charlebois et al. 1997) compared with 3 years (this study).

Round goby abundance might have been underestimated by the trawl catches due to decreased efficiency of trawl nets over uneven bottoms (Hayes 1983) and because trawls tend to underestimate the abundance of small cylinder-shaped bottom fishes (Adams et al. 1995). The abundance and size distribution of age-0 fish might have been underestimated because these fish are too small to be caught by the net or because they occupy different habitats than ones we sampled. However, we also found that seining with finer mesh along the Detroit River shoreline was ineffective in obtaining juvenile round gobies in 1996. Numbers of male round gobies were probably also underesti-

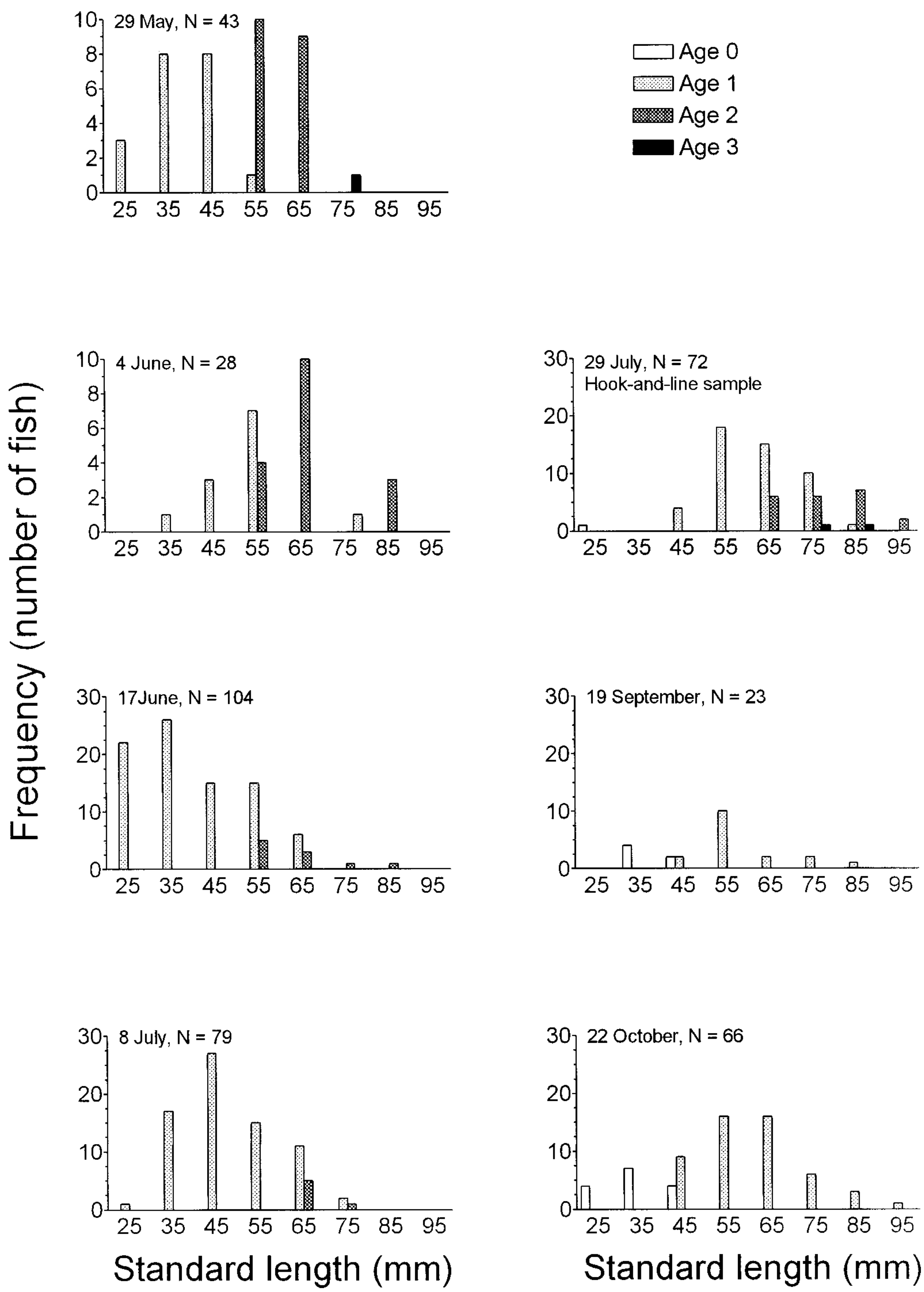

FIGURE 1.—Size-frequency distribution by age for each sample date on which round gobies were collected by hook and line (29 July) or by trawling (all other dates) in 1996.

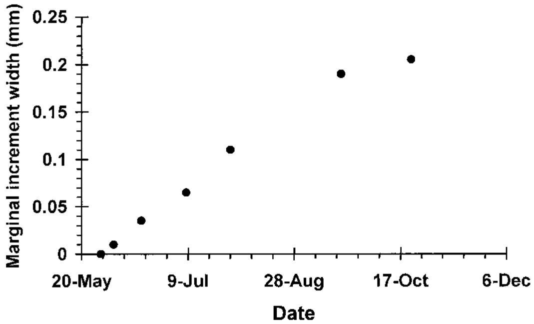

FIGURE 2.—Otolith marginal increment width plotted by sample date for age-1 round gobies collected in 1996. Data points correspond to collections on 29 May, 4 June, 17 June, 8 July, 29 July, 19 September, and 22 October.

mated because large males guard nests under rocks and within burrows, which are inaccessible to nets. Adult males that were collected were 1–2 years of age; Bil'ko (1971) observed mature fish in Europe at age 1. However, sexual maturity in females (age 2) and males (age 3) in Europe is typically later than age 1 (Charlebois et al. 1997).

Sex-specific mortality rates of round goby males are important, because the ratio of adult males to females is a strong predictor of year-class strength of round gobies in Europe (Kovtun 1980). In the Sea of Azov, juvenile survivorship is reduced considerably when the number of males is less than the number of females. Adult males are assumed to die after a single spawning season because they do not feed while guarding a nest (Miller 1984). In the Detroit River, females outnumbered males (1.27:1). Adult males older than age 1 were not present in the October 22 sample (presumably after the breeding season), providing indirect evidence for this phenomenon. However, no age-2 females were collected in the October 22 sample either. This may be because older fish leave shallow-water breeding habitats in autumn as water temperatures decline. In their native range, round gobies migrate to deeper water in the winter (Miller 1986). The reason for the appearance of large numbers of small age-1 gobies in the June 17 sample is unknown. It may result from inshore migration by round gobies that moved offshore in autumn, as was observed in the central basin of Lake Erie (Knight 1997).

Annulus formation in the Detroit River occurred in late May–early June, corresponding to annulus formation in the Sea of Azov, which begins in May and can extend to July (S. Rudnicka, Institute of Fisheries, Varna, Bulgaria, personal communication). In the St. Clair River, annulus formation appears to occur in August, based on age determination with sagittae (D. Jude, University of Michigan, personal communication). This may be a result of the cooler thermal regime in the St. Clair River because annulus formation has been shown to be affected by temperature for both coldwater and warmwater species (Lentsch and Griffith 1987; Samuel et al. 1987).

TABLE 1.—Mean (±SE) standard lengths (mm) and numbers (N) of round gobies collected from the Detroit River, Ontario, 1996.

Age (years)	Female (N)	Male (N)
1	58.4 ± 0.92 (99)	62.8 ± 1.26 (92)
2	64.6 ± 0.93 (44)	75.9 ± 2.28 (30)
3	82.7 ± 4.90 (3)	

Higher mortality of the larger, faster-growing individuals may explain the smaller back-calculated lengths at age for older fish than for younger fish captured (Ricker 1975). Bil'ko (1971) observed that mature male gobies of age 1 or older had a greater back-calculated size at age 1 than did immature males of age 1 or older. Mature males

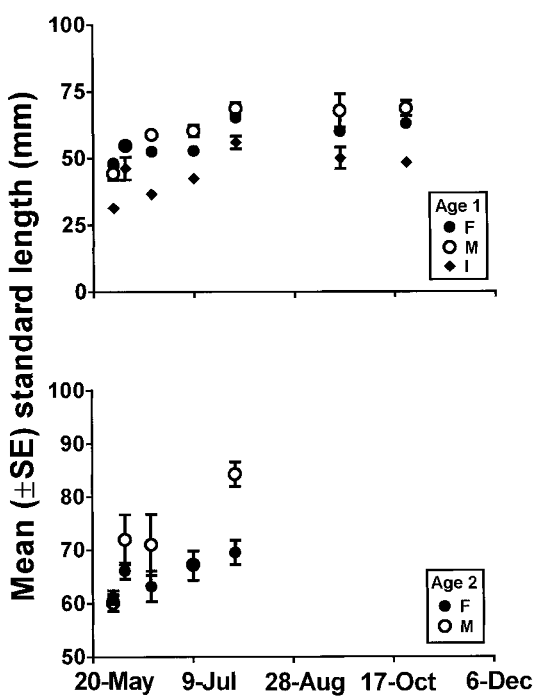

FIGURE 3.—Mean standard length of **(top)** age-1 and **(bottom)** age-2 round gobies (F, female; M, male; I, immature) plotted by date.

died at the end of the spawning season. Bil'ko (1971) also observed the same phenomenon in female round gobies and attributed it to post-spawning-season mortality. The large numbers of age-1 gobies shorter than 35 mm from the 17 June sample suggests that size-selective winter mortality does not appear to be a factor in determining the abundance of age-1 round gobies. The maximum age for males is unknown because so few were collected, but it is at least age 3 because immature males of age 2 were collected on 29 July and 19 September 1996.

Both Ehrlich (1989) and Leach (1995) stressed that successful invaders have short generation times. Rapid growth and early maturity appear to be two mechanisms contributing to the success of the round goby in the Laurentian Great Lakes.

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