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ABSTRACT

The yellow perch fishery of the Les Cheneaux Islands (LCI) region of Lake Huron, MI suffered a collapse in 2000, attributed in part to the increase of double-crested cormorants (*Phalacrocorax auritus*) in the region. A management program involving egg-oiling and lethal culling was initiated in 2004 to reduce cormorant foraging on yellow perch in the LCI. Counts of cormorant nests, nests oiled, cormorants culled, and aerial counts and telemetry surveys were used to evaluate management. Management contributed to a 74% reduction of cormorants on breeding colonies from 2004 to 2007. Cormorants used the LCI area significantly more ($P<0.05$) than surrounding areas. Aerial counts of foraging cormorants declined significantly ($P<0.05$) over the entire survey area but not within the LCI proper. However, aerial counts of cormorants in the LCI were five-fold less than cormorant counts in the same area in 1995. Reduced cormorant numbers were attributed in part to the elimination of cormorant nesting on a large colony due to the introduction of raccoons. Although the numbers of cormorants using the LCI did not decline, flocks were significantly smaller and more dispersed after management began. The reduced number of cormorants from 1995 levels and more dispersed foraging likely reduced predation on fish stocks including yellow perch in the LCI. Our findings indicate that the relationship between reduction in cormorant breeding numbers and reduced cormorant foraging in a given area is complex and may be influenced by density dependent factors such as intraspecific competition and quality of the forage base.

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Populations of the double-crested cormorant (*Phalacrocorax auritus*; hereafter cormorant) increased dramatically throughout the 1980s and 1990s, most notably in the eastern United States and Canada, and the Great Lakes (USFWS, 2003; Wires et al., 2001; Hatch and Weseloh, 1999). Cormorants in Michigan as elsewhere in the Great Lakes have increased markedly since being added to the state's endangered species list in 1976 (MDNR, 2005). Wires et al. (2001) estimated Michigan's cormorant abundance at more than 30,000 pairs by 1997. The trend in numbers of cormorants in the Les Cheneaux Island (LCI) area of Lake Huron, MI, follows that of the state as a whole. In 1980, cormorants began nesting at St. Martins Shoal, in the western part of the LCI (Ludwig and Summer, 1997). Cormorant numbers increased nearly 6-fold from the early 1990s to a local breeding population of >5500 nests in the LCI in 2002 (Fielder, 2004). Trexel (2002) found that growth of the LCI cormorant population had slowed by 2000 and was probably stabilizing. However, this finding is complicated by reproductive suppression of nesting cormorants (and all other nesting bird species) on the largest colony at the time through the introduction of raccoons about 2002 and possibly earlier (F. Cuthbert, University of Minnesota, pers. comm.).

Yellow perch (*Perca flavesence*) had been a very popular sportfish supporting an important recreational fishery in the LCI area since the early 1900s (Lucchesi, 1988). The perch fishery recently has experienced unprecedented declines, to the point of near total collapse in 2000 (Fielder, 2004, 2008). Concurrent with this collapse of the fishery was an increase in numbers of cormorants in the region during the migratory and breeding seasons (April–October). Research findings regarding cormorant impacts to the yellow perch population and fishery in the LCI have been mixed. Diana et al. (2006) estimated losses by number of 270,000–470,000 yellow perch in 1995 to cormorant predation but concluded the impact to the fishery and population was negligible due to the large perch population and because cormorants mostly ate sublegal sized perch (<178 mm). Conversely, Fielder (2008) examined the relationship between cormorant abundance and key yellow perch population demographics with data from1969–2004 and concluded that cormorant caused mortality was an important factor contributing to the decline of yellow perch in the region.

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Concurrent with increases in cormorant numbers in the LCI and concern over their potential contribution to the decline of the yellow perch fishery and population in the LCI the U.S. Department of Agriculture (USDA), Wildlife Services state program in Michigan (WS–MI), developed and implemented a plan for cormorant management in the LCI region. Management was implemented under authority of United States Fish and Wildlife Service (USFWS) Public Resource Depredation Order (USFWS, 2003) in consultation with the Michigan Department of Natural Resources (MDNR) and Native American tribes in the LCI region. Management included control activities that sought to suppress cormorant reproduction via annual egg-oiling and to lethally cull a proportion of adult cormorants from the local breeding colonies each year. The goal of this management was to reduce the number of cormorants and consequently their foraging in the LCI as a means of improving the yellow perch fishery. As part of the cormorant management evaluation effort the MDNR continued monitoring of the LCI fish community including the yellow perch fishery and population but increased the intensity of monitoring effort to an annual basis (D. Fielder, Michigan Department of Natural Resources, pers. comm.).

Concomitant with initiation of management and intensified fishery monitoring was an effort to evaluate the success of management efforts in reducing the number of cormorants on the colonies and on cormorant foraging in the LCI. Specific objectives were: 1) to determine if management reduces the number of nesting cormorants, 2) to determine if the cormorants being managed forage in the LCI, and 3) to evaluate whether management causes a subsequent decline in cormorant foraging in the LCI and surrounding areas.

Study site

The Les Cheneaux Islands is an archipelago of at least 23 named islands, located in northern Lake Huron (Maruca, 1997a; Diana et al., 2006). The LCI encompasses an area of about 11,860 ha (terrestrial and aquatic) and stretches for 19 km along the southeastern end of Michigan's Upper Peninsula (Fig. 1). The LCI is part of a 129 km stretch of northern Lake Huron shoreline designated as one of The Nature Conservancy's "Last Great Places." The channels and embayments of the area form pristine coolwater habitat that supports a diverse fish community (Fielder, 2008). Since the early 1900s, one of the main attractions of the LCI portion of Lake Huron has been its yellow perch fishery (Diana et al., 1987; Fielder, 2004, 2008). Between the straits of Mackinac joining Lake Huron and Lake Michigan and the St. Mary's River and encompassing the LCI area are five cormorant colonies subject to management and research. These islands include Green Island, St. Martins Shoal, Goose Island, Crow Island and Little Saddlebag Island collectively referred to here as the LCI colonies (Fig. 1).

Methods

Breeding colony management

A cormorant management program of egg-oiling and lethal culling was initiated in 2004 with a stated goal of oiling eggs in 100% of all accessible ground nests and removal of 15% of adult breeding cormorants from breeding colonies. The management goal for removal of adult breeding cormorants was increased to 25% in 2005, and 50% in 2006 and 2007. Three of the five LCI colonies were initially targeted for control, St. Martins Shoal, Goose Island, and Crow Island (Fig. 1). Little Saddlebag Island and Green Island were added to control efforts in 2006 (Fig. 1). Cormorant nests were treated with pure food-grade corn oil at two to three week intervals between May 12 and July 8, 2004–2007. Oil was applied from a backpack sprayer at a rate of approximately 6 ml/egg (Farquhar et al., 2002). Nests were marked with orange paint to prevent double-counting nests and re-oiling the same nests. Concomitant with treatment applications, the total number of nests, number of eggs per nest, total nests oiled, total eggs oiled, number of inaccessible nests, and number of chicks was recorded. Peak nest counts in each year were used to estimate the total number of breeding cormorants in the LCI in each year. Cormorants were lethally culled on the colony using suppressed 0.22 caliber rifles. Some cormorants were also lethally culled in the vicinity of colonies and for food-habits research (M. Bur, U.S. Geological Survey, Lake Erie Biological Station, unpublished data).

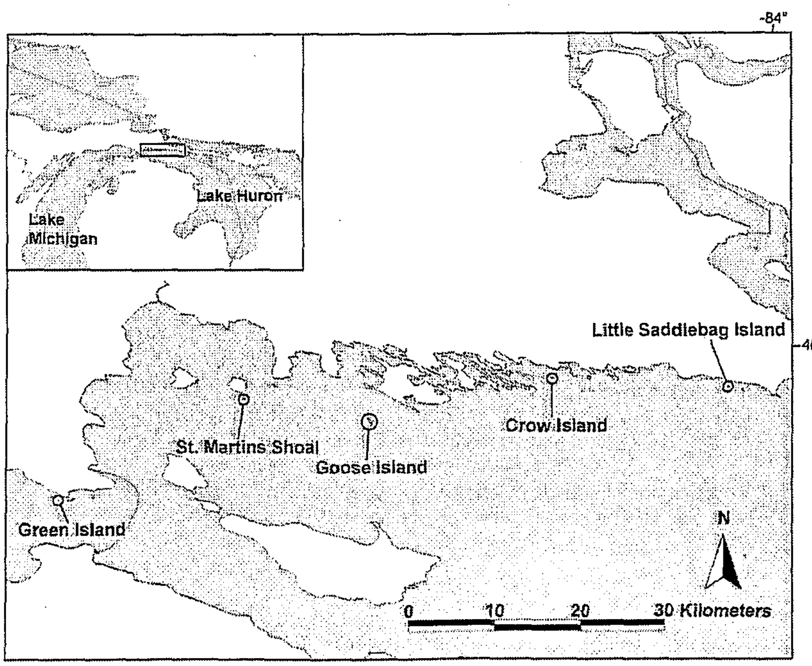

Fig. 1. Les Cheneaux Islands archipelago of northern Lake Huron, MI, and locations of double-crested cormorant breeding colonies.

Cormorants collected off-colony and for food-habits research were lethally culled with 12 gauge shotgun using non-toxic shot. Wildlife Services personnel recorded the total number of cormorants lethally culled from each targeted colony site and total lethally culled off-colony.

Aerial survey counts

Aerial survey counts of cormorants in the LCI, were scheduled every two weeks from April to October 2004–2006 and conducted by personnel with WS-MI. Aerial surveys were also conducted in the LCI area from July to October 2003, to obtain baseline data prior to implementation of the control program. Aerial surveys encompassed a 68,452 ha of near-shore areas from Green Island to Drummond Island, Lake Huron Michigan (Fig. 2). This area also included the 9802 ha area of embayments of the LCI proper (Fig. 2) as defined by Belyea et al. (1999). Aerial surveys were conducted in a Cessna 172 at between 150 and 215 m above ground level, at a flight speed of about 150–175 kph and were comparable to surveys of cormorants conducted by Belyea et al. (1999). Surveys took approximately 4 h to complete. Surveys were alternated between AM (08:00–12:00) and PM (13:00–17:00) and between each end of the survey area with the first survey selected at random and alternated thereafter to reduce possible sampling bias with respect to diurnal foraging activity. Two observers counted from each side of the plane on transects approximately 500 m wide on each side. A total of 6 observers were used in teams of 2 over 4 years. To maintain consistency in counts over years new observers were trained by more experienced observers until counts were consistent. In each survey a GPS location and estimated number of foraging individuals were recorded. Each individual or group was considered a flock for subsequent analyses. Aerial survey counts were used to develop indices of annual changes in the number of foraging cormorants counted for the entire survey area as well as specific to the embayments of the LCI. The mean flock size between years for cormorants observed in the embayments of the LCI was also compared. An ANOVA with Tukey's multiple range test to test for differences in mean instantaneous cormorant counts between years was used for the entire survey area and specific to the embayments of the LCI, and in flock size specific to embayments of the LCI (Proc GLM, SAS Institute Inc., 1999). All response variables for parametric tests yielded normal distributions.

Aerial VHF telemetry

Cormorants were marked from selected colonies with very high frequency (VHF) transmitters to evaluate whether the cormorants being managed were the cormorants using the LCI area and extent of use. Between May 11 and June 16, 2004, nine, 33, and 31 adult breeding cormorants were captured near active nests on Crow Island, Little Saddlebag Island and St. Martins Shoal (Fig. 1), respectively (i.e. 73 total) using modified soft-catch leg-hold traps (King et al., 2000). Between May 24 and June 9, 2005, 20 adult breeding cormorants were captured on each of the same three colonies (i.e. 60 total). Cormorants were fitted with Advanced Telemetry Systems, Inc.® (ATS, Inc.®, Insanti, MN) 25 g VHF transmitters ($\leq$2% body weight) using a backpack harness (Dunstan, 1972; King et al., 2000) and US Geological Survey metal leg-band and released at the capture site. The VHF transmitters were programmed to transmit 8 h each day for 220 days then turn off for 145 days and turn on again for another 220 days. All cormorants were handled according to an IACUC and attending veterinarian approved U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center study protocol, a Michigan Department of Natural Resources Scientific Collecting Permit, and a United States Department of Interior Scientific Collecting Permit.

Cormorant locations were determined from aerial telemetry surveys of a 1,275,645 ha area extending from the Beaver Island archipelago, Lake Michigan to Drummond Island, Lake Huron (Fig. 3). Surveys were approximately 4 h in duration. Surveys were alternated between AM (08:00–12:00) and PM (13:00–16:00) and between each end of the survey area (Fig. 3) with the first survey selected at random and alternated thereafter to reduce possible sampling bias with respect to diurnal foraging activity. A flight preceded over the study area at an altitude of approximately 1000 m on approximately 30 km transects (Melvin and Temple, 1987). Aerial surveys were flown in a

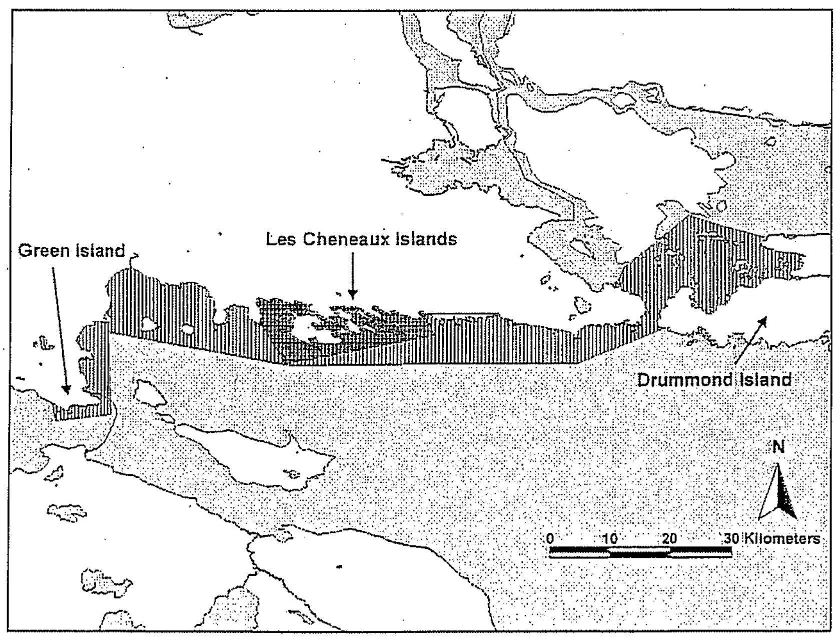

Fig. 2. Area of aerial survey counts of double-crested cormorants conducted in northern Lake Huron, MI, 2003–2006. The vertical lines represent the area of near-shore aerial surveys from Green Island at the western end to Drummond Island at the eastern end of the survey area. The darker cross-hatched area represents the Les Cheneaux Islands archipelago proper as described by Belyea et al. (1999) in surveys of cormorants conducted in the area in 1995.

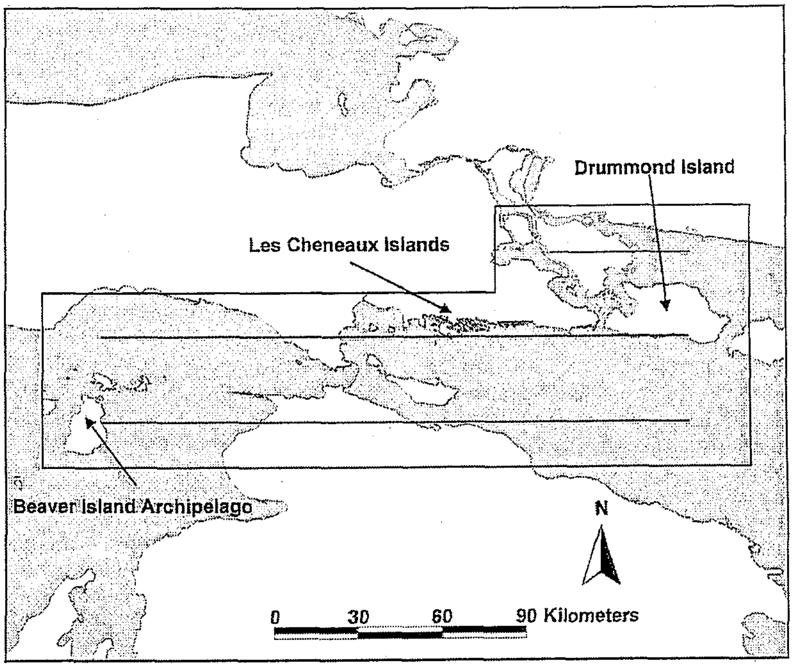

Fig. 3. Aerial telemetry survey area (solid lines) for relocation of double-crested cormorants marked with VHF transmitters from 3 breeding colonies in the area of the Les Cheneaux Islands archipelago in northern Lake Huron, MI. The dotted lines represent VHF aerial survey transects within the survey area. Surveys were conducted at two week intervals from May to September 2004 and April–September 2005.

Cessna 172 fitted with FAA-certified dual three-element yagi antennae mounted on the wing struts and R4500S VHF receivers (ATS, Inc.®, Insanti, MN) to detect signals. Once a signal was found cormorants were located based on the relative strength of signal from each antenna, while circling with the aircraft then gradually decreasing altitude and search area to home in on the marked cormorant (Gilmer et al., 1981; Melvin and Temple, 1987). Consistent observations were made of cormorants or groups of cormorants at these locations. During aerial observations, the cormorant location (latitude and longitude), date, time, and transmitter frequency of all detected signals were recorded. Latitudinal and longitudinal coordinates of cormorants were determined by built in GPS navigational system on the R4500S receiver.

Analyses were conducted on locations for all marked cormorants rather than individuals because of the small maximum sample size (≤14) for each marked cormorant within each year. To account for potential serial autocorrelation between observations made on the same individual (Kenward, 1992), only the first location of a marked individual was recorded during each survey (Anderson et al., 2004). We evaluated the distributions of relocations between survey dates at three spatial scales. A geographic information system (ArcView 3.2a, ESRI Inc., Redlands, California) was used to determine the number of relocations in the telemetry survey area, aerial count survey area, and LCI embayment survey area (Fig. 2) for each month surveyed in each year. The expected number of relocations in each area was then determined by multiplying the proportion of each sub-sampled survey area relative to the total area by the total number of relocations in each month and year.

Because the probability of foraging declines with increasing distance from colonies (see Nemeth et al., 2005) a maximum limit for total area was set to determine proportional distribution by estimating foraging extent around each colony (Lewis et al., 2001; Ridgeway et al., 2006). The mean foraging radius around a colony was determined by the equation $\sqrt{N}/2$, where N is the number of nests for a colony and the value generated represents the maximum foraging distance (km radius) from a colony (Lewis et al., 2001; Ridgeway et al., 2006). The total area was then determined as the sum of the foraging areas around each colony based on year-specific nest counts. Differences in distribution of relocations among the three survey areas were tested using χ^2 tests of observed versus expected relocation frequency (SAS Institute Inc., 1999; Anderson et al., 2004). The observed versus expected values for relocations in the LCI versus the total expected for the aerial count survey were also compared to determine if the LCI was selected disproportionately to expected relocations in the near-shore aerial survey area. For all tests of significance an alpha level of 0.05 was used.

Results

Breeding colony management

From 2003 to 2007, the total number of pairs of cormorants nesting in the LCI decreased 73.8% from 5487 to 1436 nests counted (Table 1). A total of 4205 cormorants were lethally culled from colony sites in 2004–2007, representing between 8.9% and 35.2% of the total number of breeding cormorants counted in each year (Table 1). A total of 886 cormorants were lethally culled off-colonies from 2004 to 2007, representing between 0.9% and 12.0% of the total number of breeding cormorants counted in each year (Table 1). The total combined lethal cull from 2004 to 2007 was between 9.7% and 47.2% of the total number of breeding cormorants. Between 819 and 1953 nests were egg-oiled from 2004 to 2007, representing 41.9–77.7% of all nests counted from all 5 colonies (Table 1). Of the total nests oiled 99.4% did not successfully hatch any chicks.

Aerial VHF telemetry and survey counts

A total of 63 (86%) of the 73 cormorants marked in 2004 were relocated at least once during the survey period. Fifty-five (92%) of the 60 cormorants marked in 2005 were relocated at least once during the survey period and 30 (41%) cormorants marked in 2004 were relocated in 2005 at least once. There were a total of 128 relocations

Table 1
Double-crested cormorant colony nest counts, number lethally culled, nests egg-oiled, and total number culled from colonies (% of total from nest counts), total number egg-oiled (% nests), total number culled off-colonies (% of total from nest counts), and total combined colony and off-colony culled (%) for each year of management on 5 breeding colonies in the Les Cheneaux Islands area of Lake Huron, MI. No management was conducted in 2003.

Location–measurement	Year 2003	2004	2005	2006	2007
Crow Island nest count	211	68	121	52	0
Lethal cull	0	129	3	123	3
Egg-oiling	0	68	121	52	0
Goose Island nest count	1867[a]	1794[a]	713[a]	0	0
Lethal cull	0	291	391	18	0
Egg-oiling	0	0	0	0	0
Green Island nest count	224	237	425	778	617
Lethal cull	0	0	0	596	242
Egg-oiling	0	0	0	328	0
Little Saddlebag Island nest count	646	672	571	524	265
Lethal cull	0	0	0	171	3
Egg-oiling	0	0	0	524	265
St. Martins Shoal nest count	2539	1885	1371	660	554
Lethal cull	0	406	887	509	433
Egg-oiling	0	1885	1371	660	554
Total nest count	5487	4656	3201	2014	1436
Total lethal cull	0	826 (8.9)	1281 (20.0)	1417 (35.2)	681 (23.7)
Total egg-oiling	0	1953 (41.9)	1492 (46.6)	1564 (77.7)	819 (57.0)
Total off-colony lethal cull	0	81 (0.9)	173 (2.7)	483 (12.0)	149 (5.2)
Total combined lethal cull	0	907 (9.7)	1454 (22.7)	1900 (47.2)	830 (28.9)

[a] Nesting attempts were eventually abandoned due to raccoon predation.

in 2004 and 279 in 2005. Expected cormorant foraging areas based on nest counts in 2004 and 2005 were 365,681 ha and 251,406 ha, respectively, although cormorants were relocated over the full extent of the survey area in both years (Fig. 4). In 2004 cormorants were relocated significantly less frequently than would be expected given a proportional distribution in the telemetry survey area ($\chi^2_1=23.68$, $P<0.0001$). Conversely cormorants were relocated significantly more frequently than would be expected given a proportional distribution of relocations in the aerial count survey area, LCI proper, and in the LCI relative to the aerial count survey area ($\chi^2_1=28.81$, $P<0.0001$, $\chi^2_1=34.78$, $P<0.0001$, and $\chi^2_1=27.92$, $P<0.0001$, respectively). An almost identical pattern was observed for 2005. In 2005 cormorants were relocated significantly less frequently than would be expected given a proportional distribution in the telemetry survey area ($\chi^2_1=38.29$, $P<0.0001$). Cormorants were relocated significantly more frequently than would be expected given a proportional distribution of relocations in the aerial count survey area, LCI proper, and in the LCI relative to the aerial count survey area ($\chi^2_1=44.20$, $P<0.0001$, $\chi^2_1=54.44$, $P<0.0001$, and $\chi^2_1=150.45$, $P<0.0001$, respectively).

The mean instantaneous total count of cormorants in the near-shore aerial surveys declined significantly ($F_{3,35}=7.94$, $P=0.0004$) over 2003 levels from a mean total count in 2003 of 1280.33 ($N=6$, SE $=370.72$) to a low of 205.60 ($N=12$, SE $=52.59$) in 2006 (Fig. 5). There was no significant relationship in mean instantaneous count of cormorants among years ($F_{3,35}=0.62$, $P=0.61$) for surveys specific to embayments in the LCI. There was a significant relationship in mean flock size of cormorants among years specific to the embayments of the LCI ($F_{3,366}=10.69$, $P<0.0001$). Flock size declined from a mean of 38.35 ($N=55$, SE $=9.28$) individuals per flock in 2003 to a mean flock size of 7.9 individuals ($N=140$, SE $=1.13$) in 2006 (Fig. 5).

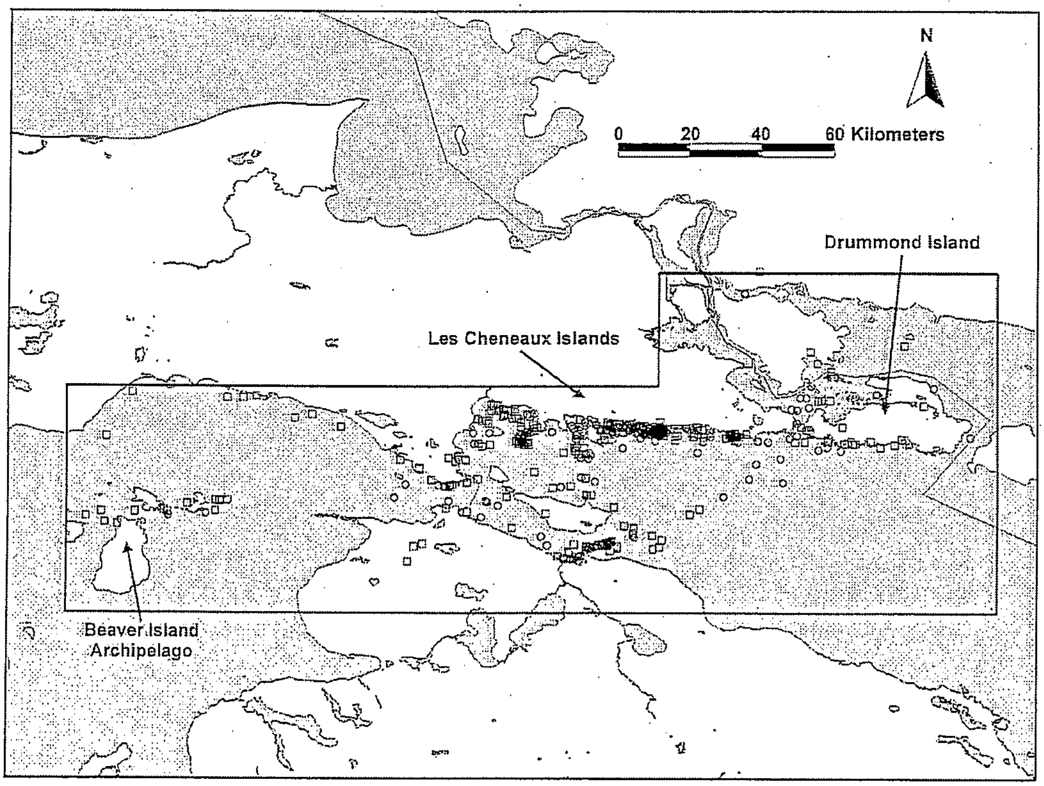

Fig. 4. Aerial telemetry survey area (solid lines) and relocations of double-crested cormorants marked with VHF transmitters from 3 breeding colonies in the area of the Les Cheneaux Islands archipelago in northern Lake Huron, MI. Surveys were conducted at two week intervals from May to September 2004 and April–September 2005. Open circles represent relocations of cormorants in 2004 and open squares represent relocations during surveys in 2005.

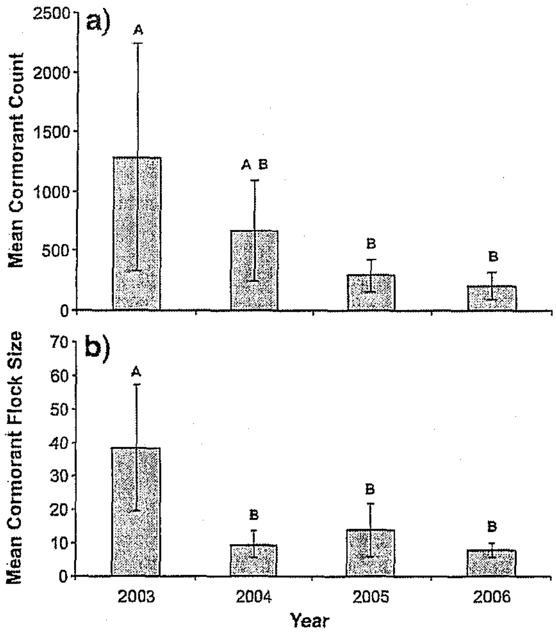

Fig. 5. a) Mean daily counts (bars) of double-crested cormorants using near-shore areas of the upper peninsula of Lake Huron, between St. Ignace and Drummond Island, MI, during April–October, 2003–2006. b) Mean flock size (bars) of cormorants in the Les Cheneaux Islands, Lake Huron, MI, during April–October, 2003–2006. Vertical lines represent 95% confidence interval estimates. Surveys in 2003 were conducted prior to cormorant management. Years with different letters are significantly different ($P<0.05$) from each other.

Discussion

Breeding colony management

Management using egg-oiling of 42–78% of all nests and culling of between 10% and 47% of primarily breeding adults contributed to reductions in the number of cormorants in the LCI by 74% in a 4-year period. However, not all of this reduction can be attributed to management. The presence of raccoons on the Goose Island colony in the spring of 2004 was discovered prior to initiation of the first year of management. The introduction of raccoons to Goose Island may have occurred as early as 2002 (F. Cuthbert, University of Minnesota, pers. comm.). Introduction of raccoons was likely the primary contributor to reducing nesting on Goose Island to zero by 2006 (Table 1). Cormorants were observed arriving on Goose Island and in some cases building and briefly occupying nests but soon abandoned these efforts.

A total of 5091 cormorants were culled for management or research purposes between 2004 and 2007. The total decline in cormorant numbers from all LCI colonies over the same period was 4051 pairs or 8102 cormorants. Cormorant numbers in the LCI declined by 37% more than the lethal cull. The decline is more rapid than what would be expected from culling and egg-oiling alone given reported adult survival (Blackwell et al., 2002; Hatch and Weseloh, 1999), and assuming strong colony philopatry, equivalent immigration and emigration, and recruitment of young from years prior to management. Egg-oiling of young on the colonies would have a delayed effect on recruitment as the majority of young do not breed until their third year (Hatch and Weseloh, 1999) so egg-oiling would be unlikely to account for the additional decline.

Bédard et al. (1999) used comparable management techniques and observed a similar pattern in decline that exceeded what would be predicted from management alone. A similar effect of management may have occurred in the LCI and at least some of this unaccounted for decline reflects emigration from the LCI. A possible consequence of emigration of cormorants is the exacerbation or creation of either real or perceived conflicts at other locations. If cormorant depredation problems are created elsewhere this would limit management success. The numbers of cormorants on Green Island increased rapidly between 2004 and 2006 when management was initiated on that colony (Table 1). This suggests that at least some cormorants may have relocated from other managed colonies. However the total increase on Green Island is far less than the difference between the total number of cormorants lethally culled and the decline in the total LCI breeding population. Unfortunately the release of raccoons on Goose Island confounds the ability to ascertain how much of this discrepancy in declining cormorant numbers may be due to disturbance by raccoons or management in the LCI.

Aerial VHF telemetry and survey counts

The 41% subsequent year return rate of VHF marked cormorants to the LCI corroborates nest count data and suggests that some emigration from the LCI was occurring. Because none of these cormorants were marked from Goose Island this low rate of return may reflect emigration to other locations subsequent to management rather than the influence of raccoon predation. A conclusive determination of how much emigration was occurring due to management cannot be ascertained because other factors such as effects of capture and marking cormorants, transmitter failure, and death of marked cormorants may also have affected the return rate. Marked cormorants were found throughout the survey area and as far away as the Beaver Island Archipelago which also has cormorant breeding colonies (Fig. 4). This result suggests that cormorants that were not successful in nesting may have prospected other potential breeding locations.

Cormorants marked from colonies in the LCI used the near-shore area between Green Island and Drummond Island in greater proportion than availability in 2004 and 2005. In addition cormorants used embayments specific to the LCI disproportionately to their availability over the total estimated foraging area and the near-shore aerial survey area. This pattern indicates that the distribution among the three areas is not random and there is disproportionately higher use of embayments specific to the LCI relative to other measured areas by VHF marked cormorants.

Why this disproportionate use occurs is more difficult to determine. However, previous research in the LCI indicates that cormorants are a common and important predator on prey fish in the area. A factor that may have influenced cormorant foraging in the LCI area was the recent (2004) collapse in the alewife population in Lake Huron (Schaeffer et al., 2008). Research indicates that when alewives are abundant they may serve as a buffer to cormorant predation on prey other than alewives (Diana et al., 2006; O'Gorman and Burnett, 2001). Conversely, the decline in alewives may have caused cormorants to utilize alternate prey and to forage more consistently in the shallow embayments of the LCI.

The fact that the LCI is in important foraging area for cormorants has been well established. Diana et al. (2006) investigated cormorant predation on yellow perch in the LCI area and documented losses of perch to cormorant predation of 270,000–470,000 individual yellow perch in a breeding season. Fielder (2008) examined the relationship between cormorant abundance and key yellow perch population demographics over a time series and concluded that cormorants were an important factor in the decline in yellow perch over the time span examined. Fishery data from the LCI indicate that abundance of yellow perch increased significantly during the study period (D. Fielder, Michigan Department of Natural Resources, unpublished data). Cormorant diet data specific to the LCI and concurrent with management also indicated increased consumption of yellow perch associated with their increased abundance (M. Bur, U.S. Geological Survey, Lake Erie Biological Station, unpublished data). It is possible that the combined effects of reduced numbers of alewives in surrounding waters of Lake Huron (Schaeffer et al., 2008) and increased numbers of yellow perch in the LCI (D. Fielder, Michigan Department of Natural Resources, unpublished data) may have attracted a larger proportion of cormorants to the LCI than would have occurred in the absence of these changes in the prey base.

Aerial survey counts corroborated nest counts in that significant declines occurred over the survey area since the initiation of management in the LCI (Fig. 5). Management effect on numbers of cormorants foraging in the LCI area is less clear. Declines were not manifested specific to the embayments in the LCI over the study period. However, Belyea (1997) estimated a mean of 3814 cormorants foraging in the LCI area in 1995 while the average mean count observed in this study was 710 or five-fold less. We cannot duplicate the observers used in Belyea (1997) a decade prior to this study. Consequently observer bias can affect comparisons between estimates (Conroy et al., 2008; Erwin, 1982). However, Bayliss and Yeomans (1990) and Erwin (1982) reported observer bias on average of 10–25% whereas we observed differences in our counts compared to Belyea (1997) of 500% and are confident this reflects a real change in abundance. This observed reduction may reflect the lack of nesting and recruitment of young due to the release of raccoons on Goose Island. At the time of the Belyea (1997) study, Goose Island was the largest colony and the closest colony in proximity to the LCI. In addition, Maruca (1997b) indicated that a larger percentage of cormorants from Goose Island used the LCI relative to cormorants from other colonies. The release of raccoons on the second largest and closest breeding colony to the LCI appeared to have reduced overall foraging numbers just prior to the initiation of our research effort. This five-fold reduction in cormorant numbers likely affected our subsequent surveys and measures of management effects.

Data from VHF marked cormorants indicates that the relatively pristine coolwater habitat of the LCI (Fielder, 2008) was used disproportionately as a foraging resource for cormorants relative to areas outside of the LCI during this study. Although the number of cormorants declined significantly over the survey area as a whole the remaining cormorants concentrated in the LCI. However, mean cormorant flock size declined significantly (Fig. 5). This decreased flock size suggests that cormorants in the LCI were dispersed in smaller flocks over a wider area within the LCI in years subsequent to initiation of management. In 2006, there were 12 surveys conducted with only three flocks greater than 45 individuals and none over 100. In 2003, prior to management, there were 14 flocks observed with over 45 individuals and three flocks over 100 individuals, in only six surveys.

There are a number of plausible reasons for the change in foraging flocks size among years. Flock size may be affected by a more widely dispersed food base. Fishery data from the LCI indicate increased abundance of yellow perch at all MDNR survey locations in the LCI area (D. Fielder, Michigan Department of Natural Resources, unpublished data). Because yellow perch are a primary prey item of cormorants in the LCI (Diana et al., 2006) their increased abundance may allow for more dispersed foraging. Failed nesting and the lack of young on the colonies may also have changed the foraging dynamics of cormorants remaining on colonies in the LCI area. Because cormorants are not tied to feeding young on the colonies adults may be able to forage more widely (Dorr et al., 2003) and therefore disperse over a wider area throughout the embayments of the LCI. Another possible reason foraging flock size declined is that in all years of the survey counts cormorants were being collected for a food-habits study in the LCI (M. Bur, U.S. Geological Survey, Lake Erie Biological Station, pers. comm.). In addition, a Spring harassment program with limited culling was initiated by WS–MI in early Spring 2005 to limit cormorant predation on spawning fish stocks in specific bays in the LCI. This program has continued through 2008. The food-habits collections in the LCI may have prevented cormorants from concentrating on specific spawning fish stocks and harassment was designed to have this effect.

Harassment of cormorant foraging flocks whether unintentional or designed may have caused the cormorants to disperse more widely throughout the LCI, reduced their ability to concentrate in large numbers on spawning fish stocks, and reduced observed foraging flock size. The reduced flock size may also make cormorants less efficient foragers. Larger foraging flock size has been shown to enhance feeding efficiency for many species (Götmark et al., 1986; Speckman et al., 2003). Harassment programs have been shown to be effective in reducing cormorant foraging on fisheries and fish populations impacted by cormorant predation (Chipman et al., 2000; Rudstam et al., 2004) and may have had the same effect in the LCI.

Management of nesting cormorants by egg-oiling and lethal culling in the LCI caused a large and rapid decline in nesting numbers in the region. Management was targeting the appropriate cormorants as VHF telemetry indicated that the managed cormorants used the LCI area disproportionately greater than would be expected given random use. Aerial survey indices indicated a significant reduction in foraging in near-shore areas between Green Island and Drummond Island concurrent with management. Aerial surveys also indicated that foraging numbers in the LCI proper had declined from similar aerial surveys conducted in 1995 (Belyea, 1997). While cormorant numbers during this study were five-fold less than previously reported, management did not reduce the numbers of cormorants foraging in the LCI during the survey period. However, mean flock size declined significantly in the embayments of the LCI and aerial counts indicate a less concentrated and more dispersed foraging pattern over the study period. The fact that cormorant foraging was five-fold less than that recorded by Belyea (1997) and less concentrated in the LCI area post management may have contributed to reduced predation on vulnerable spawning fish stocks. Fishery data from the LCI suggest that this may be the case as both the yellow perch fishery and fish population have improved (D. Fielder, Michigan Department of Natural Resources, unpublished data) since the initiation of cormorant management in the LCI.

Our data indicate cormorant's selectively forage in the LCI which may be a behavioral response to increases in the prey base at that location, decreases of alewives or other prey elsewhere or a combination of these factors. In addition, reduced intraspecific competition (due to reduced numbers) may allow for a higher relative proportion of cormorants from nearby colonies to forage in the LCI (Lewis et al., 2001). Our findings indicate that the relationship between reduction in cormorant numbers and effect on reduced consumption is complex and may be influenced by density dependent factors such as intraspecific competition, and quality of the forage base. These density dependent effects on cormorant foraging can be an important factor in cormorant management as there is no one to one relationship between reductions on breeding colonies and reduced foraging in a given area.

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