CHANGING MOVEMENTS OF DOUBLE-CRESTED CORMORANTS IN THE BEAVER ARCHIPELGO, NORTHERN LAKE MICHIGAN

Taaja Tucker

A thesis submitted in partial fulfillment of
the requirements for the degree of
Master of Science

Department of Biology

Central Michigan University
Mount Pleasant, Michigan
April 2011

Accepted by the Faculty of the College of Graduate Studies,

Central Michigan University, in partial fulfillment of

the requirements for the master's degree

Thesis, Doctoral Project, or Dissertation Committee:

_____ Committee Chair

_____ Faculty Member

_____ Faculty Member

_____ Faculty Member

Date: _____

_____ Dean
College of Graduate Studies

Date: _____

Committee:

Nancy Seefelt, Ph.D., Chair

Andrew Scott McNaught, Ph.D.

Thomas Gehring, Ph.D.

R. Gregory Corace III, Ph.D.

This thesis is dedicated to my friends and family

who helped me along the way.

ACKNOWLEDGEMENTS

First I would like to thank my advisor, Dr. Nancy Seefelt, for making my work possible, helping me draft this thesis, and guiding me through teaching and the rest of my graduate career. I would also like to thank my thesis advisory committee: Dr. Greg Corace, Dr. Tom Gehring, and Dr. A. Scott McNaught for all of their time helping answer my questions and aiding in the revision process. In the field, I was aided by my lab mates Maggie Van Guilder and Chris Finch, and thank them for their hard work, patience, and understanding. Many thanks go to the Central Michigan University Biological Station for the use of equipment and lodging. Support from Seney National Wildlife Refuge and Central Michigan's Biology Department also made this work possible. Thank you to Zach Nichols for the many years of emotional support, and to Bun and Tuckerbun for being such good furry companions when he was not available. In addition, I would like to thank my parents, Julia Davis and Mitch Tucker, for their support and for visiting me on Beaver Island. Finally, I wish to acknowledge the support of Central Michigan University in producing this work.

ABSTRACT

CHANGING MOVEMENTS OF DOUBLE-CRESTED CORMORANTS
IN THE BEAVER ARCHIPELGO, NORTHERN LAKE MICHIGAN

by Taaja Tucker

In the Beaver Archipelago of northern Lake Michigan, the rise in numbers of the Double-crested Cormorant (*Phalacrocorax auritus*), or DCCO, is seen by some as an explanation for a reduction in the populations of fish species of commercial and sporting interest. This has led to culling adult DCCOs and egg oiling in an effort to reduce DCCO numbers. Earlier research documented that DCCOs focused mainly on the invasive alewife (*Alosa pseudoharengus*) in this region. Despite past reliance on alewives as prey in the Beaver Archipelago, DCCOs are now focusing on another invasive species, the round goby (*Neogobius melanostomus*). This study was conducted to better identify whether changes in DCCO diet and/or DCCO management have caused changes in DCCO foraging behavior in the Beaver Archipelago.

To test the hypothesis that DCCO foraging locations have changed over time, I used radio telemetry to track the movements of 10 tagged DCCOs in the summer of 2010, while also noting the location of rafts (groups of foraging DCCOs) across the Beaver Archipelago. These spatial data were then compared to those from 2003, prior to DCCO population management, to see if differences existed in foraging area use between the sample periods. I then collected and analyzed diet samples from DCCO colonies in 2009 and 2010 to examine possible influence of diet change on DCCO movements. The tagged DCCOs in 2010 were found foraging farther from their original colony of capture than those in 2003. Rafting DCCOs still foraged in the same key locations on the eastern side of Beaver Island, but their foraging range expanded to include areas north and west of Beaver Island. This shift may be due to the use of Whiskey Island as a nesting

colony in response to management. The raft and telemetry data from 2010 both show the early departure of DCCOs from the Beaver Archipelago, most likely due to low reproductive success. Although rafts were found closer to shore in 2010, which could be a response to the presence of round gobies, overall the effects of management may have provided much of the change in DCCO foraging distributions.

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CHAPTER I

INTRODUCTION

The Double-crested Cormorant (*Phalacrocorax auritus*) is a common and widespread, piscivorous waterbird endemic to coastal and interior regions of the United States, including the Laurentian Great Lakes (Hatch and Weseloh 1999). Whereas population numbers are high today, this has not always been the case; Double-crested Cormorants (DCCOs) were once listed as state-endangered in Illinois, Michigan, and Wisconsin. Cormorant populations in this region have been subject to the continuous flux of human conflict and resolution, ecosystem degradation and restoration—all of which led to subsequent population crashes and expansions, with associated problems (Weseloh *et al.* 1995). In the Beaver Archipelago of northern Lake Michigan, the rise in DCCO population numbers is seen by some as an explanation for a reduction in fish populations of sporting and commercial interest. Some regard DCCOs as a nuisance, and some members of the public have called for reductions in their numbers (Solle 2008).

Cormorants in the Great Lakes

Considered a competitor for fish of commercial value by many fishermen, the DCCO has been much maligned in the Great Lakes and elsewhere (Lewis 1929; Ludwig *et al.* 1989; Craven and Lev 1987; Hatch and Weseloh 1999). Once numerous across their range during the 1800s, DCCOs were scarce in the early 1900s, but found to be breeding in the Great Lakes again around 1913 (Lewis 1929; Baillie 1947). In the 1940s, the population grew to an estimated 1000 pairs (Postupalsky 1978). Concerned with this boom in growth, fisheries managers in Ontario instigated control measures, such as coating eggs with soap and formaldehyde, while fishermen

and other managers across the Great Lakes routinely destroyed nests and shot adults and chicks (Ludwig 1984; Weseloh *et al.* 1995). Around the same time, rampant use of pesticides in the Great Lakes basin led to the biomagnification of organochlorides in DCCOs and other piscivorous birds, reducing their ability to hatch young due to egg-shell thinning (Faber and Hickey 1973; Weseloh *et al.* 1995). Great Lakes DCCO populations declined more than 80% from 1947 to 1972 due to the combined effects of persecution and chemical contamination (Postupalsky 1978).

Just when extirpation seemed most likely, a combination of factors arose that allowed for renewed population growth. Some of these factors were a ban on organochloride use, state and federal protection of the species by inclusion in an amendment to the 1918 Migratory Bird Treaty Act, and a significant increase in DCCO prey base, specifically the non-native fish species alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) (Weseloh *et al.* 1995; Hatch and Weseloh 1999). Increases from 1972 to 1991 were remarkable; in just 21 years, the number of nests found in the Great Lakes increased from only 89 to over 38,000 (Weseloh *et al.* 1995). Most likely, more DCCOs exist in the Great Lakes now than have ever before, but population growth has been stabilizing (Wires and Cuthbert 2006).

Public outcry against DCCOs has risen with the increasing number of birds. Commercial and sports fishermen worry that DCCOs are responsible for declines in catch of game fishes such as walleye (*Sander vitreus*), yellow perch (*Perca flavescens*), and smallmouth bass (*Micropterus dolomieu*; Bur 1999; Lantry *et al.* 2002; Diana *et al.* 2006). However, many dietary studies have found that DCCOs consume primarily forage fishes and not those of commercial value (Lewis 1929; Craven and Lev 1987; Ludwig *et al.* 1989; Neuman *et al.* 1997; Hatch and Weseloh 1999;

Johnson *et al.* 2002; Diana *et al.* 2006; Seefelt and Gillingham 2008). Few studies have suggested that DCCOs are significantly and directly detrimental to Great Lakes commercial fisheries (Lantry *et al.* 2002; Fielder 2008). It is possible, however, that consumption of forage fishes by DCCOs may have an impact on community dynamics, reducing available food for commercial fishes and indirectly affecting their population growth (Craven and Lev 1987). Types of prey items consumed are numerous and dependent on the locality; DCCOs are opportunistic feeders, taking many kinds of slow or schooling fish usually <15 cm in length (Craven and Lev 1987; Ludwig *et al.* 1989; Hatch and Weseloh 1999). Typical prey items in the Great Lakes include alewife, ninespine sticklebacks (*Pungitius pungitius*), yellow perch, and rainbow smelt (Craven and Lev 1987; Ludwig *et al.* 1989; Neuman *et al.* 1997, Johnson *et al.* 2002; Seefelt and Gillingham 2004; Diana *et al.* 2006).

Cormorants in the Beaver Archipelago

In 1984, Ludwig found 250 DCCO nests throughout the Archipelago, while in 2000 Seefelt and Gillingham (2008) found a total of 10,125 nests. This number decreased slightly in 2001, indicating a possible stabilization of DCCO growth and range expansion (Seefelt and Gillingham 2004) or sampling error. The number of nests counted has fluctuated by the thousands and sampling variance is not known, but since management actions (egg-oiling and culling adult birds) were implemented in 2007, a more steady decline has been observed.

Usually by mid-April, DCCOs migrate from their wintering grounds in the Gulf of Mexico to colonies on the Great Lakes to breed (Hatch and Weseloh 1999; Seefelt and Gillingham 2004). Breeding sites are generally chosen based on nearby prey availability and lack of predators (Blackwell and Krohn 1997; Hatch and Weseloh 1999). The colony sites chosen in

the Beaver Archipelago tend to be on small, rocky islands with sparse or short vegetation (e.g. Pismire Island, Hat Island, Grape Spit, and Timm's Spit), but some are on larger islands where DCCOs tend to nest in trees (Whiskey and Gull Islands; Seefelt and Gillingham 2008). Nesting in trees is likely a mechanism to escape predation (Lewis 1929), which is more likely on some of the larger islands such as Whiskey Island and Gull Island that can support ground predators.

Feeding represents a relatively small portion of the DCCO's daily activities during the breeding season. Fowle (1997) found that adult DCCOs with chicks spent slightly more than half of their day resting, compared to 12% of time spent foraging. Cormorants often forage alone, but can form larger flocks from a few individuals to several hundreds where prey items become abundant and birds may work together to catch fish (Hatch and Weseloh 1999). A dietary study from 1986-1989 indicates that primary prey species in the Beaver Archipelago were alewife and white sucker (*Catostomus commersonii*), which made up 72% and 14% of consumed biomass, respectively (Ludwig *et al.* 1989). A similar study was performed from 2000-2001 and found that alewife made up 72% of DCCO diets by biomass (Seefelt and Gillingham 2004). The DCCOs of the 1986-1989 study shifted 100% of their feeding to alewife by August, and a similar trend was noted in the later study (Ludwig *et al.* 1989; Seefelt and Gillingham 2004). Cormorants preferentially shift their focus from other species of fish to alewives when they come close to shore to breed as lake temperatures increase (Neuman 1997; Johnson *et al.* 2002). Smallmouth bass, an important game fish in the area, made up 3% of diet biomass in 1986-1989 (Ludwig *et al.* 1989). Conversely, only one smallmouth bass was found from 2000-2001. This discrepancy is suspected to be because DCCOs were not foraging in areas where bass were likely to be found (Seefelt and Gillingham 2004, 2006).

Despite the heavy reliance on alewives in the past, DCCOs may be turning their focus to another invasive species. The round goby (*Neogobius melanostomus*), indigenous to the Black and Caspian Seas, is a relatively new and prolific invasive species in the Great Lakes ecosystem. First discovered in the St. Clair River in 1990, the round goby has since spread to all five Great Lakes (Jude *et al.* 1992; Corkum *et al.* 2004). These benthic creatures spend most of their time at depths 10-20 m, but are commonly found in shallower waters where crevices and rocks are available (Jude *et al.* 1992; Weimer and Keppner 2000). Studies have provided evidence that these invasives are detrimental to other fish species through niche competition and predation of eggs of native species (Chotkowski and Marsden 1999; Charlebois *et al.* 2006). Densities of round gobies in the Great Lakes are variable, and can range from 5 to 133 individuals per m^2 (Charlebois *et al.* 1997; Wiemer and Keppner 2000). At these densities and based upon their use of shallow waters, round gobies can act as an easily accessible food source for DCCOs, especially considering that the average prey fish density for Lake Michigan (round gobies withstanding) in 2008 was roughly 1,000 per hectare, based on acoustic and bottom trawl surveys (Bunnell *et al.* 2009).

Stomach and regurgitate analyses have provided evidence that populations of round goby form a significant prey base for DCCOs in the Great Lakes and in the Beaver Archipelago, specifically. A study from Lake Ontario found round gobies in DCCO regurgitate at 18% of colony nests and individual round gobies accounted for 1.8-11% of all food items recorded in regurgitates (Somers *et al.* 2003). A follow-up study in 2006 showed an increase of round gobies in the DCCO diet: round gobies accounted for 68% of the diet of nesting DCCOs and dominated (83%) the diet of adults during the post-chick feeding period (Johnson *et al.* 2007).

Cormorant Population Management

Management of DCCOs populations through lethal means has occurred throughout the United States. In the Great Lakes, management actions began in 2004 in the Les Cheneaux Islands of northern Lake Huron. Cormorants were implicated in the demise of Les Cheneaux Island yellow perch populations so a program of egg oiling and culling of adult birds was implemented. It has been argued that management of DCCOs has allowed for the increased survival of young yellow perch (Fielder 2010). However, management in the area has also led to differences in how and where the DCCOs forage. Overall, DCCOs were found to forage over a wider area post-management action, and were more dispersed. Whether this is due entirely to management, or to a change in the food base or to intraspecific competition is unknown (Dorr *et al.* 2010).

Culling of adult birds and egg oiling have had mixed effects in other locations. After egg oiling took place on Vermont DCCO colonies, cormorants simply nested on colonies where threat of egg oiling was absent. Although specific birds were not followed, it was shown that after management occurred DCCOs were found attempting to colonize new areas as far as 100km from the original management sites (Duerr *et al.* 2007). A similar effect was observed in the Les Cheneaux area, where DCCO numbered on non-targeted colonies increased post management (Dorr *et al.* 2010). Studies of wintering DCCOs show similar trends. In the southern United States, DCCO predation on channel catfish (*Ictalurus punctatus*) results in the loss of potentially millions of dollars in revenue (Glahn and Brugger 1995). Starting in the early 1990s, DCCOs were dispersed from roosts in problem areas and in 1998 a depredation order was issued by the U.S. Fish and Wildlife Service that allowed catfish farmers to shoot DCCOs on

their properties (Glahn *et al.* 2000). After these activities occurred, DCCOs were found to be more widespread and to inhabit novel roost sites (Mott *et al.* 1998, Glahn *et al.* 2000).

Management may have a cumulative effect, wherein DCCO populations decrease due to management but also with secondary factors caused by the effects of management. For instance, egg-predation by gulls (*Larus* spp.) can occur simultaneously with, or just after, egg oiling (Duerr *et al.* 2006). In addition, DCCOs and other colonial waterbirds rely on an expansive colony structure to prevent egg predation on more internally located nests, so a reduction in occupied nests could further increase predation rates (Siegel-Causey and Hunt Jr 1981). In Lake Champlain, it was found that egg predation by gulls associated with management activities was more influential in determining when DCCOs would switch colonies than egg-oiling alone. Egg predation indicates a poor-quality habitat to DCCOs, leading them to choose higher-quality habitat elsewhere, whereas egg-oiling by itself fools DCCOs into staying at their colony (Duerr *et al.* 2006).

Wildlife Services, a subsection of the Animal and Plant Health Inspection Service (APHIS) and the U. S. Department of Agriculture (USDA), performs management activities in the Beaver Archipelago on Hat, Pismire, and Gull Islands. The USDA's 2010 management proposal calls for a yearly 50% reduction in the number of nesting DCCOs in the Beaver Archipelago to determine whether the smallmouth bass population experiences any increases (USDA 2010). The effects of management on DCCO and fish populations in the Beaver Archipelago have not yet been quantified and how management affects the movements of DCCOs in the region is unknown.

Objectives

My objectives in this study were to:

1. Identify the distribution of DCCOs in space using sighting surveys and telemetry, and quantify how these relationships have changed over time from 2003 (Seefelt and Gillingham 2006) to 2010.
2. Describe where DCCOs in the Beaver Archipelago typically forage relative to potential explanatory variables such as colony proximity, proximity to the nearest shoreline, water depth, lake bottom slope, and other waterscape characteristics.
3. Form possible hypotheses to describe the changes in DCCO distributions.

In conjunction with sighting surveys, I used telemetry data to show how the distances of DCCOs from their colonies of capture have changed after management actions occurred. The results from this study were compared to a previous telemetry study and raft surveys performed in 2003 (Seefelt and Gillingham 2006). Foraging location data are also compared to the diets of breeding and nestling DCCOs in the Beaver Archipelago from 2000, 2001, 2009, and 2010. Corroborating diet data with pre- and post- management foraging locations I attempt to ascertain whether diet changes or management have influenced DCCO movements. I hypothesized that management would have a measurable impact on DCCO movements but the diet shift from alewives to gobies would have a lesser effect, due to the DCCO's generalist nature. The information gathered from this study could be useful to help managers ascertain possible impacts on local fisheries and provide information for managing DCCO populations within the Beaver Archipelago.

CHAPTER II

MATERIALS AND METHODS

Study Site Description

The Beaver Archipelago is a collection of approximately 11 small islands in northern Lake Michigan, ranging in size from <1km^2 to 145km^2 (Figure 1). Changing water levels influence the number and size of islands in the region. DCCOs nesting on Hat Island (45º48'58.69”N, 85º18'00.01”W, area: 0.05km^2), in the Beaver Archipelago northeast of Beaver Island, were the focus of this study.

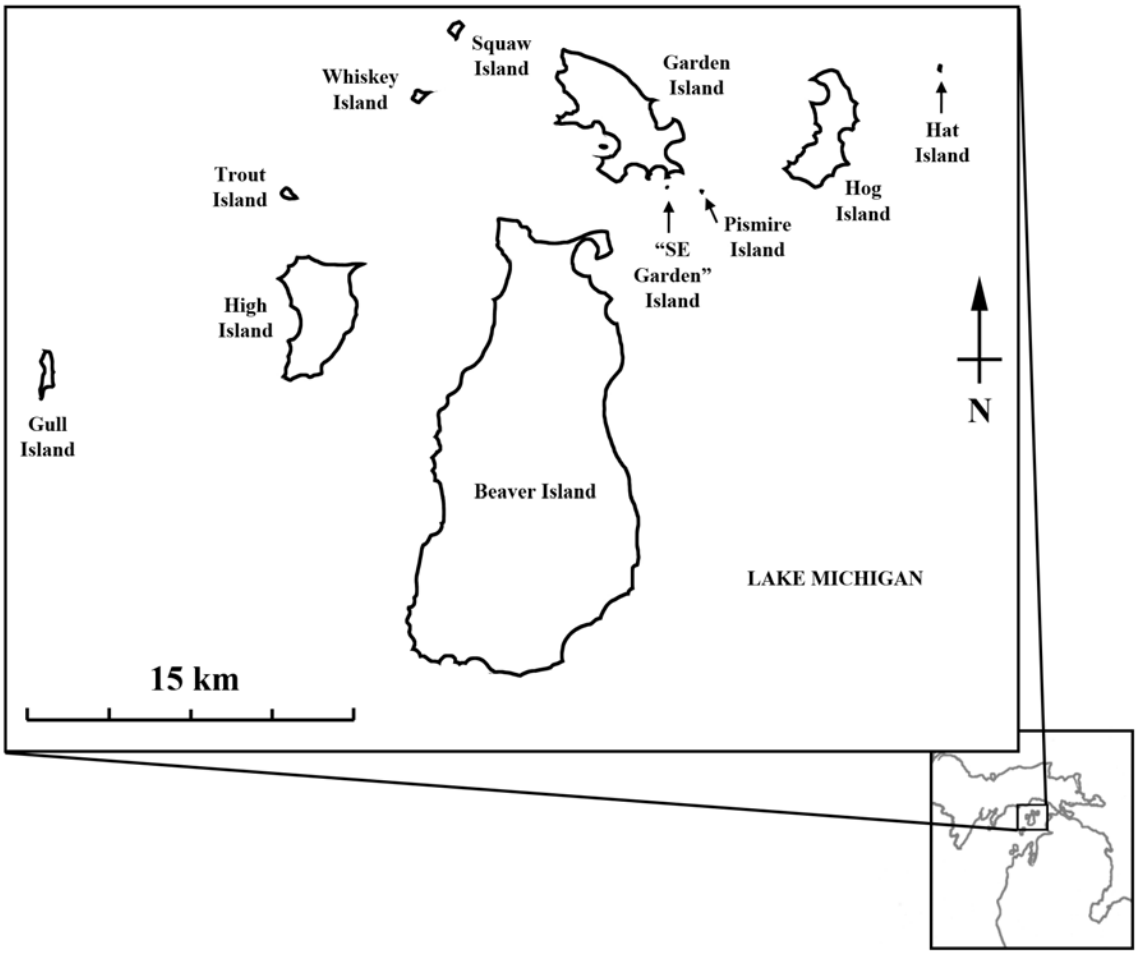


Figure 1. Map of the Beaver Archipelago, northern Lake Michigan.

Hat Island is part of the Michigan Islands National Wildlife Refuge (NWR) and is managed by the U.S. Fish and Wildlife Service as a satellite refuge of Seney NWR. This site was chosen because it generally yields successful DCCO breeding colonies. In the mid to late 1980s, Hat Island supported 54 to 294 breeding pairs of DCCOs. From 1997 until 2009, the island has supported a minimum of 3515 pairs to a maximum of 7942 pairs (N. E. Seefelt unpublished data).

Hat Island is mostly rocky with weedy vegetation that can grow >1m in height near the end of the breeding season. Taller shrubs and dead trees are dotted across the island. Cormorants tend to nest on the ground in the areas where vegetation is scarce, but may also attempt to nest in the lower branches of dead trees. Other waterbird species that frequently nest on the island include Ring-billed Gulls (*Larus delawarensis*), Herring Gulls (*Larus argentatus*), Great Blue Herons (*Ardea herodias*), and Caspian Terns (*Sterna caspia*).

Throughout the duration of the study, APHIS Wildlife Services performed DCCO management (egg oiling and killing of adult birds) on Hat Island and elsewhere in the Archipelago. Management activities on Hat Island occurred on four days during the breeding season. All eggs on the island were oiled 17-18 May 2010 and 218 adult DCCOs were killed. On 7 June 2010, 213 DCCOs were killed and 1864 eggs were oiled. The last management trip on 1 July 2010 occurred concurrently with our research, when APHIS oiled 1419 eggs. Birds were also killed and eggs were oiled on Pismire Island and on Gull Island, both also part of Michigan Islands NWR. Management activities prevented DCCOs from nesting on Pismire Island, while only tree nests remained on Gull Island (Wildlife Services unpublished report 2010).

Capture of Double-crested Cormorants

Field methods follow those used by Seefelt and Gillingham (2006). Ten DCCOs were captured on Hat Island using soft-catch leg hold traps (model SN35798, Forestry Suppliers, P.O. Box 8397, Jackson, Mississippi, USA, 39284) on 3 June 2010, during the time when DCCOs typically incubate eggs. These traps were composed of two padded jaws that clamped down on the leg of the bird when the trap was triggered (stepped on). Each trap was further padded using foam pipe insulation on one of the jaws. Traps were placed on the ground in the central area of the nesting colony to catch more experienced birds (Seefelt and Gillingham 2006). Trap locations coincided with designated focal areas in which trail cameras (Moultrie Game-spy 40D) from another research project had been placed. The cameras were used in an effort to capture the behavior of these 10 radio tagged birds and others nesting nearby. Traps were set near the cameras and checked after researchers had left the area and the DCCOs had flown back to the nests. This process was repeated as necessary to obtain the 10 birds necessary for the project.

Once caught, the DCCOs were removed from the traps and placed into wet pillowcases to reduce stress and prevent overheating while waiting to be processed. Birds were then weighed in the pillowcase using a spring scale. The DCCOs were then outfitted with backpack harnesses adapted from Duncun (1972). Harnesses were constructed from Teflon tubing, marine/sport adhesive, Teflon-coated fiberglass tape, and cotton thread. The harnesses were constructed beforehand, leaving one loop open to sew shut in the field once the rest was attached to the bird. Each harness held one radio transmitter (Backpack Transmitter, A1300, Advanced Telemetry Systems, 150.020-150.200 MHz range). The combined weight of both backpack and transmitter was 1.5-2% of each bird's body weight (King *et al.* 2000). The DCCOS were measured and

fitted with metal and colored bands (APPENDIX A). Measurements used to sex DCCOs found that our sample included five females and five males (APPENDIX B). Birds were released as soon as the backpack was attached. Handling and disturbance were minimized as much as possible and the researchers left the island as soon as all birds were processed. The study was performed under a permit from the U. S. Geological Survey Patuxent Wildlife Research Center Bird Banding Laboratory (#23467) and under guidelines approved by Central Michigan University's Institutional Animal Care and Use Committee (IACUC#: 10-06).

Tracking of Double-crested Cormorants

Radio tagged DCCOs were located via a Yagi antenna attached to a receiver (Fieldmaster 100, Advanced Telemetry Systems, 150 MHz range) from a small boat several times a week, weather permitting, from 3 June 2010 to 21 July 2010, for a total of 27 sampling days. Trips were made circling Beaver Island, to and from all northern islands in the Beaver Archipelago, slightly north of the Archipelago, and on one occasion to Gull Island (approximately 18 km from Beaver Island). Standardized routes were maintained between islands and around Beaver Island, but when DCCOs were scarce more exploratory routes were taken. Cormorant relocations were found using standard telemetry techniques outlined by Mech (1983). Once the direction of the DCCO in question was established, a compass (Brunton Outback digital compass) reading was taken and current location (in decimal degrees) of the boat noted by a handheld Global Positioning System (GPS; Thales Mobile Mapper). The boat was then driven within several minutes to two other points where two more sets of compass bearings and GPS locations were recorded. Attempts were made to locate DCCOs with telemetry from seven locations on Beaver

Island's open shores on days when the weather was unsuitable for boat travel or when only one boat trip was completed in a day (Figure 2). Twenty-five trips were made to these Beaver Island locations during the same study period as the boat surveys. Start and end times for data collection ranged from 0815 h to 1700 h. Each trip to all seven locations lasted 1.5 to 2 hours. If a signal was found at a sampling location, I would walk as far as possible to two other points on land to obtain additional bearings.

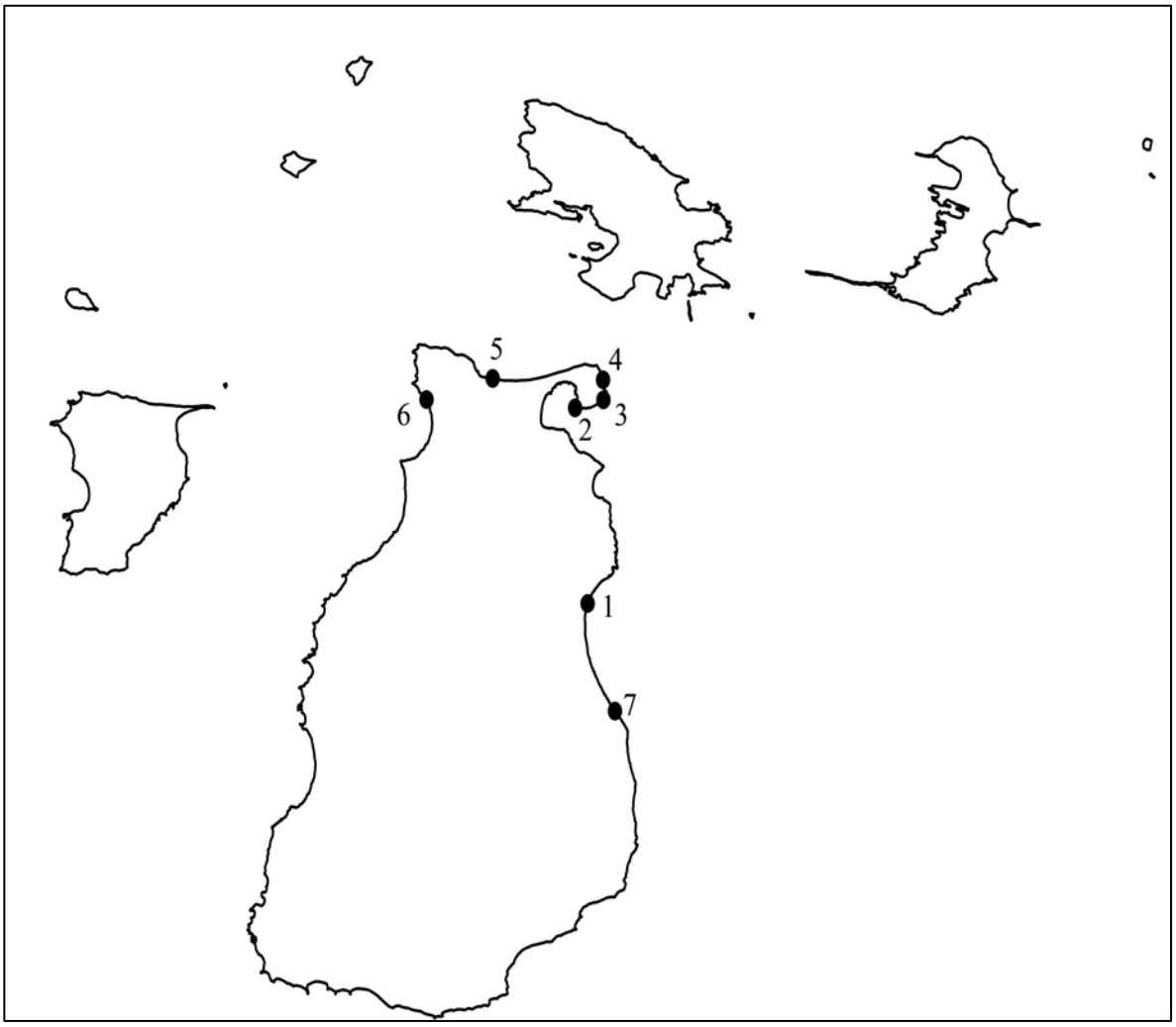


Figure 2. Black dots denote the seven Beaver Island locations from which radio telemetry attempts were made. The numbers represent the visitation sequence per sampling effort.

Rafting locations in Lake Michigan were determined by sight from the boat from 17 May 2010 to 21 July 2010, for a total of 34 sampling days. Each raft was assumed to represent a foraging group of DCCOs; the DCCOs' wettable plumage reduces buoyancy and increases heat loss, preventing extended loafing on the water (Wilson *et al.* 1992). We navigated the boat toward the raft location and the coordinates were recorded by the handheld GPS in the approximate spot from which the birds dispersed. Attempts were made to prevent counting birds that had been frightened and had scattered to another feeding location; each raft observed during a sampling period was assumed to contain different birds and were assumed to be independent of one another. Four observers were present to ensure counting accuracy. Due to the limited duration and speed of each boat survey, habitat specified as 'unused' during our surveys may have been used at another time without our knowledge. The number of birds that composed the raft, the time, and approximate location in relation to noticeable landmarks were noted. When the number of birds composing the raft was too large to count, we estimated the total count to the nearest 10 birds. Water depth at the raft location was recorded with a Humminbird Fish Finder depth sensor. This sensor was only available for part of the 2010 field season so depths from a bathymetry map were used instead (see Data Analysis section below). A small airplane was used on one occasion to look for rafts throughout the entirety of the Beaver Archipelago on 13 July 2010. A GPS was used to note the location of these rafts as they were flown above.

Foraging location data gathered from this study were compared with those from 2003 (Seefelt and Gillingham 2006). Rafting locations and locations of 10 telemetered DCCOs from 2003 were collected using the same methodology, but using different radio transmitters (Model RI-2C Backpack, Holohil Systems Ltd., 112 Cavanagh Road, Carp, Ontario, Canada, K0A 1LO;

6.4 g with whip antennae; frequency range 150.026-150.204 MHz) and a different receiver (model LA 12-Q, AVM Instrument Co. Ltd, 1213 S. Auburn, P.O. Box 1898, Colfax. California, U.S.A., 95713; frequency coverage 150.000 – 151.999 MHz). Raft locations were noted from 18 May 2003 to 13 September 2003. Rafting surveys occurred in the same areas and along the same routes in 2003 and 2010, although the routes were more standardized in 2003 due to the frequency at which birds were encountered. Eight of the telemetered DCCOs were captured and tagged on Pismire Island (45°46'06.97"N, 85°26'41.46"W) on 4 June 2003, while two others were captured and tagged on the SE Garden colony (45°46'04.28"N, 85°28'00.88'W). The 10 birds were tracked and monitored until 13 September 2010. Telemetry locations were found using triangulation via Locate II (Nams 2001). I restricted the data used from the 2003 study to those which fell within the same study period as the 2010 study for consistency. Within the selected time period, sampling occurred on 45 days.

Data Analysis

Each 2010 telemetered DCCO's approximate location was found using triangulation via Locate III (Nams 2006). If possible, the size of the error ellipses generated around each location were minimized by rotating slightly the direction of one imprecise telemetry bearing, but all points were used in the interest of sample size. Error ellipses were generated using Maximum Likilihood Estimation, and ranged from 0.5km^2 to >100km^2. Telemetered DCCO locations and rafting observation locations for 2003 and 2010 DCCOs were imported into ArcGIS 9.2 (ESRI) for spatial analysis. All analyses were performed under the extent of the entire Beaver Archipelago, including Gull Island, at a 1:120,000 scale. Each layer created or imported into

ArcGIS was projected under the 1984 WGS UTM Zone 16N projection. Depths from a 1996 Lake Michigan bathymetry raster map (National Geophysical Data Center, NESDIS, NOAA, U.S. Department of Commerce) were found for the 2010 rafts due to the lack of a depth finder during part of the field season. Depths from the bathymetry map were substituted for the depths at which the 2003 rafts locations were found for consistency between study periods. The depths obtained from the bathymetry map were not significantly different from the 2003 field measurements (N=504, P=0.6176, Mann-Whitney), or from the few observations from 2010 (N=70, P=0.665, t-test). The bathymetry raster map was used to generate maps of lake bottom slope, plan curvature, slope of lake bottom slope, and aspect using the Spatial Analyst extension of ArcGIS. The slope of the slope provides a measure of how quickly the slope changes, while the plan curvature provides an idea of the shape of the landscape (i.e. concave, convex, or flat). These are a selection of lake bottom characteristics that have been considered possible predictors of fish abundance in other ecosystems, especially the slope of the slope (the acceleration of the lake bottom slope; Pittman *et al.* 2009).

I used ArcGIS 9.2's Extract Values to Points function in Spatial Analyst to add the environmental variables from the underlying raster layers to the 2010 and 2003 raft locations. I used the Hawth's Tools' 'Distance Between Points' tool (Beyer 2004) to find the distances between telemetry points and the colony from which each tagged bird was captured, as well as the distance from each raft to the nearest colony. The Nearest Features extension for ArcView 3.3 (Jenness 2007) was used to calculate the distance between rafts and the nearest shoreline of islands in the Beaver Archipelago. Statistical tests performed outside of ArcGIS or other spatial software were executed in Minitab 15 unless otherwise noted. I chose an alpha=0.05, except in cases where a Bonferroni correction was needed.

Multi-Response Permutation Procedure

Program BLOSSOM's multi-response permutation procedure (MRPP; USGS 2008) was used to determine whether the 2003 and 2010 raft location data represent two unique point distributions (or groups) in space. The MRPP is a distribution and assumption-free test which compares the distances in Euclidean space between points in two or more a priori groups against permutations of the same points but within random groupings (Zimmerman *et al.* 1985). Two different iterations of the MRPP were performed: the moments-based approach and a Monte-Carlo resampling procedure. The moments-based approach uses the mean, variance, and the skewness of the data to generate a p-value from the Pearson type III distribution. The Monte-Carlo resampling procedure is useful when data are clumped. I performed 10,000 iterations of the Monte-Carlo resampling procedure.

Kernel Estimation

I used Animal Space Use 1.3 (Horne and Garton 2009) to determine the best home-range model for each data set, using the lowest Akaike's Information Criterion (AIC) and Likelihood Cross-validation Criterion (CVC) to find the best statistical methods to represent the 2003 and 2010 raft data (APPENDIX C). Kernel models were determined to be the most appropriate tool for all data sets analyzed. Although an adaptive kernel was shown to best represent the 2003 raft dataset, I used a fixed kernel density estimator to find the volume contours of both the 2003 and 2010 data sets because no one kernel density estimator extension I tested for ArcGIS produced both fixed and adaptive kernels, could add weights to the kernels, and could produce reliable adaptive kernel results. In addition, adaptive kernel models have been found to overestimate the size of volume contours in peripheral areas where animals spend little of their time (Seaman and Powell 1996). When choosing between adaptive and fixed kernel density models, one has not been found to be better than the other, but fixed kernel models are the most common kernel model used to estimate home ranges (Horne and Garton 2006, Laver and Kelly 2008). I also chose to use only one type of kernel density estimator for consistency and comparability between data sets. Kernels were not generated for the telemetry data due to the low number of observations in 2010.

The ABODE for ArcGIS extension (Laver 2005) was used to find the 50% and 95% volume contours, weighted by the number of birds in each raft, denoting the most probable and important DCCO foraging ranges for the 2003 and 2010 rafts. This extension generates a biweight probability kernel, a region around coordinates in which it is likely the animals may be found (Seaman and Powell 1996). The different volume contours denote the percentage of

location data used to generate the contour; a 50% volume contour will contain approximately 50% of all the location points, and is the most conservative home range generated in this study. A 50% volume contour was chosen because it is a conservative estimate thought to represent the area where the animals spend most of their time, whereas a 95% contour shows the total extent of the animals' range but ignores occasional sallies farther away (Powell 2000, Laver and Kelly 2008). A "core" volume contour was created in ABODE using a technique that compares the percentage of the home range with a certain probability of use versus the percent maximum probability of use (Seaman and Powell 1990, Powell 2000). Graphs of these data were then plotted to determine whether the animals exhibited clumped use of the study area, a requisite for core determination (Powell 2000, Laver 2005).

When estimating kernels/volume contours, the smoothing factor is the most important model element because it can significantly alter the shape and size of the resulting kernel (Horne and Garton 2006). The width of the kernels was estimated using the least squares cross-validation LSCV smoothing factor, which is the most commonly accepted smoothing factor (Seaman and Powell 1996, Laver and Kelly 2008). The LSCV smoothing factor was chosen over the competing likelihood cross-validation (CVh) smoothing factor because the LSCV is no less accurate than the CVh for sample sizes over 50 (Horne and Garton 2006) and is the only method used by the ABODE extension. I chose to standardize the location data using the unit variance and chose a fine-scale grid resolution of 50 m to generate the kernels.

The area of each density contour was calculated using the 'Add Area Tools' in Hawth's Analysis Tools for ArcGIS. Each density contour from the 2003 rafts was overlaid with its corresponding density contour from the 2010 rafts and the 'Polygon in Polygon Analysis' in

Hawth's Analysis Tools for ArcGIS calculated the area of overlap between the polygons. Using these area estimates, I calculated the ratio of overlap between 2010/2003 data and the percent of each polygon the overlap encompassed**.**

Sample Size

As a measure of adequate sample size, I used ABODE (Laver 2005) to generate home range asymptote graphs for the 2003 and 2010 raft 95% volume contour kernels (Laver and Kelly 2008). The program generates increasingly large kernels from random points and determines whether home range size increases with the number of locations or stays constant. An asymptote indicates that ample data points have been collected to accurately estimate home range size, while the presence of multiple asymptotes indicate animal transience.

Autocorrelation

Spatial autocorrelation, which occurs when location data are clumped across the landscape than would be expected from random data, is commonly observed in ecological data due to animal behavior or sampling too frequently (Swihart and Slade 1985, De Solla et. al 1999). However, spatial autocorrelation can alter the results of statistical tests if it is not compensated for because it violates the assumption of independence (Legendre 1993, De Knegt *et al.* 2010). I tested for spatial autocorrelation in the 2003 and 2010 rafts against the number of birds per raft, lake depth, and the lake bottom slope using the Spatial Autocorrelation (Moran's I) tool in ArcGIS 9.2, which generates a Moran's I value, an associated z-score, and a p-value. The Moran's I was generated using the inverse distance function, while distances were calculated as Euclidean Distances. The Moran's I value specifies whether there is clustering (values close to

+1), dispersion (values close to -1), or a random assortment of the data (values near 0). The z-score is the number of standard deviations, and is used to estimate the probability of the degree of spatial autocorrelation. Each data set was analyzed in total and by month. Removing data points to remove autocorrelation has been deemed acceptable by some studies, but is not necessary for kernel estimation (Swihart and Slade 1985, Swihart and Slade 1997, De Solla et. al 1999).

Space-Time and Hot Spot Analyses

I used CrimeStat 3.3 (Levine 2010) to calculate the Knox and Mantel Indices for 2003 and 2010 rafts in total and by month. The Knox Index compares closeness in distance to closeness in time in a 2x2 contingency table, and produces a Chi-square statistic. CrimeStat 3.3 uses a Monte Carlo simulation to generate comparable Chi-square statistics from random points to produce a range of p-values. This is a one-tailed test, where significance indicates some interaction between space and time. The Mantel Index is similar to the Knox Index, but looks for a correlation between distance and time. CrimeStat 3.3 once again performs a Monte Carlo simulation to generate a range of p-values, which show the results of a two-tailed test. For both Knox and Mantel tests, 1000 simulations were performed using the mean distance and time interval. These tests were performed for all 2003 and 2010 rafts and then by month to compare to hot spot analyses.

I performed Hot Spot Analyses for both 2003 and 2010 rafts by month in CrimeStat 3.3, which were corroborated with the above space-time analyses. I used the Nearest Neighbor Hierarchical Clustering (Nnh) method, which identifies high-use areas within a certain threshold distance. Grouping smaller-order clusters can produce different hierarchies of clusters. For the

threshold distance, I used the random nearest neighbor distance with a threshold probability of 95%, so that 5% or fewer of the points would have smaller nearest neighbor distances than a randomly selected threshold distance (if the points had been randomly distributed). I specified that each cluster must have a minimum of five points. The simulation was run 100 times to generate ellipses. The ellipses encompassed one standard deviation, which included about 50% of the points.

Influence of the Environment

Ordinal logistic regression was used to determine which environmental variables (lake depth, lake bottom slope, slope of the slope, aspect, plan curvature, distance from nearest occupied colony, and distance to nearest island shoreline) could predict the size of rafts in 2003 and then in 2010. Rafts were broken into three groups for analysis: small (10 or fewer birds), medium (11-30 birds), and large (more than 31 birds) and coded as 1, 2, and 3 respectively. Each one of these breaks represented approximately one-third of the data set. This method was chosen so that an adequate number of data points would be in each group, considering that the 2010 data had many fewer points than in 2003. Ordinal logistic regression was used in lieu of linear regression because many of the environmental metrics display highly skewed distributions and a variety of data transformations were ineffective at achieving normality. When creating logistic regression models, correlation between variables should be minimized; a correlation coefficient value of 0.7 is suggested as a maximum (Fielding and Haworth 1995). Only non-correlated or slightly correlated variables (rho<0.5; Spearman Rank) were incorporated into models. The best model was chosen based on the lowest adjusted Akaike Information Criterion (AIC_c). Models were also compared using the change in AIC_c (Δ_i) and the Akaike weights (w_i), which provide

the probability that the chosen model best represents the data (Anderson *et al.* 2000). All analyses were performed using SAS software. The ordinal logistic regression was performed using the PROC LOGISTIC command functions for 2003 and 2010 raft data sets separately.

Diet Analysis

Diet samples were removed from the stomachs of lethally taken birds provided by APHIS from 2009 and compared to similar data collected in 2000 and 2001 (Seefelt and Gillingham 2008). Regurgitate samples from adult DCCOs and chicks were collected by hand from Hat Island and Whiskey Island during the 2009 and 2010 breeding seasons and frozen for later analysis. Once removed from the stomach or thawed, the intact prey item or partial prey item was identified to species or genus. Partial and intact prey items were weighed.

CHAPTER III

RESULTS

Telemetry

During the 2010 study period, 13 foraging locations were determined via telemetry (Figure 3). Every tagged bird was found loafing or nesting on an island at some point within the study period (Table 1). When locations could not be estimated due to birds in motion or lost signal, general locations of tagged birds were noted (APPENDIX D). Unfortunately, Hat Island was abandoned in mid-July and no further signals were detected on the island from then on. It was assumed that all telemetered birds left the Archipelago or lost their transmitters before or around 12 July 2010, the day when the last signal was recorded. Maps of actual telemetry points, loafing/nesting locations, and estimated telemetry locations of each individual bird show random behavior, not concentrated near their original capture site on Hat Island but dispersed widely throughout the Archipelago (APPENDIX E). No differences existed between the sexes in average distance traveled per bird (APPENDIX B; N=8, P=0.705, T-test). The average distance traveled per female from colony of capture ranged from 12.5km to 41.5km while the average distance traveled ranged from 14.1 to 22.45km for males.

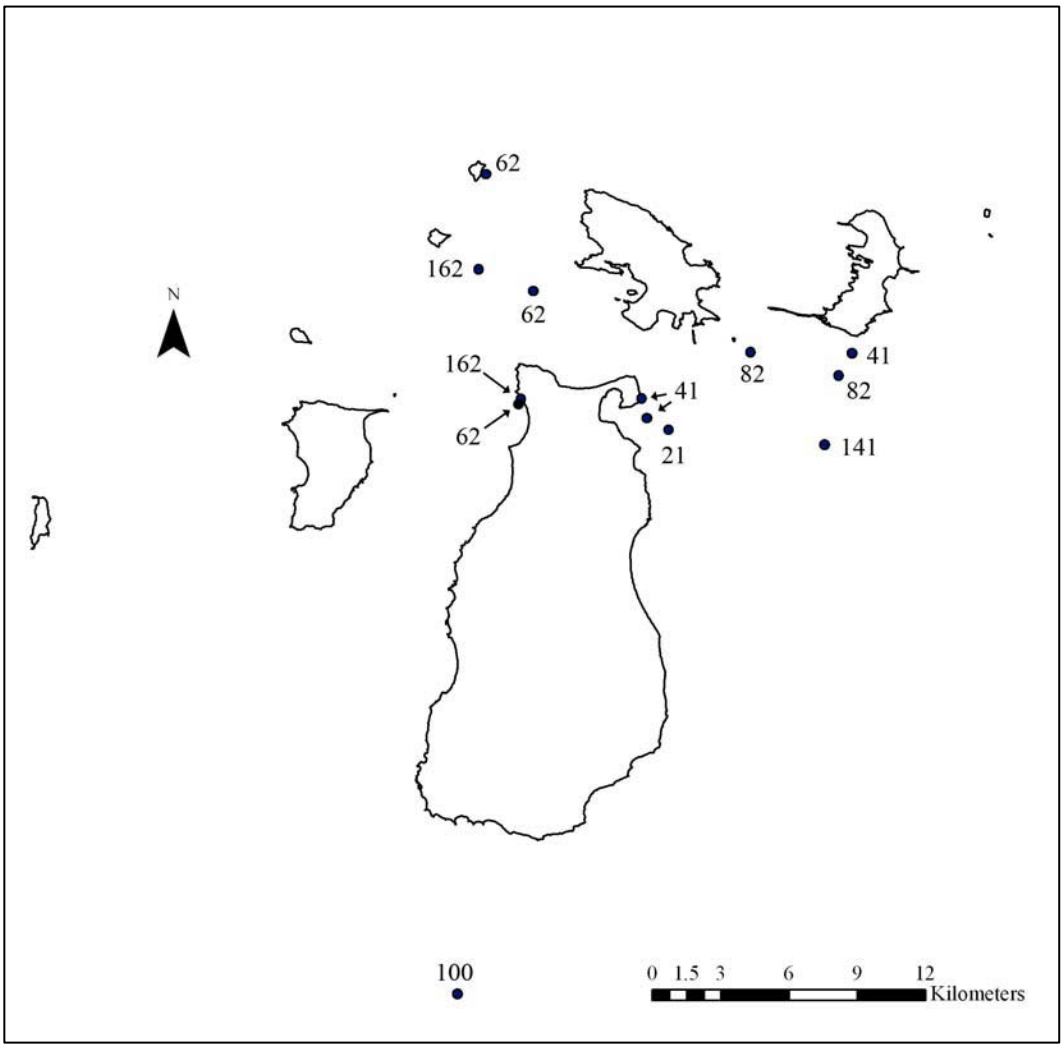


Figure 3. Locations of Double-crested Cormorants found via telemetry in 2010. Labels relate to the frequency of the bird identified (150.###).

Table 1. Dates and locations where tagged birds were found loafing or nesting.

Date	Bird (Transmitter 150.###)	Island
7 June 2010	82	Whiskey
13 June 2010	21, 62, 82, 122, 183, 202	Hat
14 June 2010	162	Whiskey
17 June 2010	41, 62, 82, 122, 141, 202	Hat
20 June 2010	21, 122, 202	Hat
20 June 2010	62	Whiskey
21 June 2010	21	E. High Spit
5 July 2010	82	Pismire
12 July 2010	82	Pismire

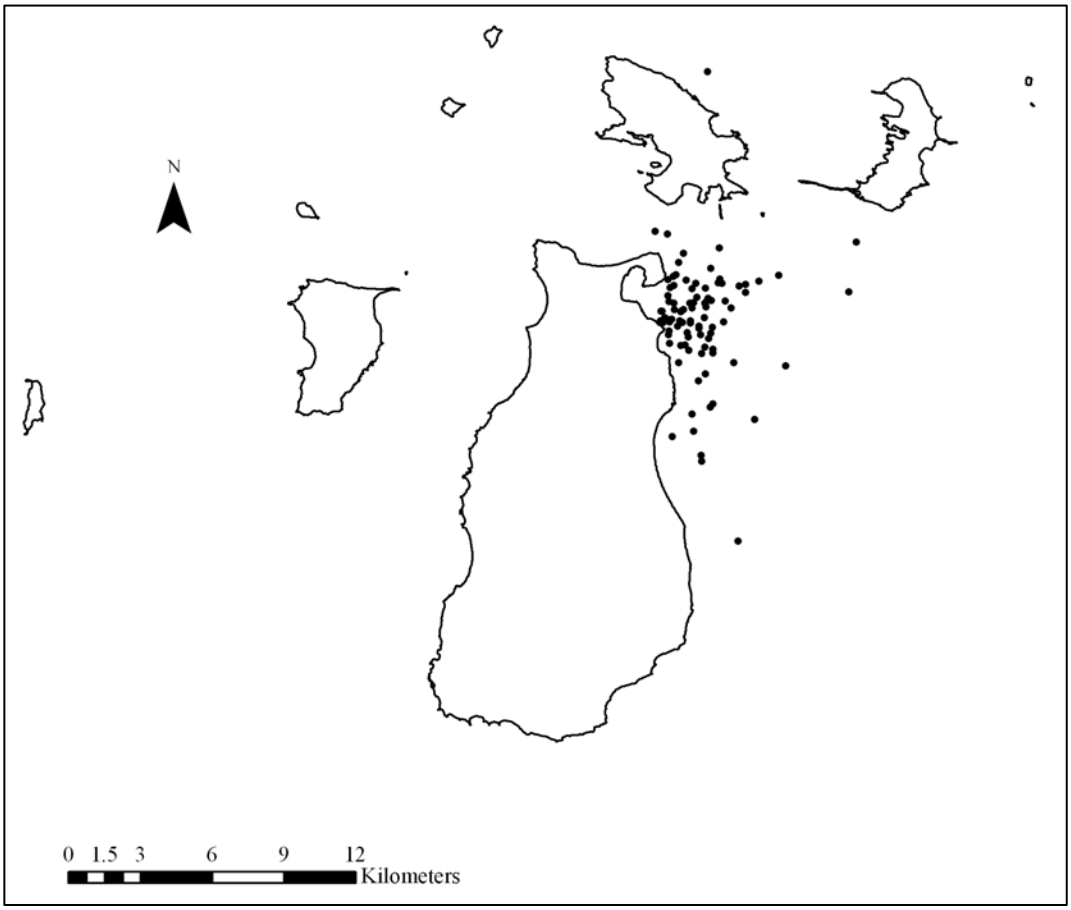


Figure 4. Locations of Double-crested Cormorants found via telemetry in 2003 (from 17 May 2010 to 20 July 2010; Seefelt and Gillingham 2006).

In contrast, 93 telemetry locations were determined via telemetry during the same time period in 2003 (Figure 4). Each of the 10 birds was relocated at least five times. Looking beyond the time period selected in my study, the tagged DCCOs in 2003 were found in the Archipelago for much longer than in 2010. Of the 10 birds tagged, seven were relocated as late as 7 September 2003, while the others were last found in August 2003. An increase in the distance traveled from original place of capture occurred between the 2003 and 2010 telemetry data sets (W=6230, N=123, $P<0.0005$; Mann-Whitney). The average distance traveled from original colony per bird increased threefold from 5.4 (±0.73 stdev) to 21.4km (±9.9).

Rafting data

Rafting data were collected at 85 locations during the study period in 2010. The 2003 data from the same time period yielded 252 locations for comparison (Figure 5). The number of birds per raft did not differ between 2003 (34.38±44.49) and 2010 overall (30.94±38.54; *P*=0.3453, Mann-Whitney). However, differences were observed between individual months of 2003 and 2010. The number of birds per raft observed during May (44.92±53.99) and July (36.67±52.48) 2003 was higher than the same periods in 2010 (May: 11.27±6.54, W=35685, N=36, *P*=0.022; July: 13.59±23.96, W=9156, N=150, *P*=0.0009), while more birds per raft were observed during June 2010 (56.46±43.30) than in June 2003 (29.92±32.04, W=3568.5, N=151, *P*=0.0001). The number of birds per raft did not differ between months during the 2003 study period (H=1.87, N=252, *P*=0.393), but the number of birds per raft did differ between months in the 2010 study period (H=41.09, N=85, *P*<0.0005). The number of birds per raft was lower in May 2010 than in June 2010 (W=104.5, N=46, *P*=0.0001) and was also lower in July 2010 than in June 2010 (W=901.5, N=74, *P* <0.00005).

No differences were observed between the distances to nearest colony of the 2003 and 2010 rafts when considering all possible colonies (documented as active some time in the past) in the analysis, whether they were occupied or not (W=14137, N=337, *P*=0.7696). However, when only occupied colonies were considered, the distance to nearest colony per raft was higher in 2010 (14.15±6.50) than in 2003 (9.09km km ±4.79; W=37410, N=337, *P*<0.00005). Distance to nearest shoreline decreased in 2010 (2.41km ±2.14) as compared to the 2003 rafts (2.74km ±2.33); W=9977, N=337, *P*<0.00005). Lake depths did not differ between the 2003 (11.77m ±6.33) and 2010 rafts (10.08±5.24; W=12947.5, N=337, *P*=0.0681). No differences were

observed between the lake bottom slopes of the 2003 (3.15 degrees ±2.04) and 2010 rafts (3.08 degrees ±2.05; W=42814.5, N=337, *P*=0.771). Similarly, no differences were observed between the slope of the lake bottom slope between 2003 (0.602±0.486) and 2010 rafts (0.578±0.564; W=43457, N=337, *P*=0.264). Aspect, or the directional orientation of the lake bottom slope where rafts occurred, was lower in 2010 (184.689±113.24) than in 2003 (244.95±83.89; W=45722.0, N=337, *P*=0.0001), indicating that rafts in 2003 were on more westerly–facing slopes and rafts in 2010 were on more southerly slopes. The plan curvature of the lake bottom did not differ between 2003 (0.00322±0.025) and 2010 (-0.00073±0.028; W=43263.5, N=337, *P*=0.385).

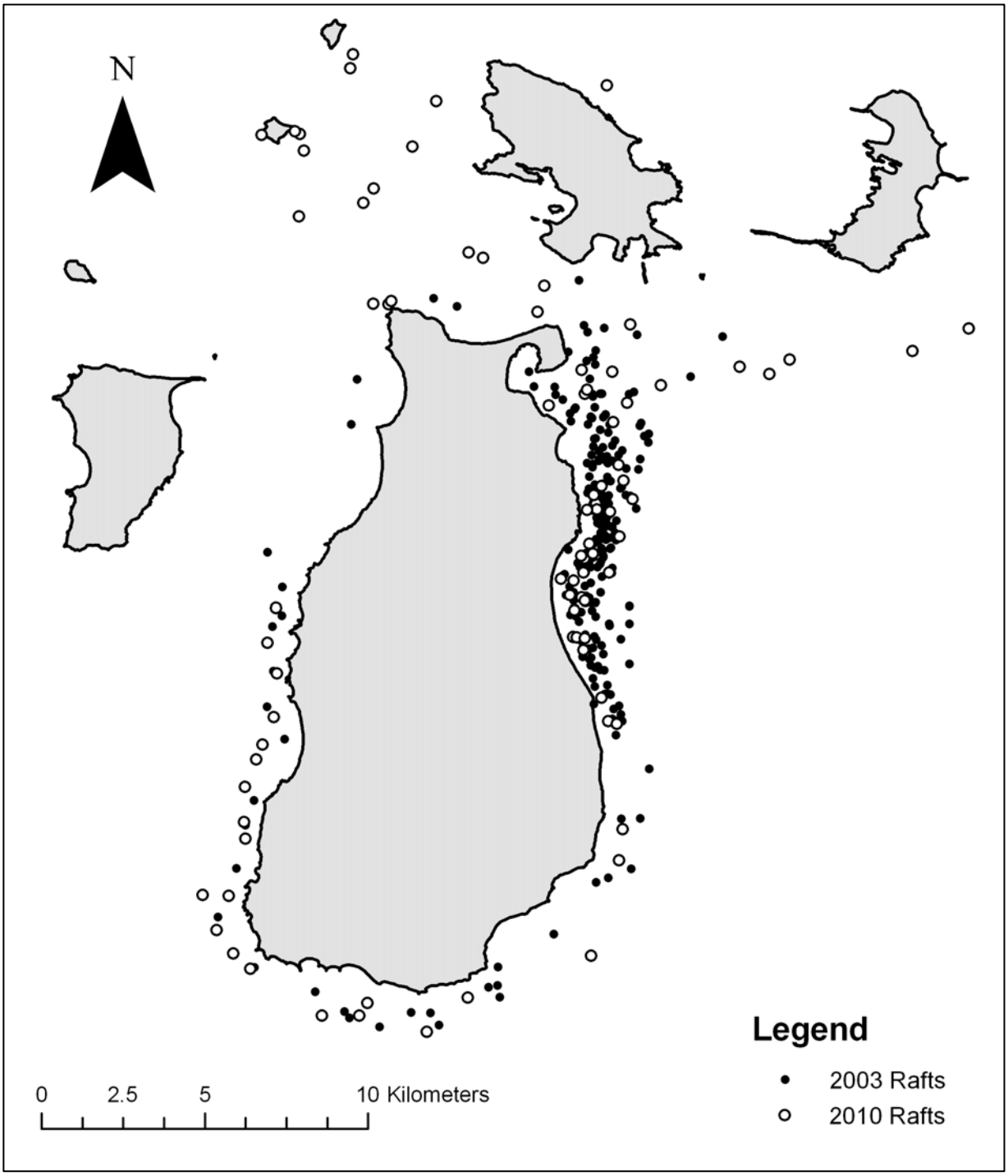


Figure 5. Rafting locations of Double-crested Cormorants observed in 2003 (N=252; Seefelt and Gillingham 2006) and 2010 (N=85).

Multi-Response Permutation Procedure

The MRPP analysis using the Pearson III distribution found that the 2003 and 2010 rafting data points occupy decidedly different areas in space and represent two unique groupings of points ($P<0.001$). The MRPP analysis with Monte-Carlo permutation (NPERM) yielded similar results, indicating a discrete shift in foraging distributions ($P=0.0001$).

The NPERM function was used to see if any differences existed between months in 2003 (Figure 6), 2010 (Figure 7), and between the two years (Bonferroni corrected alpha=0.005). The May and June 2003 rafts exhibited different distributions from one another ($P=0.0001$) as did the June and July rafts ($P=0.0001$). The May and July rafts, however, did not differ ($P=0.088$). A slightly different pattern was found in 2010. Only the June and July 2010 were different ($P=0.001$), while the May/June and May/July rafts were the same ($P=0.077$; $P=0.136$). Between the two study years, all months (May vs. May, June vs. June, and July vs. July) differed from one another ($P=0.0001$ for all pairings).

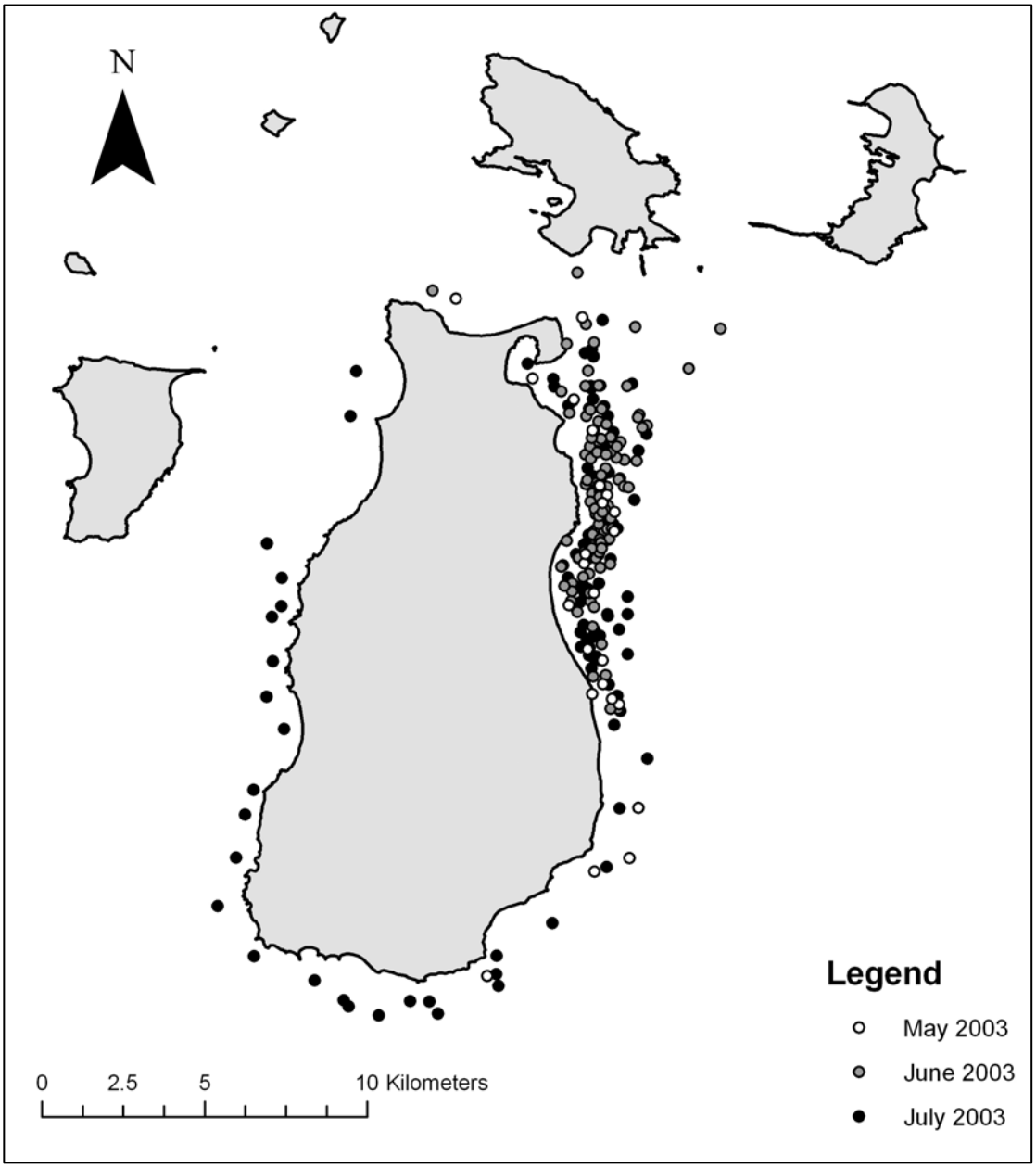


Figure 6. Double-crested Cormorants raft locations depicted by month in 2003 (N=252; Seefelt and Gillingham 2006).

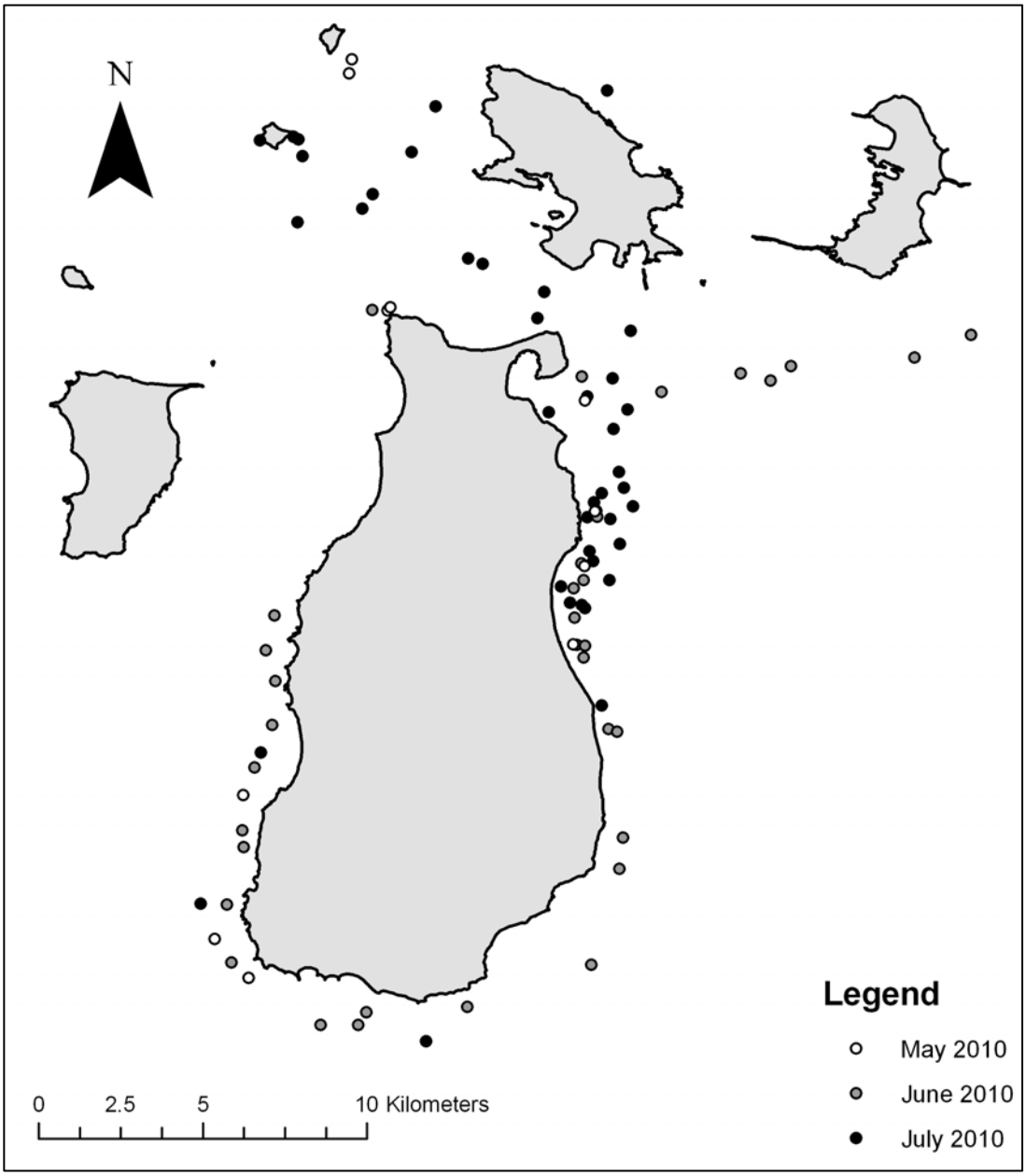


Figure 7. Double-crested Cormorants raft locations depicted by month in 2010 (N=85).

Kernels

The 2003 kernels, at all volume contours, were focused mainly in the St. James Bay area and on the eastern side of Beaver Island, while the 2010 kernels were more widely distributed around the island (Figure 8). The percentage of the home range with a certain probability of use versus the percent maximum probability of use graphs all showed clumped distributions, allowing core volume contours to be generated. The core volume contour generated by ABODE for the 2003 rafting data was 71%, while the 2010 rafting data had a core volume contour of 66%. All volume contours (50%, core, and 95%) created for the 2010 rafting data were larger by 3.3 times on average in total area than those from the 2003 rafting data. Due to the large size of the volume contours generated for the 2010 rafting data, the 2003 volume contours were almost completely overlapped (Table 2).

Table 2. Total volume contour area and overlap area for 2003 and 2010 rafts, where "%year" indicates the proportion of that year's volume contour overlapped by the other year.

Volume contour	2003 area (km^2)	2010 area (km^2)	Overlap area (km^2)	% 2003	% 2010
50%	12.84	49.99	12.84	1.00	0.26
Core	26.27	79.61	22.62	0.86	0.28
95%	88.39	265.91	82.36	0.93	0.31

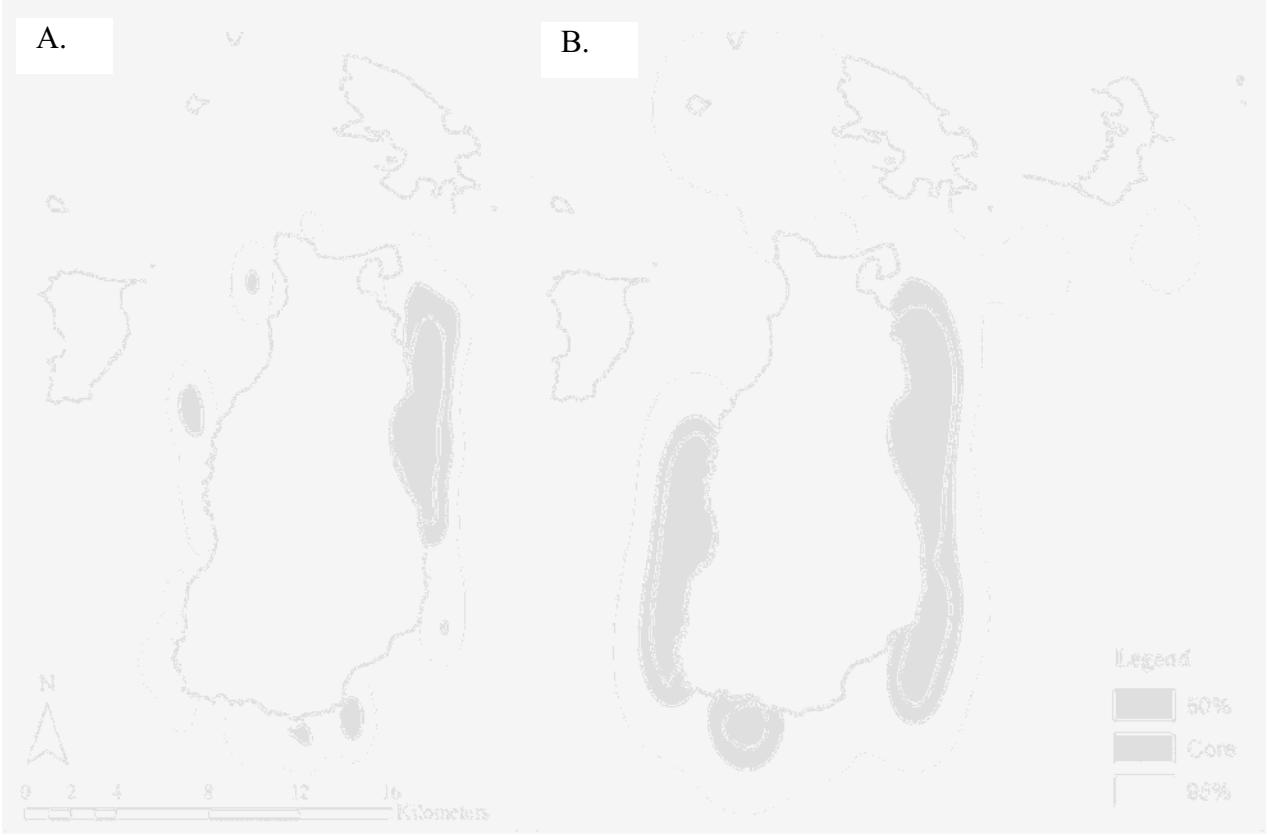


Figure 8. Rafting location volume contours from A. 2003 and B. 2010, determined using a fixed kernel density estimator.

Sample Size

The asymptote data generated by ABODE for each data set shows the increase in area with an increase in the number of data points. The increase occurs due to the inclusion of all months in the data set, when DCCOs are migrating to the archipelago (May) and away from the archipelago (August). During June, the area of the kernels stays relatively constant in 2003 (Figure 9) and 2010 (Figure 10) with an increasing number of points gathered, and appears to asymptote in the 2003 data set. The stabilization observed reflects the birds' nesting period, when most migration has stopped. In July, however, the area of the kernels increases, reflecting a range shift. A range shift could indicate a change in diet or DCCO migration.

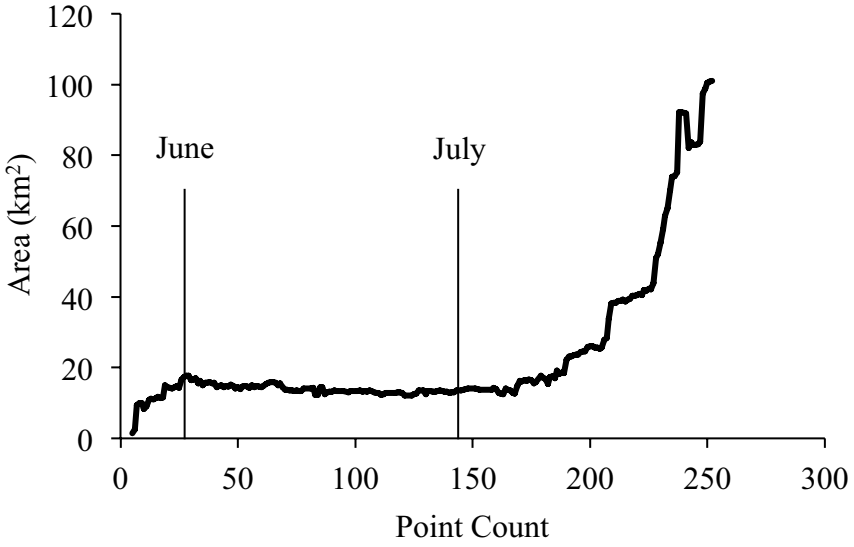


Figure 9. Asymptote graphs for kernel estimation of 2003 rafting data.

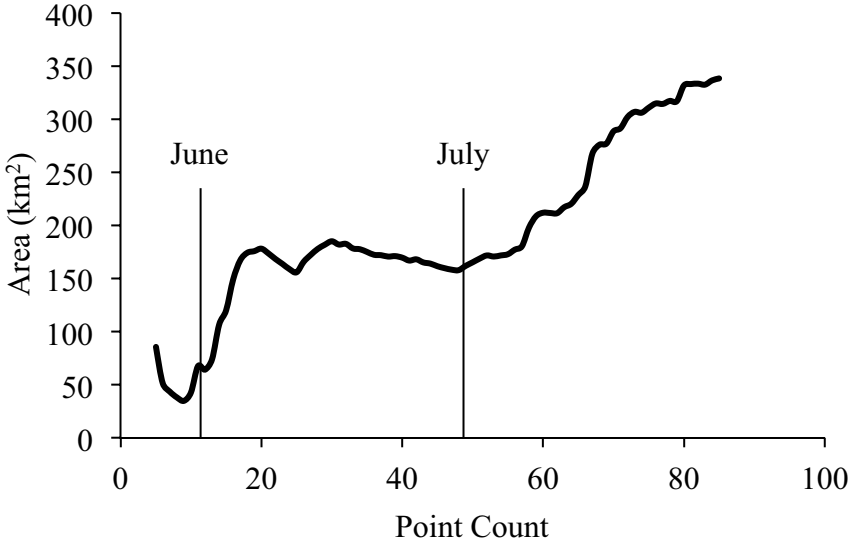


Figure 10. Asymptote graphs for kernel estimation of 2010 rafting data.

Autocorrelation

The 2003 rafts had significant autocorrelation values associated with the number of birds per raft (Moran's Index=0.04, z=3.37, *P*=0.01) and depth (Moran's Index=0.22, z=17.16, *P*=0.01) throughout the study period. Data collection times were as little as one minute apart during 2003 because birds were so numerous in the Archipelago. Although the birds counted in each raft were always different individuals, the short time interval observed between rafts results in significant autocorrelation. In 2010, the number of birds per raft was not autocorrelated (Moran's Index=0.01, z=0.47, *P*>0.05), nor was depth (Moran's Index=0.09, z=1.81, *P*>0.5).

Space-time and Hot Spot Analyses

In some cases the Knox Index for a particular study period could not be generated due to the number of samples, but in all cases Mantel Indices were generated. All rafts throughout the 2003 study period were found to be close together not only in space but also in time (Knox *P*=0.01; Mantel *P*=0.01). However, in May 2003 a non-significant pattern was observed (Mantel *P*=0.2), indicating more dispersion of rafts; whether the rafts were dispersed in time and/or in space is unknown. In both June (Knox *P*=0.0001; Mantel *P*=<0.05) and in July 2003 (Knox *P*=0.0001; Mantel *P*=<0.01) rafts were clustered in space and in time. Although it falls outside the time period used in my study I generated the Mantel Index for August 2003 rafts and found that they were not significantly clustered in space-time (*P*>0.2).

Similar to the 2003 rafts, the 2010 rafts all together were clumped in space and in time (Knox *P*=0.0001; Mantel *P*=<0.05) but where not clumped in May 2010 (Mantel *P*>0.2). Rafts were clumped in space and time in June (Knox *P*=0.0001; Mantel *P*<0.01) but were not clumped in July 2010 (Mantel *P*>0.2).

Hot-spot analysis of the 2003 rafts found no significant clusters in May, which corroborates the space-time results. Five first-order clusters were identified in June, and five more first-order clusters were identified in July. Both sets of clusters were centered in Sand Bay (Figure 11). The hot-spot analysis did not identify any clusters for the May 2010 rafts. One significant first-order cluster was found in June 2010, with its center just out from Sand Bay and another first-order cluster was found close by in July (Figure 11).

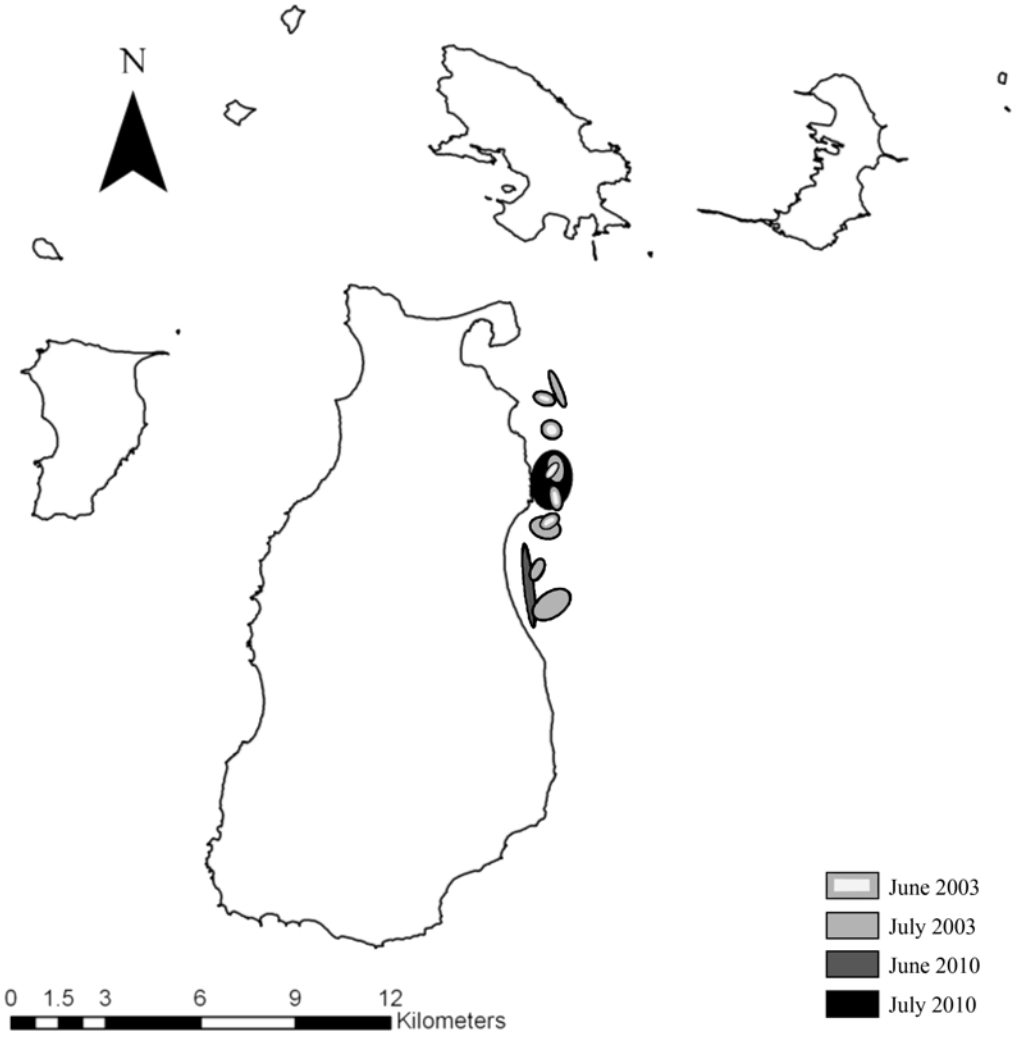


Figure 11. Hot spot ellipses showing where the most rafts of Double-crested Cormorants were grouped together in June and July 2003 and 2010.

Influence of the Environment

Of the environmental and behavioral variables used in the model (distance to nearest shoreline, distance to nearest occupied colony, depth, slope, aspect, and plan curvature), none were significantly correlated with one another. A total of 64 models were created for each raft data set, the 'best' 10 of which are shown in Table 3 (2003 rafts) and Table 4 (2010 rafts). The model with the greatest AIC weight (w_i) in 2003 showed that for every increase in plan curvature (displaying more convex areas) the odds of finding a larger raft decrease as all other variables are held constant, whereas for every increase in distance to nearest used colony the odds of finding a larger raft increase (if all else is held constant; Table 5):

P("large raft")

$$! \frac{!"\#!!!!!"\#!\ !!"\#!"\#\$\ !\ !!"\#!"\#\$\%\&'!}{!!\ !"\#!!!!!"\#!\ !!"\#!"\#\$\ !\ !!"\#!"\#\$\%\&'!}$$

P("large raft + medium raft")

$$! \frac{!"\#!!!!!"\#!\ !!"\#!"\#\$\ !\ !!"\#!"\#\$\%\&'!}{!!\ !"\#!!!!!"\#!\ !!"\#!"\#\$\ !\ !!"\#!"\#\$\%\&'!}$$

For both 2003 and 2010 models, P("small rafts")=1-(P"large" +P"middle") and P("medium rafts")= (P"large" +P"middle")-(P"large") (Figure 12).

In 2010, the odds of finding larger rafts increased with steeper lake bottom slopes and greater distances to nearest used colony, but decreased with increases in depth. The model with the second highest Akaike weight in 2010 included the same parameters as the first, but with the addition of aspect. In this case, as aspect increases, the probability of finding a large raft decreases (with all other variables held equal).

The probabilities of finding a specific raft size in 2010 following the model with the lowest Akaike weight are as follows:

P(“large raft”)

$$! \frac{!"\#!!!!!!!"!\ !!"\#!"\#\ !\ !!"\#!"\#\$\%\ !\ !!!"!"\#\$\%\&'}{!!\ !"\#!!!!!!!"!\ !!"\#!"\#\ !\ !!"\#!"\#\$\%\ !\ !!"\#!"\#\$\%\&'}$$

P(“large raft + medium raft”)

$$! \frac{!"\#!!!!!!"\#!\ !!"\#!"\#\ !\ !!"\#!"\#\$\%\ !\ !!"\#!"\#\$\%\&'}{!!\ !"\#!!!!!!"\#!\ !!"\#!"\#\ !\ !!"\#!"\#\$\%\ !\ !!"\#!"\#\$\%\&'}$$

Table 3. The top five ordinal logistic regression models representing the environmental variables that had an effect on the number of Double-crested Cormorants per raft in 2003. SHOREDIST=Distance to nearest shoreline (km), PLAN=Plan curvature, DEPTH=depth (m), COLDIST=Distance to nearest occupied colony (km).

AICc	Δ_i	w_i	Variables
519.71	0.00	0.15	PLAN, COLDIST
521.10	1.40	0.07	DEPTH, COLDIST
521.33	1.62	0.07	ASPECT, COLDIST
521.42	1.71	0.06	SHOREDIST, COLDIST
521.42	1.71	0.06	SLOPE, COLDIST

Table 4. The top five ordinal logistic regression models representing the environmental variables that had an effect on the number of Double-crested Cormorants per raft in 2010. SHOREDIST=Distance to nearest shoreline (km), PLAN=Plan curvature, DEPTH=depth (m), COLDIST=Distance to nearest occupied colony (km).

AICc	Δ_i	w_i	Variables
164.69	0.00	0.24	DEPTH, SLOPE, COLDIST
165.08	0.39	0.20	DEPTH, SLOPE, ASPECT, COLDIST
166.63	1.94	0.09	DEPTH, SLOPE, SHOREDIST, COLDIST
166.81	2.12	0.08	DEPTH, SLOPE, ASPECT, SHOREDIST, COLDIST
166.98	2.29	0.08	DEPTH, SLOPE, PLAN, COLDIST

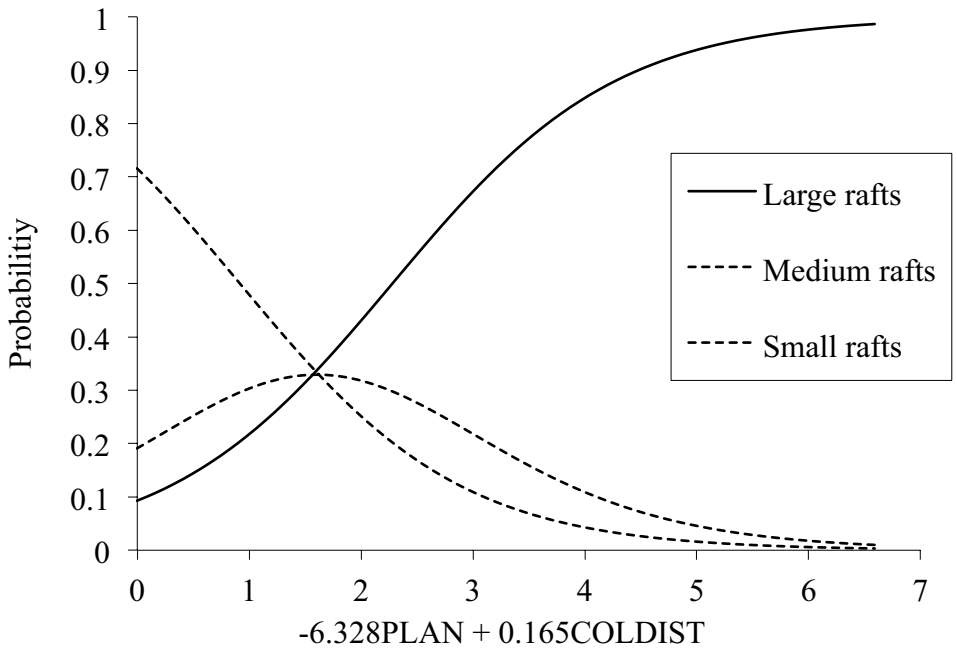


Figure 12. Probabilities of detecting a small, medium, or large Double-crested Cormorant raft in 2003 based on the plan curvature and the distance from inhabited colony.

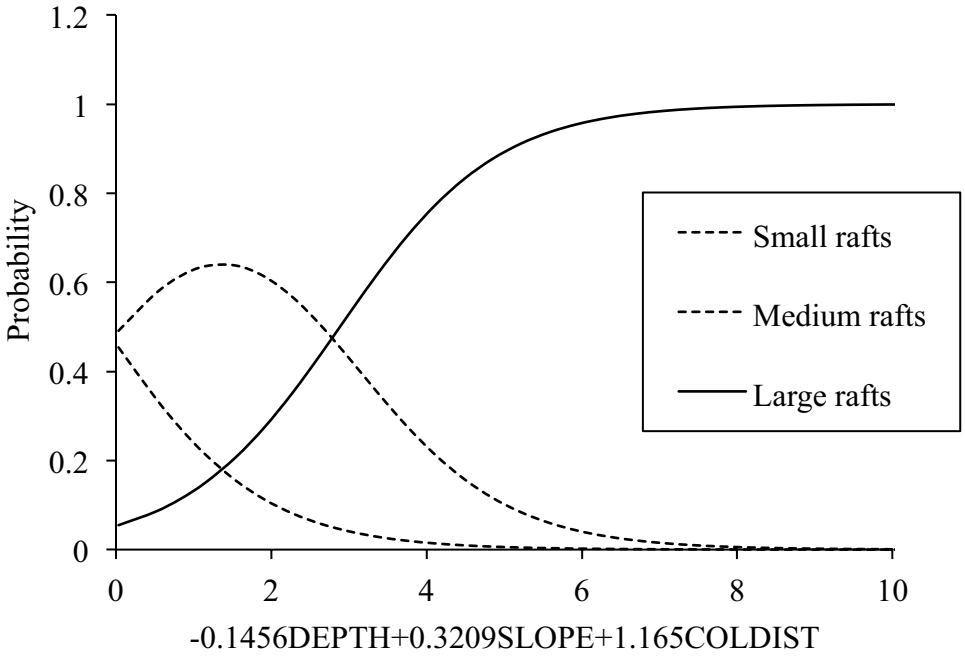


Figure 13. Probabilities of detecting a small, medium, or large Double-crested Cormorant raft in 2010 based on the lake depth, lake bottom slope, and the distance from inhabited colony.

Table 5. Ordinal logistic regression models with the lowest Akaike weights for 2003 and 2010 rafts showing the influence of lake characteristics on approximate Double-crested Cormorant raft size.

Model	Int. 2	Int. 3	Depth (m)	Slope	Aspect	Distance (km) to Nearest Colony	Plan Curve
2003 Rafts	-0.926	-2.8	…	…	…	0.165	-6.328
	(0.279)	(0.309)	…	…	…	(0.029)	(4.86)
2010 Rafts 1	-1.385	-2.884	-0.146	0.321	…	0.153	…
	(0.724)	(0.777)	(0.054)	(0.131)	…	(0.041)	…
2010 Rafts 2	-0.933	-2.45	-0.155	0.361	-0.003	0.158	…
	(0.772)	(0.814)	(0.056)	(0.136)	(0.002)	(0.041)	…

Note: Numbers in parentheses represent the standard errors of the parameter estimates. "Int" refers to the intercept.

Distance to nearest colony can be considered a behavioral variable rather than a strictly environmental variable. Distance to nearest colony was removed from the list of variables in an effort to understand which strictly environmental variables were more important in determining the size of rafts. When distance to nearest colony was removed from the 2003 raft analysis, distance to nearest shoreline alone became the most important predictor variable but this model and all following it had very low support (w_i<0.08; Table 6 and Table 7; Figure 14). In 2010, depth and slope became the most important environmental variables without distance to nearest inhabited colony (Table 6 and Table 7; Figure 15).

Table 6. The top ten ordinal logistic regression models representing the environmental variables (except distance to nearest colony) that had an effect on the number of Double-crested Cormorants per raft in 2003 and 2010. SHOREDIST=Distance to nearest shoreline (km), PLAN=Plan curvature, DEPTH=depth (m), COLDIST=Distacne to nearest occupied colony (km).

Data Set	AICc	Δ_i	w_i	Variables
2003 Rafts	554.16	0.00	0.11	SHOREDIST
	554.23	0.07	0.10	PLAN
	554.52	0.36	0.09	PLAN, SHOREDIST
	555.46	1.30	0.06	DEPTH, SHOREDIST
	555.68	1.52	0.05	DEPTH
2010 Rafts	178.58	0.00	0.33	DEPTH, SLOPE
	179.57	0.98	0.20	DEPTH, SLOPE, ASPECT
	180.76	2.17	0.11	DEPTH, SLOPE, SHORE
	180.82	2.24	0.11	DEPTH, SLOPE, PLAN
	181.70	3.12	0.07	DEPTH, SLOPE, ASPECT, SHOREDIST

Table 7. Ordinal logistic regression models with the lowest Akaike weights for 2003 and 2010 rafts showing the influence of lake characteristics (minus distance to nearest colony) on approximate Double-crested Cormorant raft size.

Model	Intercept 2	Intercept 3	Distance to shore	Depth	Slope
2003 Rafts	0.642	-0.564	-0.067	…	…
	(0.190)	(0.189)	(0.050)	…	…
2010 Rafts 2	0.355	-0.916	…	-0.135	0.405
	(0.486)	(0.498)	…	(0.052)	(0.126)

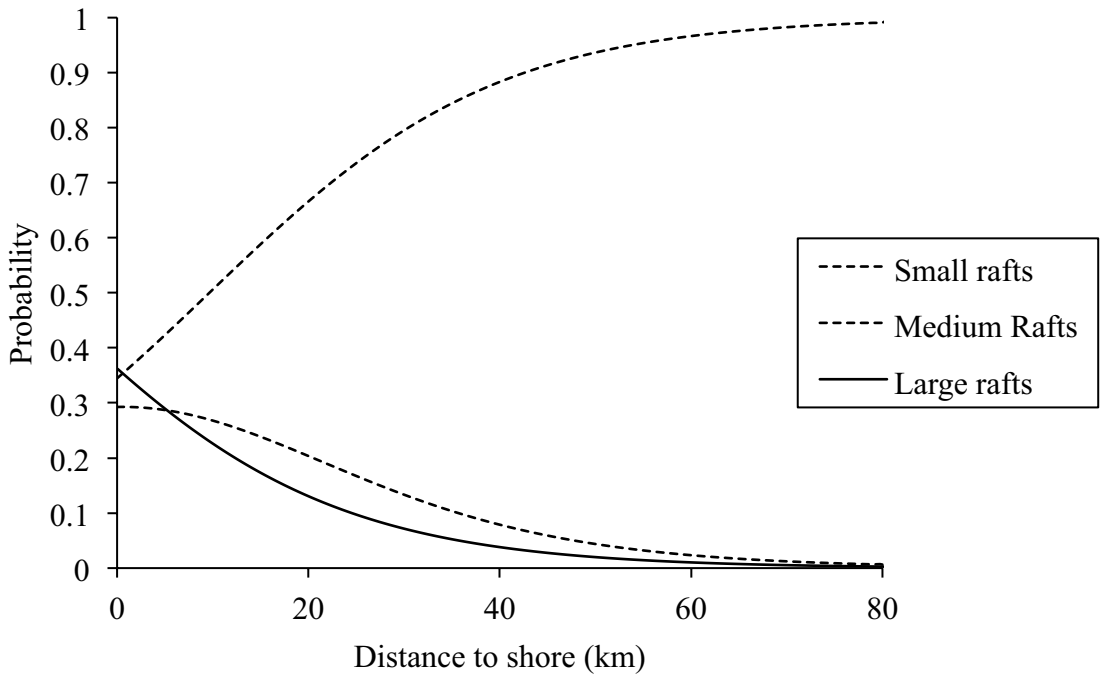


Figure 14. Probabilities of detecting a small, medium, or large Double-crested Cormorant raft in 2003 based on the distance to shore.

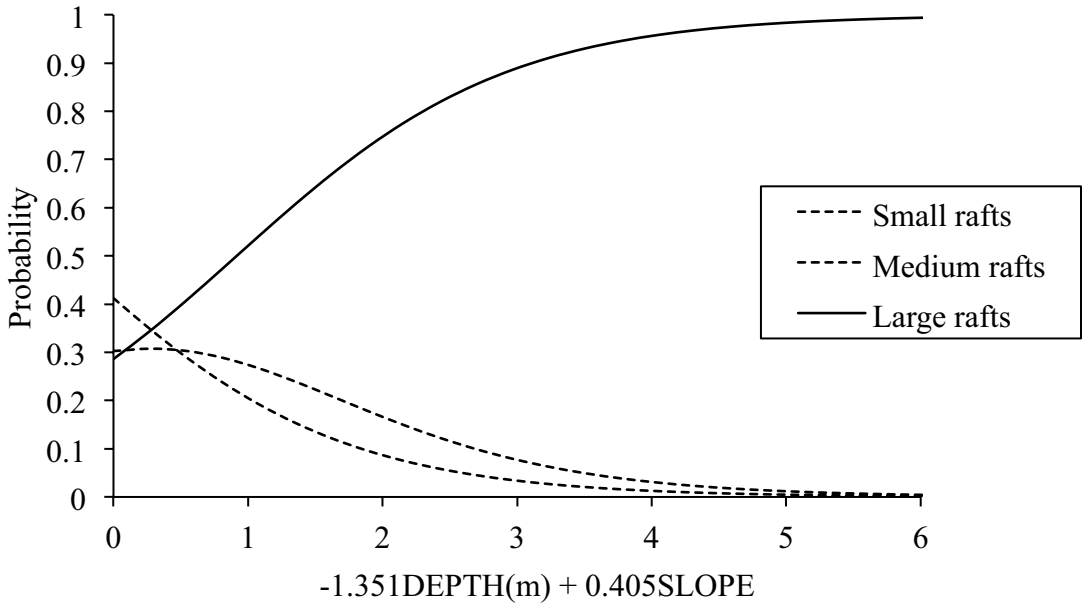


Figure 15. Probabilities of detecting a small, medium, or large Double-crested Cormorant raft in 2010 based on the lake depth and lake bottom slope.

Diet Analysis

Regurgitate data and prey items from harvested birds in 2009 and 2010 show marked differences from earlier years in prey type consumed, namely in the appearance of the round goby. A total of 1,468 prey items were identified in 2009. Round gobies made up 79% of the total mass consumed and made up 82% of the identifiable fish species counted. Alewife, conversely, only made up 11% of total biomass and 11% of identifiable fish species counted. As in 2000 and 2001, crayfish (*Orconectes* spp.) and sticklebacks (*Pungitius* spp.) were present in the diet, but at reduced levels (0.5% and 4% of biomass, respectively). In 2010, no harvested birds were obtained and regurgitate was scarce; only 245 prey items were identified. Of these, 62% were round gobies and 37% were alewives. In terms of biomass, round gobies represented 43% of total mass consumed (including unidentifiable and partial fish) while alewives composed 24% of total mass consumed. Sticklebacks (*Culaea* spp.), crayfish, and suckers (*Catostomus* spp.) were the only other prey items observed.

A Kruskal-Wallis test found significant differences between the median masses of alewives found per harvested bird during 2000, 2001, and 2009 ($P =< 0.0005$). The median mass of alewives per harvested bird increased in 2000 from 140g to 231g in 2001, but then severely decreased to 7g per harvested bird during 2009.

Colony Cameras and Population Changes

Management activities on the Hat Island DCCO colony caused a decline over the course of the summer from an initial 3,700+ nests to only 10 successful nests by mid-July. The cameras posted in the Hat Island colony showed that by 6 July 2010 all DCCOs on Hat had stopped nesting and had gone elsewhere. In the absence of management in 2003, DCCOs remained on

Pismire and SE Garden colonies until late August. Only several hundred remaining DCCOs were observed loafing or on colonies during the survey of the Archipelago completed by plane on 13 July 2010. An aerial survey performed by APHIS in late July found 300-400 birds loafing on Shoe Island, which is located next to Hat Island, but does not mention the existence of DCCOs elsewhere (Wildlife Services unpublished report 2010). The aerial survey performed as part of this project confirmed that only several hundred DCCOs remained in the entirety of the Archipelago.

CHAPTER IV

DISCUSSION

By analyzing both rafting DCCOs and DCCOs observed using telemetry, I observed a shift in areas of use between 2003 and 2010. Teasing apart the potential causes of this shift are difficult, considering the confounding factors of both diet change and the occurrence of management actions. In lieu of a concrete experimental design involving management or analyses of area-specific densities of fish species in the Beaver Archipelago, I have formed my hypotheses based on the data available.

As observed from the 2003 telemetry data, cormorants that are incubating eggs or caring for young tend to forage near their colonies. Feeding trips were spread out in a general ring around the focal colonies with little deviation. These data are similar to those found in other tracking studies performed during the breeding season, where birds tended not to stray more than 2-3km from their colonies in Lake Michigan and only rarely made excursions outside of this range (Custer and Bunck 1992). Feeding trips made by tagged DCCOs in 2003 never occurred as far, on average, as those of the birds captured in 2010. The locations where DCCOs were observed in 2010 varied wildly, with trips made across the entirety of the Archipelago, sometimes even on the same day. The small number of relocations makes it difficult to determine the reasons for this shift in movements throughout the Archipelago. A larger sample size of telemetry relocations could have allowed for us to observe birds staying on a certain colony for an extended period, possibly showing a switch in nesting locations. As the data stands, it is difficult to differentiate between non-nesting birds and nesting birds with certainty. That being said, it is possible that tagged birds #21, #41, #120, and #202 attempted to nest on Hat Island or

at least stayed in the vicinity until almost all birds left Hat Island in early July. These four birds were relocated on or near Hat several times until July, suggesting some bond to the island. Based on the foraging locations of these birds, it appears that all but #21 stayed relatively close to Hat, only venturing as far as the east side of Beaver. Even though a very small number of points exist, they support the idea that these birds, which may be still attempting to nest, stay closer to their colony to forage and used similar areas to the birds that nested on SE Garden and Pismire in 2003. Bird #21 stayed within the same area as the others until late June, at which point in time maybe the bird had given up nesting and was foraging on the west side of Beaver with other rogue DCCOs, as it was observed loafing with a large group on High Island spit. Bird #162 may have moved to Whiskey Island to nest after disturbances at Hat Island, considering it was found only there after it was tagged. It is probable that bird #100 left the Archipelago, died, or lost its transmitter soon after its tagging since it was only observed away from Hat and then never again after 8 June.

The rest of the captured birds tended to venture far from Hat, making very unpredictable movements. To the best of my knowledge, birds #62 and #82 traveled the farthest between locations. They both made trips back and forth from Hat and Whiskey Islands. Whether these birds were attempting to nest on one of the two islands or if they simply loafed where there were large numbers of other DCCOs is unknown. Loafing can occupy a large percentage (14-20%) of a DCCO's day, and usually occurs with conspecifics (King *et al.* 1995). What is known is that in July, after many of the DCCOs had finished nesting on Hat and Whiskey, bird #82 stayed in the Archipelago and chose to forage and loaf with a large group of DCCOs on Pismire Island. It is also possible that DCCOs were prospecting for future nest sites (Duerr *et al.* 2006). Egg-oiling

and gull predation of eggs on Hat Island may have lead these birds to view Hat as poor-quality habitat, whereas Whiskey may have appeared to be good-quality habitat (Duerr *et al.* 2006).

Birds #141 and #183 were both found not only on Hat but near High Island. The cause of this erratic behavior is unknown and begs further research. It may be that when trapping and tagging occurred, loafing birds that were not nesting were captured, which then traveled throughout the Archipelago to feed. It could also be that loss of eggs due to management and/or gull predation freed the birds from their nesting responsibilities early in the season. The distances traveled between relocations of the potentially non-nesting birds are similar to those observed during the winter season, when birds travel an average of 15.7 kilometers from their roosts to a foraging area (King *et al.* 1995). Wintering birds not only travel great distances between their roosts and their foraging locations, but also travel great between roosts, exhibiting little site fidelity (King 1996). This study suggests that when birds are relieved from nesting in the presence of management, they may stay in the Archipelago for a time and make unpredictable feeding trips throughout the Archipelago or they may leave the area and forage elsewhere.

Due to the low number of relocations, only qualitative judgments can be made about the differences in relocations between tagged males and females. The two most active birds, #62 and #82, were both males, while of the five birds that may have been nesting, three were males and two were female. The rest of the transient or missing birds were females. The movements of the males in this study are comparable to those found during a study in the Columbia River Basin, wherein male DCCOs were relocated away from their colonies twice as often as females (Anderson *et al.* 2004).

Attempts from land to find DCCOs were marred by the inability to move far enough away from the original sampling location to obtain another bearing further away because the signal was often lost in transition. Taking another reading too close to the first sampling area resulted in major errors in triangulation of the actual points. For example, while looking toward Whiskey Island from the north end of Beaver Island, I would often locate bird #62 in this direction. No birds were ever in sight, so I assumed it to be nearer to Whiskey Island than to Beaver. Upon mapping the triangulated points, however, showed the bird very close to Beaver and probably within my range of sight (this sampling location was on a steep bluff). It is likely this was due to the bearings being measured too close to one another. No amount of adjusting the bearings could fix this since it was not possible to know where the bird was in between the more than 8km from the sampling site to Whiskey Island. When sampling, it was common to pick up irregular and distorted signals from boats and structures on land. Coming into the range of one of these irregular signals meant ending the sampling session in that area, which could have led to missed observations.

The small number of telemetry locations observed could also be due to transmitter and/or receiver error. The receiver used claims a range of 10-16km, but the observed range was often much shorter. On approach to a colony island I would check to see if any tagged birds were present before we landed and it was usually within 5km that birds could be detected. This small telemetry range was a great disadvantage considering the scale of the Archipelago. Considering the average distance of my sampling locations on Beaver Island from Hat Island was approximately 20km, my detection range from the island on bad weather days probably would not be far enough to detect any activity (APPENDIX F).

As mentioned above, using DCCOs captured on Hat Island poses a problem in terms of telemetry range from Beaver Island. However, it also poses a problem in terms of telemetry range from just about anywhere in the Beaver Archipelago other than the east side of Hog Island. It is possible that the DCCOs nesting on Hat Island could have been foraging too far north or east for the telemetry signal to reach, even when sampling within range of Hat Island. It is also possible that tagged birds were frequently feeding in close proximity to Hat Island while sampling occurred throughout the rest of the Archipelago, making them difficult to detect unless sampling occurred very close to Hog Island or Hat Island. Because of Hat Island's importance as a waterbird colony, trips to and from Hat were minimized to reduce disturbance. Taking extended boat trips toward the island were thus reduced in comparison to trips elsewhere, due to the remote nature of the island.

The change in the median number of birds per raft observed between months in 2010 indicates a response not observed in 2003, perhaps due to the effects of management. A surge in the median number of birds per raft occurred in June 2010 that was higher than the number of birds observed in any other month during the study period and higher than the median number of birds observed at any time throughout the 2003 study period. This surge then leveled to a relatively low median number of birds per raft in July. This rise in the number of birds in June could have been due management actions, which may have caused birds to leave their colonies to form larger foraging groups. By July, many of these birds probably left the Archipelago, resulting in smaller numbers of birds per raft. This change is corroborated by the space-time analyses, which show in July 2010 a similar response to August 2003, when bird locations became more random as opposed to clustered and DCCOs started to leave the Archipelago.

Observations of rafts were not close in time or in space in July 2010, as opposed to July 2003, when rafts were still frequently observed in regularly in close proximity.

The noteworthy amount of autocorrelation in the 2003 raft study calls into question the strength of the sampling methods used in the rafting surveys. Rafting surveys generally took place en route to a colony that needed to be monitored and although standardized routes were taken, we often left them to search for DCCOs when they were not found otherwise. These exploratory routes did not always follow the same pattern or occur at designated times of day. Due to the scale of the Archipelago, which encompasses a rectangular area approximately 1600 km^2, this method is the most economical. Although this method was used as a way to efficiently perform several tasks at once, it does not allow for consistency between sampling years. Due to the areas where birds were nesting and the number of birds in the archipelago, the number of trips/routes taken to a specific island is likely different between the 2003 and 2010 sampling periods, providing different numbers of raft locations found en route. If this study were to be performed again, I would suggest the use of line transects to measure the density of birds in an area at specific times (Heithaus 2005). Having overall density measures for certain areas would reduce autocorrelation, as would setting sampling periods far enough apart.

Larger rafts in 2003 were more likely to occur further from occupied colonies in all of the models relating raft size to environmental variables with the lowest Akaike weights. When distance to nearest occupied colony was removed, none of the models were better than the others and some other, unknown, variable may explain the size of rafts in 2003. In 2010, larger rafts were also more likely to occur further from occupied colonies, but the Akaike weights of the top model suggest that depth and slope are also important factors in predicting raft size. After

removing distance to nearest occupied colony, depth and slope were still good predictors of raft size. There are a number of possible explanations for this change between 2003 and 2010. Large rafts of DCCOs in 2003 may have formed to forage farther to the colony to increase their foraging efficiency of schooling fish (like alewives, which were prevalent in the diet of nesting DCCOs at the time). Because alewives are pelagic fishes, they are less dependent on substrate differences, which may explain why no purely environmental variables were best at explaining raft sizes in this year. The higher number of breeding birds in the archipelago in 2003 may have also led to density-dependent differences between study years; perhaps raft sizes change based on population estimates or on the densities of prey items. In 2010, the larger rafts keying in on shallower depths and steeper slopes could be related to prey densities and prey accessibility in these areas. Unfortunately, detailed surveys of prey densities in the Beaver Archipelago are not available. However, because benthic round gobies formed a major dietary component in 2009 and in 2010, it is possible that more were encountered in these shallow areas. Although round gobies are solitary and theoretically easier to capture, large rafts could have formed around high-density goby areas based on observations of other foraging birds in the area, rather than forming large rafts to increase foraging efficiency. Birds in 2010 were found in shallower areas overall than in 2003, and the goby-based diet may serve as one explanation for this change.

A discrete shift in raft locations occurred between 2003 and 2010, as evidenced by the change in distances between points (MRPP analysis) and by comparing the 50%, core, and 95% volume contours generated in kernel analysis. Occupancy of Whiskey Island is one of the leading causes of the shift in rafting locations overall. Rafts, some of considerable size, were observed more often surrounding the island an en route to the island from other areas in the

Archipelago. Cormorants taking up residency on Whiskey Island in 2010 are likely a result of management activities on other islands. The current lack of a large mammalian predator on the island would also allow colonization of ground nests that may not have been allowed previously. The reduction in the amount of autocorrelation in the data may have been different between 2003 and 2010 due to the spread of the birds to other areas in the Archipelago. It is also likely due to a reduction in the number of nesting birds, as indicated by yearly nest counts, since 2003. With more birds concentrated into fewer colonies, autocorrelation using our methodology is more likely to occur. Looking at the changes that occurred in raft locations per month, it is apparent that birds started foraging on the western side of Beaver Island since the beginning of the breeding season, whereas birds in 2003 did not forage on the west side until July, when some of their nesting efforts may have failed.

The western side of Beaver Island also showed an increase in the number of birds found rafting in 2010 as compared to 2003. Whereas birds from the northeastern colonies like Hat, Pismire, and SE Garden tended to forage on the eastern side of Beaver Island, it is possible that this increase in rafts on the western side reflects foraging efforts of birds nesting on Whiskey Island. This increase could also be reflective of the birds that left their colonies early and started to loaf on High Island spit. Regardless of the reason, the shift is more likely due to the effects of management rather than a change in diet. Overall, DCCOs were found in the same areas as in 2003, as evidenced in some cases by the complete overlap of the 2003 kernels by the 2010 kernels. The hot spot analyses showed very similar distributions of the most popular foraging locations on the east side of Beaver Island. Few differences in habitat variables were observed between years for rafting DCCOs; only depth and aspect differed. Aspect did not change in an

unexpected way, however. In 2003, DCCOs foraged on western-facing slopes on the eastern side of Beaver Island, which is sheltered from the southwesterly winds of Upper Lake Michigan. In 2010, they still chose more sheltered areas as opposed to open areas on the western side. The prevalence of round gobies in the diets of DCCOs is likely due to an expansion of round gobies into the areas where DCCOs generally forage, regardless of colony.

Although the time spent sampling for raft locations may differ between the 2003 and 2010 study periods, an average of 6 rafts were observed per sampling day in 2003, while only about 4 were observed per sampling day in 2010. This could be a reflection not only of the decrease in the number of birds in the Archipelago over all, but also of a change in diet. Cormorants are more likely to forage singly when searching for concealed, benthic prey items (Voslamber *et al.* 1995), which could indicate a shift toward more solitary foraging for round gobies.

Conclusions

Based on the observations in this study, the occurrence of management action in the Beaver Archipelago may encourage DCCOs to nest in previously uninhabited areas free from persecution and may prematurely direct them to locations outside of the Archipelago. These changes in nesting distribution and the time when birds leave the Archipelago can affect where birds are choose to forage, in this case leading to an expansion in foraging range. This increase in foraging range, albeit performed by a reduced number of birds, does not appear to have to led to the appearance of novel species in the diet or an increase in the number of native species consumed. While this is the case within the vicinity of the Beaver Archipelago, the impact that prematurely dispersing birds may have on fishes in other areas is unknown. Although foraging

range increased overall in 2010 compared to 2003, DCCOs tended to forage in the same key locations, possibly in response to the abundance or density of prey items.

APPENDICES

APPENDIX A

MORPHOMETRIC AND OTHER DATA COLLECTED FROM DOUBLE-CRESTED CORMORANTS CAPTURED IN 2010, WHERE FREQ. DENOTES THE FREQUENCY OF THE TRANSMITTER ATTACHED TO THE BIRD, TUML=TOTAL UPPER MANDIBULAR LENGTH, BW=BILL WIDTH, BD=BILL DEPTH, UNL=UPPER NAIL LENGTH, AND LNL=LOWER NAIL LENGTH.

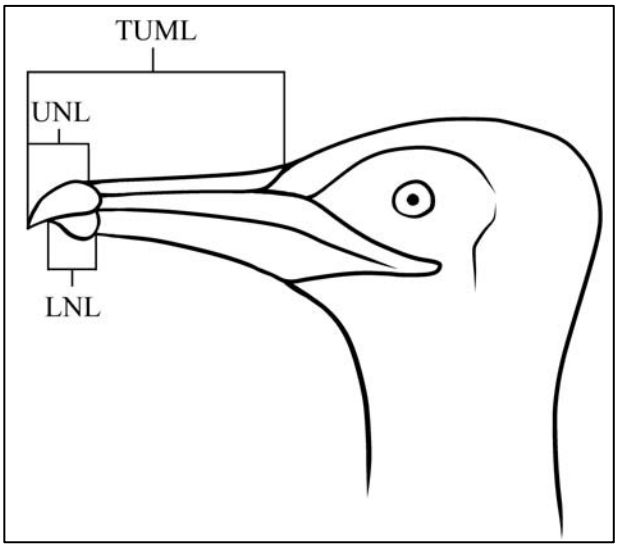
Freq.	Mass (g)	TUML	BW	BD	UNL	LNL	Tarsus
21	2025	60.73	13.5	17.47	24.46	20.9	68.49
41	1800	57.85	11.1	15.66	20.97	16.4	65.92
62	2200	57.73	13	16.96	24.8	20.59	66.81
82	2150	61.91	12.97	16.93	23.98	19.04	64.6
100	2000	56	11.18	15.75	19.26	16.91	64.59
122	2250	54.4	11.8	17.16	22.86	19.53	66.95
141	1900	54.38	11.03	14.28	20.84	17.88	65.11
162	2000	57.35	11.49	14.68	20.91	16.22	66.15
183	2050	51.24	11.97	14.49	19.1	15.44	67.44
202	1850	57.85	12.9	17.81	21.84	18.16	60.65

Band Number	Blue Band
1008-19641	P41
1008-19642	P42
1008-19643	P43
4007-83129	N/A
1008-19644	P44
1008-19645	P45
1008-19646	P46
1008-19647	P47
1008-19648	P48
1008-19649	P49

APPENDIX B

SEXING DCCOS

Visual determination of DCCO sex in the field is not possible. I used morphometric and sex data from DCCOs lethally taken in 2000 and 2001 (Permit Number MB022886; N. E. Seefelt, unpublished data) and those taken by APHIS/Wildlife Services in the Beaver Archipelago from 2009 in a binary logistic model to determine sex of birds captured in 2010. Model metrics included tarsus length, total upper mandibular length, upper nail length, lower nail length, upper beak width, and bill depth (see image below). Upper mandibular width and bill depth were measured at the point where the nares had closed, yet where a ridge remains on the upper mandible.



Beak measurements used in logistic regression model of sex where TUML=total upper mandibular length, UNL=upper nail length, and LNL=lower nail length.

Metrics were determined in the lab and in the field using digital calipers. Discriminant models have been used elsewhere to sex cormorants based on morphometric data, but used measurements that were not taken from captured birds in 2003 nor 2010 (Bédard *et al.* 1995,

Glahn and McCoy 1995). A binary logistic model of sex was used instead of a discriminant model because of its ability to produce the probability surrounding the predicted sex and because it had greater predictability of the data used to build the model.

A total of 102 harvested adult DCCOs from 2000, 2001, and 2009 were used to build the sex logistic regression model (42 males, 60 females). Mass was not used in the analysis, due to the discrepancy between the accuracy of lab and field measurements. The best logistic model ($p<0.0005$) for sexing captured DCCOs contained only three of the original measured morphometrics: lower nail length ($p=.004$), upper mandible width ($p=0.012$), and bill depth ($p<0.0005$). The model, below, was used to predict ‘p’, the probability that the DCCO in question is a male:

$$!"\left[\frac{!}{!\ !\ !}\right]!\ !\ !"!!"\ !\ (!"!!!!!"\#!)!\ (!"\#\ !!!")!\ !!"!!!""!$$

where UNL=upper nail length, LNL=lower nail length, UMW=upper mandible width, and BD=bill depth. The model suggests that of the 10 DCCOs captured for the telemetry study in 2010, 5 were males and 5 were females (see graph below). Although bill depth and both lower nail length and upper mandible width were highly correlated (rho=0.337 and rho=0.4, respectively), this variable was kept due to the increased descriptive power of the model. The model with bill depth predicted 98% of all sexes used, while just lower nail length and upper mandible width alone predicted 85% of the sexes used to build the model.

Predicted sexes of DCCOs used in 2010 telemetry study. The ‘probability’ refers to the probability that a bird is a male.

Transmitter Number	Probability	Sex
21	1.000	Male
41	0.115	Female
62	0.999	Male
82	0.998	Male
100	0.218	Female
122	0.995	Male
141	0.015	Female
162	0.019	Female
183	0.014	Female
202	0.999	Male

APPENDIX C

AKAIKE'S INFORMATION CRITERION (AIC) AND CROSS-VALIDATION CRITERION (CVC) VALUES FOR MODELS DESCRIBING EACH LOCATION DATA SET

Data Set	Home Range Method	AIC	CVC
2003 Rafts	Adaptive Kernel Density	N/A	8932.09
	Fixed Kernel Density	N/A	8975.64
	2 Mode Bivariate Normal	9052.57	9057.18
	2 Mode Bivariate Circle	9461.12	9477.61
	1 Mode Bivariate Normal	9611.37	9621.59
	Exponential Power Model	9745.14	9744.36
2010 Rafts	Fixed Kernel Density	N/A	3284.91
	Adaptive Kernel Density	N/A	3291.93
	2 Mode Bivariate Normal	3428.50	3429.79
	2 Mode Bivariate Circle	3458.78	3457.15
	1 Mode Bivariate Normal	3465.43	3464.18
	Exponential Power Model	3482.66	3480.27

APPENDIX D

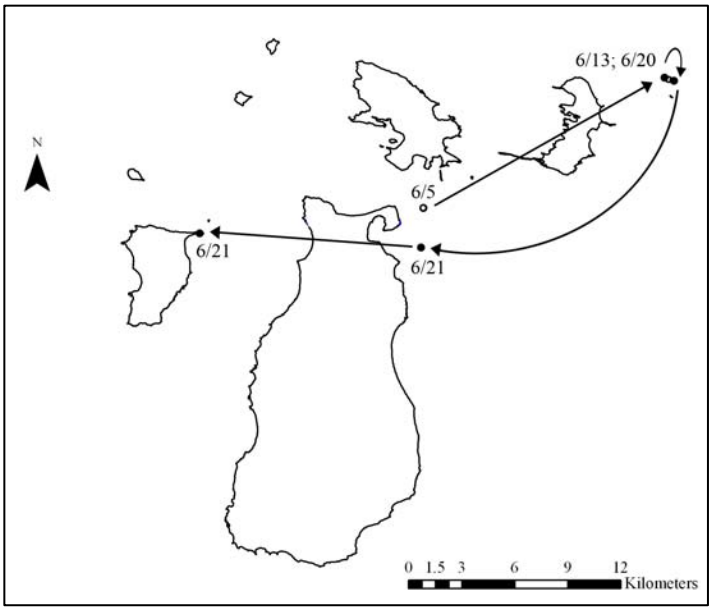
GENERAL LOCATIONS OF TAGGED DOUBLE-CRESTED CORMORANTS

Date	Freq.	Time	Sampling Location	Notes
5 June 2010	21	----	NE Beaver Island (from boat)	Near Lookout Point
7 June 2010	82	9:25	Between Squaw and Garden Island (from boat)	Between Squaw and Garden, flying south
7 June 2010	100	9:25	Between Squaw and Garden Island (from boat)	Between Squaw and Garden, flying south
7 June 2010	100	10:07	Just outside of St. James Harbor (from boat)	East side of Beaver (187°)
7 June 2010	183	13:00	West side of Beaver (from boat)	SE of High Island
7 June 2010	202	10:27	Southeast of Hog Island (from boat)	Moved east toward Hat
11 June 2010	62	11:31	St. James Campground	Northeast of Beaver
12 June 2010	41	15:14	Bill Wagner Campground	Northeast of campground (345°)
12 June 2010	62	15:15	St. James Campground	Toward Whiskey
12 June 2010	183	13:54	St. James Campground	Toward Garden Island
14 June 2010	62	11:51	Near Squaw Island (from boat)	Near Whiskey
14 June 2010	141	11:46	North of Indian Point, between Beaver and Garden Islands (from boat)	Between High and Beaver Islands
16 June 2010	62	13:52	St. James Campground	Toward Whiskey
26 June 2010	62	10:00	St. James Campground	Toward Whiskey
26 June 2010	62	13:26	Donegal Bay	Toward Whiskey

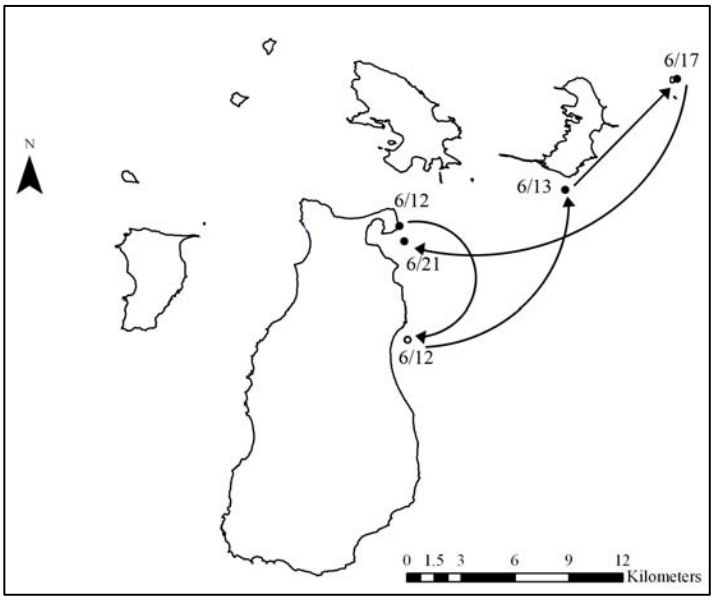
APPENDIX E

MAPS REPRESENTING THE DATES AND LOCATIONS OF TAGGED CORMORANTS

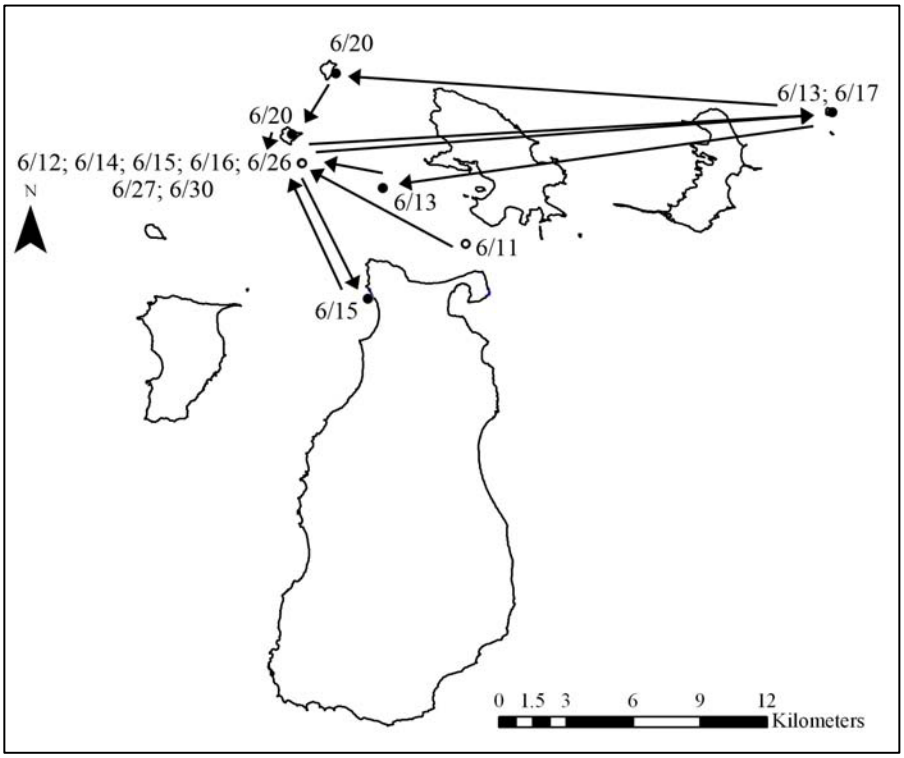
The number below the graph refers to the frequency of the radio transmitter (150.###). Hollow circles designate estimated locations.



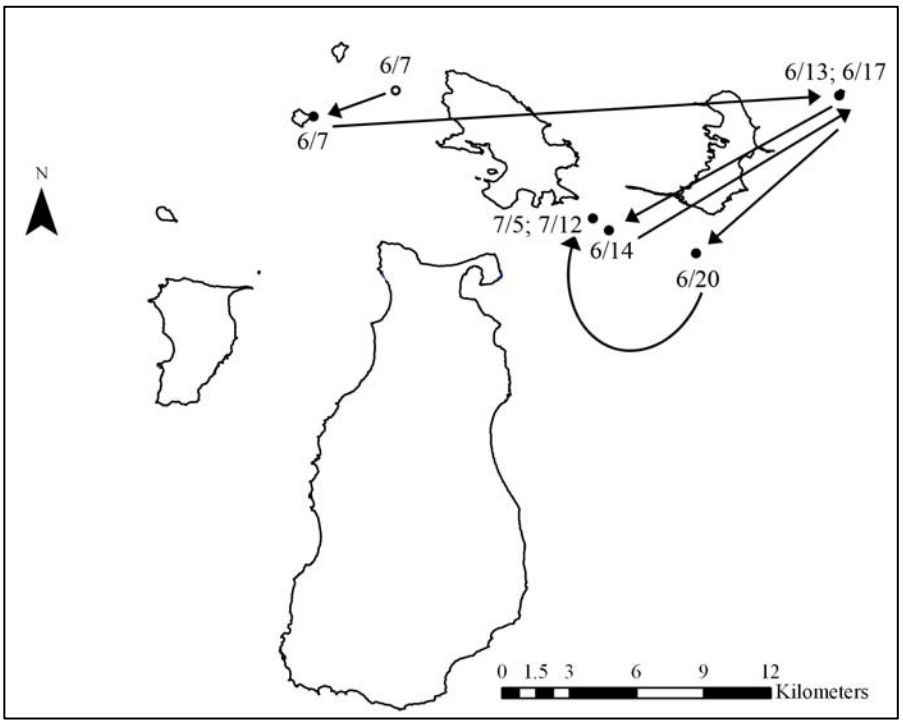
Double-crested Cormorant #21.



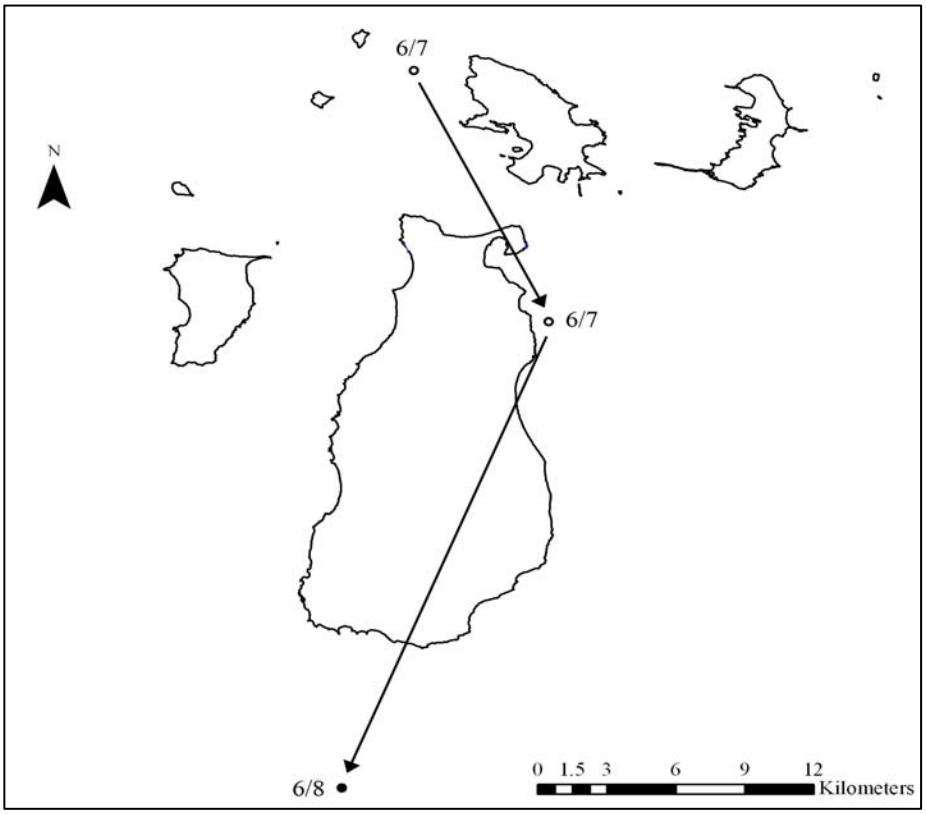
Double-crested Cormorant #41.



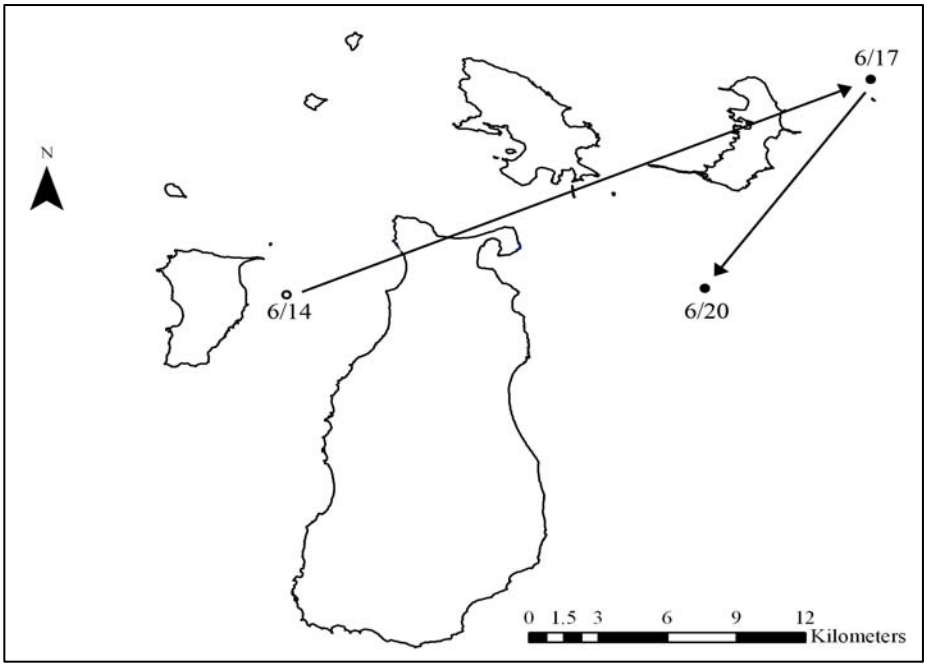
Double-crested Cormorant #62.



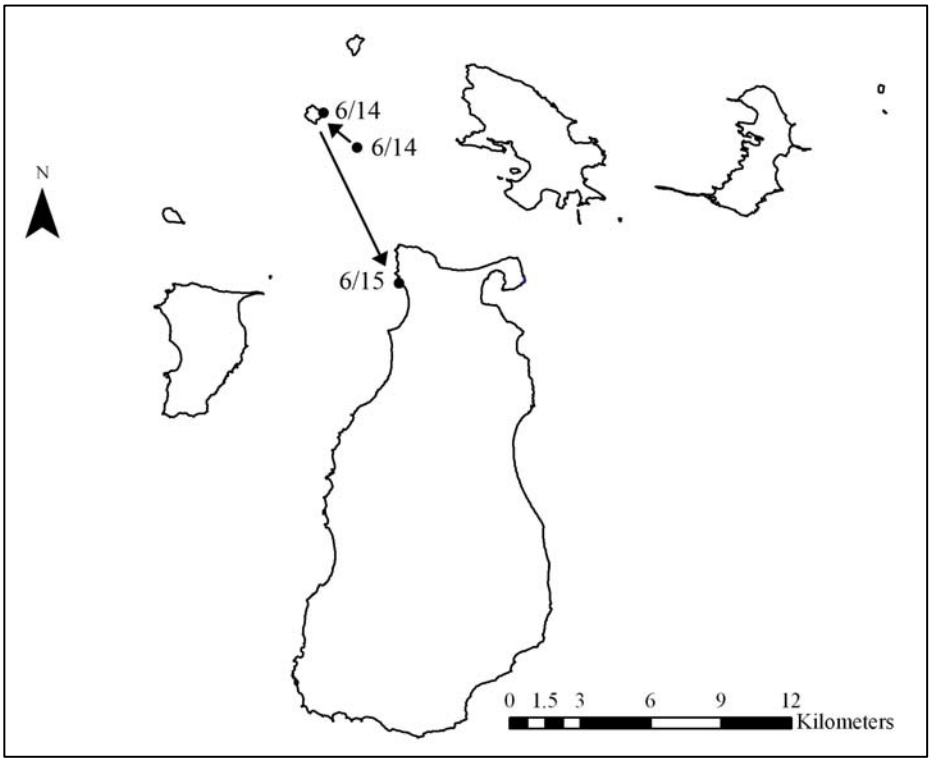
Double-crested Cormorant #82.



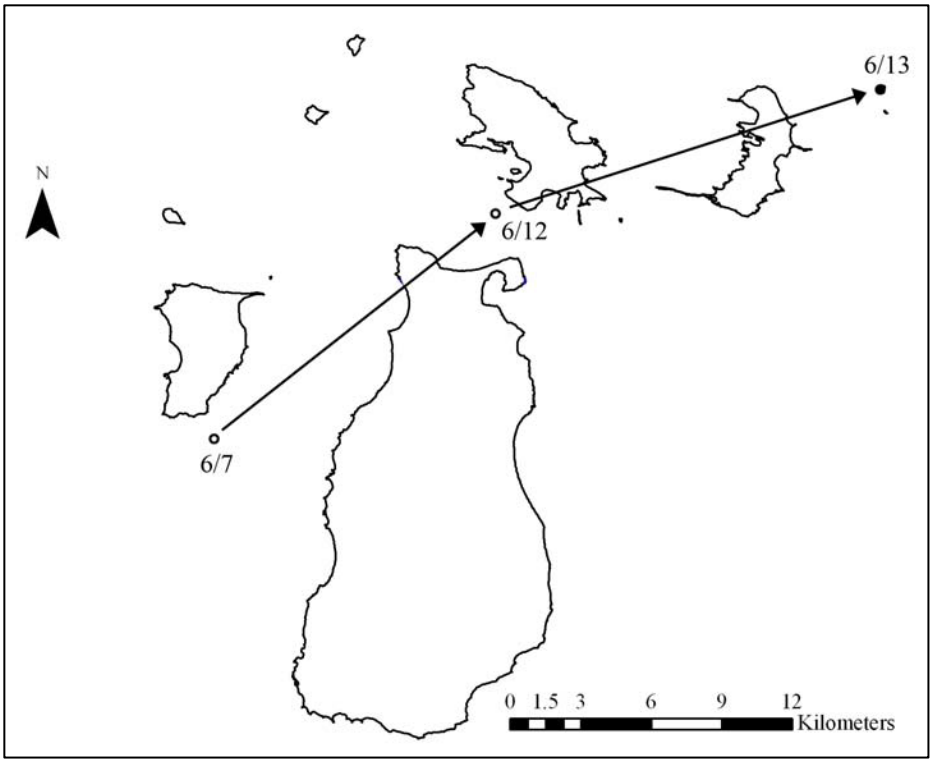
Double-crested Cormorant #100.



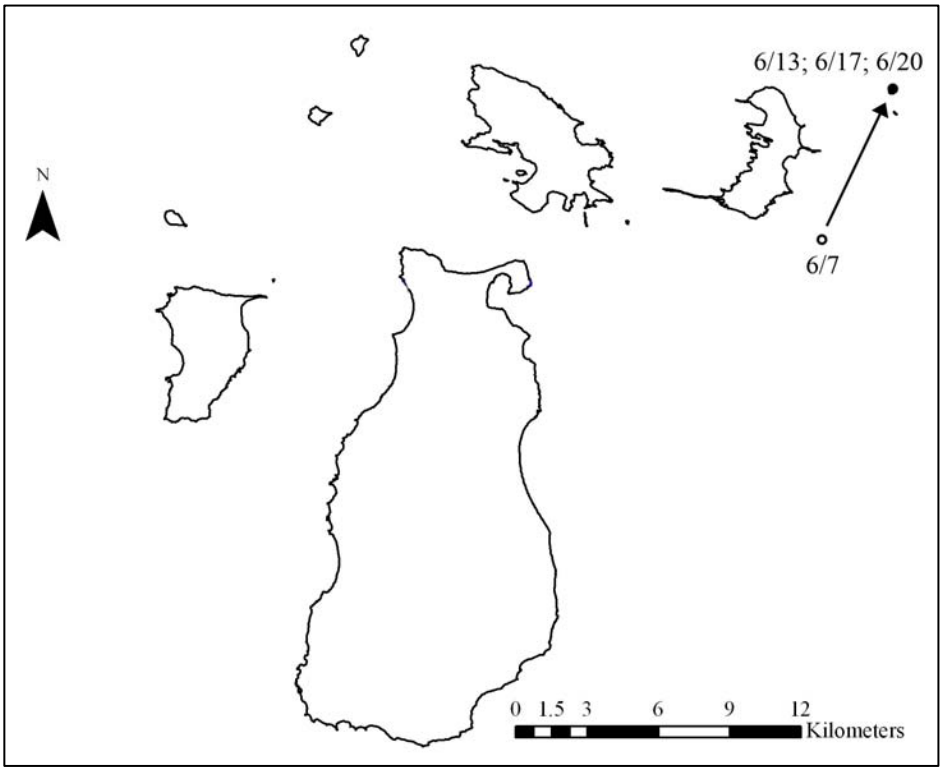
Double-crested Cormorant #141.



Double-crested Cormorant #162.



Double-crested Cormorant #183.



Double-crested Cormorant #202.

APPENDIX F

DISTANCES OF SAMPLING LOCATIONS FROM DOUBLE-CRESTED CORMORANTS COLONIES IN THE BEAVER ARCHIPELAGO

Sampling Location	Colony	Distance (km)
Bill Wagner Campground	Hat	23.26
Bill Wagner Campground	Pismire	12.94
Bill Wagner Campground	Whiskey	19.14
CMU Biological Station	Hat	21.40
CMU Biological Station	Pismire	10.13
CMU Biological Station	Whiskey	15.82
CMU Boat House	Hat	18.24
CMU Boat House	Pismire	5.80
CMU Boat House	Whiskey	10.73
Donegal Bay	Hat	21.99
Donegal Bay	Pismire	9.61
Donegal Bay	Whiskey	8.08
St. James Campground	Hat	20.00
St. James Campground	Pismire	7.62
St. James Campground	Whiskey	8.49
Gull Harbor	Hat	17.40
Gull Harbor	Pismire	4.98
Gull Harbor	Whiskey	11.14
Sucker Point	Hat	17.13
Sucker Point	Pismire	4.69
Sucker Point	Whiskey	10.73

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