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Double-crested Cormorants (*Phalacrocorax auritus*) on the Move in the Beaver Archipelago, Northern Lake Michigan

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Abstract.—Double-crested Cormorant (*Phalacrocorax auritus*) foraging locations in northern Lake Michigan were recorded in 2003 and 2010. In the interim, the invasive round goby (*Neogobius melanostomus*) appeared in 2006, and control of Double-crested Cormorants was initiated in 2007. Spatial data from 2003 and 2010 were analyzed to determine whether foraging distributions differed between sample periods. A multi-response permutation procedure found that a significant shift in foraging locations occurred between sample periods. Groups of Double-crested Cormorants foraged in the same key locations in both years, but foraging range expanded overall in 2010. Range expansion could be a response to the presence of the round goby, which is an abundant food source throughout Lake Michigan. The 2010 foraging location data corresponded with the early departure of Double-crested Cormorants from the Beaver Archipelago. The combined effects of control and the appearance of round goby in diets resulted in changes in numbers and distributions of foraging Double-crested Cormorants. *Received 22 January 2013, accepted 4 November 2013.*

Key words.—distribution, Double-crested Cormorant, foraging patterns, *Neogobius melanostomus*, *Phalacrocorax auritus*, round goby.

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Double-crested Cormorants (*Phalacrocorax auritus*; cormorants) are common piscivorous waterbirds endemic to coastal and interior North America, including the Great Lakes (Hatch and Weseloh 1999). Dietary studies from 1986-2001 indicated that the primary prey of cormorants in the Beaver Archipelago of northern Lake Michigan was the invasive alewife (*Alosa pseudoharengus*; Ludwig *et al.* 1989; Seefelt and Gillingham 2004). Despite past reliance on alewives, stomach and regurgitate analyses indicate that newly invasive round gobies (*Neogobius melanostomus*) currently make up a significant proportion of the diet of Great Lakes cormorants (Johnson *et al.* 2010). Round gobies appeared in the archipelago in 2006 (Kaemingk *et al.* 2012), and in 2009-2010 round gobies made up 63-82% of identifiable fish species counted in regurgitate and stomach samples from cormorants in the area (Tucker 2011).

In the Great Lakes region, the increase in cormorant numbers is seen as an explanation for a reduction in fish populations of sport and commercial interest (Lantry *et al.* 2002; Rudstam *et al.* 2004; Fielder 2008; but see Diana 2010). Control activities (culling adult cormorants and oiling eggs), which can displace adults to new locations or increase abundance on non-targeted colonies (Mott *et al.* 1998; Glahn *et al.* 2000; Duerr *et al.* 2007; Dorr *et al.* 2010), were implemented in the Beaver Archipelago in 2007. The effects of control on cormorant and fish populations in the Beaver Archipelago have not been quantified, and how these actions affect the movements and foraging distributions of cormorants in the region is unknown.

The goal of this study was to assess changes in cormorant foraging distributions in the Beaver Archipelago that occurred between 2003 and 2010. Specific objectives were to: 1) examine differences between the location and size of rafts (foraging flocks) sighted in 2003 prior to control and the invasion of the round goby (Seefelt and Gillingham 2006), and those sighted in 2010 after the initiation of control and post-round goby invasion; and 2) describe how cormorant foraging locations were related to colony proximity, proximity to the nearest shoreline, water depth, lake bottom slope, and other landscape characteristics.

METHODS

Study Site

This study was conducted in the Beaver Archipelago, northern Lake Michigan (Fig. 1), a group of approximately 11 permanent islands (< 1-145 km^2). The islands on which cormorants choose to nest fluctuate from year to year (Wires and Cuthbert 2010). In 1984, 250 cormorant nests were located throughout the Archipelago (Ludwig 1984), while 10,125 nests were located in the same area in 2000 (Seefelt and Gillingham 2008). This number decreased slightly in 2001, suggesting cormorant population growth and range expansion may have been stabilizing (Seefelt and Gillingham 2004). Since 2003, Gull, Hat, and Pismire islands had the largest cormorant colonies (Wires and Cuthbert 2010).

Surveys

Double-crested Cormorants often forage alone, but can form rafts comprising a few to several hundred individuals, in which birds may work together to catch fish (Hatch and Weseloh 1999). Seefelt and Gillingham (2006) used boat surveys to document rafting locations during the 2003 breeding season. We collected raft location data from 17 May to 21 July 2010 (34 sampling days) following similar methods to Seefelt and Gillingham (2006) and used data only from the corresponding time period for comparison. Each raft was assumed to represent a foraging group. We navigated the boat toward each raft and recorded the latitude and longitude of the approximate spot from which cormorants dispersed using a handheld GPS. When the number of cormorants composing the raft was too large to count precisely, we estimated the total count to the nearest 10. Four observers were present.

Analysis

Using ArcGIS (Environmental Systems Resource Institute 2005), maps of lake bottom depth, slope, plan curvature, and aspect were generated from a raster bathymetry map (National Oceanic and Atmospheric Administration 1996) and distances were calculated between rafts and the nearest island shoreline and nearest colonies (all possible and only those occu-

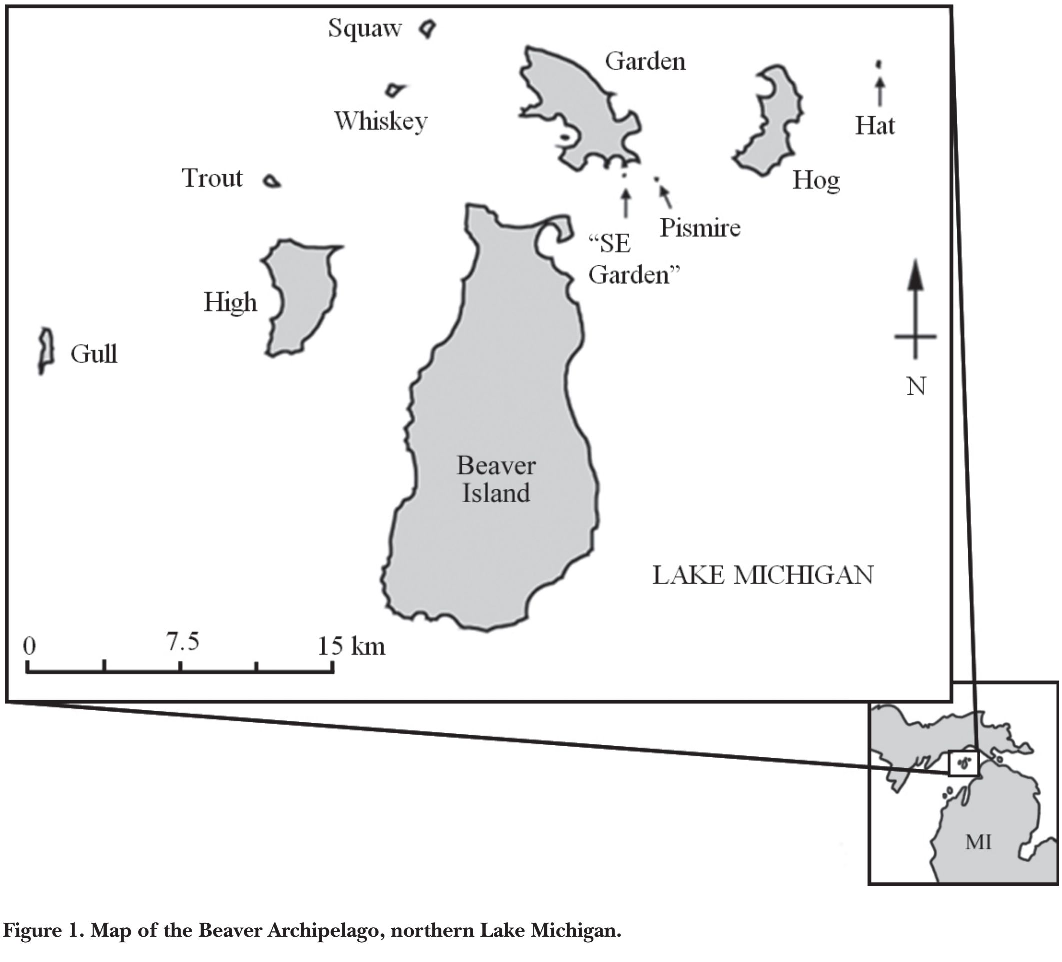

Figure 1. Map of the Beaver Archipelago, northern Lake Michigan.

pied) in the Beaver Archipelago. We used Minitab (Minitab, Inc. 2007) to conduct statistical tests performed outside of ArcGIS or other spatial software unless otherwise noted.

The ABODE for ArcGIS extension (Laver 2005) was used to find 50% and 95% volume contours (weighted by cormorants per raft) denoting the most probable and important cormorant foraging ranges for the 2003 and 2010 rafts (containing approximately 50% and 95% of the raft locations respectively; Powell 2000). Location data were standardized using the unit variance. Using the area estimates of the volume contour polygons, we calculated the ratio of overlap between 2003/2010 data and the percent of each polygon the overlap encompassed.

To determine whether the 2003 and 2010 raft location data represented two unique point distributions (or groups) in space, program BLOSSOM, a multi-response permutation procedure (MRPP) was used (Cade and Richards 2005). The MRPP compares the distances in Euclidean space between points in two or more a priori groups against permutations of the same points within random groupings (Zimmerman *et al.* 1985). We performed 10,000 iterations of the Monte-Carlo resampling procedure (Cade and Richards 2005). CrimeStat (Levine 2010) was used to calculate Mantel Indices, which identify correlations between distance and time, for 2003 and 2010 rafts in total and by month. Mantel tests were performed for all 2003 and 2010 rafts and then by month using the mean distance and time interval (1,000 simulations).

RESULTS

Double-crested Cormorant rafting data were collected at 85 locations in 2010, while the 2003 data yielded 252 locations for comparison from the same time period (Fig. 2). The number of cormorants per raft did not differ significantly between 2003 and 2010 during the season overall, but differences were observed between individual months (Table 1, Fig. 3). The number of cormorants per raft did not differ among months in the 2003 study period ($H = 1.87$, $n = 252$, $P = 0.39$), but did differ in 2010 ($H = 41.09$, $n = 85$, $P < 0.001$).

Distance to nearest colony (considering all possible colonies) and distance to nearest shoreline did not change between the 2003 and 2010 rafts (Table 1). However, when only occupied colonies were considered, the distance to nearest colony per raft was significantly greater in 2010 than in 2003. No differences were observed between lake bottom depths, slopes, or curvature of the 2003 and 2010 rafts. Aspect, or the directional orientation of the lake bottom where rafts occurred, was significantly lower in 2010, indicating that rafts in 2003 faced westerly and rafts in 2010 faced southerly.

At both 50 and 95% contours, the 2003 kernels were found mainly on the northeastern side of Beaver Island, while the 2010 kernels were more widely distributed around the island (Fig. 2). The 2010 raft volume contours were 3.3 times larger on average in total area than those from the 2003 rafting data, due to increased foraging around western Beaver Island and Whiskey Island (Table 2).

The MRPP analysis found that there were often significant differences in spatial distribution among months in 2003, 2010, and between the two years (Bonferroni corrected $\alpha = 0.005$; Table 3; Fig. 4). The 2003 and 2010 rafting data points overall (all months) occupy significantly different areas in space and represent two unique groupings of points. Mantel Indices showed all rafts in both years were found to be close in space and time but differed between months (Table 4).

DISCUSSION

The appearance of round goby in the diet of Double-crested Cormorants may have enabled the increase in foraging range observed in 2010. Lake Michigan trawl surveys found dramatic increases in round goby abundance from 2003 to 2012, and estimated round goby biomass per hectare was highest in 2010 (Bunnell *et al.* 2013). The prevalence of round gobies in the diets of cormorants is likely due to the expansion of round gobies into areas where cormorants previously foraged: in 2010 cormorants were found in the same key areas as in 2003, as evidenced by the complete overlap of the 2003 50% volume contours kernels by those of 2010. The addition of Whiskey Island as a 2010 nesting site—where control is difficult to per-

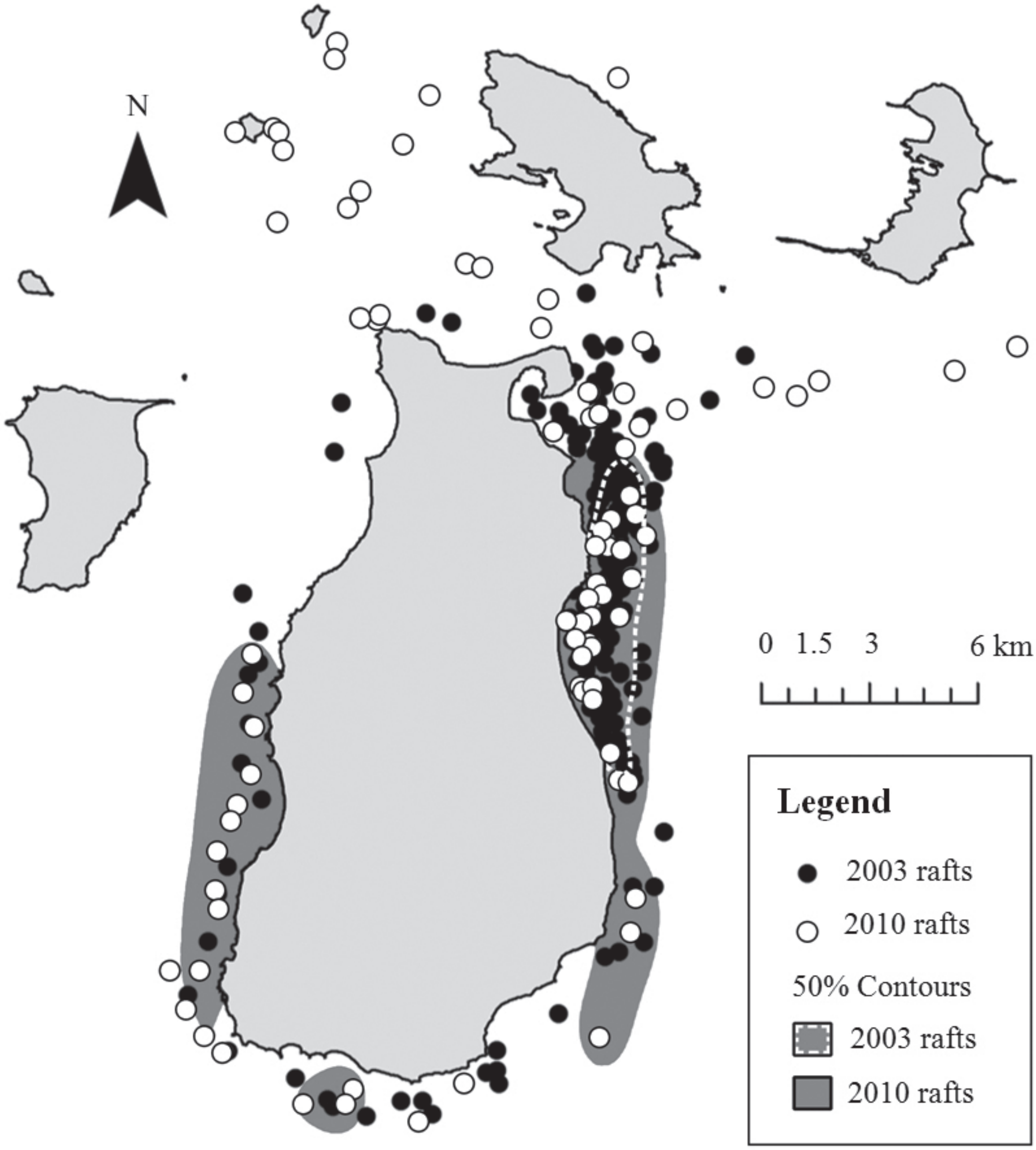

Figure 2. Rafting locations of foraging Double-crested Cormorants observed in 2003 ($n = 252$; Seefelt and Gillingham 2006) and 2010 ($n = 85$) and 50% volume contours of raft locations determined using a fixed kernel density estimator.

form due to tree nesting (Van Guilder and Seefelt 2013)—contributed to the increase in foraging range to the northwest.

The shift in foraging distributions found here was coupled with changes in raft sizes and raft dispersion. In May and July 2010, rafts were smaller than in 2003, as observed in other areas where control took place (Dorr *et al.* 2010), but raft sizes increased dramatically in June 2010. Data from radio-tagged cormorants showed that control provoked them to leave colonies earlier

Table 1. Summary of average values (± SD) for Double-crested Cormorant raft data collected in 2003/2010 and associated Mann-Whitney test results (U = Mann-Whitney test statistic, * indicates significance). Environmental variables were measured from the approximate location of each raft. Possible colonies include those occupied during the year of interest plus those that have been occupied in the past.

Parameter	2003	2010	U	n	P
Number cormorants per raft					
Overall (May-June)	34.4 ± 44.5	30.9 ± 38.5	11,443.5	337	0.35
May	44.9 ± 54.0	11.3 ± 6.5	35,685.0	36	0.02 *
June	29.9 ± 32.0	56.5 ± 43.3	3,568.5	151	< 0.001 *
July	36.7 ± 52.5	13.6 ± 24.0	9,156.0	150	< 0.001 *
Environmental variables					
Distance to nearest occupied colony (km)	8.9 ± 4.7	13.9 ± 6.4	5,519.0	337	< 0.001 *
Distance to nearest possible colony (km)	8.9 ± 4.7	9.5 ± 6.6	10,962.0	337	0.75
Distance to nearest shoreline (km)	0.9 ± 0.5	1.1 ± 0.8	10,792.0	337	0.92
Lake depth (m)	11.8 ± 6.3	10.1 ± 5.2	12,947.5	337	0.07
Lake bottom slope (degrees)	3.2 ± 2.0	3.1 ± 2.1	42,814.5	337	0.77
Lake bottom aspect (degrees)	245.0 ± 83.9	184.7 ± 113.2	45,722.0	337	< 0.001 *
Lake bottom plan curvature	$3x10^{-3} \pm 3x10^{-2}$	$-7.3x10^{-4} \pm 3x10^{-2}$	43,263.5	337	0.39

Table 2. Total volume contour area and overlap area for 2003 and 2010 rafts of foraging Double-crested Cormorants, where "% year" indicates the percentage of the year's volume contour overlapped by that of the other year.

Volume Contour	2003 Area (km^2)	2010 Area (km^2)	Overlap Area (km^2)	% 2003	% 2010
50%	12.8	50.0	12.8	100	26
95%	88.4	265.9	82.4	93	31

than usual (Tucker 2011); newly displaced cormorants may have flocked together to feed prior to leaving the archipelago. The increased distance between rafts and the nearest occupied colony in 2010 indicates a release from nesting pressure: wintering cormorants travel great distances between roosts and foraging locations, and from roost to roost, exhibiting little site fidelity (King 1996). Cormorant rafts in 2010 displayed similar dispersion patterns as those in 2003 (from dispersed, to clumped, to

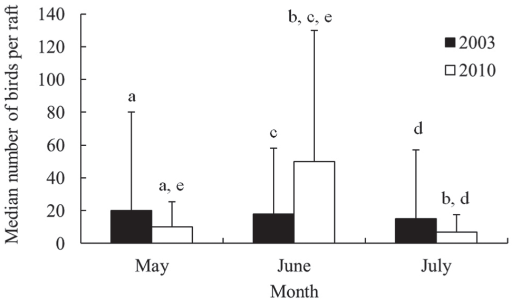

Figure 3. The median number of foraging Double-crested Cormorants per raft observed in the Beaver Archipelago in 2003 and 2010. Similar letters above bars indicate significant differences between two groups, identified by Mann-Whitney tests. Error bars represent the 3rd quartile.

Table 3. Results of multi-response permutation procedure analysis determining whether rafts of foraging Double-crested Cormorant differ in spatial distribution between months in the 2003 and 2010 study periods. * indicates a statistically significant P-value (Bonferroni corrected $\alpha = 0.005$ for month vs. month comparisons).

Months	P	
May / June 2003	< 0.001	*
June / July 2003	< 0.001	*
May / July 2003	0.09	
May / June 2010	0.08	
June / July 2010	0.001	*
May / July 2010	0.14	
All months 2003 / 2010	< 0.001	*
May 2003 / May 2010	< 0.001	*
June 2003 / June 2010	< 0.001	*
July 2003 / July 2011	< 0.001	*

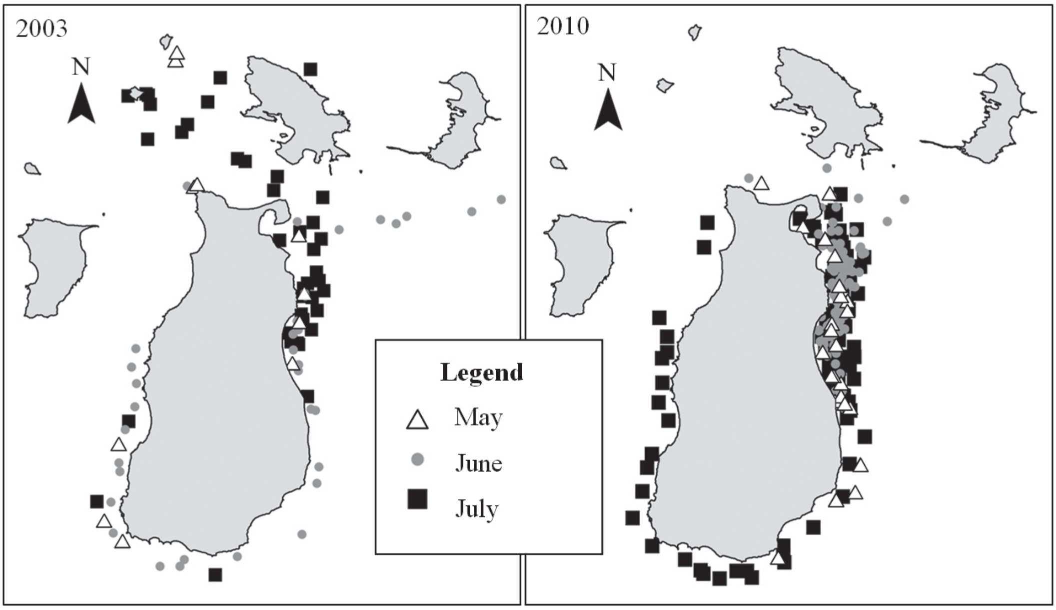

Figure 4. Double-crested Cormorant raft locations depicted by month in 2003 (n = 252; Seefelt and Gillingham 2006) and 2010 (n = 85).

dispersed), but nest failure due to control (Van Guilder and Seefelt 2013) may have prompted dispersion earlier in the season in 2010. By July 2010, many cormorants had left the Archipelago (Tucker 2011), resulting in smaller numbers of cormorants in rafts that were more dispersed (a result observed later in August 2003, post-nesting).

The concurrence of control measures in the Beaver Archipelago, rapid widespread changes in food webs, oligotrophication, and reduced productivity in the Great Lakes (Evans *et al.* 2011; Eshenroder and Lantry 2012; Riley 2013) makes it difficult to pinpoint a single cause of change in cormorant foraging locations. Widespread nest failure due to control in 2010 prompted cormorants to colonize other islands and disperse prematurely in 2010. Food web changes also have the potential to affect densities of Double-crested Cormorants (Ridgway 2010); changing fish communities in the Beaver Archipelago (Kaemingk *et al.* 2012) and in Lake Michigan (Bunnell 2012) likely played a role in the decrease in abundance of cormorants. Round gobies could function as a low-density food source, which may further decrease cormorant productivity over time (Van Guilder and Seefelt 2013). The complex interactions of a changing lake environment should be considered in the development of future cormorant management plans.

Table 4. *P*-values resulting from Mantel Index analysis of spatial and temporal clumping of Double-crested Cormorant rafts (* indicates significant difference). Dispersion in May and August 2003 corresponded with pre- and post-nesting periods (Seefelt and Gillingham 2008). Dispersion in July 2010 corresponded with a premature end to the nesting season caused by control measures (Van Guilder and Seefelt 2013).

Year	May	June	July	August	May, June, July
2003	0.2 Dispersed	< 0.05* Clumped	< 0.01* Clumped	> 0.2 Dispersed	0.01* Clumped
2010	> 0.2 Dispersed	< 0.01* Clumped	> 0.2 Dispersed	NA	< 0.05* Clumped

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