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Management of double-crested cormorants to improve sport fisheries in Michigan: three case studies

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Abstract: Impacts of double-crested cormorants (*Phalacrocorax auritus*) to fisheries have been documented, but evaluation of the process and outcomes of cormorant management to reduce impacts on fisheries is lacking. We provide a synthesis of adaptive management of double-crested cormorants in the Les Cheneaux Islands (LCI), Brevoort Lake, and Drummond Island, Michigan from 2004 to 2007. The LCI management focused on reducing numbers of nesting cormorants in the region as a means of improving the yellow perch (*Perca flavescens*) population and fishery. At Brevoort Lake and Drummond Island, management focused on lethal and nonlethal harassment of spring migrating cormorants to reduce their foraging on spawning walleye (*Sander vitreus*) and yellow perch and to improve those fisheries and increase fish populations. At each location, management efforts reduced cormorant foraging, and fishery data indicated increased abundance of sport fish species. The 3 locations combined provided evidence for the underlying hypotheses that cormorants can influence mortality of local sport fish populations and that short-term management goals have been met. Continuation of adaptive management and monitoring programs will determine whether the improvement of targeted sport fisheries through cormorant management is sustainable.

Key words: adaptive management, cormorants, culling, fisheries, harassment, human–wildlife conflicts, predation

Populations of the double-crested cormorant (*Phalacrocorax auritus*; hereafter, cormorant) increased substantially throughout the 1980s and 1990s, most notably in the eastern United States and Canada and the Great Lakes (Hatch and Weseloh 1999, Wires et al. 2001). Corresponding to this increase in numbers were increases in the level of concern over real and potential damages associated with cormorants (Taylor and Dorr 2003). A growing body of evidence in the United States and Canada demonstrates the reality of impacts that abundant cormorant populations can have on their environment (Shieldcastle and Martin 1999, Taylor and Dorr 2003, Rudstam et al. 2004, Hebert et al. 2005, Fielder 2008). The degree of significance for all categories of resource damages (e.g., ecological, economic, and aesthetic) associated with cormorants varies considerably from site to site. This variability in actual and perceived impacts is the impetus for much of the need for research and evaluation prior to and concurrent with management actions.

In the United States, nearly all bird species are protected by the Migratory Bird Treaty Act of 1918, and the conservation of their populations is a responsibility of the U.S. Fish and Wildlife Service (USFWS). The USFWS revisited its policy for cormorant management when the increasing abundance of cormorants and concomitant upward trend in resource conflicts brought them to the forefront of migratory bird management priorities. In keeping with the National Environmental Policy Act, the USFWS and the U.S. Department of Agriculture, Wildlife Services (WS) cooperated on the development of an environmental impact statement (EIS) to address the environmental effects of potential policy revisions. In August 2003, after 4 years, 22 public meetings, and >12,000 public comments, the USFWS published the final EIS (USFWS 2003*a*).

The most significant regulatory change that came out of the final EIS was the public resource depredation order (PRDO). This regulation authorizes officials of state wildlife agencies, WS, and Native American tribes to control cormorants to protect fish, wildlife, plants, and their habitat in 24 states, including Michigan (USFWS 2003*b*). The PRDO's purpose is to protect natural resources that are managed by public agencies for public benefit (USFWS 2003*b*).

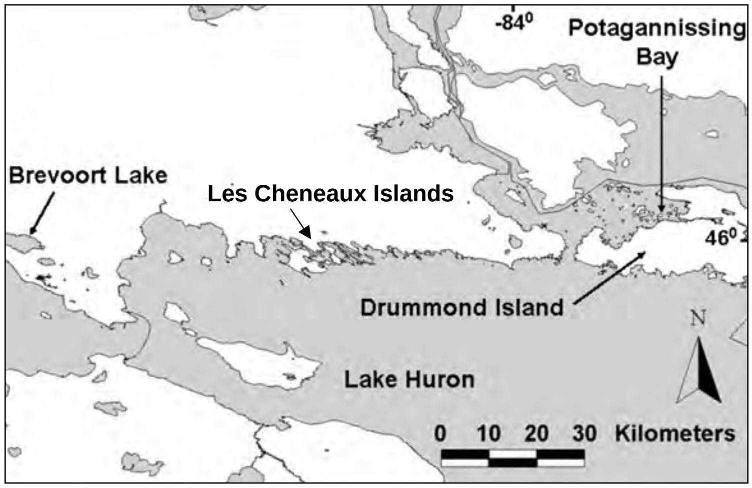

Figure 1. Les Cheneaux Islands archipelago of northern Lake Huron, Michigan, site of cormorant breeding colony management from 2004 to 2007. Brevoort Lake and Drummond Island, Michigan, sites of spring harassment of double-crested cormorants evaluated in 2005-2007 and 2004–2007, respectively.

The first year of implementation of the PRDO on the northern breeding grounds occurred in 2004 in New York, Vermont, and Michigan. In this paper, we discuss the cormorant management, monitoring, and research activities conducted by the WS program in Michigan (WS-MI), WS, National Wildlife Research Center (NWRC), Michigan Department of Natural Resources (MDNR), U.S. Forest Service (USFS), U. S. Geological Survey (USGS), and Lake Superior State University from 2004 to 2007. We evaluate management actions in an adaptive format (Holling 1978, Walters 1986, Lee 1993) to link learning with policy and implementation. Specifically, we focus on research and management efforts in the Les Cheneaux Islands (LCI), Brevoort Lake, and Drummond Island, Michigan (Figure 1).

Background and methods

Les Cheneaux Islands

Cormorants have made a remarkable comeback in Michigan since they were placed on the state's endangered species list in 1976 (MDNR 2005). By 1986, >1,000 cormorant nests were documented in the state (MDNR 2005). By 1997, Wires et al. (2001) estimated Michigan's cormorant abundance at > 30,000 breeding pairs. The LCI population trend mirrors that of the state as a whole. In 1980, cormorants established the

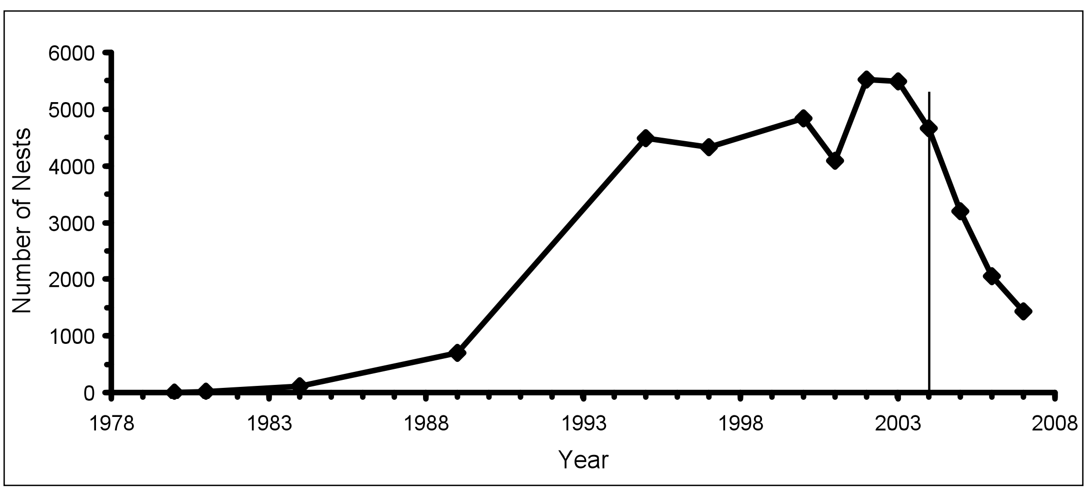

Figure 2. Number of nesting pairs of cormorants in the Les Cheneaux Islands, Michigan, 1980–2007. The vertical line indicates when control activities began.

first colony in the western part of the LCI at St. Martins Shoal (Diana et al. 1997). Cormorant numbers in the LCI increased nearly 6-fold from the early 1990s to a local breeding population of >5,500 nests in 2002 (Figure 2).

The LCI is an archipelago of at least 23 named islands, located in northern Lake Huron. Since the early 1900s, the yellow perch (*Perca flavescens*) fishery has been one of the main natural resources attracting visitors to the LCI (Diana et al. 1987, Fielder 2008). Starting in the late 1970s, the LCI yellow perch fishery underwent a decline, remained relatively stable through the mid-1990s, then fell to the point of near total collapse in 2000 (Fielder 2004, Fielder 2008). Many residents of communities in the region believed that increasing cormorant numbers were the cause of the yellow perch crash, given the simultaneous decline and collapse of the fishery and the significant increase in the abundance of nesting cormorants in the LCI (Diana et al. 1987, Belyea et al. 1999, Fielder 2004).

Diana et al. (2006) reported on the degree to which cormorant predation on yellow perch competed with anglers. This study examined the diet of cormorants and evaluated yellow perch population data from April to October 1995. Diana et al. (2006) estimated that cormorants consumed 270,000 to 720,000 yellow perch in 1995, but concluded that the overall impact of cormorant predation was low. This finding was due partly to a high estimate of overall abundance of yellow perch in their study and because most perch consumed were less than the minimum length limit of the sport fishery (Belyea et al. 1999, Diana et al. 2006). Alewives (*Alosa pseudoharengus*) also were relatively abundant, possibly acting as a buffer to cormorant predation on yellow perch (Fielder 2008).

Although Diana et al. (2006) concluded that cormorant predation in 1995 was not a significant factor on the perch fishery and that overall perch mortality was relatively low, the fishery collapsed by 2000 (Fielder 2004). Yellow perch total annual mortality was 88% in 2000, despite the near absence of recreational fishing activity (Fielder 2004, Fielder 2008). Fielder (2008) evaluated the data related to the yellow perch decline in the LCI and determined that cormorant predation accounted for the contin-ued high total annual mortality rate. Fielder (2008) concluded that cormorant predation explained the greatest amount of variation in yellow perch abundance of the explanatory factors evaluated. Wildlife Services–Michigan (WS–MI) implemented a cormorant damage management program in the spring of 2004, in light of the substantiation of fishery and fish population declines for the LCI and in response to stakeholder concern (Dorr et al. 2010*a*, Fielder 2010).

Drummond Island and Brevoort Lake

Fielder et al. (2007) made community assessments of fish communities in the St. Mary's River from 1975 to 2006 (including Potagannissing Bay, which is adjacent to Drummond Island and the source of the Potagannissing River; Figure 1). A 2002 study revealed that yellow perch and walleye (*Sander vitreus*) abundance in Potagannissing Bay had declined relative to previous surveys (Fielder et al. 2003). While not definitive, the fishery survey and angler reports of fishery declines were consistent with potentially higher mortality caused by increased predation on yellow perch and walleye by cormorants. A program of nonlethal harassment, supplemented by limited lethal take of spring migrating cormorants, was implemented by WS-MI in 2004 with the goal of improving the yellow perch and walleye fishery at Drummond Island (Dorr et al. 2010*b*).

Walleye abundance, survival, and recruitment in Brevoort Lake have been monitored regularly since 1984 by the USFS and MDNR. Prior to 1984, the walleye fishery in Brevoort Lake was maintained by stocking walleye fry and fingerlings, resulting in a sustainable sport fishery (USFS, unpublished data). In 1984, a spawning reef was constructed by USFS and MDNR that greatly increased natural walleye reproduction (Bassett 2006) and allowed walleye stocking to be discontinued. Numbers of adult walleye declined steadily after 1991, resulting in resumed walleye stocking in 1997 (Dorr et al. 2010*b*). Fishery assessments from 1994 to 2005 indicated unusually high mortality of walleye occurring between fall-age (0) and spring-age (3), and walleye numbers did not rebound (Dorr et al. 2010*b*). The decline in the walleye population occurred despite substantial natural reproduction, stocking of fingerlings, and regulatory protection of walleye <38 cm in length. Concurrent with the decline in the walleye fishery was an increase in the numbers of cormorants foraging at Brevoort Lake during the cormorant's spring migration (Basset 2006). Consequently, increased walleye mortality was attributed largely to an increase in predation by spring migrating cormorants of vulnerable spring spawning walleye and yellow perch (Bassett 2006). A program of nonlethal harassment supplemented by limited lethal take of spring migrating cormorants was implemented by WS-MI in 2005 as a means to improve the walleye fishery (Dorr et al. 2010*b*).

Management and monitoring

Les Cheneaux Islands

The LCI cormorant management program was part of an effort to investigate the feasibility of reducing cormorant foraging in the LCI as a means of improving yellow perch survival and, ultimately, improving the yellow perch fishery (Dorr et al. 2010*a*, Fielder 2010). A principal criterion in the determination of how cormorants would be managed was the desired outcome of a sustainable and satisfactory yellow perch fishery commensurate with pre-collapse abundance, catch, and harvest, and a viable cormorant population.

Research began during initial planning of cormorant management in the LCI. Several factors were identified that would influence the management, research, and monitoring programs. Stage-based population models, coupled with lessons from previous management efforts in Canada, were used to determine the optimal management strategy to reduce local cormorant numbers (Dolbeer 1998, Bédard et al. 1999, Blackwell et al. 2002). This existing information suggested that a combination of egg-oiling and lethal take of adults from breeding colonies would best meet management goals (Dorr et al. 2010*a*).

A number of questions arose and focused on how management would affect nesting and foraging numbers of cormorants in the LCI. Would removal of cormorants on the colonies produce a sink that would be filled by cormorants from other breeding colonies? Conversely, would management activities cause abandonment and possible extirpation of the LCI breeding colonies, contravening desired management outcomes? How would a sustainable endpoint for management be recognized and measured? Are the appropriate cormorants being targeted for management? These questions identified some of the risks that were addressed through research and monitoring effort associated with the implementation of cormorant management in the LCI. The NWRC collaborated with MDNR Fisheries Division, USGS, and LSSU in monitoring and evaluating management effects on cormorants, the targeted fish populations, and fishery response.

To determine if control efforts were reducing cormorant numbers and foraging, WS–MI and NWRC conducted nest counts on the colonies and aerial surveys of cormorants in the LCI and surrounding areas (Dorr et al. 2010*a*). In addition to surveys, research and evaluation efforts included food habit studies and evaluations of cormorant movements and distribution associated with management activities using VHF telemetry (Dorr et al. 2010*a*). Rather than set a specific numerical goal for nesting cormorants, an end-point for cormorant management was determined as the point at which the yellow perch population and fishery recover to approximately pre-collapse levels. Although a specific goal for cormorant numbers was not set, historical cormorant counts and fishery data indicated that a satisfactory yellow perch fishery existed in the late 1980s when cormorant numbers on all 5 colonies in the LCI were at about 1,000 nesting pairs (Fielder 2010; Figure 2).

Concurrent with cormorant management, the MDNR conducted annual surveys of the fish community and recreational fishery in the LCI. Fielder (2010) identified 7 key metric, for yellow perch population and fishery metrics and tested for significant relationships with trends in cormorant abundance. The MDNR increased the sampling frequency of these data from once every 3 to 5 years to annually to better inform and adapt management to changing yellow perch population and fishery demographics (Fielder 2010). These data also provided information on yellow perch population and fishery metrics that could be used to evaluate whether cormorant management was providing the intended results (Fielder 2010).

Questions addressed through this research and monitoring effort included if management effectively reduced the number of nesting cormorants on managed colonies, targeted the appropriate cormorants, affected a consequent reduction in foraging, and if the yellow perch fishery responded, given the underlying hypothesis that cormorants are a significant source of yellow perch mortality (Dorr et al. 2010*a*, Fielder 2010).

Drummond Island and Brevoort Lake

In 2004, WS launched a pilot project to address potential impacts to spawning perch and walleye during spring migration when high numbers of cormorants forage in the mouth of the Potagannissing River on Drummond Island (Dorr et al. 2010*b*). In 2005, a similar program was initiated on Brevoort Lake due to documented declines in the walleye population and fishery (Dorr et al. 2010*b*). The management programs at these 2 locations differed substantially from management in the LCI. The depredation on sport fish was caused by spring migrating cormorants consuming fish prey during their spring spawning period. This cormorant depredation occurred in relatively small geographic areas over a short period relative to impacts of breeding cormorants in the LCI. The transitory nature of migrating cormorants at spring stopover sites, and their foraging on spawning assemblages of prey fish presented unique management challenges. To address these challenges, a program of nonlethal harassment with pyrotechnics and boat chases, combined with limited lethal shooting was initiated (Dorr et al. 2010*b*).

To determine if control efforts were actually reducing cormorant foraging, WS and NWRC trained and supervised volunteers to conduct counts of foraging flocks of cormorants at both management areas (Dorr et al. 2010*b*). Surveys of foraging cormorants were conducted from dawn to dusk in April and May 2004 to 2007 on Drummond Island and on Brevoort Lake from 2005 to 2007 (Dorr et al. 2010*b*). In addition to surveys, research and evaluation efforts included prey studies from samples collected concurrent with management to identify the proportion and biomass of fish in the cormorant diet (Dorr et al. 2010*b*).

Walleye abundance in Brevoort Lake was monitored by spring trap-netting to estimate spawner abundance and fall electrofishing to assess spawning success, consistent with survey methods since 1984 (Dorr et al. 2010*b*). Mark-recapture methods were used to determine walleye abundance and age specific growth and mortality. The percentage of survival of stocked fingerlings was determined from population estimates derived from mark-recapture analyses.

Periodic fisheries assessments also were conducted in the St. Mary's River, including Potagannissing Bay at the mouth of the Potagannissing River adjacent to Drummond Island (Fielder et al. 2003, Fielder et al. 2007). The MDNR assessments in 2002, prior to management, and in 2006, 2 years after initiation of management, were used to evaluate fishery response to cormorant harassment at Drummond Island. Demographic measures of perch and walleye populations were abundance indices determined by catch-per-unit-effort (CPUE) and mortality estimated by catch curve analyses (Fielder et al. 2003, Fielder et al. 2007). Questions addressed through research and monitoring at both sites included whether cormorants were consuming targeted sport fish, the biomass consumed, the relative proportion of prey in the diet, whether harassment reduced foraging, and the response of the fish population to management (Dorr et al. 2010*b*).

Although different methods were used, all management actions had the goal of reducing foraging by cormorants and, subsequently, the mortality of sport fish species, thereby increasing recruitment to the associated fisheries. Underlying these strategies was the hypothesis that cormorants are an important limiting mortality factor on those sport fish populations. The management goal in its simplest terms is a measure of a binomial outcome. The outcome is the affected fish population's abundance and survival increase after management (goal attained) or they decrease or there is no measurable change (goal not attained). In all management cases an adaptive framework of consideration of alternatives, prediction of outcomes, implementation of management, and monitoring and evaluation of goal attainment were pursued.

Results and discussion

Les Cheneaux Islands

Management of nesting cormorants by egg-oiling and lethal culling in the LCI contributed to a large and rapid decline in nesting numbers in the region (Figure 2). However, the total decline in the number of nesting cormorants from all LCI colonies over the same period was 37% more than the number culled (Dorr et al. 2010*a*). This rapid decline suggests that management may have caused some increased emigration from managed colonies. Although rapid decline and, possibly, increased emigration was observed, cormorants did not completely abandon nesting due to management and were not extirpated from managed colonies (Dorr et al. 2010*a*).

Dorr et al. (2010*a*) indicated that VHF-marked cormorants used the LCI area disproportionately more than in surrounding areas and that management was targeting the appropriate cormorants. Aerial survey counts of cormorants indicated a mixed response to management. While foraging in near shore areas encompassing all the colonies declined significantly, foraging did not decrease significantly within the LCI proper (Dorr et al. 2010*a*). However, mean flock size declined in the embayments specific to the LCI area, and aerial counts indicated a more dispersed foraging pattern over the study period (Dorr et al. 2010*a*). These aerial surveys also indicated that foraging numbers in the LCI were 5 times lower than indicated in the surveys conducted in 1995 (Belyea 1997, Dorr et al. 2010*a*). This decline was attributed to management and the elimination of nesting on a large colony due to the introduction of raccoons (*Procyon lotor*) just prior to the initiation of management in the LCI (Dorr et al. 2010*a*). Although the introduction of raccoons complicated interpretation of management effects, the number of cormorants foraging in the LCI was conclusively less than that recorded by Belyea (1997) preceding the yellow perch fishery collapse (Dorr et al. 2010*a*).

An initial concern regarding management in the LCI was that management may create a sink attracting cormorants from areas outside the LCI. Dorr et al. (2010*a*) suggested that increased use of the LCI by cormorants outside the management area was not an issue. Data from VHF marked cormorants from LCI colonies indicated a clear preference for use of the LCI relative to regions outside the LCI (Dorr et al. 2010*a*). Dorr et al. (2010*a*) hypothesized that reduced intra-specific competition among cormorants and increased yellow perch abundance may have created a positive feedback that resulted in a greater percentage of the remaining cormorants from the LCI colonies foraging in the LCI area. A positive feedback response in cormorant foraging may have implications for cormorant management at other locations and at larger scales. If a positive feedback response is demonstrated at other locations then management targeted at larger scales (e.g., flyway level management) may not provide desired results at a local level.

Fielder (2010) found that all yellow perch population and fishery metrics for the LCI were significantly correlated with changes in cormorant abundance. All metrics trended in the direction expected, given the underlying hypothesis that cormorants are an influential mortality factor. Yellow perch abundance increased (Figure 3), total mortality rate decreased and the angler catch rate and harvest in the recreational fishery improved (Fielder 2010). Yellow perch growth rate declined, and mean age increased, which was consistent with expected population density-dependent effects associated with increased yellow perch abundance (Fielder 2010). Increased yellow perch recruitment was documented during cormorant management, but, more importantly, survival (longevity) of year classes improved during cormorant management relative to pre-management year classes (Fielder 2010). Analysis of cohort based mortality rate of yellow perch indicates a decline in mortality during management to its lowest level since 1996 (Fielder 2010).

Fielder (2010) showed improvement in the yellow perch fishery concurrent with cormorant management but concluded that the long-term projection for the recovery of the LCI yellow perch fishery to pre-collapse levels was still not clear. Numerically, the present yellow perch population (in 2007) likely does not equal historical levels in the region (Fielder 2010). Although angler CPUE has increased to pre-collapse levels, fishing effort and harvest have not (Fielder 2010). In addition cormorants are only one of many potential factors affecting the yellow perch fishery. Angler harvest, alewife (*Aloso pseudoharengus*) abundance, changes in fish community structure, invasive species, spring water levels, and temperatures can all impact the yellow perch fishery (Fielder 2010). Alewives, when abundant, may serve as a buffer for predation on perch by cormorants (Diana et al. 1997, O'Gorman and Burnett 2001), but alewives can also be an influential predator on newly hatched larval percids (Kohler and Ney 1980, Wells 1980, Brandt et al. 1987, Brooking et al. 1998). Fielder (2008) demonstrated that spring water levels and temperatures in the LCI can influence yellow perch abundance. Lucchesi (1988) concluded that anglers in the LCI can affect the abundance and size structure of the perch population. The future of yellow perch in the LCI will likely be influenced by a variety of ecological and environmental factors, including cormorant abundance.

Drummond Island and Brevoort Lake

Dorr et al. (2010*b*) reported a significant ($P < 0.05$) inter-annual decline of 79% in the average number of cormorants at Brevoort Lake and Drummond Island subsequent to initiation of the harassment programs (Figure 4). In addition, harassment deterred on average 90% of cormorant foraging attempts at both locations (Dorr et al. 2010*b*). Because similar patterns of declining use over the study period were observed at both locations, Dorr et al. (2010*b*) hypothesized that cormorants may be exhibiting learned avoidance behavior to harassment resulting in reduced use in years subsequent to initiation of harassment. This inter-annual decline in use of the harassment sites added to the effectiveness of the program in reducing cormorant foraging.

Paralleling the observed inter-annual decline in numbers of cormorants was a decline in harassment effort, lethal take, and use of associated pyrotechnics and shotgun shells (Dorr et al. 2010*b*). Lethal take of cormorants was on average <5.4% of the cormorants migrating through each site during the study period (Dorr et al. 2010*b*). The effectiveness of the harassment program in reducing cormorant foraging, and the limited lethal take associated with the program, would likely make these programs a viable option for managers where the programs can be effectively applied.

At both locations, yellow perch were a pre-

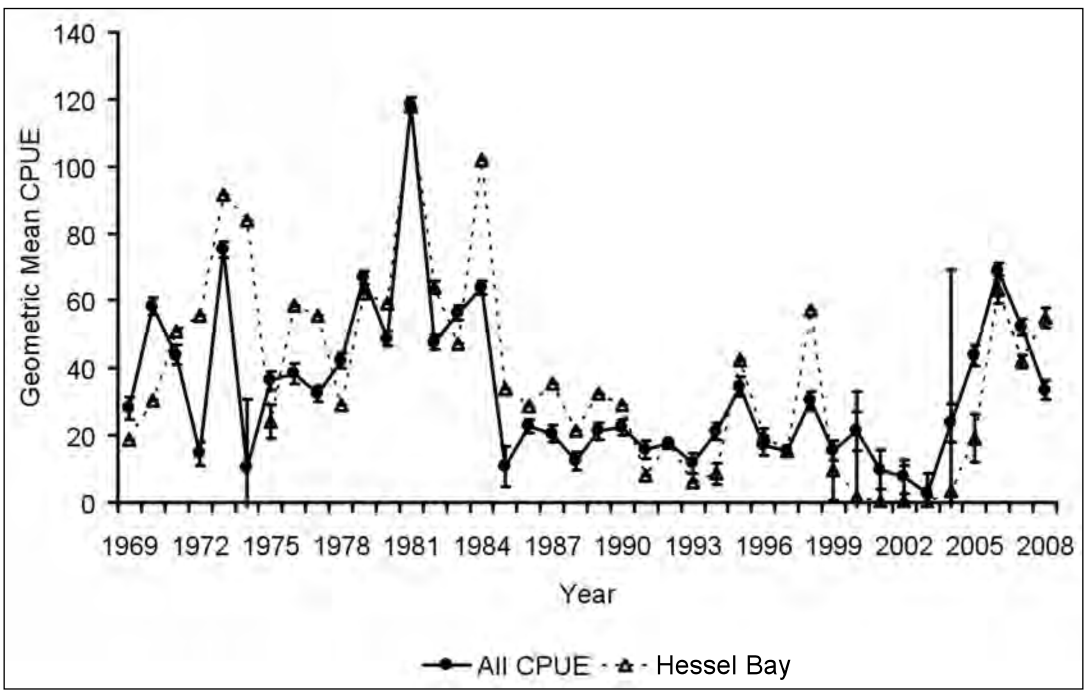

Figure 3. Geometric mean gill-net catch of yellow perch/305 m of net for all the Les Cheneaux Islands sets combined and for Hessel Bay only, 1969–2008. Cormorant control was implemented in 2004 (from Fielder 2010).

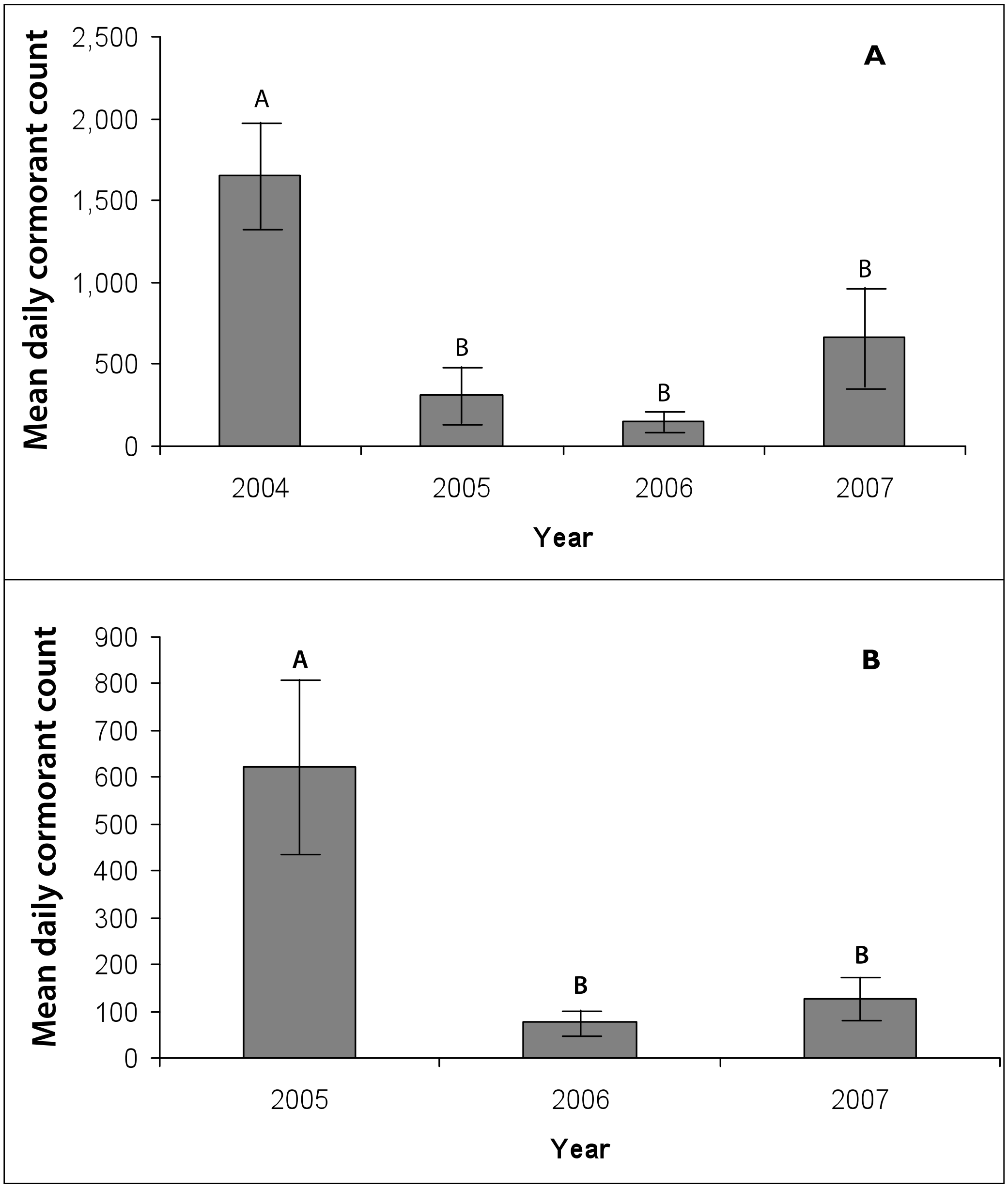

Figure 4. (**A**) Mean daily counts (bars) of double-crested cormorants using the Drummond Island area of Lake Huron, Michigan, during spring migration 2004–2007. (**B**) Mean daily counts (bars) of double-crested cormorants using Brevoort Lake, Michigan, during spring migration 2005–2007. Vertical lines represent 95% confidence interval estimates. Bars with different letters are significantly different ($p < 0.05$) from each other (from Dorr et al. 2010*b*).

dominant prey item in terms of number and in all years. Walleye composed a small proportion of the diet at both locations. However, diet data reported by Dorr at al. (2010*b*) at Brevoort Lake indicated that cormorants target specific walleye age classes and that observed numbers of cormorants could consume the majority of those age classes. Dorr et al. (2010*b*) reported that combined lethal and nonlethal harassment significantly reduced this age-specific effect of cormorant foraging and walleye abundance at age 3 increased to near record levels in 2008 at Brevoort Lake (Figure 5). Additionally, the increased survival of walleye fully recruited during the management period provides further evidence of a link between cormorant predation and walleye survival in Brevoort Lake (Dorr et al. 2010*b*).

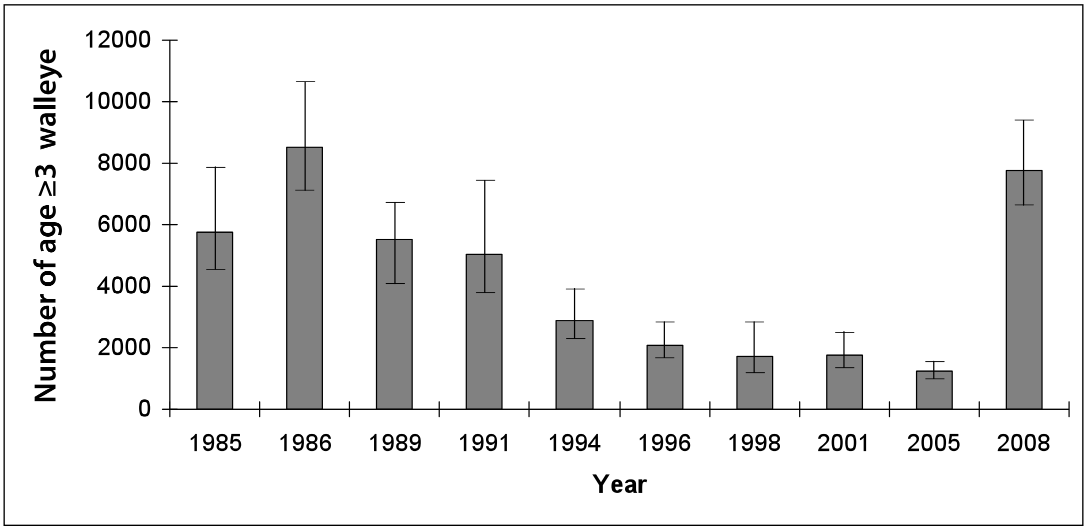

Figure 5. Spring population estimates and 95% confidence intervals (vertical lines) for age ≥3 year walleye in Brevoort Lake, 1985–2008. Double-crested cormorant management was initiated in spring 2005 (from Dorr et al. 2010).

A key finding of Dorr et al. (2010*b*) was that, although walleye made up a small percentage of the cormorant diet at Brevoort Lake, cormorant predation can still reduce cohort-specific survival. Historically, measures of cormorant impacts to fisheries have focused on the proportion of prey in the diet (Craven and Lev 1987, Ludwig et al. 1989) or total biomass of fish consumed relative to total abundance of prey (Draulans 1988, Madenjian and Gabry 1995). Results of these management actions suggest the aforementioned approaches are inadequate, as cormorants do not randomly consume fish of all age and size classes, but, instead, consume a limited range of prey age and size classes. This foraging behavior may result in a cropping effect and reduced recruitment to older age classes (Rudstam et al. 2004, Dorr et al. 2010*b*, Fielder 2010). This cropping effect results in a very different predator–prey population dynamic than random prey consumption proportional to age class availability.

A pronounced decline in cormorant foraging was observed at Drummond Island after initiation of management (Figure 4), and both walleye and yellow perch abundance increased significantly at Drummond Island post management (Dorr et al. 2010*b*). In the first year of management at Drummond Island (2004), the estimated biomass consumption of yellow perch by cormorants exceeded the total reported harvested in the entire open water fishery of Potagannissing Bay in 1999 (Fielder et al. 2002, Dorr et al. 2010*b*). However, harvest by anglers and predation by cormorants was not directly comparable because age classes taken by cormorants and anglers differ. The level of cormorant consumption of yellow perch presents a possible allocation issue to fishery managers (Dorr et al. 2010*b*). Efforts to limit angler harvest and maintain sustainable fisheries through regulatory means may be ineffective if cormorant consumption negates regulatory effects on angler harvest. Conversely, cormorant management may re-allocate those fishery resources from cormorants to anglers (Dorr et al. 2010*b*).

Mortality data for fish populations in Potagannissing Bay were lacking, due to small sample size or violation of assumptions in the estimation methods (Dorr et al. 2010*b*). This lack of reliable mortality estimates makes it difficult to evaluate management, as there may be more walleye and yellow perch, due to improved reproductive success, lower mortality, or a combination of these factors (O'Gorman and Burnett 2001, Dorr et al. 2010*b*).

Harassment programs at Brevoort Lake and Drummond Island have been successful to date with respect to management goals of improving fish populations. Success at these locations reflects situations where a combination of factors made harassment a viable management method. At both of these locations there were vulnerable spawning fish stocks, a relatively limited geographic area to be harassed, large numbers of migratory cormorants arriving concurrent with spawning, and a pool of dedicated and willing volunteers to undertake the considerable harassment effort safely and effectively (Dorr et al. 2010*b*). However success at these locations does not mean that harassment programs will be successful in the long term or are applicable in all cases even if the aforementioned factors are present.

Management at each of the 3 locations described in this paper had varying levels of research and monitoring associated with management, particularly with the fisheries component. Brevoort Lake was the most intensive effort using mark-recapture methods over time, providing age specific population and mortality estimates. The methods used at Brevoort Lake provided the most information with respect to evaluation of management objectives but were also the most logistically intensive. The LCI used indices of several population demographics and included cohort-specific survival collected over time. This method provided a reasonable alternative to the more intensive mark-recapture methods in evaluating management. At Drummond Island there was evidence of increased abundance of sport fish following cormorant management, but evaluation of the management was less conclusive because age and size class specific information and particularly mortality estimates were not available.

The management goal of the Les Cheneaux Islands, Brevoort Lake, and Drummond Island cormorant management programs was to reduce cormorant caused sport fish mortality as a means of improving targeted sport fisheries by increasing fish survival and abundance. Each management program independently provides evidence that short-term management goals have been met. The strength of evidence varies for each location, and in some cases was complicated by other contributing factors. However, all 3 locations together provide weight of evidence for the underlying hypothesis that cormorants can be an influential mortality factor on some local sport fish populations. Continuation of adaptive management programs, if needed, and fishery assessments at all locations will determine whether improvement of targeted sport fisheries is sustainable. Information gathered from these management actions can also provide further input for adaptive management programs and to link learning and policy.

The cormorant management programs we describe in Michigan are just a few of several projects that have been implemented or are being planned under authority of the PRDO to address localized cormorant damage. With the intensified management of cormorants taking place under the PRDO, the need for interagency cooperation, research, monitoring, and feedback on management programs has increased greatly. As more programs are put in place, a means of monitoring flyway or population level effects will be important to evaluate cumulative impacts of local control.

The efforts at LCI, Brevoort Lake, and Drummond Island reflect situations where long-term fishery data were available and there was strong stakeholder support and concern. Additionally, expertise and resources and institutional commitment to a multiyear management and research program were confirmed. These circumstances are not always present. In the absence of pre-existing data, researchers and managers should attempt to develop clear and objective means of identifying resource conflicts associated with cormorants. In some cases (e.g., vegetation damage), identification of cormorant impacts may be readily apparent. In other cases (e.g., fisheries issues), identification of cormorants as an influential factor can be difficult, at best. When the origin of suspected impacts is poorly defined but considered important enough to warrant management, adaptive management approaches offer the best means for reducing uncertainty and risk associated with management strategies.

The information we present here, highlights the importance of cormorants as a top tier predator in aquatic systems. Other scientists have noted that cormorants and other fish-eating birds are a significant influence on aquatic food webs (Steinmetz et al. 2003, Rudstam et al. 2004, Ridgway et al. 2006). Research also has highlighted the cormorant's role as a sentinel species with regard to contaminants and ecosystem health (Weseloh et al. 1995, Ryckman et al. 1998). Although management may be prescribed in cases where cormorant abundance causes conflicts, effectiveness of management should be evaluated in the context that cormorants are an important part of the ecosystems in which they exist.

Management implications

We described how researchers and managers through public and agency meetings, planning and implementation of management, and collection and analysis of data, developed and evaluated measurable objectives within the context of defined impacts of cormorants to sport fisheries. We found that several key measureable objectives were important to successful adaptive management: (1) are the cormorants being managed the cormorants that are impacting the resource?; (2) how much cormorant predation was occurring and what was the response to management action?; (3) what were the estimates of prey age and size class specific impacts by cormorants, including measures of prey mortality?; (4) what was the prey response to cormorant management, and was that response consistent with cormorants as a limiting mortality factor?; and (5) were desired management outcomes attained?

A flexible and responsive adaptive management program can address and adjust to uncertainty and risk associated with management actions. However, successful achievement of such programs requires considerable commitment and coordination among all parties involved, as well as leadership from managers willing to take risks (Riley et al. 2003). The evaluation of management we described here focused primarily on biological outcomes. We suggest research on the socioeconomic impacts of these management actions to further inform management and policy decisions.

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