J. Great Lakes Res. 29(3):392–399
Internat. Assoc. Great Lakes Res., 2003

The Invasive Round Goby (*Neogobius melanostomus*) in the Diet of Nestling Double-crested Cormorants (*Phalacrocorax auritus*) in Hamilton Harbour, Lake Ontario

Christopher M. Somers, Marie N. Lozer, Victoria A. Kjoss, and James S. Quinn*

McMaster University
Department of Biology
1280 Main St. West
Hamilton, Ontario, Canada L8S 4K1

ABSTRACT. *Populations of the invasive round goby* (Neogobius melanostomus) *have expanded dramatically since their discovery in the Laurentian Great Lakes in 1990. The abundance of these fish and possible competitive displacement of native species from aquatic food webs suggest that they will become an important prey item for predatory birds and sport fish. To date, there is very little information on the predation of round gobies by piscivorous birds in the Great Lakes. We used an abdominal palpation technique to stimulate regurgitation by double-crested cormorant* (Phalacrocorax auritus) *chicks in ground nests from colonies in Hamilton Harbour, western Lake Ontario, during the 2002 nesting season. We collected and identified all fish species present in regurgitated boluses. For tree-nesting birds, we collected fish that were regurgitated and fell to the ground as a result of targeted disturbance of particular nest trees. At all locations and times, alewife* (Alosa pseudoharengus) *was the most abundant fish species present by a large margin. The second most abundant species was the round goby, which was present in the regurgitated stomach contents of chicks in a total of 18 percent of nests surveyed, and made up 1.8 to 11 percent of all individual fish specimens identified. Our results show that the round goby is already an important food item for breeding cormorants in Hamilton Harbour, despite relatively recent establishment of goby populations in western Lake Ontario. Fish species of sport or commercial interest were detected in our samples with extremely low frequency (< 0.1%).*

INDEX WORDS: *Round goby, double-crested cormorant, diet analysis.*

INTRODUCTION

Many non-indigenous fish species have been accidentally or purposefully introduced to the Laurentian Great Lakes over the past 200 years (Mills *et al*. 1993). The most recent accidental exotic is the round goby (*Neogobius melanostomus*), a small benthic fish native to the Ponto-Caspian area of Europe (MacIsaac and Grigorovich 1999). Round gobies were first discovered in the St. Clair River in 1990 (Crossman *et al*. 1992, Jude *et al*. 1992), and have since spread to all five Great Lakes more rapidly than any previously introduced fish species (Dillon and Stepien 2001). This extremely rapid population expansion is predicted to have serious negative impacts on native aquatic ecosystems (Charlebois *et al*. 2001); however, our current understanding of how gobies interact with other species and how their abundance may change aquatic food webs is limited.

In laboratory experiments, round gobies aggressively disrupted spawning of the native mottled sculpin (*Cottus bairdi*) by usurping nesting habitat and consuming their eggs (Dubs and Corkum 1996). This behavior is likely responsible for the complete extirpation of sculpin from certain areas in Lake Michigan following the arrival and expansion of round goby populations (Janssen and Jude 2001). In addition, the diet of round gobies in shallow water has been shown to overlap significantly with that of several native species, suggesting that they may be in direct competition for food resources (French and Jude 2001). Egg predation by the round goby and competition for food and spawning habitat could cause major basin-wide declines in sculpin and other native forage species.

*Corresponding author. E-mail: quinn@mcmaster.ca

Round goby populations have already reached high densities in some areas of the Great Lakes (MacInnis and Corkum 2000, Ray and Corkum 2001), and as they become more abundant relative to native fish species, the diet of piscivorous birds and sport fish is likely to shift to include them. Despite these predictions and concerns, there has been little systematic monitoring of the diet of any bird species to determine whether this is occurring.

Double-crested cormorants (*Phalacrocorax auritus;* hereafter cormorants) are abundant piscivorous top predators in the Great Lakes. Dramatic expansion of cormorant populations over the past 25 years has resulted in a general concern for their impact on sport and commercial fisheries (Lantry *et al*. 2002, Stapanian 2002, Stapanian and Bur 2002, Weseloh *et al*. 2002), and has made quantitative assessment of their diet an important issue for biologists (Johnson and Ross 1996, Johnson *et al*. 2002). Cormorants forage by pursuit-diving in water generally less than 10 m deep (Neuman *et al*. 1997, Stapanian *et al*. 2002), which makes them a likely candidate predator of the round goby. Here we introduce the non-invasive technique of manual abdominal palpation to stimulate regurgitation of stomach contents by cormorant chicks. We apply this method and opportunistic collection of regurgitated fish to determine fish species abundance in the diet of nestling cormorants in three breeding colonies in Hamilton Harbour, western Lake Ontario. Specifically, our objective was to determine whether adult cormorants feed round gobies to their young.

METHODS

Study Site

We studied the diet of cormorant chicks in three breeding colonies on western Lake Ontario in the greater Hamilton, Ontario, area (43°15′N, 79°51′W): (1) Eastport—a colony of approximately 1,400 ground and tree-nesting pairs on the mainland; (2) Farr Island—approximately 100 pairs nesting on the ground and in the remains of a fallen tree on a small man-made island; (3) Hickory Island—a colony of approximately 150 pairs nesting in trees on a small island in Cootes Paradise, a large wetland at the western end of Hamilton Harbour. Colony sizes reported are from nest-counts conducted by the authors and the Canadian Wildlife Service in May 2002. For more information on cormorant colonies and other colonial waterbird species in the Hamilton Harbour area, see Quinn *et al*. (1996) and Pekarik *et al*. (1997).

The exact timing of round goby establishment in western Lake Ontario is unknown. Electro-fishing surveys of transects in Hamilton Harbour did not detect round gobies in June of 1995, but they were the most abundant species detected in the same transects 6 years later in 2001 (Dr. S. Balshine, McMaster University, *pers. comm*.). The population of round gobies must therefore have become established and grown substantially in Hamilton Harbour beginning in 1995 or later. The current sizes of round goby populations in western Lake Ontario, Hamilton Harbour, and Cootes Paradise are unknown.

Stomach Content Sampling

We used two non-invasive methods to obtain stomach content samples from cormorant chicks. In the first, we selected nests that were accessible from the ground and contained large chicks (> 400 g) that were old enough to have begun developing a down layer (at least 12 days post-hatching). We temporarily removed the two largest chicks from each nest and stimulated them to regurgitate by gentle manual palpation of the abdomen. We collected pooled regurgitated samples from each nest and sealed them in individual plastic bags for later identification of fish species. This allowed for the quantification of fish species presence on a per-nest basis. Chicks were weighed and then returned to their nest immediately after handling. We palpated a total of 410 chicks from 205 nests from the Eastport and Farr Island colonies on 8 days between 2 June and 4 July 2002. We focused sampling efforts during the periods 3 hours after dawn and 2 hours before sunset to maximize the probability that chicks had recently been fed (Leger and McNeil 1985). Nests sampled in this manner were numbered and marked so that they would not be re-sampled on later dates. To determine the impact of abdominal palpation on the short-term survival of chicks, we temporarily marked 25 chicks from 13 sampled nests in the Eastport colony with masking tape on the tarsus, and returned 5 days later to assess their status.

In the second sampling technique, we stimulated regurgitation by chicks in tree nests by creating a mild disturbance (*i*.e., talking and hand-clapping) in the vicinity of several different trees in each colony. We collected all fish that were regurgitated and fell to the ground for later identification of species. Samples were collected in this way on 20, 25, and 28 June 2002 from the Eastport colony, and 20, and 28 June 2002 from the Hickory Island colony. All

animal procedures were approved by the McMaster University Animal Research Ethics Board following the guidelines of the Canadian Council on Animal Care.

Fish Species Identification

Species native to North America were identified according to Scott and Crossman (1973) and Page and Burr (1991). The exotic round goby was identified using field markings summarized in Jude *et al.* (1992) and Charlebois *et al.* (1997). Partial or highly digested specimens that resembled round gobies but did not include clear diagnostic field markers were not included in our analyses.

Statistical Analyses

The overall per-nest incidence of fish species, excluding alewife, detected in samples from palpated chicks was compared using a chi-squared test. The expected values were generated based on equal per-nest incidences in all species categories (excluding alewife).

To analyze temporal trends in the relative abundance of round goby specimens (*i.e.*, Tables 1 and 2), we used a chi-squared test to compare the num-

TABLE 1. The relative abundance of individual fish specimens in pooled regurgitated samples from all palpated chicks in the Eastport and Farr Island colonies on eight collection days during the spring / summer 2002. The percentage of the total sample made up of each species is given in parentheses.

Date	Total # fish identified	Alewife	*Round goby	Smelt	Stickleback	†Other
2 June	47	46 (98)	0	0	0	1 (2)
6 June	61	52 (85)	6 (10)	2 (3)	0	1 (2)
9 June	112	104 (93)	6 (5)	0	0	2 (2)
10 June	37	27 (73)	8 (21)	1 (3)	0	1 (3)
12 June	251	173 (69)	42 (17)	10 (4)	17 (7)	9 (3)
16 June	172	138 (80)	25 (4.5)	3 (2)	5 (3)	1 (0.5)
19 June	137	93 (68)	5 (4)	3 (2)	3 (2)	33 (24)
4 July	52	48 (92)	2 (4)	1 (2)	0	1 (2)
TOTAL	869	681 (78)	94 (11)	20 (2)	25 (3)	49 (6)

* Degraded or partial specimens that were likely round gobies (n = 22) were excluded from this dataset because of uncertainty regarding identification.

† Other species consisted mainly of emerald shiner and Johnny darter, but also included one yellow perch, and single specimens of unidentified sculpin and juvenile Pacific salmon species.

TABLE 2. The relative abundance of individual fish specimens collected from the ground under nesting trees in Eastport (Hamilton Harbour) and Hickory Island (Cootes Paradise) double-crested cormorant colonies in the spring / summer of 2002. The percentage of the total sample made up of each species is given in parentheses.

Location	Date	Total # fish identified	Alewife	*Round goby	Smelt	Stickleback	Other
Eastport	20 June	440	414 (94.2)	8 (1.8)	1 (0.2)	9 (2.0)	8 (1.8)
	25 June	443	425 (95.9)	14 (3.2)	0	3 (0.7)	1 (0.2)
	28 June	311	286 (92.0)	19 (6.1)	2 (0.6)	1 (0.3)	3 (1.0)
	TOTAL	1,194	1,125 (94.2)	41 (3.4)	3 (0.3)	13 (1.1)	12 (1.0)
Hickory Island	20 June	176	161 (91.5)	9 (5.1)	0	1 (0.6)	5 (2.8)
	28 June	117	112 (95.7)	5 (4.3)	0	0	0
	TOTAL	293	273 (93.2)	14 (4.8)	0	1 (0.3)	5 (1.7)

* 7 fish specimens from Eastport and 1 from Hickory Island that were likely round gobies were excluded from this dataset because of uncertainty of identification caused by digestion.

ber of round gobies vs. the total number of individuals of all other species on each sampling date. In each test we adjusted the degrees of freedom based on the number of sampling dates in the analysis. Similar methods were used to compare the overall frequency of round goby occurrence between Eastport and Hickory Island colonies. The alpha value for all tests was set at 0.05.

RESULTS

On average, the nests that we sampled by abdominal palpation in the Eastport and Farr Island colonies contained 3.3 ± 0.8 chicks. The average mass of chicks palpated was 923.9 ± 189.5 grams (range 400–1480 g). Two hundred and seventy five of 410 (67%) palpated chicks from 170 / 205 (83%) nests produced 10,986 g of regurgitated fish. In these samples we positively identified seven fish species: alewife (*Alosa pseudoharengus*), round goby, rainbow smelt (*Osmerus mordax*), threespine stickleback (*Gasterosteus aculeatus*), emerald shiner (*Notropis atherinoides*), Johnny darter (*Etheostoma nigrum*), and yellow perch (*Perca flavescens*). We found single specimens each of sculpin (*Cottus* spp.) and Pacific salmon (*Oncorhynchus* spp.) that could not be identified beyond genus.

Alewife was present in almost all bolus samples collected from palpated chicks, and on a per-nest basis was by far the most commonly detected species (Fig. 1). The round goby was detected at the second highest frequency overall, and was present in regurgitated samples from more nests than all other species except alewife ($X^2 = 8.63$, df = 3, $P < 0.05$, alewife excluded). The per-nest incidence of the round goby varied substantially by sample date. In the first three samples (2, 6, 9 June) chicks in relatively few nests regurgitated round gobies (range 0 to 11%), followed by an increase from 10 to 19 June (20 to 35%), and then a decrease on 4 July 2002 (7%). Other species were present sporadically and at relatively low frequencies.

Alewife also made up the largest percentage of individual fish specimens collected both in total and on all individual sampling dates (Table 1). The round goby was the second-most abundant species overall and on six of eight sampling dates. The proportion of total fish made up of round gobies varied significantly by date ($X^2 = 34.78$, df = 7, $P < 0.01$), with the highest numbers detected on 10 and 12 June 2002. Other species were generally present at very low levels, with the exception of 19 June 2002; however, this was due primarily to two individual nests that contained relatively large numbers of Johnny darters and emerald shiners.

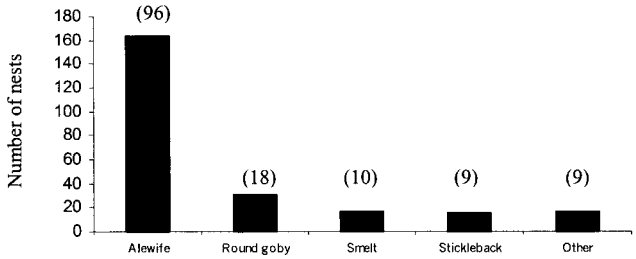

FIG. 1. The number of nests sampled in Eastport and Farr Island colonies in which double-crested cormorant chicks regurgitated various fish species (% of nests in parentheses). Data are from 170 nests sampled on eight days spanning 2 June to 4 July 2002. Degraded specimens that were likely round gobies (n = 22) were excluded from this dataset because of uncertainty regarding identification.

We found 23 of 25 (92%) marked chicks alive and visibly in good condition five days after abdominal palpation. The two chicks that we were unable to locate belonged to a single nest that had lost its flagging tape marker and could no longer be identified in the colony. These two chicks were large at the time of marking (1,050 and 1,280 g) and were likely unaffected by the handling.

In the samples collected from the ground under nest trees in the Eastport colony, we identified six fish species, five of which were identical to those listed above. We did not find yellow perch or emerald shiner in these samples, and the sixth species was a single specimen of freshwater drum, *Aplodinotus grunniens*. Despite the fact that sampling occurred over a span of only 8 days in late June, there was temporal heterogeneity in the relative abundance of round gobies present (Table 2; $X^2 = 10.27$, df = 2, $P < 0.01$). Similar to the results obtained from palpating chicks, alewife was by far the most common species present on all dates, with the round goby a distant second.

We identified seven fish species in ground-collected samples from the Hickory Island colony. Four of these species were the same as those found in ground-samples from Eastport. We did not find rainbow smelt, Johnny darter, or freshwater drum, although we did find a single emerald shiner. Two goldfish (*Carassius auratus*) and a single gizzard shad (*Dorosoma cepedianum*) were species unique

to the Hickory Island colony in our study. Unlike the Eastport colony, we did not detect temporal heterogeneity in the relative abundance of round gobies in samples from Hickory Island (Table 2; X^2 = 0.10, df = 1, P > 0.05). Similar to the other locations and sampling methods, alewife and round goby were consistently the most abundant species. Overall, the relative abundance of round gobies did not differ between ground samples collected at Eastport and Hickory Island (X^2 = 1.23, df = 1, P > 0.05).

DISCUSSION

At nearly all times and locations, and using two different sampling techniques, the round goby was the second most abundant fish species in the diet of cormorant chicks in Hamilton Harbour. To our knowledge, this is one of only two studies to systematically document this invasive fish species in the diet of a piscivorous waterbird in the Great Lakes (see Ross *et al.* 2003). Our findings have two potentially important implications. First, cormorants tend to forage opportunistically on the most readily available fish (Kirby *et al*. 1996, Neuman *et al*. 1997), suggesting that the round goby population in the Hamilton Harbour area must be large relative to other fish species (except alewife). Second, the consistently high frequency of round gobies we observed in cormorant diet is evidence that top predators in aquatic food webs may be changing their diet to incorporate this newly abundant prey species.

A shift in the diet of piscivores to include a high proportion of round gobies may have toxicological consequences. Zebra mussels (*Dreissena polymorpha*) make up a large percentage of round goby diet, but are not an accessible prey item for most native forage fish species (Ghedotti *et al*. 1995, French and Jude 2001). Filter-feeding can cause zebra mussels to accumulate high tissue-loads of environmental contaminants (Dauberschmidt *et al*. 1997, Regoli *et al*. 2001). As round gobies become a more important forage species for top predators in the Great Lakes, their zebra mussel diet may increase bioaccumulation of environmental contaminants at the top of aquatic food webs (Charlesbois *et al*. 2001). We did not monitor contaminant levels in our study, but many of the round goby specimens collected from the stomachs of cormorant chicks contained zebra mussels in their guts. We suggest that future studies examine the potential transfer of contaminants through the zebra mussel—round goby—cormorant pathway.

In addition to cormorants, it is likely that other piscivorous birds are also consuming round gobies at a high frequency in Hamilton Harbour, and at other locations where goby populations are large and/or dense. The benthic nature of round gobies suggests that birds foraging by pursuit-diving, such as loons (*Gavia immer*) and mergansers (*Mergus* spp.), are particularly likely to catch and consume them. Plunge-divers such as gulls and terns are less likely to encounter benthic fish species, but both herring gulls (*Larus argentatus*) and Caspian terns (*Sterna caspia*) have been observed feeding on round gobies in Hamilton Harbour (C.M. Somers and V.A. Kjoss, personal observation). Wading birds, such as black-crowned night herons (*Nycticorax nycticorax*) and great-blue herons (*Ardea herodias*), may also prey on round gobies in shallow waters. All of these species may be at risk of higher exposure to environmental contaminants through consumption of round gobies as described above. An assessment of the diet of additional bird species is necessary to determine the extent to which round gobies have become an important prey item for Great Lakes waterbirds.

Previous studies of cormorant diet have relied primarily on samples of regurgitated fish and pellets of indigestible material collected from the ground in breeding colonies or loafing areas (*e.g.*, Neuman *et al*. 1997, Burnett *et al*. 2002, Johnson *et al*. 2002). This approach to sample collection does not generally permit precise quantification of the number of nests or birds involved. We introduced the technique of abdominal palpation of chicks to overcome this difficulty. Collection of stomach contents using this method allowed us to determine round goby presence on a per-nest basis, which is a direct reflection of the proportion of adult cormorants that catch and feed this fish species to their young. For example, our analyses showed that up to 35% of breeding adult cormorants fed round gobies to their young at the Eastport and Farr Island colonies.

The second advantage of acquiring samples by chick palpation is that diet composition can be determined from fish specimens that are largely intact. This eliminates the need for species identification based on otoliths, scales, and bones (*e.g.*, Johnson and Ross 1996), markedly reducing the time and expertise required for determining diet composition compared to pellet analysis. This gain in efficiency in the laboratory is offset to some degree by the fact

that chick palpation requires more field time than pellet collection because the chicks from each nest must be handled for several minutes. Nevertheless, a small number of field workers in a colony of ground-nesting birds can obtain reasonable sample sizes in a short time period. Our team of four field technicians was able to obtain samples from fifty nests in a 2.5-hour period (0.2 person hours per nest sampled).

In addition, abdominal palpation of chicks is a non-invasive technique that eliminates the need for controversial lethal collection of animals to obtain stomach contents (*e.g.*, Campo *et al.* 1993). However, at this time we do not know the relationship between adult and chick diet in Hamilton Harbour cormorants. Previous research has identified more fish species in the diet of adult birds than in chicks (Harris and Wanless 1993, Neuman *et al.* 1997), but the age and size of the chicks sampled was not indicated in these studies. Logically, fish size may limit which species can be fed to small chicks. In our study, the largest chicks sampled (approximately 1,400 g) were nearly fledged and close to adult size. These large chicks may provide a suitable surrogate for direct sampling of adult birds during the chick-rearing period, but this remains to be directly tested.

Chick palpation is a promising method for short-term surveying of cormorant diet, particularly for addressing questions about fish species presence (*e.g.*, invasive species like the round goby or ruffe, *Gymnocephalus cernuus*) at different colonies in the Great Lakes. The general methodology may also be transferable to other bird species. A major limitation to this approach, however, is that it is temporally restricted to the specific window of chick-rearing. In the case of double-crested cormorants, this represents only approximately one-fifth of the time they spend in the Great Lakes. Assessment of the potential for cormorants to impact fish populations must therefore also employ other techniques (such as pellet analysis) to determine what is happening outside of the chick-rearing period.

We observed significant temporal variation in the frequency of round gobies in the diet of cormorant chicks at the Eastport and Farr Island colonies. The ecological significance of this short-term temporal heterogeneity is not clear; however, since little is known about the round goby in Great Lakes food webs, some comment is warranted. Goby incidence was low in early June, more than tripled in mid-June, and then receded in early July. We do not know what factors influence local abundance of round gobies in the Hamilton Harbour area, or their susceptibility to cormorant predation. Adult round gobies have small home range sizes and show high site-fidelity (Ray and Corkum 2001), suggesting that their availability to cormorants should not be highly influenced by schooling behavior or large-scale fish movements. Cormorants opportunistically feed on the most locally abundant fish species (Kirby *et al.* 1996, Weseloh *et al.* 2002), which may indicate that round gobies are more readily available than other fish (except alewife) in Hamilton Harbour in mid-June than at earlier or later times. We suggest that future studies attempt to correlate surveys of round goby location and density with cormorant foraging and diet analysis.

MANAGEMENT IMPLICATIONS

Breeding colonies of double-crested cormorants have generated public concern regarding the depletion of sport fish stocks and hindrance of fish community restoration efforts. Similar to other studies (*e.g.*, Campo *et al.* 1993, Blackwell *et al.* 1995, Neuman *et al.* 1997), our analyses of cormorant diet show that breeding birds in the Hamilton Harbour area did not often prey on fish species of sport or commercial interest. Our study covered only the chick-rearing period, about 20 percent of the time cormorants spend in Hamilton Harbour each year, so we do not know whether they are feeding on sport fish at other times. We are therefore unable to make any general comments on the overall potential for Hamilton Harbour cormorants to negatively impact local sport fish populations. One possibility is that cormorants may be indirectly affecting sport fish through competition for forage species (Johnson and Ross 1996). However, bioenergetics modeling for other areas on the Great Lakes has suggested that this is unlikely, because even very large numbers of piscivorous birds are predicted to have little impact on prey fish populations (Madenjian and Gabrey 1995). We suggest that managers who make decisions about the control of cormorant numbers based on damage to fisheries should consider diet analyses conducted both during and outside of the breeding season.

From the perspective of managing the round goby invasion, cormorants may have a positive effect. Our results indicate that breeding adults in Hamilton Harbour killed large numbers of round gobies to feed their young. We estimated the number of round gobies consumed based on the detec-

tion of this species in 18 percent of our surveyed nests. If each chick in these nests (approximately 3 chicks in 1,500 nests) was fed just one round goby daily, this would result in a total of 810 gobies consumed per day. Over the 33-day period of chick-rearing that we studied, this per-day consumption rate would result in a total of 26,730 round gobies eaten by chicks alone. This is likely an underestimate of the total number of round gobies consumed because predation by adults was not considered, and in most nests where gobies were detected, the chicks were fed several individuals. At this time we cannot determine the overall impact of this predation on the population of round gobies in western Lake Ontario. However, having hundreds or thousands of gobies removed daily by cormorants may aid in reducing their local population size. In addition, we have observed chicks in certain cormorant nests repeatedly regurgitating a high proportion of round gobies on several different sampling days (data not used in this study), suggesting that some adult birds may be learning to specialize on round goby predation. Birds that specifically target round gobies may further reduce their numbers. Careful monitoring of round goby populations in areas with and without large cormorant colonies will aid in making this determination.

ACKNOWLEDGMENTS

This project was supported by funds from the Natural Sciences and Engineering Research Council of Canada, Human Resources and Development Canada, and the Ontario Premier's Research Excellence Award to JSQ. We thank the Hamilton Port Authority and the Hamilton Royal Botanical Gardens for property access, B. Pomfret and B. Farmer for aiding in collection of diet samples, and Dr. S. Balshine for guidance on round goby identification. We are grateful to Dr. R. D. Morris, Dr. M. A. Stapanian, and 2 anonymous reviewers for providing helpful comments on earlier drafts of this manuscript.

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Submitted: 27 December 2002
Accepted: 15 May 2003
Editorial handling: Martin A. Stapanian