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Adaptive Management of Double-crested Cormorants on Four Brothers Islands

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Final Report

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Project Summary

Double-crested Cormorants nest on Four Brothers Islands, a preserve owned by The Nature Conservancy, in densities that threaten standing trees and other species of nesting birds. Control activities on other Lake Champlain islands where the species has nested have concentrated the lake-wide nesting population almost entirely on the Four Brothers islands. This report presents findings from 4 years of study, 2008-2011, during which numbers of cormorant nests on the four islands averaged about 3800 per year. The Nature Conservancy, UVM researchers, and government agencies cooperated to conduct experimental population control designed to reduce numbers of nesting cormorants on the two islands with remaining tree cover, without causing dispersal of these birds to other islands in Lake Champlain where they are not wanted. The design of the experimental management approach was to treat nests on two islands with corn oil, preventing eggs from hatching, and to determine success of egg oiling by measuring four indicators: (1) nesting pairs of cormorants on the two experimental islands; (2) nesting success of herons and egrets on these islands; (3) rates of dispersal of cormorants to and from the experimental islands; and (4) numbers of cormorants nesting or attempting to nest in other locations on Lake Champlain. An additional product from the work is a decision model that will guide development of management options for cormorants as part of an ongoing process for a Lake Champlain Colonial Waterbird Plan.

The two islands with significant numbers of standing trees are known as A and B. Nest counts decreased markedly on Island A after the first year of egg oiling, but not on Island B. In total, there was little evidence that egg oiling resulted in fewer nests on these two islands. Island B is the primary site for nesting of herons and egrets, although about 25 nests of Great Blue Herons remain in the tops of standing dead trees on Island D. On both islands, numbers of herons and their breeding success remained consistent throughout the 4-year period.

Although a portion of nests on all four islands were treated by spraying corn oil on eggs, an attempt was made to treat all nests on Islands A and B, but fewer than half the nests on Islands C and D, with the expectation that near-zero levels of hatching success would discourage cormorants from returning to A and B in subsequent years. However, this was not the case: 85% of color-banded birds observed remained on the same islands from year to year. Of those that did disperse among islands, almost an identical number moved from A or B to C or D, and vice versa. It was clear that after 3 years of egg oiling, the treatment did not produce the intended result of reducing numbers of cormorant nests on Islands A and B. Egg oiling did produce a significant reduction in numbers of young fledged, however, and thus should contribute to an overall decrease in numbers of cormorants on the islands.

In addition to egg oiling, management agencies have culled more than 10,000 cormorants on Lake Champlain during the period of this study. Many of these were shot over open water, although most were removed when attempting to nest or roost on other islands in Lake Champlain where they were not wanted. Management agencies from Vermont and New York have consistently prevented successful nesting of cormorants everywhere on Lake Champlain except Four Brothers Islands and Missisquoi

National Wildlife Refuge. And, only on Four Brothers are the birds consistently successful in producing young.

Using data on 3389 cormorants captured and color-banded on Lake Champlain since 1995, survival rates have been estimated and incorporated into a population model that allows managers to evaluate options for further reductions in cormorant numbers on Lake Champlain. Although the model predicted estimates of the nesting population that closely matched the trend of nest counts, the predicted populations were consistently lower than those determined by a census of nests. This led to the conclusion that immigration of nesting cormorants was underestimated by the predictive model. An extension of this conclusion is that--despite the successes of restricting successful nesting to the Four Brothers, reducing productivity through egg oiling, and eliminating a substantial proportion of the population through culling—achieving a desired density of cormorants on Lake Champlain may be complicated by immigration.

Introduction

Four Brothers Islands, a small archipelago in Willsboro, NY, is the most celebrated location for nesting of colonial waterbirds in Lake Champlain. Only Young Island, in Vermont, has a similar history of hosting thousands of gulls, herons, and cormorants. Four Brothers is a preserve of The Nature Conservancy, locally managed by the Adirondack Chapter. There has never been active management of any of the bird populations on the islands, but data have been gathered regularly for several decades on numbers of nesting birds and their nesting chronology.

Since 2001, researchers from the University of Vermont (UVM) and USDA Wildlife Services (WS) have conducted intensive studies on Double-crested Cormorants in Lake Champlain. Studies began on Young Island to evaluate effects of using corn oil to prevent hatching of eggs, a management practice that was initiated in 1999. A result of that practice was that numbers of nesting cormorants declined on Young Island but increased sharply at other locations, including Four Brothers Islands. This trend has continued with increasingly aggressive population control on Young Island, resulting in more than 95% of Lake Champlain's nesting cormorants concentrated on Four Brothers Islands.

UVM studies have focused on population dynamics of the species and an ongoing assessment of the effects of management on the distribution and demography of the cormorant population on Lake Champlain. The primary field method for these studies involves the use of colored, numbered leg bands that are easily resighted from season to season, or within a season. Even before this project began, more 2500 cormorants had been banded in this manner and as many as 800 different birds had been sighted and recorded in a single season. These data support calculations of rates of survival and dispersal. Investigators are especially interested in patterns of dispersal in response to different management techniques. These have included different levels of egg oiling, mortality from shooting, and gull predation on eggs as a result of disturbances.

The ultimate goal of this research is to support an objective system of population modeling and decision-making. Investigators have developed models that predict results of different management scenarios and can serve as the basis for adaptive management. The final step, however, requires a management plan for the lake-wide population that embodies the practices of adaptive management, i.e., a plan that combines a research design with a management regime. Such a plan is consistent with the Lake Champlain Basin Program's *Opportunities for Action*.

Study Area

The islands known as Four Brothers are located 2.6 km from Willsboro Point, NY, and 5 km from Shelburne Point, VT. Named Islands A, B, C, and D (Fig. 1), each is unique in terms of size, structure, and biota. Island A, 0.4 ha, has steep cliffs that make access difficult, a modest density of trees, thick herbaceous vegetation, and a population of large garter snakes. Island B, 0.5 ha, also has steep cliffs, an increasingly dense forest of buckthorn trees, and a diverse population of nesting herons and egrets. Island C, 1.2 ha, is mostly covered by dense grass and even more dense ring-billed gulls. The south side of the island has a rocky face, but the north and west sides have gravel beaches and allow easy access. Island D, 1.3 ha, is easily recognized by the many standing dead trees, a reminder of a the park-like forest of white pine trees that existed a couple of decades ago. All four islands are populated by cormorants, some nesting in trees and others on the ground.

Figure 1. Four Brothers Islands, from left (west) to right, D, C, A, and B.

Objectives And Methods

Objective 1: To continue on-going surveys of cormorants, herons, and gulls nesting on Four Brothers Islands.

The most essential information required to assess the adaptive management protocol on Four Brothers Islands and to develop management plans for colonial waterbirds is a count of nesting birds. This effort has taken place in mid to late May, a time when most nesting was established and incubating birds showed a strong attachment to nests. Islands A, B, and D have been surveyed during daylight hours. Nest counts on Island C are conducted at night to prevent predation by Ring-billed Gulls on eggs of cormorants and Caspian Terns.

Nest counting was done at the same time as egg oiling. A crew of four to six individuals, walking transects back and forth on each island, tallied nests and eggs as they were either oiled or not, and marked nests with paint after they were counted. On Island A, nearly all nests belonged to cormorants and were in low trees, fallen logs, or the ground. The count was quite straightforward. On Island B, nests also were in small trees, but herons and egrets occupied many of these, so the process was for one person to identify and count heron and egret nests, while others counted cormorant nests. A similar approach was used on Island D, where most cormorant nests were on the ground. Some were in the trees, however, along with as many as 25-30 nests built by Great Blue Herons. Again the approach was to count all nests, then subtract out the heron nests.

Island C was the most challenging. As many as 11,000 Ring-billed Gull nests occurred here, all on the ground. There were also ground nests of cormorants and Caspian Terns. All were counted simultaneously by walking transects back and forth across the island. It is easy to distinguish nests among the three species, and they are mostly in single-species groups. Transects for this survey have been established and marked with survey stakes because most of this island is covered only with grassy vegetation. When nests were counted, several observers walked side-by-side across strip transects, marking each nest tallied with surveyors paint.

Objective 2: To assess the effectiveness of egg oiling by documenting nesting behavior and nesting success of cormorants.

The number of nests on Island A ranged from 438 to 725 during the 4-year study. Nests were on or near the ground or in small trees. This is an island where Black-crowned Night Herons have nested regularly in the past and should be expected to return if competition from cormorants is reduced. Accordingly, all cormorant nests within reach were oiled during each of the 4 years.

Island B is the most important island for nesting herons and egrets, but as many as 970 pairs of cormorants also nested in the trees on this island during the study. Similar to Island A, all cormorant nests within reach were oiled in each year.

Most cormorants on Islands C and D nested on the ground. Few trees are left standing, so little habitat is available for herons. Previous research has shown that oiling eggs in 50% of cormorant nests does not result in dispersal from the colony. Thus, approximately 50% of ground nests was treated on Islands C and D. The objective for egg oiling on these two islands was simply to contribute to an overall reduction in productivity and the nesting population of cormorants on Lake Champlain.

After eggs were treated with oil, a sample of nests on each of the four islands was monitored to determine the success of both oiled and not oiled nests. This is the same procedure used to determine productivity, the numbers of eggs that resulted in fledglings. At intervals of about one week, the status of each nest was recorded, with particular attention to the pattern of abandonment from nests where eggs do not hatch.

Objective No. 3: To continue observations of cormorants on Four Brothers Islands to record numbers of color-banded birds, and to continue the capture and banding of cormorants.

Observation of color-banded cormorants provided data for determining rates of dispersal among islands where different management regimes were implemented. Procedures for observing banded birds differed from island to island depending on the mix of other nesting species. On Island C, where numerous terns and gulls nest, observations were conducted with binoculars and spotting scopes from elevated blinds, which were accessed with little or no disturbance of nesting birds. A blind also was used for such observations on Island D in 2011. Elsewhere, observers moved slowly around the islands with spotting scopes, reading band numbers from a distance. Although some cormorants leave their nests when observers initially move onto the island, they return quickly.

Visits to the islands to observe color-banded birds occurred throughout the nesting season, beginning in April and continuing until young birds fledge, usually in late July or early August. One or two visits per week are routine, usually with two people.

To maintain a sizeable population of color-banded cormorants, a new cohort of birds was captured and banded each year. A crew of 4-5 people, working at night, used headlamps to freeze birds on the nests and long-handled nets to capture them. Once captured, cormorants are banded within minutes and released to return to their nests. Banding was conducted on 4-5 nights per season, alternating among islands on different nights.

Objective 4: To refine the population model for cormorants on Lake Champlain and to construct a decision model to support adaptive management.

A basic tool in population ecology and management is a life table with parameters for numbers of breeding females, number of young produced per female, age classes, and survival for each age class. An improvement to the basic life table is the Leslie matrix that combines a vector of numbers of birds in each age class with a matrix of age classes, number of females, and productivity per female. When the matrix and population vector are multiplied together, new population projections result. Earlier research with cormorants on Lake Champlain has produced parameter estimates for such a model and used the model to simulate results of various management alternatives, such as egg oiling to reduce productivity and culling to reduce numbers of breeding females (Duerr 2007). The most important parameter estimates in the model are age-specific survival rates and productivity.

The current study has collected data to refined estimates of survival rates, in addition to estimates of productivity for Four Brothers Islands. No other site on Lake Champlain produced more than 10 successful nests in any year, so the breeding population on Lake Champlain is almost totally concentrated on the study area. With revised survival and productivity estimates, models present effects of actual and proposed management activities.

Objective 5: To continue the monitoring of vegetation responses to management of colonial waterbirds on Four Brothers Islands.

In 2005, a series of photographic plots was established on Islands A, B, and D. Three to five sites on each island were marked with survey stakes. Digital photographs were taken in May and in July, and a compass bearing was recorded for the direction of each photograph. The intent was to repeat this inventory periodically to record the density and composition of vegetation on the islands, with special attention to woody species that serve as nesting substrate for waterbirds. A re-survey was conducted in 2011.

Results and Discussion

Surveys of cormorants, herons, and gulls nesting on Four Brothers Islands.

Nest counts of cormorants did not change markedly from 2008 to 2011; the sum of nests tallied for all four islands ranged from 3833 in 2008 to 3936 in 2011 (Table 1). Variable degrees of effort were allocated to nest counts of other species. Several species are relatively easy to census accurately: Great Blue Herons, Great Egrets, Cattle Egrets, and Caspian Terns. Counts of Black-crowned Night Heron nests were most accurate in 2008 and 2009, but a subjective assessment of the density of nests built by this species was that numbers had not changed noticeably from 2008. The same nest sites are usually occupied year after year, and all appeared to be occupied in 2010 and 2011. Great Egrets and Cattle Egrets are easy to count because of their distinctive appearances and their tendency to return to the same nest sites. Caspian Terns nest on the ground in an open area on Island C, where nest counts are conducted at night. Because they nest together in tight quarters, it is easy to identify and count their nests. Great Blue Herons nest almost entirely in the tops of dead pine trees on Island D, and are easily observed on their nests.

Productivity for species other than cormorants has not been objectively estimated, but frequent visits to the islands throughout the nesting season indicate that most nesting birds are successfully producing fledglings. Particular attention has been directed to Caspian Terns because they can be observed from blinds and because this species has only recently pioneered into Lake Champlain and nests almost exclusively on Four Brothers Islands. Terns have had excellent success hatching eggs and producing young to fledge.

Ring-billed Gulls are exceptionally dense on Island C, where more than 20,000 adults nest each year. A sharp increase in numbers of nests counted in 2011 was likely the result of ring-bills abandoning Young Island, in Grand Isle, as a result of a fox on the island during the 2011 breeding season. With cormorants and terns competing for nesting space on the ground, there is little room for a growing population of ring-bills. An on-going effort to reduce numbers of ring-bills on Young Island could cause more gulls to nest on Four Brothers, thus careful monitoring of their numbers should continue.

Table 1. Nest counts of colonial waterbirds on Four Brothers Islands, 2008-2011.

Species	**Island A**	**Island B**	**Island C**	**Island D**	**Totals**
Double-crested Cormorant					
2008	725	838	787	1483	3833
2009	458	860	1018	1660	3996
2010	438	766	692	1455	3351
2011	486	970	468	2012	3936
Ring-billed Gull					
2008			9904		9904
2009			8740		8740
2010			10,159		10,159
2011			11,549	656	12,205
Herring Gull					
2008	36	31	44	65	176
2009	17		35	65	117
2010	10	10	28	25	73
2011	46	29	18	88	181
Black-backed Gull					
2008	3	2	0	3	8
2009	3	1	0	3	8
2010		1	2	5	8
2011	3	3	0	4	10
Black-crowned Night Heron					
2008		128			128
2009		129			129
2010					0
2011		100			100
Great Blue Herons					
2008				25	25
2009		1		24	25

2010		2		25	27
2011				25	25
Great Egret					
2008		5			5
2009		7			7
2010		7			7
2011		5			5
Cattle Egret					
2008		2			2
2009		3			3
2010		2			2
2011		1			1
Caspian Tern					
2008			34		34
2009			34		34
2010			46		46
2011			76		76

Egg oiling and nesting success of cormorants

Duerr et al. (2007) experimented with egg oiling on the Young Island cormorant colony from 2001-2004 and found that oiling 50% of the nests for 4 years resulted in a negligible (3%) rate of dispersal away from the colony. They also observed, however, that cormorants did move over that time from blocks of nests with 100% egg oiling to blocks with no treated nests. (The study design employed a checkerboard pattern of treating all nests in one block and none in the next, averaging 50% for the entire colony.) This study was the basis for proposing that oiling all nests on Four Brothers A and B and 50% or less on C and D would result in a shift in numbers of nesting cormorants from A and B to C or D.

Island A did show a significant drop (37%) in nests after the first year of egg oiling, and the lower numbers were maintained for the next three years (Table 1). But Island B did not show such a trend and no apparent response to high levels of egg oiling. Similar changes were documented on Island C, where nest counts ranged from 1018 in 2009 to 468 in 2011, and Island D, where nest numbers increased by 36% from 2008 to 2011.

The most objective assessment of the effectiveness of egg oiling for initiating movements away from the heavily oiled islands to the lightly oiled islands was the observation of color-banded birds. Data from these observations were summarized by counting the banded birds that moved from “oiled” to “not-oiled” islands (i.e., AB to CD) and vice versa. Movements were considered for 2008 to 2009, 2008 to 2010, and 2008 to 2011; 2009 to 2010, 2009 to 2011, and 2010 to 2011 (Table 2). For instance, from 2008-2009, a total of 254 different banded cormorants were observed in both years; in 2009, 214 of these were seen on the same island (oiled or not-oiled) as in 2008. Twenty-one cormorants did move from oiled to not-oiled islands, but 19 moved in the other direction, from not-oiled to oiled. Even after 3 years of egg oiling, most (82%) of the 87 color-banded birds observed in both 2008 and 2011 stayed on the same islands.

Table 2. Movements of nesting cormorants among islands, 2008-2011.

		To year					
From year	Movement	2009		2010		2011	
		No.	%	No.	%	No.	%
2008	Oil to Not	21	8.3%	16	8.7%	10	11.5%
	Not to Oil	19	7.5%	20	10.9%	6	6.9%
	Stayed	214	84.3%	147	80.3%	71	81.6%
	Total	254		183		87	
2009	Oil to Not			13	6.3%	3	3.6%
	Not to Oil			21	10.2%	3	3.6%
	Stayed			171	83.4%	77	92.8%
	Total			205		83	
2010	Oil to Not					6	5.9%
	Not to Oil					4	4.0%
	Stayed					91	90.1%
	Total					101	

Although not related to egg oiling, there were some significant movements among the four islands during the period of study, as evidenced by both nest counts and observation of marked birds. These changes were most likely related to differences in habitat among the islands and other species competing for nesting space. Islands B and D appear to be the sites most favored by nesting cormorants. Both islands have abundant structure, standing trees on both islands and many fallen trees on Island D. Cormorants will build nests on bare ground, but they clearly prefer to be in trees, off the ground on logs, or even touching a structure on the ground (researchers in Ontario have been successful in causing cormorants to shift their nesting merely by pounding stakes in the ground).

Island A has a number of standing trees and some downed logs. All were occupied with cormorant nests, and another 50-80 nests have been built on the ground; thus all preferred nest sites have been occupied. Island B is still densely covered by small trees, mostly buckthorns, and still offers above ground nest sites, thus preferred habitat remains available. Island C is the most open island. Despite some trees around the shoreline, this island is mostly covered with dense grass, and most cormorant nests are built on bare ground. Nesting space also is shared with thousands of Ring-billed Gulls. Island D was a mature forest of white pine trees 3 decades ago, but they have all died as a result of cormorant nesting density, and many have fallen. But, the standing dead trees still provide several hundred nest sites, with most of the remaining nests on fallen logs.

Although the heavy-oiling treatment did not succeed in causing nesting cormorants to disperse away from islands A and B, treating eggs with corn oil did reduce hatching success and overall productivity (Table 3). In the years preceding this study, estimates for average productivity (fledglings per nest) for the Four Brothers cormorant colony ranged from 1.1 to 1.6. Population models developed for cormorants on Lake Champlain (Duerr 2007) indicated that approximately 1.4 fledglings per nest would result in a stable population, thus levels of production as high as 1.6 would contribute to a growing population. Average productivity during the 4 years of egg oiling on Islands A and B was calculated to be 0.31 and 0.43, respectively, opposed to 1.02 and 1.01 on Islands C and D. The overall average for the four islands, weighted by numbers of nests, was 0.77. Thus, productivity for the entire colony is low enough that some reduction in population should be expected over time. Since cormorants normally nest for the first time as 3-year-olds, any decrease in numbers of nesting pairs would have been documented only in 2011. On the contrary, nesting pairs increased by 4%.

In short, it appears that habitat quality is more important in determining which island is selected for nesting than is the ultimate nesting success of the community of nesting cormorants on each island. Thus attempts to manipulate numbers of cormorants on individual islands by oiling eggs will not be successful. A better approach to reduce numbers and relax the pressure on habitat and other species is to continue egg oiling at a level that will lead to fewer nesting cormorants overall.

Table 3. Nest monitoring and estimates of productivity, 2008-2011.

	2008	2009	2010	2011	Avg.
Numbers of nests monitored					
Island A	98	91	85	102	
Island B	61	101	78	97	
Island C	14	55	148	31	
Island D	36	25	61	57	
Estimates of productivity (fledglings/nest)					
Island A	0.20	0.21	0.57	0.24	0.31
Island B	0.48	0.39	0.44	0.41	0.43
Island C	1.19	0.90	1.04	0.97	1.02
Island D	1.16	0.73	1.50	0.66	1.01
Weighted average	0.82	0.64	1.04	0.58	0.77

Capture, banding, and observation of marked cormorants

Eight hundred forty-four cormorants were captured and color-banded on Four Brothers Islands during the period of this study (Table 4). The effort to capture and band cormorants on Lake Champlain began in 1995, so a substantial number of color-marked birds were already in the population when this investigation began. A summary of banding data after the 2011 season produced the following statistics:

Number of cormorants color-banded: 1072 on Young Island; 2317 on Four Brothers; 3389 total
Number of cormorants resighted at least once, 2002-2011: 1753
Percentage of banded cormorants resighted at least once: 52%
Percentage of banded adult cormorants resighted at least once: 78%

On average, from 2008-2011, 9.7 banded birds per hour were observed, resulting in a total of 2461 recorded sightings. More significantly, the number of different banded cormorants observed was 513, 429, 382, and 217 in 2008-2011, respectively. These data supported a precise analysis of survival.

Table 4. Cormorants banded and resighted, 2008-2011.

	2008	2009	2010	2011	Totals
Numbers of cormorants banded					
Adults	221	182	133	35	571
Fledglings	154	90	41	221	506
Total	375	272	174	256	1077

Number color-banded	324	272	174	74	844
Numbers of banded cormorants resighted					
Island A	189	62	103	48	
Island B	27	39	41	13	
Island C	357	214	180	95	
Island D	365	296	264	168	
Total	938	611	588	324	2461
Number of person hours	92.7	64.6	59.9	35.8	253
Bands observed/hour	10.1	9.5	9.8	9.1	9.7
Number of different bands observed	513	429	382	217	

Population and decision models

Estimates of Survival.--Adam Duerr, working as a consultant, calculated rates of survival for four age classes and 11 years of observing color bands. He did so with Program MARK, software for the analysis of data from marked individuals (refer to on-line "book," Cooch and White. 2012. Program Mark, A Gentle Introduction). The first step was to propose several models with different assumptions about age classes, fidelity to Lake Champlain, probabilities of resighting, survival until the next resighting periods, etc. Data from the 13 years of banding and 11 years of resighting were fit to the proposed models with the Cormack-Jolly-Seber (CJS) function, and strength of fit was determined with a Maximum Likelihood (MLE) method. This process resulted in the selection of the model that included terms for apparent survival rates and resight probabilities for four age classes. This model received the support of 86% of the data. It is important to note that subsequent references to survival refer to each marked bird's ability to stay alive and to stay within the Lake Champlain system, i.e., permanent emigration from the system is treated the same as death in the CJS model.

The CJS model has a number of familiar assumptions: (1) every marked animal in the population has the same probability of being resighted; (2) every marked animal [of the same age] in the population has the same probability of survival until the next sampling period; (3) marks are not lost, overlooked, or lost; (4) sampling periods are instantaneous; (5) emigration is permanent; and (6) the fate of each animal with respect to capture and survival probability is independent of the fate of any other animal. Conformance to these assumptions is part of the MLE assessment.

Apparent survival was estimated for four age classes of cormorants on Lake Champlain (as illustrated by different color shades in Table 5): FY, SY, TY, and ATY, representing first year, second year, etc. Cormorants normally mature and breed after the third year. Note that survival rates are quite high for third-year birds, but decrease somewhat for older birds that undergo the stresses of nesting. ATY survival also reflects culling efforts on Lake Champlain (bottom three rows of table). Estimates for the first three age classes were derived only from cormorants banded as fledglings and resighted in subsequent years. As a result, the sample size for third year birds was small and the corresponding confidence intervals were wide, but confidence intervals for the adult age class (ATY) were narrow, i.e., estimates of survival are quite precise.

Table 5. Estimates of apparent survival for four age classes of cormorants on Lake Champlain.

CSJ SURVIVAL MODELING WITH PROGRAM MARK				
Parameter	Estimate	SE	Lower	Upper
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1:Phi	0.37	0.07	0.25	0.50
2:Phi	0.37	0.07	0.25	0.50
3:Phi	0.36	0.07	0.24	0.49
4:Phi	0.36	0.07	0.24	0.49
5:Phi	0.37	0.07	0.25	0.50
6:Phi	0.36	0.07	0.24	0.49
7:Phi	0.33	0.06	0.22	0.46
8:Phi	0.35	0.06	0.24	0.49
9:Phi	0.36	0.07	0.24	0.49
10:Phi	0.27	0.06	0.17	0.40
11:Phi	0.23	0.06	0.13	0.36
12:Phi	0.25	0.06	0.15	0.38
13:Phi	0.61	0.11	0.39	0.79
14:Phi	0.61	0.11	0.39	0.79
15:Phi	0.60	0.11	0.38	0.79
16:Phi	0.60	0.11	0.38	0.78
17:Phi	0.61	0.11	0.39	0.79
18:Phi	0.60	0.11	0.38	0.78
19:Phi	0.57	0.11	0.35	0.76
20:Phi	0.60	0.11	0.38	0.78
21:Phi	0.60	0.11	0.38	0.78
22:Phi	0.49	0.11	0.28	0.71
23:Phi	0.44	0.12	0.24	0.67
24:Phi	0.47	0.12	0.26	0.69
25:Phi	0.98	0.05	0.33	1.00
26:Phi	0.98	0.05	0.33	1.00
27:Phi	0.98	0.05	0.32	1.00
28:Phi	0.98	0.05	0.33	1.00
29:Phi	0.98	0.05	0.32	1.00
30:Phi	0.97	0.06	0.30	1.00
31:Phi	0.98	0.05	0.32	1.00
32:Phi	0.98	0.05	0.32	1.00
33:Phi	0.96	0.08	0.24	1.00
34:Phi	0.96	0.10	0.20	1.00
35:Phi	0.96	0.09	0.22	1.00
36:Phi	0.82	0.01	0.80	0.83
37:Phi	0.82	0.01	0.80	0.83
38:Phi	0.81	0.01	0.79	0.83
39:Phi	0.81	0.01	0.79	0.83
40:Phi	0.81	0.01	0.80	0.83
41:Phi	0.81	0.01	0.79	0.82
42:Phi	0.79	0.01	0.78	0.80
43:Phi	0.81	0.01	0.79	0.82
44:Phi	0.81	0.01	0.79	0.82
45:Phi	0.74	0.02	0.70	0.77
46:Phi	0.69	0.03	0.64	0.75
47:Phi	0.72	0.02	0.67	0.76

Adaptive Management Model.—The model developed—again by Adam Duerr-- to evaluate adaptive management of the Lake Champlain population of cormorants is a matrix model, programmed in Excel. It is based on the familiar Leslie matrix (Leslie 1945), whereby (for Lake Champlain cormorants) a vector of numbers of breeding pairs is multiplied by a square matrix that features fecundity and survival rates for each age class. The product of multiplying the breeding pair vector, time *t*, by the square matrix is a new population vector for time *t*+1.

The Excel version of the adaptive management model involves several steps:

1. Input percent of birds breeding by age; from observations of banded birds, we estimate that 28% of third-year birds breed and that 97% of ATY birds breed.
2. Populate a matrix with the vector of years (1995-2011); fecundity for each year (estimates of productivity presented earlier in the report); nest counts; and estimates of survival for each year.
3. Input the starting population size by age class.

In addition to what is entered to produce a new population vector, fixed values are used to estimate immigration into the breeding population and to incorporate the effect of culling in simulations that do not include culling in survival estimates, i.e., projections for future years. Immigration rates were derived by Duerr (2007) from bands observed on Lake Champlain that were placed on birds in other locations, most notably Lake Ontario.

Using the derived survival rates and estimates of productivity described earlier, the matrix model consistently underestimated the number of projected nesting birds (Table 6). The most logical explanation seems to be an underestimate of immigration into the breeding population. Arbitrarily adding 700 immigrants per year to the breeding population produced projected breeding numbers that more closely matched observed numbers.

Table 6. Projected numbers of cormorant nests on Lake Champlain, compared to actual counts of nests. The first projections are based on the adaptive management model and its estimates of immigration. The second set of projections arbitrarily add 700 immigrants per year.

POPULATION PROJECTIONS FROM MANAGEMENT MODEL				
Year	Projected No. Nests	Actual No. Nests	Actual - Projected	Immigrants ATY
1995	2232	2233	1	350
1996	2459	3076	617	341
1997	2653	2927	274	327
1998	2832	4023	1191	308
1999	3041	4459	1418	280
2000	3124	3533	409	267
2001	2843	3806	963	307
2002	2624	3880	1256	329
2003	2576	4109	1533	333
2004	2675	4001	1326	325
2005	2734	4312	1578	319
2006	2667	4245	1578	326

2007	2565	4137	1572	334
2008	2526	4311	1785	337
2009	2369	4173	1804	346
2010	2104	3892	1788	352
2011	1778	3936	2158	343
POPULATION PROJECTIONS WITH ADDED IMMIGRATION				
Year	Projected No. Nests	Actual No. Nests	Actual - Projected	Immigrants ATY
1995	2232	2233	1	1050
1996	2799	3076	277	1041
1997	3256	2927	-329	1027
1998	3648	4023	375	1008
1999	4071	4459	388	980
2000	4306	3533	-773	967
2001	4049	3806	-243	1007
2002	3876	3880	4	1029
2003	3933	4109	176	1033
2004	4179	4001	-178	1025
2005	4337	4312	-25	1019
2006	4281	4245	-36	1026
2007	4180	4137	-43	1034
2008	4184	4311	127	1037
2009	3980	4173	193	1046
2010	3611	3892	281	1052
2011	3173	3936	763	1043

The decision model is available as an Excel spreadsheet and will be submitted along with numerous other products in the same format (Appendix A).

Management implications.—Results of the adaptive management modeling seem to highlight a consistent underestimate of immigration into the breeding population of cormorants on Lake Champlain. Additional evidence of immigration came from a separate analysis of the ratio of banded to unbanded cormorants culled on Lake Champlain during 2011 (Capen, presentation to cormorant managers, April 2012). Unfortunately, there is little way to generate a more accurate estimate of immigration because almost no color banding of cormorants is being conducted elsewhere. Thus, in the true sense of adaptive management, discussions among managers should focus on ways to vary the management regimes and document results on numbers of nesting cormorants. In theory, cormorants should immigrate to nest on Lake Champlain only if they expect that nesting will be successful. If egg oiling continues to reduce nesting success on Four Brothers Islands and managers continue to prevent cormorants from nesting in other locations, immigration should be low, and populations of nesting cormorants on the lake should decline as a result of recent culling and egg oiling. The Nature Conservancy has approved the continuation of egg oiling on Four Brothers through 2014.

Monitoring changes in vegetation

Photo plots on Islands A, B, and D were revisited in July 2011. Photos and the investigator's frequent visits to these islands for 8 years support the following descriptions of changes in vegetation cover, especially woody vegetation:

Island A—Conditions changed little on Island A since 2005. Formerly an island with numerous large white cedar trees, the cedars were all felled in a windstorm in the mid-1980's. The fallen cedars remain and provide favorable substrate for nesting cormorants. Numerous small trees, mostly basswood, elm, and birch were visible in photos in both 2005 and 2011. Dense understory, dominated by stinging nettles, appears between the May and July sets of photographs. Nesting cormorants have not resulted in noticeable tree mortality during this 6-year period, but egg oiling and the subsequent reduction in numbers of nestlings in the trees may have contributed to this condition.

Island B—Dramatic increases in vegetation density occurred in the interval between photographs, the result of vigorous growth of buckthorn trees that dominate about 60% of the island. Investigators have had to cut paths through buckthorns just to move about the island. Despite a dense nesting population of cormorants and herons, woody vegetation seems to be flourishing on Island B. Buckthorn appears to be more resistant to the whitewashing that results from cormorant and heron nesting, but again the reduction of nestling density by egg oiling may have contributed.

Island D—Formerly a forest of white pine, this island is widely recognized for the many skeletons of standing dead trees. As many as 400 cormorant nests and 25 heron nests are still built each year in the standing dead trees. The fallen trees also provide favorable habitat for cormorant nests. Photos and personal observations document little change over 6 years, although four or five large, dead pine trees are known to have fallen, not obvious on photographs. Certainly more trees will fall in future years, and there is no significant regeneration of any woody vegetation. A few, scattered elderberry shrubs and a small patch of sumac remain intact.

Island C—No photo plots were established on this island because only a small number of trees are found around the perimeter. They were all dead in 2005, but most remain standing and support 150+ cormorant nests each year. The interior of the island has traditionally been vegetated with a dense cover of reed canary grass, which has provided cover for the thousands of young gulls hatched on this island each year. However, cormorants began to establish ground nests more than a decade ago and have created large bare areas (cormorants pull the grasses for nesting material) from which the gulls are largely excluded. One of these bare areas has been taken over by Caspian Terns, a positive result.

Literature Cited

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A.E. Duerr. 2007. Population dynamics, foraging ecology, and optimal management of Double-crested Cormorants on Lake Champlain. Ph.D. Dissertation, University of Vermont, Burlington. 198pp.

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Appendix A. Summary of results and data files submitted with the final report.

Data set or population metric	2008	2009	2010	2011	2008-2011	File reference
					Average or Sum	
Numbers of nests						*Summary table nest counts.xlsx*
Island A	725	458	438	486	527	
Island B	838	860	766	970	859	
Island C	787	1018	692	468	741	
Island D	1483	1660	1455	2012	1653	
Total	3833	3996	3351	3936	3779	
Numbers of nests oiled						*Summary table nest oiling.xlsx*
Island A	720	420	381	429	488	
Island B	790	842	618	828	770	
Island C	297	442	289	280	327	
Island D	414	572	487	1057	633	
Total	2221	2276	1775	2594	2217	
Nests oiled as percentage of nest count	0.58	0.57	0.53	0.66	0.59	
Numbers of nests monitored						*Field books*
Island A	98	91	85	102		
Island B	61	101	78	97		
Island C	14	55	148	31		
Island D	36	25	61	57		
Estimates of productivity (fledglings/nest)						*Field books*
Island A	0.20	0.21	0.57	0.24	0.31	
Island B	0.48	0.39	0.44	0.41	0.43	
Island C	1.19	0.90	1.04	0.97	1.02	
Island D	1.16	0.73	1.50	0.66	1.01	
Weighted average	0.82	0.64	1.04	0.58	0.77	
Numbers of cormorants banded						*Banding data 2008-2011.xlxs*
Adults	221	182	133	35	571	
Fledglings	154	90	41	221	506	
Total	375	272	174	256	1077	
Number color-banded	324	272	174	74	844	
Numbers of banded cormorants resighted						*2008 Final Band Resight data.xlsx*

Island A	189	62	103	48		*2009 Final Band Resight data.xlsx*
Island B	27	39	41	13		*2010 Final Band Resight data.xlsx*
Island C	357	214	180	95		*2011 Final Band Resight data.xlsx*
Island D	365	296	264	168		
Total	938	611	588	324	2461	*Band resight effort.xlsx*
Number of person hours	92.7	64.6	59.9	35.8	253	
Bands observed/hour	10.1	9.5	9.8	9.1	9.7	
Number of different bands observed	513	429	382	217		
Numbers of banded cormorants moving to/from islands AB, where nests were oiled						
Oiled to Not Oiled		21	13	6	40	*Movements Oiled to Not Oiled, 2008-2011.xlsx*
Not Oiled to Oiled		19	21	4	44	
Stayed on same island		214	171	91	476	
Total bands observed		254	205	101	560	
Numbers of cormorants culled on Lake Champlain	1101	1605	1363	6088	10,157	*DCCOs Culled on L. Champlain 2008-2011.xlsx*
Numbers of cormorants culled on Lake George	19	20	25	23	87	*DCCOs Culled on L. Champlain 2008-2011.xlsx*
Numbers of banded cormorants recovered in culling operations	60	71	40	120	291	*Band Recoveries Culled DCCO 2008-2011.xlsx*
Numbers of banded cormorants encountered away from Lake Champlain and reported to USGS Bird Banding Lab					94	*DCCO band encounters from BBL 2012.xlxs*
Decision model for projecting results of cormorant management options						*LC Population Model Adam.xlxs*