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BREEDING DISPERSAL, MIGRATION, AND WINTER MOVEMENTS OF THE
EASTERN INTERIOR POPULATION OF DOUBLE-CRESTED CORMORANTS

A Thesis Submitted to the Committee on Graduate Studies in
Partial Fulfillment of the Requirements for the Degree of Master of Science in the Faculty
of Arts and Science

TRENT UNIVERSITY

Peterborough, Ontario, Canada

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Abstract

Breeding Dispersal, Migration, and Winter Movements of the Eastern Interior Population of Double-crested Cormorants

Heidi Scherr

Double-crested cormorants (*Phalacrocorax auritus*) have been perceived to be direct competition for commercial and sports fishers throughout the Great Lakes, and thus management has been sought. This study focuses on the population of breeding Double-crested Cormorants in Georgian Bay, Ontario, which has increased exponentially since 1979. The two objectives of this thesis were: to look at whether disturbance would cause breeding cormorants to abandon their colony and redistribute outside of Georgian Bay indicating that this population was apart of a Great Lakes metapopulation; and to identify fall migration routes, staging sites, winter habitat use, foraging area, and fidelity. These objectives were completed with the use of aerial photographs of colonies and implanted satellite platform terminal transmitters (PTTs) that allowed us to accurately track the movements of 28 individuals from 2007 to 2008.

Keywords: Double-crested Cormorant, Georgian Bay, Lake Huron, disturbance, metapopulation, migration, winter range, habitat use, aquaculture, fidelity, satellite transmitters

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Chapter 1: General Introduction

The Ontario Ministry of Natural Resources (OMNR) established a Double-crested Cormorant (*Phalacrocorax auritus*) (here-after referred to as cormorant) monitoring and research program in 2000 in response to public concerns about the substantial population increase over the previous 20 years (Ridgway et al. 2006). One element of the program focused on community and population-level responses of fish to cormorant predation (M. Ridgway Pers. Comm.). That research used oiling of cormorant eggs throughout the Georgian Bay and the North Channel portions of Lake Huron in an experimental framework to measure fisheries response. Preliminary conclusions were that removal of a portion of cormorant predation (i.e., parental feeding of young at the nest) was sufficient to cause local increases in fish biomass although the effect was short-lived in the experimental time frame (M. Ridgway, Pers. Comm.). Questions about cormorant life-history arose from that study, particularly about patterns of movement and settlement and connectivity among geographical groupings of breeding cormorants. One outstanding question focused on whether cormorants could be managed effectively at a local scale, or whether dispersal would be too great a factor for this scale of management to be effective. Although previous studies, such as Mazzocchi (2003), have shown that management can be effective, subsequent abandonment of breeding birds still occurs.

My study was undertaken to look at the behaviour (primarily seasonal and interannual movements) and ecology of cormorants throughout their breeding and winter ranges. The first objective of this study was to look at the effects that disturbance (which could represent activities such as boat traffic, trespassing and illegal destruction of breeding colonies, or management activities such as egg oiling or culling) would have on the behaviour of these birds and whether it would disrupt breeding activities.

Specifically, I was interested in whether cormorants from Georgian Bay were a part of a larger Great Lakes metapopulation, whether disturbance of breeding colonies would result in reproductive failure and whether the disturbance these birds experienced during breeding would affect their breeding site fidelity in the following breeding season. Secondly, I wanted to obtain a better understanding of migration routes, winter ranges and habitat use, fidelity, and whether there was a relationship between general winter habitat use and return to the breeding grounds that would be predictive of fitness.

A metapopulation is an ensemble of subpopulations that are loosely linked through dispersal. Although these subpopulations may be independently fluctuating, experiencing extinction or growth, at the regional level the population appears to be stable (Krebs 2001). Metapopulation dynamics therefore, includes the movement of individuals from one subpopulation to another due to some stimulus so that the regional metapopulation changes less than each local subpopulation (Krebs 2001). Subpopulations of migratory species are much harder to identify as they cannot be defined just as geographic areas; rather, they must be defined in conjunction with behavioural mechanisms such as philopatry and dispersal (Esler 2000). In this study, I induced a stimulus that was meant to resemble a cull. In regard to cormorants, since it was intended to disperse breeding birds from their colony, metapopulation responses could be recognized as relocated birds successfully breeding on a new colony elsewhere in the Great Lakes system (Esler 2000).

Lethal population management has been observed to have unpredictable effects at a metapopulation level because it can influence immigration and emigration rates between colonies. Bosch et al. (2000) initially observed increased emigration of surviving Yellow-legged Gull (*Larus cachinnans*) adults to other colonies after a cull

reduced the colony by 29%. In the year following this cull, immigration to the culled colony increased due to the availability of nest sites. This type of metapopulation response has also been observed in non-avian species such as the badger (*Meles meles*) (Pope et al. 2007), and the African elephant (*Loxodonta Africana*; Chamille-Jammes et al. 2008) post cull. Henaux et al. (2007) has even observed this behaviour in a similar species, the Great Cormorant (*Phalacrocorax carbo*), where increased emigration of banded individuals to smaller colonies was observed after culling a colony in Denmark.

However, this type of response has also been observed when breeding has been disrupted through other disturbances. Reproductive management strategies, such as egg oiling, have been attempted many times to control cormorant populations throughout the Great Lakes. Mazzocchi (2003) found that egg oiling was effective at limiting the productivity of cormorants at Little Galloo Island in Lake Ontario; however the repetitive disturbance necessary to apply the oil caused nest abandonment and caused the birds to relocate elsewhere. Duerr et al. (2007) also observed this in Lake Champlain, Vermont; however they noted that this effect was intensified by subsequent gull predation. A complete breeding failure due to the predation caused significantly more abandonment of birds, which were observed to relocate to a colony that was not being disturbed (Duerr et al. 2007).

Although many studies in the past have looked at the response of cormorants to disturbance, few have been able to determine specifically where birds go after they abandon their colony. Should management be considered in Georgian Bay, it should be known whether these birds from disturbed colonies remain in the local area and cause local problems, or whether they relocate and potentially cause problems elsewhere. My study is unique in that I followed individuals post-disturbance to determine how far these

birds relocated, and asked whether a cormorant metapopulation existed throughout the Great Lakes. The use of internal platform terminal transmitters (PTTs) made tracking the behavioural response, and any subsequent movement, of cormorants to disturbance much easier. PTTs also allowed me to see such metapopulation responses and accurately track the movement of individuals throughout the non-breeding season. As stated above, I was interested in migration routes, winter ranges, habitat use, and fidelity, particularly if any differences in these categories existed between the sexes. Previous studies have tried to determine migration routes, however no studies have tried to determine whether differences exist between the sexes in these behaviours, or at the relationship between winter habitat use, foraging area size, and return to the breeding ground. This question about habitat use is of particular interest following the expansion of the aquaculture industry in the cormorant's winter range.

The Great Lakes breeding population of cormorant winters from North Carolina to the Gulf of Mexico (Hatch and Weseloh 1999). Anthropogenic influences throughout the winter range of this species, specifically the aquaculture industry expansion throughout the Mississippi River delta in the last few decades, has changed the survival and distribution of this species greatly (Blackwell et al. 2002, Stapanian et al. 2002, Dorr et al. 2004). Christmas Bird Counts from 1959-1988 showed a significant increase of 18.7% per year in inland areas of Mississippi, and a 7.3% increase for all interior areas combined (Hatch and Weseloh 1999). In the 1990s alone, the number of cormorants wintering in the Mississippi River delta region has tripled (Werner et al. 2001). Because of the increase in cormorants, significant economic losses have occurred at aquaculture facilities (Blackwell et al. 2002) and the United States Fish and Wildlife Service (USFWS) has implemented a depredation order that allows aquaculture facilities in 13 states to kill

unlimited numbers of cormorants if they are found depredating ponds (Stapanian et al. 2002). Although it is perceived that a large majority of these birds now winter in areas surrounding these facilities, one must question whether this ongoing disturbance has had effects on the distribution of wintering cormorants.

As for sexual differences in migration strategies for cormorants, I am particularly interested in differences in the departure from the breeding location and the time spent in staging areas, arrival times in the wintering areas, and whether there is a latitudinal distinction whereby females winter farther south than males. Studies of a similar species, the Great Cormorant have discovered differences in migratory behaviour between the sexes. Reymond and Zuchuat (1995) found that female cormorants winter farther south to avoid competition for winter roost sites in northern Switzerland. These observations were also made by Van Eerden and Munsterman (1995) who suggested that males remained farther north so that they could be closer to the breeding grounds, which would allow the males to return to the breeding colonies first, facilitating early nest site selection. Van Eerden and Munsterman (1995) proposed a hypothesis for this sex difference in distribution called the arrival time hypothesis. Although it is known that male Double-crested Cormorants arrive in the breeding grounds first to defend nest sites (Hatch and Weseloh 1999), it is unknown if males winter farther north than females.

Many bird species have long-distance annual migrations, which are often interrupted by stops at staging sites where they can stop and replenish their body stores (Yosef et al. 2006). For some species, such as the Western Sandpiper (*Calidris mauri*), such stops are necessary to ensure survival and completion of a migration (Ydenberg et al. 2002). In cormorants, if the arrival time hypothesis is correct, and females winter

farther south than males, then it would seem logical that females might spend more time in such staging sites than males to prepare for a longer flight.

Another aspect of interest that has not been considered for cormorants is winter habitat use and the “carry-over” effect (Marra et al. 1998, Norris and Marra 2007). Early arrival time at a breeding ground is a measure of good physical condition for migrating species, and has been found to be directly related to winter habitat quality. Hebert et al. (2008) found through isotope analysis that cormorants returning to breeding grounds that fed in freshwater habitats in winter were in much better physical condition than those that wintered in marine habitats. They suggested that enhanced foraging opportunities at aquaculture facilities (freshwater habitats) may improve fitness of birds feeding there. According to this idea, cormorants found on aquaculture facilities during the winter should arrive back in Georgian Bay before individuals that winter on non-aquaculture sites.

Finally, little is known about the fidelity of cormorants, especially following disturbance. Hatch and Weseloh (1999) suggest that natal philopatry is probably high. Band recoveries of 3 year old birds had a median distance of 25 km from natal colony (Dolbeer 1991). Less is known about breeding site fidelity but it is thought that once established, this is also high (Hatch and Weseloh 1999). As the breeding birds in my study have been subject to capture and disturbance on their breeding colony, site fidelity will be dependent on where the bird’s location is post-disturbance. This factor will be especially important should the bird abandon its colony and relocate elsewhere. The information gathered in this study will help identify how disturbance can affect the breeding behaviour of this species, as well as migration strategies and winter habitat use.

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Chapter 2. Response of Breeding Double-crested Cormorants to Disturbance

2.1 Abstract

Response of Breeding Double-crested Cormorants to Disturbance

Heidi Scherr

The population of breeding Double-crested Cormorants (*Phalacrocorax auritus*) in Lake Huron increased from 150 pairs in 1979 to 19,421 nesting pairs in 2008. There is a public perception that this increase has placed the Lake Huron fishery under stress from cormorant predation. Management of cormorants through lethal means has been considered. However, if a metapopulation of cormorants exists throughout the Great Lakes, lethal management of individual Georgian Bay colonies may not be successful. With the use of 28 satellite transmitters and aerial photographs, movement in response to disturbance was observed at both an individual- and colony-level. Positive relationships were found between disturbance and gull predation, which increased the rate of abandonment at a colony-level. At an individual level, 12 individuals that abandoned breeding attempts showed responses indicative of a large metapopulation by redistributing outside of Georgian Bay. The use of implanted satellite transmitters was also found to cause behavioural effects as 11 of 28 birds abandoned their colony after the surgical procedures.

Keywords: Disturbance, satellite transmitters, Double-crested Cormorants, abandonment, metapopulation, gull predation

2.2 Introduction

When a species becomes problematic or overabundant and management becomes necessary, control practices may not always be successful if managers do not take movement or metapopulation dynamics into consideration. For example, when badgers (*Meles meles*) infected with bovine tuberculosis spread the disease to cattle in the United Kingdom, attempts to stop the spread included large-scale badger culls, a controlled reduction of the breeding population. Unfortunately, this only led to increased badger movement from culled areas to undisturbed areas, introducing the infection to neighbouring cattle farms. Infection also spread into surrounding previously uninfected social groups of badgers demonstrating a metapopulation effect (Pope et al. 2007). In an avian example, the culling of a single gullery of Yellow-legged Gulls (*Larus cachinnans*) in Scotland had unpredictable effects at the metapopulation level because it influenced immigration and emigration rates between colonies (Bosch et al. 2000). The mass culling of breeding individuals disturbed neighbouring birds enough to cause them to emigrate to nearby colonies where they re-nested. The sudden opening of available nest sites also attracted a large influx of immigrants. Therefore, culling was less effective than predicted and its unintended effects could only be neutralized once the management ceased (Bosch et al. 2000). Such an effect has also been suggested in the highly vagile Double-crested Cormorant (*Phalacrocorax auritus*). In two breeding colony control efforts in the Great Lakes of North America (Mazzocchi 2003) and Lake Champlain, Vermont, USA (Duerr et al. 2007), control activities resulted in increased emigration.

The Double-crested Cormorant, hereafter referred to as the cormorant, is a piscivorous, foot-propelled pursuit diver (Hatch and Weseloh 1999, Stapanian 2002, Weseloh et al. 2002) distributed throughout North America from Alaska to

Newfoundland, south to Mexico and the western Caribbean Sea. It has an extensive breeding population in the Great Lakes (Hatch and Weseloh 1999). The long history of persecution of this bird first began in the 19th and early 20th century due to the belief that the cormorant was responsible for a reduction in fish populations (Stapanian 2002), which led to ad hoc control efforts and subsequent population declines. Cormorant populations continued to decline through the 1970s due to exposure to the organochlorine contaminant DDE which reduced reproductive success and eventually the number of breeding pairs in the Great Lakes declined to 150 by 1972 (Stapanian 2002). Since then, numbers have increased exponentially owing to a combination of different factors including decreases in levels of DDE, cormorant protection, and an abundance of forage fish, especially the alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*), which were introduced to the Great Lakes in 1931 (Alvo et al. 2002).

The expansion of the aquaculture (especially catfish) industry in the Mississippi River delta region since 1985 has been identified as another large contributor to the recent success of the cormorant (Blackwell et al. 2002, Stapanian 2002, Dorr et al. 2004). The enhanced food supply at aquaculture facilities is believed to have increased the winter survival of the species and improved the body condition of returning migrants. In the last decade alone, the number of cormorants wintering in the Mississippi River delta region has tripled (Werner et al. 2001). Because of this, significant economic losses have occurred at aquaculture facilities (Blackwell et al. 2002) and the United States Fish and Wildlife Service (USFWS) has implemented a depredation order that allows aquaculture facilities in 13 states to kill unlimited numbers of cormorants if they are found depredating ponds (Stapanian 2002).

Another problem associated with cormorants, primarily in the Great Lakes region, is destruction of island and coastal vegetation (Herbert and Sprules 2002, Grieco 1999) caused by accumulation of cormorant excreta (Stapanian 2002). The largest concern surrounding cormorants, however, is their perceived direct competition with the Great Lakes commercial and sport fisheries (Stapanian et al. 2002). Many studies show that cormorants are opportunistic feeders that eat mostly small prey fish that have little to no commercial value (Stapanian 2002), but Diana et al. (2006) found that birds could consume large amounts of commercially important stocked trout and salmon in some circumstances. Along with recent cormorant population increases, this has caused a large public concern about their effect on Great Lakes fisheries (Diana et al. 2006).

The Georgian Bay and North Channel regions of Lake Huron are highly productive areas for fish and have also experienced exponential increases in cormorant numbers, from only 150 breeding pairs on five colonies in 1979, to 19,421 breeding pairs on 117 colonies in 2008. These areas have also shown indications of direct predation effects of cormorants on local fish populations (M. Ridgway Pers. Comm.). Commercial and recreational fishers in these areas have expressed their concerns and have pushed for local management of cormorant colonies to control populations. Interest in local-scale management of cormorants in Lake Huron raises questions about the possible behavioural response of the birds.

Evidence for the influence of disturbance on movement of cormorants is varied. Some studies suggest that surviving birds are unaffected by management, such as culling, and remain on their breeding colony (Werner et al. 2001, Bedard et al. 2005). Others show that nest abandonment occurs (Mazzocchi 2003), or that birds will relocate to another undisturbed colony nearby (Ellison and Cleary 1978, Duerr et al. 2007). The

purpose of my study was to assess the behavioural response (movement, fidelity, nest abandonment) of breeding cormorants to human disturbance. I aimed to collect individual movement data over long distances, including time, date, and location, with the use of satellite transmitters. Although other studies have used satellite transmitters on cormorants both in their winter (Werner et al. 2000, Dorr et al. 2004) and summer ranges (Dorr et al. 2002, Werner et al. 2001), none has used internal transmitters. In a previous study of the effects of disturbance on cormorants breeding in Lake Ontario, the use of backpack transmitters had low success because many of them were lost within the first few months, likely due to the diving behaviour of the bird (Dorr et al. 2002).

The definition of a metapopulation is an ensemble of subpopulations that are connected through dispersal (Krebs 2001). Subpopulations, on the other hand, must be sufficiently independent populations so that the extinction of a subpopulation can occur irrespective of the demographics of other subpopulations. Also, dispersal among subpopulations must be frequent enough that recolonization of an extinct subpopulation's range can occur (Esler 2000). Subpopulations of migratory species are much harder to identify as they cannot be defined just as geographic areas; rather, they must be defined in conjunction with behavioural mechanisms such as philopatry and dispersal (Esler 2000). In regards to cormorants in this study, a metapopulation could be identified through the relocation and successful breeding attempt of abandoned on new colonies throughout the Great Lakes system (Esler 2000). For this reason, I tentatively defined the Georgian Bay cormorants as a subpopulation of a Great Lakes metapopulation because philopatry to a breeding region is high in cormorants, and cormorants have been well established breeders in Lake Huron since 1979 (Henaux et al. 2007, Hatch and Weseloh 1999). I hypothesized that Georgian Bay cormorants could be a part of a larger Great Lakes

metapopulation, and that local-scale management would simply result in the redistribution of birds to new or unmanaged sites within the system. If cormorants move to other areas throughout the Great Lakes during the breeding season in response to disturbance, then this will could the metapopulation hypothesis. However, this idea that a cormorant metapopulation exists could only be completely be supported through the observation of abandoned birds breeding on new colonies. This idea could also further be supported if this birds return to their new colony in the following year and attempt to breed (Esler 2000). In another study by Weseloh and Shutt (Unpubl. Manuscript) that looked at shifts in the populations of cormorants in Lake Ontario, birds appeared to move from the Eastern to the Western Basin in response to disturbance. Although this study was based on yearly census data and not on marked birds, which would give a better picture of the individual movement occurring, it still provides a clear cut example of the effect that disturbance can have on breeding birds.

During this study, I have also examined the relationship between disturbance and gull predation. Some studies of colonial waterbird species have shown that in mixed colonies with gulls, nesting success can be greatly reduced, including abandonment in relation to disturbance (Harris and Wanless 1997). Duerr et al. (2007) observed that gull predation increased when cormorant nests were oiled during the day and that when nests were depredated, birds moved to a nearby colony and re-nested. These birds also attempted to establish 10 new colonies in the area, and were reported to be more numerous on the St. Lawrence River in the following year, 100 km north of the study site. Ellison and Cleary (1978) also observed gull predation to increase due to researcher disturbance and that new sub-colonies appeared outside of the study area. This type of group adherence and relocation has also been documented in larids in association with

unstable habitat or disturbance. Groups are more likely to move together to another colony or establish a new colony because of group adherence (McNicholl 1975). I therefore have hypothesized that depredation of nests by gulls will be facilitated by disturbance and will have a positive relationship with probability of nest or colony abandonment by nesting cormorants. For this hypothesis, I have taken into consideration observed predation during disturbances, as well as the number of gulls in each colony. I predicted that the amount of predation would increase with larger numbers of gulls present on a colony.

2.3 Methods

2.3.1 Site Description

This study was conducted at a group of cormorant colonies near Parry Sound in Georgian Bay, Ontario from 2007-2008 (Figure 2.1). This area was selected for three reasons: the population has been documented since 1979 by annual cormorant nest counts; Ridgway et al. (2006) used these same colonies for a previous study on the effects of cormorants on local fish populations; and local interest existed for a study to evaluate population management.

The colony sites consisted of low-lying bald rock islands with sparse vegetation. The colonies each had 40-500 ground nesting cormorants depending on the size of the island and availability of suitable nest sites. Other species, such as Herring Gull (*Larus argentatus*) and Ring-billed Gull (*Larus delawarensis*), were observed nesting on most of the colonies at a variety of densities. Both species of gull were observed depredating

cormorant nests during visits to the colonies, and have the ability to take considerable numbers of both eggs and chicks.

2.3.2 Study Design

This study occurred during the cormorant breeding seasons of 2007 and 2008. In both years, study colonies were pre-classified by treatment as disturbed, trapped, or undisturbed colonies (Table 2.1, Figure 2.1). Disturbed colonies were disturbed with pyrotechnics and air horns to achieve an acoustic disturbance similar to that associated with lethal management activities utilizing fire-arms. Trapping also occurred on disturbed colonies to catch individual birds for the implantation of the transmitters. Twenty-eight individuals were implanted with Argos Satellite Platform Terminal Transmitters (PTTs). Fourteen were from the three disturbed colonies in 2007 and seven were from one of three disturbed colonies in 2008. The remaining seven birds were from a trapped but not disturbed colony in 2008. I used PTT technology to directly measure individual-level responses to disturbance. To account for the effect of trapping and handling alone (i.e., not surgery-related trauma or pyrotechnic disturbance), birds were trapped on other colonies so that any abandonment related to the trapping procedures could be measured. Each of these trapping-only colonies was visited once and traps were set in order to duplicate the trapping disturbance on the surgical colonies, where traps were used to capture birds for the implantation of PTTs. Abandonment associated with trapping and disturbance was determined through aerial photography to assess colony-level responses. Colony-level changes could only be measured by gains or losses in the number of active nests, assessed from aerial photographs (Figure 2.2). I chose to include all colonies within the area surrounding Parry Sound that would represent a range of

distances to disturbed colonies. Undisturbed colonies in aerial photographs were used to measure gains and losses of nesting birds in relation to the proximity of disturbed colonies.

2.3.3 Trapping

Adults were captured upon returning to their nests from 15 May to 6 June 2007 during the laying or early incubation period. I used modified and padded Victor 3.0 foothold traps designed to specifications provided by King et al. (2000). These traps were placed on the edge of a nest and anchored with two stakes driven into the base of the nest. These traps were successful at capturing the birds; however, they caused leg injuries. I replaced them with smaller Victor 1.5 traps padded with surgical gauze to prevent abrasions on the birds' legs. Although these traps were less successful at capturing birds, they caused no apparent injuries in multiple trap runs. These traps were used again in year 2 of the study, during early incubation from 11-14 May 2008.

2.3.4 Surgical Procedures

Surgeries to implant the PTTs took place on 19-20 May and 2 June in 2007, and 12-13 May 2008. Veterinarians performed all surgeries on a nearby adjacent island, or if trapping occurred on an isolated island, then as far from the nesting birds as possible to reduce disturbance to just the trapping procedure. Birds were removed from the traps and placed in well-aerated pet carriers in the shade for approximately an hour until the surgical procedure took place. PTTs were inserted into the coelem of the bird in the abdominal cavity with the external antennae whip exiting through a small incision in the back. The antennae protruded in such a way as to minimize interference with the wings.

Birds were administered antibiotics to reduce inflammation and chance of infection and painkillers to reduce stress, and were monitored for an hour following the procedure (detailed accounts of surgical procedures can be found in the Appendix). There were no complications with the surgical procedures, or any associated mortalities. In 2007, some birds did apparently respond to the surgeries by abandoning their colony before disturbance treatments even began (see results). In 2008, the treatment regime was modified to include seven PTTs implanted on a colony that did not receive any additional disturbance so that I could better determine an abandonment rate associated with the surgery alone. All birds were sexed via blood samples taken during the surgical procedures.

2.3.5 Disturbance and Movement

The PTTs had an expected battery life of fourteen months. They were expected to collect position data during the first breeding season, the subsequent fall migration, winter and spring migration and a second breeding season; to maximize battery life and measurement of breeding season responses, PTTs were programmed to provide positions at varying rates by season (Table 2.2). All data from the PTTs were received and transmitted by Service Argos Inc. equipment situated on two National Oceanographic and Atmospheric Administration (NOAA) polar-orbiting satellites (Werner et al. 2001). All data received from these PTTs were received electronically via weekly email. Only data that were of good quality (within 150 – 350 m of actual location, Class 3 and Class 2 data) were used to monitor the birds' locations. These specifications were chosen because some of the colonies within Georgian Bay were less than 1000 m apart and I needed to be able to distinguish clearly in which colony a bird was residing.

Disturbance of the colonies where PTTs were deployed occurred from 9-13 June 2007 and from 15-21 May 2008. In addition to disturbance of the new colony in 2008, the three colonies disturbed in 2007 were disturbed again because 9 birds with PTTs from 2007 returned to Georgian Bay. If these birds returned to their former colonies by the time the disturbance was initiated, this would present an opportunity to measure the response of the birds not subject to within-year surgical and capture trauma. Each colony received 3, 3-hour periods of equal disturbance sessions. Disturbance consisted of firing small fireworks above the colony at a distance of approximately 100 m. Fireworks were fired at an interval of 17 minutes and disturbance occurred anywhere between 0900-1800 hrs throughout a given day.

To analyze the individual-level responses to disturbance, movement of each individual was classified into 3 time periods; after surgery, during disturbance, and after disturbance was complete. This allowed me to determine which disturbance, harassment or surgery, caused these birds to abandon their colony if abandonment occurred (Table 2.3). If a bird left its colony of capture and did not return during any of these three periods, I considered it abandonment. If a bird abandoned its colony and moved outside of Georgian Bay, I considered it a long distance movement. Surgical abandonment was defined as any bird that abandoned its colony after the surgery, but before disturbance began. Disturbance abandonment was defined as any bird that remained after surgery but abandoned its colony during the disturbance treatments, or within one week after the final disturbance treatment was completed. I monitored all remaining birds for any movement that occurred until the end of September when migration was most likely to start; however, these birds were not considered to have abandoned their colonies if they did relocate well after the disturbance period.

2.3.6 Colony Census

In 2007, 11 colonies were photographed, and in 2008, photographs were taken of 18 colonies. Color, digital photographs were taken from a Cessna Aircraft at a height of 500 m above the colony, which caused no apparent disturbance to the nesting birds, on clear sunny days. In 2007, control colonies were chosen at random before I had any observations that suggested that there could be a relationship between proximity and disturbance. The increase in the number of colonies in the second year was to get a more complete understanding of movement between colonies influenced by disturbance by providing a greater range of distances among colonies. In 2008, control colonies occurred at varying distances (from < 1 km to > 10 km) to colonies that were disturbed, and the distance between the farthest two colonies was 56.3 km.

Pre-disturbance photographs were taken in both years before any of the study colonies were visited, and when I believed the majority of experienced breeding birds would have been settled and incubating (the dates were 15 May 2007 and 10 May 2008). In 2007, the second set of photographs was taken on 16 June, 3 days after final disturbance, and in 2008, the second set of photographs was taken on 25 May, 4 days after treatments ceased. A slight change in the timing of disturbance by three weeks allowed me to ensure disturbance of colonies before hatch in 2008. In 2007, two of the colonies that were disturbed, GB 6 and GB 12.1, had large and small chicks respectively, by the first week of June.

Changes in the number of nesting adults on each colony were measured from the photographs. Each picture was taken at a resolution that clearly defined any empty nests, which were counted as abandoned. Only birds that were sitting on nests were included in the census. The number of gulls on each colony was also counted and used as an

indication of the potential predation pressure. The distance between each undisturbed colony and the nearest disturbed colony were also measured.

2.3.7 Gull Predation

To measure gull predation, 30 cormorant nests were randomly selected, by means of a random numbers sheet, on each of the disturbed colonies, and the number of eggs and chicks were recorded in each nest before and after each disturbance treatment. The number of gulls was also recorded during disturbance and in photographs to get an indication of potential predation pressure. In the case of colony GB 18 where counting gulls was too difficult, the number of gulls was calculated by counting individuals in a smaller section of the photograph, which was then used to estimate an overall abundance of approximately 5000 individuals. A disturbance session consisted of an initial tally of the 30 study nests, a disturbance every 17 minutes over three hours, and a final tally of the 30 nests at the end. Aside from the tally of the 30 nests, all observations and disturbance procedures were done in the concealment of a blind to minimize visual disturbance. Predation was noted if broken eggs were found in a nest following predation, or if small chicks that were not yet mobile were missing. Larger chicks, which are known to wander (Hatch and Weseloh 1999), were searched for in the general area if they were not present in the nest following disturbance. Predation was also monitored for during our arrival and departure.

2.3.8 Statistical Procedures

Pre- and post-disturbance nest numbers were compared for each treatment type using paired t-tests to determine if significant changes occurred. Regressions between

pre- and post-disturbance nest numbers were also estimated to test for 1:1 correspondence between the variables present. Akaike's Information Criterion corrected for small samples (AICc) was used to evaluate models that explained the changes in the number of nesting adults between pre- and post-disturbance photographs on all colonies. The model selection incorporated the following independent variables: proximity of the colony to the nearest disturbed colony, the number of gulls counted on the disturbed colony, and whether or not each colony was disturbed (Y = disturbed, N = undisturbed), or trapped (Y = trapped, N = not trapped) and the response variable was the percent change in the number of nesting adults. All undisturbed colonies were compared based on their distance to the nearest disturbed colony. A total of 8 models was considered using linear regression including: a global model that included all parameters, whether a colony was disturbed, whether a colony was trapped, the number of gulls, proximity to the nearest disturbed colony, disturbed plus the number of gulls, interaction between disturbed and the number of gulls, and disturbed plus proximity. These models were chosen because I believed they were all contributors to a bird's decision to abandon, but I believed that the combinations between disturbance and proximity and number of gulls would likely yield the strongest results. Each of these models was assessed using AICc to determine which of the three parameters and models had the best ability to explain changes in the abundance of nesting adults. Importance weights were calculated using the models that consisted of 95% of AIC weights. These models were in turn used to calculate a combined model that best explained the response variable.

2.4 Results

2.4.1 Individual Level Response

In 2007, 3 of the 14 birds equipped with transmitters abandoned due to surgery alone (i.e., before disturbance), and 3 birds abandoned due to disturbance (i.e., returned after surgery but left after disturbance). All of the birds that abandoned belonged to either GB 12.1 or GB 19, which were disturbed at early nesting stages, and were highly susceptible to nest depredation by gulls. Six of the 8 birds that remained on their capture colonies belonged to GB 6 and likely did not abandon due to the disturbance because of the later nesting stage of the colony, i.e. large chicks were present. The remaining 2 birds that did not abandon belonged to GB 12, which also had some hatching occur before disturbance treatments. In 2008, 2 of the 7 birds on disturbed colony GB 15 abandoned due to surgery, and 2 more abandoned after disturbance. Five of the 7 birds with PTTs on undisturbed GB 7 abandoned the colony immediately after surgery.

Including all 28 birds over the 2 years, 17 abandoned their colonies due to all causes, of which 11 abandoned due to surgery (39.3%). One of these birds, ID #74298, did not actually abandon its colony during the first week after surgery; however, because it did abandon its colony in the time between surgery and before disturbance, it was included in the surgery group as an exception. Of the 21 birds with transmitters on colonies that were disturbed, 9 birds did not abandon their colony (42.9%) and 12 abandoned due to either surgery or disturbance (57.2%). Of the 12 that abandoned, 6 did so after surgery but before disturbance treatments (28.6%), and 6 abandoned just due to disturbance (28.6%). These assignments of cause to either surgical or disturbance stress were determined by looking at the exact dates they left their colonies (Table 2.4). Of the

17 birds that abandoned their colony, 11 (64.7%) traveled large distances outside Georgian Bay, whereas the remaining 6 (33.3%) stayed within Georgian Bay and moved to a nearby colony. Two birds (74302 and 81062) traveled to the regions of Montreal and Niagara, respectively, immediately after their surgery was completed but continued to travel widely among 4 different locations (Figure 2.3), whereas birds 74298, 74303, 81059, 81068, and 81071 moved to the nearest undisturbed colony in Georgian Bay (Table 2.5). These colonies were within 10 km of their previous colony, and these birds remained in GB until the start of fall migration. Two additional birds (81060 and 81064) made long distance relocations later in the summer after nesting around the end of July; however these were unrelated to disturbance (Table 2.5).

2.4.2 Colony Level Response

In 2007, disturbed colonies GB 6, GB 12.1, and GB 19 showed the greatest loss of nests (12.9 %, 83.7%, and 100%, respectively) (Table 2.6). Of the 3 colonies that were only trapped, GB 20 showed a large loss of nests (85%), GB 15 had a loss of 1.5%, and GB 9 had a 33.1% increase. With regard to proximity, GB 12.2, which was <100 m from disturbed colony GB 12.1 showed an increase in birds of 32%; GB 18.3, which was just over 1 km away from disturbed colony GB 19, showed a loss of 10.5%. Colonies at greater distances, such as GB 23 at 13.5 km and GB 5 at 19.7 km, from the nearest disturbed colonies showed a loss of 1.5% and a gain of 26.1% respectively. There was no obvious relationship between proximity and disturbance since colonies both near and far showed gains and losses in birds (Table 2.7).

Plots of the pre-disturbance nest count versus the post-disturbance nest counts of each colony over both years, irrespective of treatment, indicated that there was a

significance in the number of nests ($R = 0.96$, $SE = 36.21$, $P < 0.05$)) (Figure 2.4). There was significant difference between pre- and post-disturbance nest numbers for disturbed colonies ($t = 2.50$, $d.f. = 5$, $P = 0.03$), but not for trapped colonies ($t = 0.54$, $d.f. = 6$, $P = 0.31$), or control colonies ($t = -1.75$, $d.f. = 15$, $P = 1.76$). Trapped and control colonies showed almost perfect, significant relationships between pre- and post-disturbance nest numbers in regressions ($R = 0.968$, $SE = 40.39$, $P < 0.05$, and $R = 0.10$, $SE = 10.27$, $P < 0.05$) with only trapped colonies indicating a slight decrease in nest numbers (Figure 2.5). All disturbed colonies indicated decreases with all points beneath the 1:1 line, and no relationship was apparent between the pre- and post-disturbance nest counts ($R = 0.51$, $SE = 41.41$, $P = 0.30$) (Figure 2.5). The proximity of the colony had no relationship to the overall percent change in nest numbers. Colonies at both close and far proximities to disturbed colonies gained or lost birds (Table 2.6).

The relationship between gull predation and disturbance was variable between years, and appeared related to nest stage. In 2007, the amount of predation that occurred was highly dependent on the nest stages of the 3 colonies. GB 6, which had mostly large chicks in the nests had only 10.0% predation in the sub-sample of nests. GB 12.1 nests ranged from eggs to large chicks and had 43.3% predation, and GB 19 only had eggs and suffered 100% predation. In 2008, disturbance occurred when all three colonies had eggs. Predation on these colonies was relatively high ranging from 40.0-70.0% (Table 2.7).

In 2007, GB 6 had little abandonment associated with disturbance (12.9%), whereas higher abandonment occurred at GB 12.1 (83.7%) and GB 19 (100%) which experienced higher predation. This pattern between nest stage (particularly egg) predation, and abandonment is not as clearly defined in 2008. Colonies GB 15 (19.1%),

GB 12.1 (24.1%), and GB 9 (28.7%) experienced less abandonment although relatively high predation occurred (Table 2.7).

Model selection demonstrated that colony response to disturbance was best represented by an interaction between disturbance status and the number of gulls on a colony (Table 2.8). The Disturbed parameter had 1.11 times the ability to predict colony response than number of gulls. The top ranked model suggested that when cormorant colonies containing gulls are disturbed, nest predation occurs, leading to a loss of nesting adults (Table 2.9).

2.5 Discussion

2.5.1 Individual-level Response

The majority of PTT-implemented birds appeared to abandon their nests and colonies apparently due to the stress related to the surgery and before any control-mimicking disturbance treatment was applied. This indicated that the use of internal PTTs may have behaviour-altering effects that must be considered by anyone wanting to use these devices. Nevertheless, the movements between Georgian Bay colonies and the other Great Lakes shown by the PTT-marked birds following the various disturbances in this study suggest that it is possible that Georgian Bay nesting birds belong to a larger metapopulation. Unfortunately one of the true measures of a metapopulation is reproduction after dispersal (Esler 2000); however because I did not actively search for these birds after their dispersal to observe them breeding I can only assume that they may have. Abandonment did occur early enough in the breeding season to still allow for a

successful breeding attempt; however it cannot be stated for certain that a metapopulation exists without observing such breeding attempts. In regards to management however, these results do support the idea that management of Georgian Bay cormorants may not be successful due to the capability of these birds to disperse throughout the Great Lakes. The second hypothesis that gull predation would be facilitated by disturbance, and that depredation in turn would influence the abandonment rate of cormorants was however supported.

The movement among colonies and lakes in response to disturbance suggested that cormorant colonies throughout the Great Lakes are connected. The disturbance in this study was intended to resemble lethal management practices only with respect to the level of activity, not in removal of birds from the pool of potential dispersers. It also mimicked disturbance associated with repeated visits for egg-oiling or other forms of management through disturbance by my repeated visits to initially capture the birds to implant the PTTs, and then for 3 subsequent visits for disturbance. Assuming that Georgian Bay cormorants belong to a metapopulation, there is a high probability that sub-lethal disturbance will cause them to redistribute elsewhere with unintended consequences at those new locations. The results show therefore that there is the potential for this type of approach to be ineffective both in reducing population size and mitigating conflicts with other resource users.

Other waterbird studies that have observed individuals emigrating to nearby colonies or populations in response to culling have concluded that metapopulations exist (Bosch et al. 2000, Pope et al. 2007, Henaux et al. 2007). When Yellow-legged Gulls were culled in a single gullery, immigration and emigration between nearby gulleries were influenced. After the cull was finished, empty nesting areas were immediately filled

by new breeders (Bosch et al. 2000), The numbers of non-breeders and immigrants available to fill this new, artificial dispersal sink created by removing animals from the area was unanticipated (Dobson 1981). This response has also been observed in African elephants (*Loxodonta africana*) where lethal management increased immigration into culled areas. Movement of disturbed elephants post-cull demonstrated that the culled population of elephants belonged to a metapopulation (Chamille-Jammes et al. 2008).

In some cases certain measures may be necessary to relieve density-dependent factors that may be affecting the overall health of a population and its ecosystem. Although this appears to solve the problem in the short-term, long-term effects of this type of density- dependent release can cause the population to rebound by increasing reproductive success. Not only can it open up nesting sites for new breeders (Duerr et al. 2006, Ellis and Elphick 2007), but it can also improve body conditions and increase body weight of surviving adults, increase egg and clutch size, and allow for a reduction in the age of recruitment through increased availability of resources (Bosch et al. 2000). In conjunction with increased immigration to new sites, this can lead to rapid increases in population. In the first six years after the cull was ceased, African elephant numbers increased at rates that were higher than ever observed before (Chamille-Jammes et al. 2008). If we look at the history of the recovery of the cormorant in North America, after they were released from persecution and the effects of DDE, the population in the Great Lakes went from 150 pairs in 1972 (Stapanian 2002) to more than 22,997 pairs in 2003 in Lake Huron alone.

2.5.2 Colony-level Response

Comparison of the pre- and post-disturbance photographs of each colony suggested that there was no relationship between proximity to a disturbed colony and gain in nesting birds on nearby undisturbed colonies, or between trapping and abandonment, but that there was an interactive effect between disturbance and gull abundance on colony-level abandonment and significant abandonment caused by disturbance treatments.

Based on the photographic evidence, it appears that the proximity of an undisturbed colony to a disturbed colony is not a determinant of where displaced birds will relocate. Although some close undisturbed colonies did experience a large gain of new nesting birds after the disturbance treatments, some did not. However, this could also mean that the birds that abandoned were only absorbed by the colonies that gained nests. If so, the other colonies, regardless of proximity, would not show gains. Also, abandoning birds may have relocated to colonies not included in the study, or outside of Georgian Bay. This movement was also observed in our marked birds, some of which remained in Georgian Bay while others went well outside of the study area. Also, in a few cases, colonies over 10 km away received new birds as well, but these birds may not have originated from the disturbed colonies to begin with. The results of the trapping treatment that was used to isolate handling effects (without surgical treatment) also indicated no clear relationship, as these colonies showed both increases and decreases in the number of nesting birds post-trapping as well. All of the disturbed colonies however, experienced significant decreases in numbers of nesting birds, which showed that disturbance at a colony-level will cause redistribution of birds.

These changes in nesting birds were also reflected in the AIC model selection, which suggested that changes in the number of nesting birds was best represented by the interaction between whether or not a colony was disturbed and the number of gulls on a colony. Assuming that the number of gulls indicates the degree of potential predation on a colony, this observation supports my second hypothesis that predation will be facilitated by disturbance and will influence the probability of abandonment. Large gulls are well-known predators of eggs and chicks of various species of colonial birds, including cormorants, and it is well documented that predation has a substantial effect on nesting success and population dynamics of their prey (Guillemette and Brousseau 2001).

Predation on disturbed colonies was varied over both years. Other studies have noted that predation by gulls will increase when a disturbance causes adults to leave their nest. Duerr et al. (2006) observed on Lake Champlain that oiling eggs during daylight hours increased the amount of gull predation that occurred in the cormorant colony. In this study, it is unclear why the predation rates were so varied from colony to colony, although gull abundance is part of the explanation. If severe enough, predation can cause the complete abandonment of a colony as it did with GB 19.

Gulls can have a huge impact on the breeding success of waterbird colonies even when they are in low densities. For example, the dynamics between American Oystercatchers (*Haematopus palliatus*) and gulls shows that predation of eggs and chicks has been the major cause of breeding failure by oystercatchers (Harris and Wanless 1997). When gulls were culled on these colonies, the number of Oystercatcher breeding immediately increased however, breeding success remained low due to predation by the gulls that were still present. Only in areas where gulls were removed completely did oystercatcher breeding success improve, which suggests that even low densities of gulls

can inflict significant damage (Harris and Wanless 1997). This is an important observation for Georgian Bay where gulls nest in low densities on most cormorant colonies. They can still destroy an entire colony as they did at GB 19 when given the opportunity via the disturbance activity. The whole purpose of disturbing the birds was to mimic the same kind of “shock” the birds would experience during a cull. My disturbance, which did mimic a cull, increased predation rates and caused cormorants to abandon their colony. Thus, any management, or scientific study, that scares adults away from their nests could have the same results.

However, what the regression model failed to show, and what the photographs clearly indicated, was that the rates of abandonment at the colony-level were quite different each year. One important factor that must be considered is that nesting stages at which the birds were disturbed differed between 2007 and 2008. In 2007, colony level abandonment was much higher than 2008. In 2008, birds were harassed three weeks earlier, all during the egg stage. This gave these birds an opportunity to remain on their colony and re-lay eggs and still have ample time to raise a successful clutch. In 2007, two of 3 these colonies, GB 6 and GB 12.1, were in the hatching stage or had already had hatched chicks, meaning the chances of birds remaining on their colony and still producing a successful clutch after losing the first was much lower. GB 6, however, which showed a 12.7% loss of nesting birds had much larger chicks compared to GB 12.1 with 85.0% loss of nesting birds, and therefore the incentive for adults to stay seemed much higher. This may be why so many birds remained on this colony. Young cormorants are also very sensitive to disturbance, especially during the first two weeks of their life before they are able to begin thermoregulation. Flushing of adults from the nests during this time can expose young chicks to extreme temperatures, either hot or cold,

which can kill small chicks within 11 minutes (Hatch and Weseloh 1999). It is likely there was such a large abandonment on GB 12.1 because the chicks were too small to thermoregulate and died before adults had a chance to return to their nests. On GB 6 however, the chicks were much larger, feathered with down, and able to survive without their parents during the disturbance treatments, therefore these birds had no reason to abandon their colony. It seems therefore that timing of disturbance in relation to nesting stage is a strong determinant of whether or not a bird will abandon its colony.

2.5.3 Considerations

Internal transmitters were used instead of externally attached devices because the latter have been documented to cause weight loss, abnormal behaviour and increased water drag in diving birds (Latty 2008). Also, there is difficulty attaching the devices to cormorants due to their diving habits (King et al. 2000). Although internal devices are preferred in diving birds, one study showed that captive Common Eiders (*Somateria mollissima*) implanted with these transmitters experienced increased lethargy, plumage wetting at incision sites, and decreased dive speeds for up to three months post surgery (Latty 2008). Although 11 of my study birds abandoned their colony apparently due to the trauma of handling and surgery, it is unclear whether these individuals experienced any of these other symptoms as well. Because 100% of these individuals survived through the surgery and the following months, and indicated high activity levels, I do not believe that these implants had any serious physiological effects. In fact, one bird (74299) was shot in February 2008 on an aquaculture facility and recovered during a night roost harassment program carried out by the US Fish and Wildlife Services (USFWS). USFWS officials performed a necropsy of the bird, which indicated that no

internal damages or infections were sustained from the transmitter, and that the external antennae whip had healed without any abrasion to the skin.

My conclusion that the Georgian Bay cormorant colonies could belong to a Great Lakes metapopulation is based on the movements of only 15 birds. As the cost of telemetry studies is so high, small samples are often used to describe distributional patterns of an entire population (Lindberg and Walker 2005); however, this practice has limitations. The purpose for looking at responses both at an individual-level and a colony-level response was to supplement the small transmitter sample sizes used to make inference of the population's response to disturbance with other data representative of birds in a state similar to the majority of the population (i.e., those unmarked). Furthermore, birds with transmitters received a different treatment than the rest of the population (e.g., trapping and surgery to implant the transmitter) that could potentially affect their survival, migration, and behaviour (Lindberg and Walker 2005) and diving. Although short-term survival was apparently unaffected, 11 (39.3%) of the PTT marked birds abandoned their colony immediately after they were released. Thus it is clear that the trauma from the capture and surgery alone can have significant effects on the outcome of any study.

Responses of birds to trapping have been variable in other studies. Mazzocchi (2003) only had 10% of 40 birds that were trapped and equipped with harnessed transmitters abandoned the study colony, whereas Werner et al. (2001) had 32% of 25 birds abandon after experiencing the same trauma. Surgery and handling adds another treatment variable that we now know needs to be considered.

Aerial photographs that were taken to compare nesting populations on each colony before and after disturbance occurred can also have limits. Colonies are dynamic

populations that are subject to natural fluxes in the number of birds as prospecting individuals come and go daily (Bedard et al. 2005). These pictures only represent a snapshot in time. In this study, an attempt was made to control this effect by conducting the counts early in the breeding season when only experienced breeders should be present, as well as by counting only birds that were clearly sitting on nests. However, these photographs represent movement only at a local-scale within Georgian Bay and do not contribute to the question of whether these birds are part of a metapopulation.

2.5.4 Conclusions

There was a clear response to disturbance at the colony level. Each of the 6 colonies that were disturbed experienced a significant decrease in nesting birds. Although some birds may have relocated to nearby undisturbed colonies, individual responses indicated that most birds moved long distances and settled throughout the Great Lakes, supporting the hypothesis that cormorants in Georgian Bay could be a part of a metapopulation. Gull predation was facilitated by disturbance and influenced abandonment on colonies. The timing of any disturbance relative to the stage of breeding phenology can also influence whether or not birds will abandon a colony. Birds were more likely to abandon their colony if their nests were lost through predation or exposure, except colony GB 6 in 2007 where chicks were large enough to survive without their parents. As their chicks were not lost, the parents had more incentive to stay. This was quite different from birds that were disturbed earlier in 2008. I had assumed that the predation would be high on these colonies and birds would abandon as they did on GB 19 in 2007. However, because it was so much earlier, it is possible they were more likely to remain because they still had a chance to re-lay and produce a successful clutch within

that season. This is an important consideration if disturbance is to be used as a means to remove cormorants from a specific area. Finally, the use of internal PTTs may affect the behaviour of individuals implanted with them and that can affect the results of a particular study, depending on its objectives. For example, if we were trying to look at the foraging area of cormorants specifically in Georgian Bay, we would have lost the results of 11 birds after they relocated outside of the study area following their surgeries. Therefore, such changes in behaviour must be considered carefully before using this equipment.

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2.7 Tables and Figures

Table 2.1. Colonies included under each treatment with their respective number of birds with transmitters and bands.

2007			
Treatment	Number of Colonies	Number of Transmitters	Number of Banded Birds
Disturbed Transmitters	3	14	0
Trapped	3	0	22
Control	5	0	0
2008			
Disturbed Transmitters	1	7	0
Control Transmitters	1	7	0
Disturbed	2	0	0
Trapped	3	0	9
Control	11	0	0

Table 2.2. Duty-cycle of the platform terminal transmitters implanted in 28 Double-crested Cormorants to monitor movement in response to disturbance.

Time	On/Off Duty Cycle
Breeding Season (May to August)	On 4 hrs per 23 hrs
Fall Migration (September to November)	On 4 hrs every three days
Winter Roosting (December to February)	On 4 hrs every week
Spring Migration (March to April)	On 4 hrs every three days

Table 2.3. Time frames used to determine whether birds abandoned their colony due to the effects of the surgery or disturbance.

Activity	2007 Time Frame	2008 Time Frame
Surgical Response	May 19 – June 9	May 12-15
Disturbance Response	June 9-20	May 15-28
Breeding Season	May 1 – September 30	May 1 –September 30

Table 2.4. Dates of departure and dates of disturbance in relation to disturbance treatment and surgery among birds that abandoned their colonies. Bird 74298 with an * did not abandon in the week following surgery, however, it abandoned before disturbance began. Birds from GB 7 that abandoned did not receive any disturbance treatments.

Bird ID	Colony	Sex	Date of Surgery	Dates of Disturbance	Departure Date	Cause
2007						
74294	GB 12	M	19-May	June 9-13	14-Jun	Disturbance
74295	GB 12	M	19-May	June 9-13	19-May	Surgery
74296	GB 19	M	2-Jun	June 9-13	5-Jun	Surgery
74297	GB 19	M	2-Jun	June 9-13	11-Jun	Disturbance
*74298	GB 12	F	19-May	June 9-13	2-Jun	Surgery
74301	GB 19	M	2-Jun	June 9-13	12-Jun	Disturbance
74302	GB 12	M	19-May	June 9-13	21-May	Surgery
74303	GB 12	F	19-May	June 9-13	13-Jun	Disturbance
2008						
81058	GB 15	M	12-May	May 15-21	17-May	Disturbance
81059	GB 15	M	12-May	May 15-21	20-May	Disturbance
81061	GB 15	F	12-May	May 15-21	12-May	Surgery
81062	GB 15	M	12-May	May 15-21	12-May	Surgery
81065	GB 7	F	13-May	---	13-May	Surgery
81066	GB 7	M	13-May	---	14-May	Surgery
81067	GB 7	F	13-May	---	16-May	Surgery
81068	GB 7	F	13-May	---	15-May	Surgery
81071	GB 7	F	13-May	---	16-May	Surgery

Table 2.5. Movements of birds that abandoned their colonies after disturbance or surgical procedure (female denoted with a *). Birds 81060 and 81064 left their colony over a month after the surgical procedure and are therefore not classified as abandoning due to surgery.

Bird ID	Colony	Cause of Abandonment	Location	Distance from Colony (km)	Date
74302	GB 12	Surgery	Montreal	508.8	25-May-07
			St. Lawrence	323.9	13-Jun-07
			Presqu'île PP	251.3	21-Jul-07
			Cobourg	212	22-Jul-07
81062	GB 15	Surgery	Lake Simcoe	127	20-May-08
			Niagara	263.1	26-May-08
			S. shore L.ON	245.7	30-May-08
			Toronto	186.8	6-Jun-08
81060	GB 7	-----	Lake Simcoe	119.6	24-Jul-08
			Little Galloo Is.	270.4	5-Aug-08
74296	GB 19	Surgery	St. Lawrence	378.7	11-Jun-07
74295	GB 12	Surgery	North Bay	118.8	25-May-07
			North Channel	216.5	31-May-07
81064	GB 7	-----	Lake Simcoe	116.3	26-Jul-08
			Glenora	199.3	26-Aug-08
81066	GB 7	Surgery	Lake Muskoka	85.6	14-May-08
			North Bay	122	18-May-08
74301	GB 19	Disturbance	Lake Simcoe	131.5	13-Jun-07
74294	GB 12	Disturbance	Lake Muskoka	71.3	14-Jun-07
74297	GB 19	Disturbance	Parry Sound	23.2	10-Jun-07
81058	GB 15	Disturbance	GB 16	5.3	17-May-08
81059	GB 15	Disturbance	GB 16	5.3	16-May-07
Mean [SE]				331.9 [110.4]	
*81061	GB 15	Surgery	Lake Simcoe	112.3	15-Jun-08
*81067	GB 7	Surgery	North Bay	124	29-May-08
*81065	GB 7	Surgery	Lake Simcoe	76.9	30-May-08
*81068	GB 7	Surgery	GB 16	20	25-May-08
*74303	GB 12	Disturbance	GB 15	9.6	15-Jul-07
*81071	GB 7	Surgery	GB 9	7.1	21-May-08
*74298	GB 12	Surgery	GB 9	1.2	7-Jun-07
Mean [SE]				50.2 [20.0]	

Table 2.6. Study colony characteristics, including treatment categories and their response to disturbance measured by the number of cormorants pre- and post-disturbance (Double-crested Cormorant = DCCO). Proximity of undisturbed and trapped colonies to the nearest disturbed colony is shown, as well as the number of gulls observed on each colony from the pre-disturbance photographs. Colonies preceded by “a” were used in 2007.

Colony	Disturbed	Trapped	Proximity (km)	Number of Gulls	Number of DCCO Pre	Number of DCCO Post	% Change in Nests
GB 6a	Y	N	0	11	147	128	-12.9
GB 12.1a	Y	N	0	28	92	15	-83.7
GB 19a	Y	N	0	33	145	0	-100
GB 15a	N	Y	9.4	20	262	258	-1.5
GB 20a	N	Y	5.5	2	60	9	-85
GB 22a	N	Y	5.7	42	52	64	23.1
GB 7a	N	N	6.8	5	416	424	1.4
GB 9a	N	N	1.1	27	114	111	-2.6
GB 12.2a	N	N	0.0	10	25	33	32
GB 18.1a	N	N	2.1	14	100	101	1
GB 18.3a	N	N	1.1	9	38	34	-10.5
GB 7	N	Y	6.8	41	438	379	-13.5
GB 9	N	Y	1.1	49	151	201	33.1
GB 18.1	N	Y	2.1	23	62	67	8.1
GB 20	N	Y	5.5	7	46	40	-13.0
GB 6	N	N	14.4	8	136	126	-7.4
GB 12.1	Y	N	0	11	58	44	-24.1
GB 15	Y	N	0	47	168	136	-19.0
GB 19	Y	N	0	33	87	62	-28.7
GB 4	N	N	19.7	34	0	0	0
GB 5	N	N	18.9	53	111	140	26.1
GB 8	N	N	6.8	4	0	0	0
GB 10	N	N	1.0	2	0	0	0
GB 17	N	N	12.9	84	53	64	20.8
GB 18	N	N	7.8	5000	433	462	6.7
GB 18.3	N	N	1.1	12	41	45	9.8
GB 22	N	N	5.7	30	38	43	13.2
GB 22.1	N	N	6.4	2	45	48	6.7
GB 23	N	N	13.5	40	326	321	-1.5

Table 2.7. Overall colony abandonment due to disturbance (D), and due to predation (P). Predation abandonment is based on the randomly sampled 30 nests that were observed during disturbance treatments.

Colony (2007)	Percent Abandonment	Colony (2008)	Percent Abandonment
GB 6	-12.9% (D) -10.0% (P)	GB 15	-19.1% (D) -70.0% (P)
GB 12.1	-83.7% (D) -43.3% (P)	GB 12.1	-24.1% (D) -53.3% (P)
GB 19	-100% (D) -100% (P)	GB 19	-28.7% (D) -40.0% (P)

Table 2.8. AICc calculations leading to the model that best describes the % Change in Nests.

Model	K	RSS	AIC	AICc	ΔAIC	$\exp(-0.5 \cdot \Delta AIC)$	AICw
Disturbed x Gulls	3	16160.6	189.37	190.33	0	1	0.8126
Disturbed	3	18774.3	193.72	194.68	4.35	0.1138	0.0924
Disturbed + Gulls	4	17551.8	193.76	195.43	5.1	0.078	0.0634
Disturbed + Proximity	4	18772.3	195.71	197.38	7.05	0.0294	0.0239
Trapped + Proximity + # Gulls + Disturbed	6	16586.7	196.12	199.94	9.61	0.0082	0.0066
Proximity	3	26662	203.89	204.85	14.52	0.0007	0.0006
Trapped	3	29188.9	206.51	207.47	17.15	0.0002	0.0002
# Gulls	3	28414.8	205.73	206.69	16.37	0.0003	0.0002

Table 2.9. AICc importance weights of the parameters that best explain the % Change in Nests, as well as the final model with coefficients.

Parameter	Disturbed	Disturbed x # Gulls	Disturbed + # Gulls	Importance Weights
Disturbed	0.0924	0.8126	0.0634	0.9684
# Gulls	0	0.8126	0.0634	0.8760
Combined Model with Coefficients [SE]				
% Change = -11.73 [1.80] + (Disturbed) 25.06 [6.81] + (# Gulls) 12.02 [2.73]				

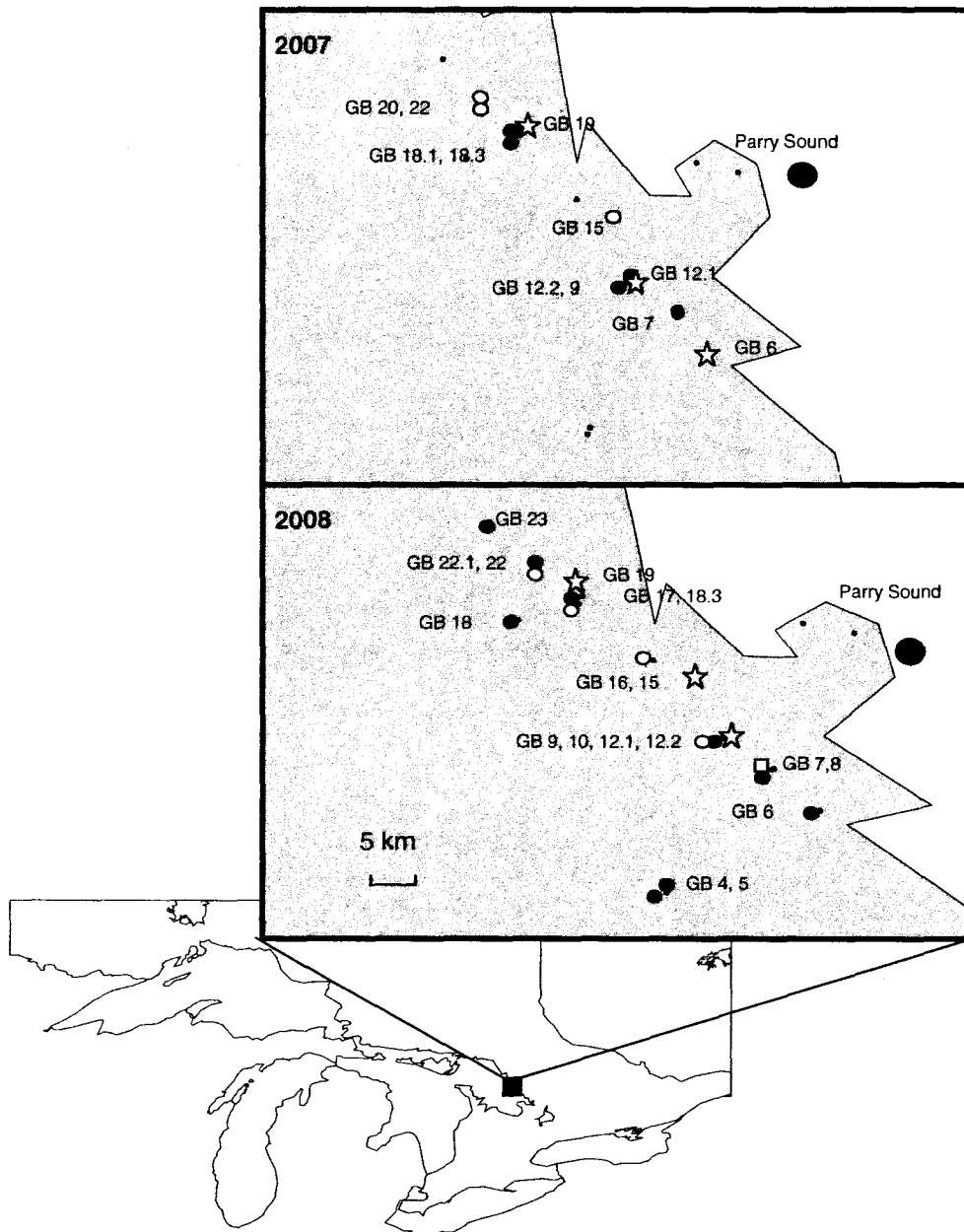
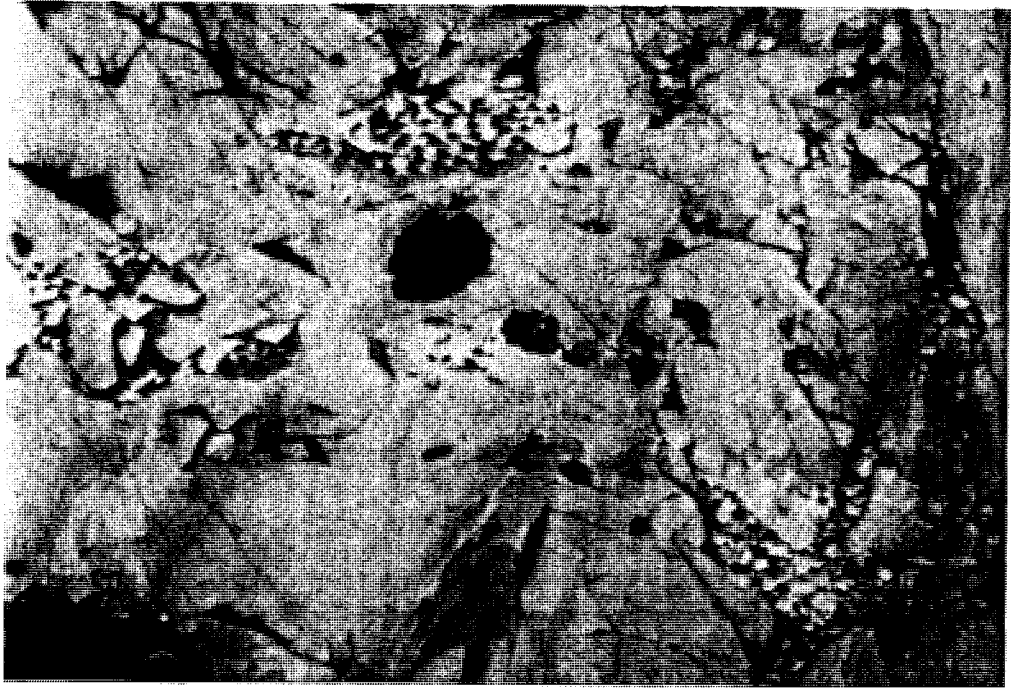


Figure 2.1. A map showing the study area in Georgian Bay in relation to the Great Lakes. Colonies included in this study can be seen in the area surrounding Parry Sound with stars representing disturbed colonies, white dots representing trapped, white squares representing control transmitters, and black dots representing control colonies.

(a)



(b)



Figure 2.2. Pre- and post-disturbance aerial photographs of colony GB 19 used to compare change in the number of nesting adults. Empty nests in post-disturbance photographs were considered abandoned, and all gulls were recorded as well. The (a) is the pre-disturbance photograph; (b) is the post-disturbance.

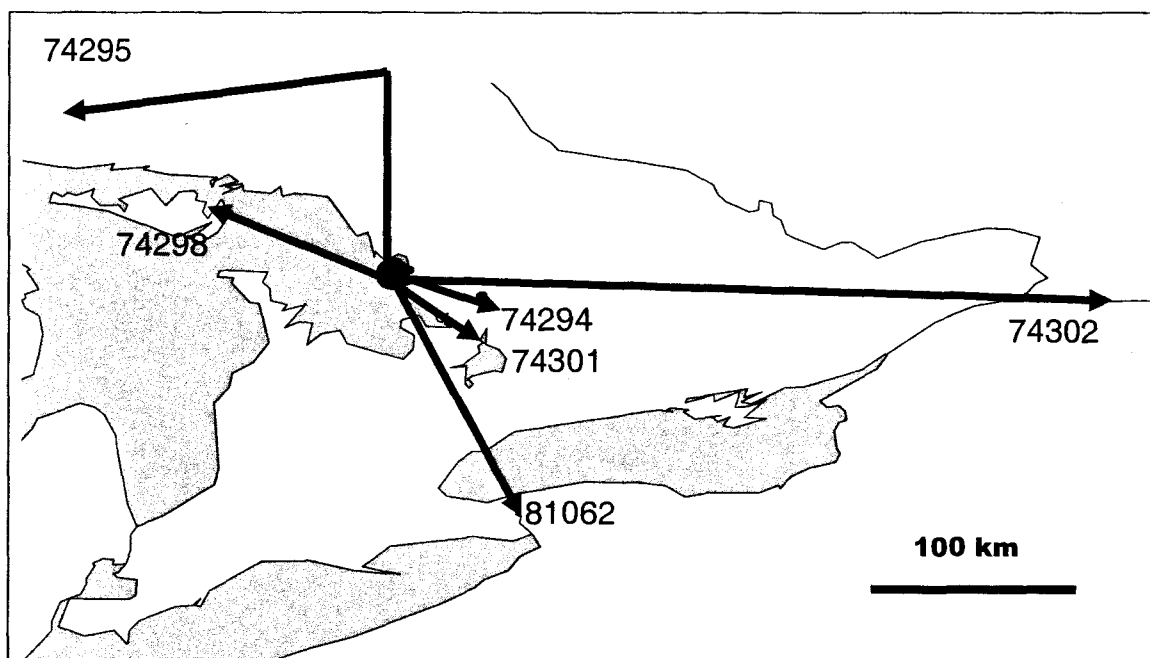


Figure 2.3. The movement of 6 implanted birds following surgery or disturbance indicating movement both within Georgian Bay and throughout the Great Lakes region. Movement occurred within 3 weeks of implant. Numbers represent individual's ID numbers.

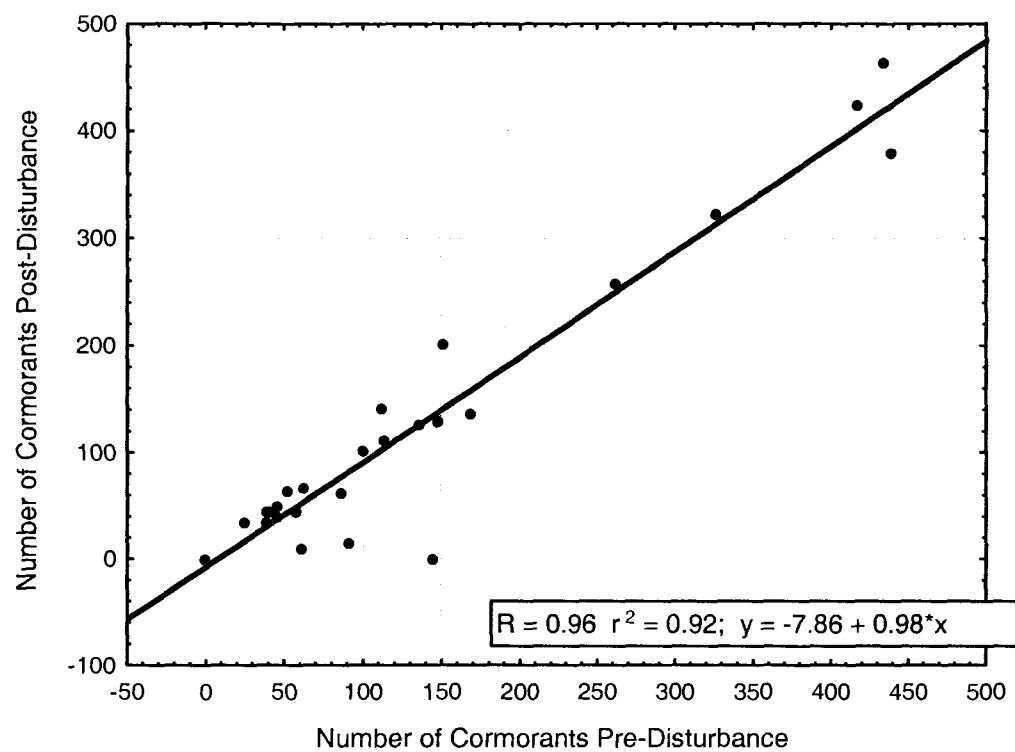


Figure 2.4. The relationship between the number of double-crested cormorants (*Phalacrocorax auritus*) on colonies in Georgian Bay, Ontario, before and after disturbance ($n = 29$).

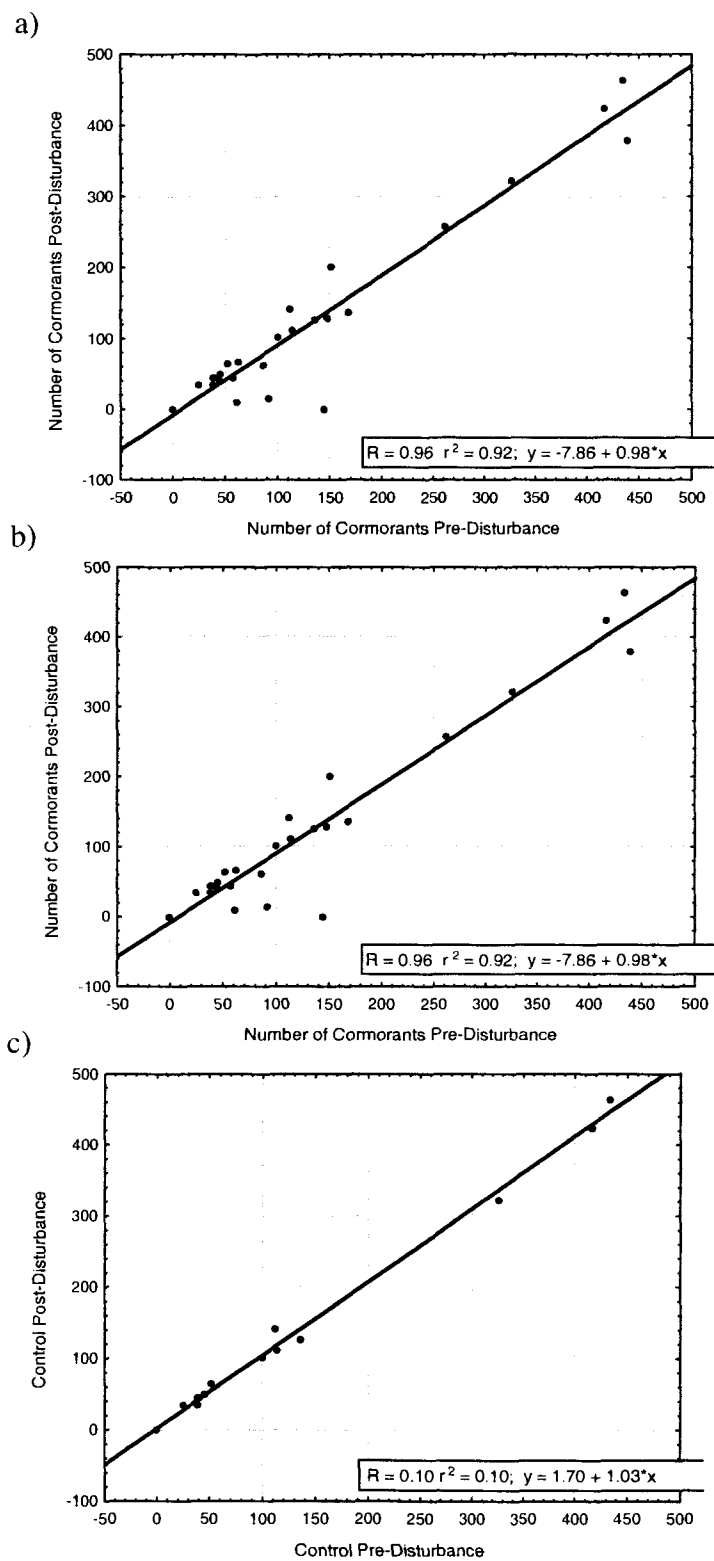


Figure 2.5. Regressions indicating the change in nest numbers from before and after disturbance for (a) disturbed colonies ($n = 6$), (b) trapped colonies ($n = 7$), and (c) control colonies ($n = 16$).

Chapter 3. Migration Routes and Winter Habitat Use of Eastern Interior Double-crested Cormorants

3.1 Abstract

Migration Routes and Habitat Use of Eastern Interior Double-crested Cormorants

Heidi Scherr

During 2007-08, 26 Double-crested Cormorants (*Phalacrocorax auritus*) from Georgian Bay were tracked from September to March to identify staging areas, identify migration routes, determine characteristics of winter habitat and winter home range size, determine philopatry of returning breeders, and test for a relationship between winter habitat type and arrival at the breeding ground. Females were found to leave the summer areas significantly earlier and spend significantly more time in the staging areas than males. Both sexes however, left the staging areas and arrived in the wintering grounds around the same time. The predominant winter habitat types were lakes and coasts with only 7 of 26 (26.9%) birds on aquaculture sites. Home ranges of birds on aquaculture sites were significantly larger than birds on non-aquaculture sites. I did not detect a carry-over effect of aquaculture; birds from all winter habitats returned north at around the same time. Fidelity to previous summer locations was observed in 6 of 9 surviving individuals.

Keywords: Migration, Double-crested Cormorants, habitat use, foraging area, home range, staging area, aquaculture facilities

3.2 Introduction

The Great Lakes breeding population of the Double-crested Cormorant (*Phalacrocorax auritus*) winters from North Carolina to the Gulf of Mexico. At the start of the fall migration in September, many birds throughout the Great Lakes begin to move into Lake Erie (Hatch and Weseloh 1999). In this area, cormorants can feed and roost in large social gatherings in what is called a staging area. Staging areas provide opportunities for birds to rest and replenish their fuel stores needed to reach their final destination (Yosef et al. 2006). In the wintering area, cormorants are found both on the coasts and inland along rivers and lakes, especially where aquaculture is prominent (Hatch and Weseloh 1999).

Over the last few decades many changes have occurred in size of the eastern population of cormorants and their habitat in the winter range. In the 1990s alone, the number of cormorants wintering in the Mississippi delta region tripled (Werner et al. 2000); however this includes birds from both the interior and eastern population. The expansion of aquaculture has influenced the explosive increase in the cormorant population throughout its range (Blackwell et al. 2002, Stapanian 2002, Dorr et al. 2004). This population increase has in turn produced a range expansion throughout both the breeding and wintering grounds (Hebert et al. 2008, Ridgway et al. 2006, Blackwell et al. 2002, Stapanian 2002, Dorr et al. 2004). Although only a small fraction of the eastern cormorant population winters inland, Christmas Bird Counts from 1959-1988 showed a significant increase of 18.7% per year in inland areas of Mississippi, and a 7.3% increase for all interior areas combined (Hatch and Weseloh 1999). Many suspect the winter survival of this species has been improved due to the expansion of the aquaculture industry in the Mississippi delta region (Blackwell et al. 2002, Stapanian 2002, Taylor

and Dorr 2003, and Dorr et al. 2004). In 2000-2001 and 2001-2002, respectively, approximately 16,500 and 22,000 cormorants were counted in winter night roosts in the primary aquaculture areas of eastern Mississippi and western Alabama (Dorr et al. 2004).

The objective of this study was to determine the migration routes, staging areas and wintering grounds used by a small group of cormorants that share a common breeding ground (eastern Georgian Bay, Ontario). The birds nesting in Georgian Bay are thought to be part of a Great Lakes metapopulation (Chapter 2); however, their cohesion among seasons (whether or not they winter in the same area), if any, is unknown. Migration routes and staging areas were not known nor was it known whether individuals wintered widely across the known range or were concentrated in specific areas or habitats. The central theme is thus an examination of different aspects of habitat selection, including 1) location of staging sites and identifying migration routes, 2) general choices of habitat, 3) home range sizes (as an indicator of area required for foraging), and 4) fidelity of returning breeders.

I also wished to examine possible cross-seasonal effects, defined as relationships between winter habitat and home range sizes, and subsequent arrival time to the breeding grounds. Early arrival time on a breeding ground is a measure of good physical condition for migrating species. This is called a carry-over effect and is highly dependent on the quality of habitat in which a bird winters (Marra et al. 1998, Norris and Marra 2007). Hebert et al. (2008) found through isotope analysis that cormorants returning to breeding grounds that fed in freshwater habitats in winter were in much better physical condition than birds foraging in marine environments. They suggested that enhanced foraging opportunities at aquaculture facilities (freshwater habitats) may improve fitness of birds feeding there. Based on these observations, I predicted that cormorants wintering on or

near aquaculture facilities would return to the breeding grounds earlier than birds wintering in other environments. Secondly, I predicted that birds wintering on or near aquaculture facilities would have smaller winter home ranges (as food density is greater there than in natural environments (Hebert et al. 2008). Dorr et al. (2004) found that birds foraging on aquaculture facilities <19 km from their winter roosts on 95% of occasions. If home range size is determined by food density, birds feeding on natural sites should have larger home ranges. Finally, I wanted to examine patterns of breeding dispersal and fidelity to a breeding site following experimental disturbance. Due to experimental disturbance in 2007 that was meant to disrupt breeding behaviour and cause colony abandonment (Chapter 2), many birds in my study had relocated to a new summer location throughout the Great Lakes. Fidelity was assessed based on the summer locations of each individual post-disturbance. Dolbeer (1991) showed with band recoveries of 3-year old breeders that distance from natal sites was a median of 25 km. Given the lack of breeding site philopatry data (Hatch and Weseloh 1999), but considering that it has been suggested to be high, I used this distance as a measure of fidelity.

3.3 Methods

Twenty-eight birds from colonies in Georgian Bay were implanted with PTTs in 2007 and 2008 for a study of responses to management disturbance (Chapter 2).

Breeding adults were captured (as described in Chapter 2) upon returning to their nests with modified and padded foothold traps designed to specifications provided by King et al. (2000). Traps were placed on the edge of a nest and anchored with two stakes driven

into the base of the nest. Victor 3.0 traps were initially used, but were replaced with smaller Victor 1.5 traps (Chapter 2).

The PTTs were made by Microwave Telemetry Inc., and had an expected battery life of fourteen months. These units were surgically implanted in the abdomen of each bird (Appendix). The battery life was expected to allow collection of location data during the initial breeding season, the subsequent fall migration and winter, and a second breeding season. I continued to monitor the 26 individuals still transmitting data throughout the fall migration and winter. Location data were received from 13 birds from spring 2007 to summer 2008, and another 13 birds from spring 2008 to winter 2009. To document fall, winter and spring locations, PTTs were programmed to transmit location information for 4 hours every 3 days from September to November, and for 4 hours per week during December to March. Duty cycles were always 1 hour less than the previous cycle so that the 4 hour on period drifted and birds are recorded at all times of day. 1 September to 31 December was assumed to encompass their fall migration and settlement in their chosen winter habitat. 1 January to mid March was assumed to encompass winter. All data from the PTTs were received and transmitted by Service Argos Inc. equipment situated on two National Oceanographic and Atmospheric Administration (NOAA) polar-orbiting satellites (Werner et al. 2001). All data received from these PTTs were sent electronically via weekly email. As I did not require locations of the birds to be at a fine resolution (e.g., at a specific colony in Georgian Bay), poorer quality data (i.e., locations with accuracy of 350 m to > 1000 m) were used as well. This provided a larger sample of location data.

Data were input into ArcView GIS 3.2 and overlaid on North American base maps to outline the migration route of each bird and its final winter destination. A central

winter location, based on a home range of all locations combined for a given individual, was input into the program Google Earth, which allowed me to zoom in on each location and get a general idea of the type of habitat each bird was using. Aquatic habitat within home ranges was classified as either natural (lake, coastal, river, swamp) or aquaculture facility. Such facilities were easy to identify.

I attempted to estimate the speed of travel per day of each bird during the migration period. As location data were not received daily in the fall, the longest distance between two consecutive points was measured and divided by the number of days it took that bird to travel between these two consecutive locations. Although this was not an accurate representation of speed, it gave a minimum estimate of how far an individual was able to travel in a given day.

I also determined when a bird left its breeding colony, when a bird left the Great Lakes area, and when it arrived at its eventual wintering location, which was identified as any wintering area where the bird remained over an extended period between December and March. The point between when a bird left its summer breeding colony or post-disturbance location and when it left the Great Lakes altogether was classified as the staging period, regardless of location. The staging site was regarded as an area where the bird remained for a number of days before initiating its migration to the winter range. These staging sites were in the Great Lakes; however, they were not the same as the summer location, and were generally a common area for many of the birds. Total migration distances from the initial point of departure to the final destination were also measured. These were calculated by taking a sum of all the segments' distances (i.e., the distance between two consecutive points of data). Any areas where birds settled for a number of days along their routes were considered staging sites. Independent t-tests were

used to determine if significant differences existed between the sexes in the time spent in staging areas, migration distances traveled, travel time, and travel speed. I used a Pearson correlation to estimate the strength of association between the amount of time males and females spent in their staging area, and the amount of time it took for them to travel to their wintering areas.

Upon reaching their winter areas, winter home ranges were estimated for the 12 remaining 2007 birds using the first transmitted location of each week in order to prevent pseudoreplication. Home ranges were estimated using 95% minimum convex polygon in ArcGIS with the Hawth's Tool extension. Mann-Whitney U-tests were used to determine whether significant differences existed between the home range sizes of birds foraging on aquaculture sites and those of birds foraging on natural sites. Home range centroids were compared among birds with a t-test to test the prediction that female birds winter farther south than male birds.

To determine whether there was a relationship between winter home range size, habitat type, and return to the breeding grounds (i.e., cross-seasonal effects), I examined arrival times at the breeding grounds in the second breeding season assuming earlier arriving birds were in better physical condition. Fidelity to capture location (assumed to be breeding location) or to 2007 summer location post-disturbance (Chapter 2) was also determined. Centroids of 2008 summer ranges were calculated for each individual and the distance was measured from the centroid to the 2007 summer location.

3.4 Results

3.4.1 Staging Sites and Fall Migration

Two staging sites were identified during this study, Long Point and Middle Island, both in Lake Erie. Seven birds stopped at both sites. An additional seven birds stopped just at Middle Island and another seven stopped just at Long Point. These 21 birds showed a funneling effect through southern Ontario and out through Lake Erie (Figure 3.1). They all initiated migration from Lake Huron, Georgian Bay or inland waters nearby, after their relocation due to the experimental disturbance study (Chapter 2). Of the remaining five birds, four began migration from east of the Bay of Quinte on Lake Ontario, where they had relocated following experimental disturbance. Three of these birds, one from Bay of Quinte, one from Little Galloo cormorant colony, and one from Montreal region, traveled along the Atlantic Coast. The fourth made a flight from Bay of Quinte through the continental interior to its winter area. The fifth bird made a flight from Muskoka Lake and traveled through the interior to its winter area (Figure 3.2).

For both years combined, the earliest date migration from staging sites began for an individual was 1 September, and the latest date was 25 October. The earliest date an individual reached its destination was 30 September, and the last date was 9 December. Over both years, females had an mean [SE] departure date of 12 September [4.29], which was significantly earlier than the males' average departure date of 7 October [3.02] ($t = -4.41$, d.f. = 24, $P < 0.05$). From the summer colony to the winter roost, the longest migration was 98 days by a female, and the shortest was 6 days by a male. The mean [SE] duration of the migration was 41.4 [4.8] days, with no significant differences between the

sexes with females arriving on average in 51.9 [8.0] days ($n = 10$), and males arriving in 34.8 [5.6] days ($n = 16$) ($t = 1.77$, d.f. = 24, $P = 0.09$).

Migration distances were estimated from the post-disturbance location (Chapter 2) to the final winter destination by calculating a sum of the segments. The mean [SE] distance that these birds traveled to reach their winter areas was 2059.7 [127.4] km, with females traveling on average 2264.0 [281.5] km ($n = 10$) and males traveling 1932.1 [106.8] km ($n = 16$) with no significant difference ($t = -0.69$, d.f. = 24, $P = 0.50$) (Table 3.1, Figure 3.3). Distances were also measured from each bird's final staging location in the Great Lakes to its winter range (Table 3.1). No significant difference in distance traveled was found ($t = -0.12$, d.f. = 23, $P = 0.90$) between males (1473.36 [131.69], $n = 15$) and females (1449.29 [139.76], $n = 10$). There was also no significant difference in the number of days en route ($t = 0.89$, d.f. = 13, $P = 0.39$) between males (14.13 [2.34], $n = 15$), and females (19 [4.91], $n = 10$); however, females (32.9 [6.08], $n = 10$) did spend significantly more days staging in the lower Great Lakes before the final travel to their winter roosts ($t = 2.13$, d.f. = 23, $P = 0.04$) than did males (17.2 [4.47], $n = 15$) (Table 3.1). No significant relationship was found between staging time and duration of migration for either sex (Female: $r = 0.06$, $P = 0.87$, Male: $r = -0.14$, $P = 0.62$). Speed of flight was calculated for each bird. Males flew a mean [SE] of 175.7 [23.5] km/d ($n = 16$), and females flew a mean of 170.7 [24.2] km/d ($n = 10$) with no significant difference between the sexes ($t = -0.46$, d.f. = 24, $P = 0.65$). The greatest overall rate of movement was 343.3 km/d by a female (Table 3.2). No significant distance was observed between the mean [SE] latitude of wintering males (30.637 °N [0.706], $n = 16$) and females (30.282 °N [0.727], $n = 10$) ($t = -0.33$, d.f. = 24, $P = 0.74$).

3.4.2 Habitat Selection

In winter, birds were spread throughout six southeastern states bordering the coast. Florida had the largest number of birds (10), followed by Louisiana (5), Alabama (4), Mississippi and South Carolina (3 each), and Georgia (1) (Table 3.2). Of the 26 birds, only 7 birds wintered in or near areas that contained aquaculture facilities. One of these 7 birds, 74299, roosted on a large river in Alabama. However, there were a few aquaculture facilities within 25 km of its location. Although it appears to be on a river, it is also possible that it may have visited the aquaculture ponds as well and therefore I included it with the aquaculture birds. The remaining 19 birds wintered in five different habitat types that were classified using Google Earth as natural habitats containing no aquaculture. Two birds roosted on rivers, 1 on swamps, 1 on an oceanic island in the Florida Keys, 8 on lakes (which included 1 golf course lake), and 7 wintered in marine areas along the coast. Clearly lake and coastal environments were used more than the other habitats such as aquaculture and river systems.

Wintering area home ranges of the 12 birds from 2007 that made the migration showed huge variances among individuals (Table 3.3). Aquaculture birds were found to have much larger home range sizes (3127.8 [2122.50] km², n = 6) than non-aquaculture birds (68.1 [37.1] km², n = 6). Using the Mann-Whitney U test to account for the heterogeneous variances, a significant difference was found between the home range sizes of aquaculture birds and non-aquaculture birds (Mann-Whitney U = 4.0, P = 0.02).

Before spring migration began in 2008, 3 of the 12 birds from 2007 stopped transmitting. Of the remaining 9 birds with active transmitters that returned to Georgian Bay, 5 wintered on natural habitats and 4 on aquaculture. I detected no difference between these 2 groups in the mean [SE] number of days to return to the breeding ground:

natural habitats (31.2 [3.3], $n = 5$) and aquaculture (42.5 [15.6], $n = 4$) ($t = -0.71$, d.f. = 3, $P = 0.53$). Arrival at the breeding grounds occurred between 17-26 April for non-aquaculture birds and from 11 April to 3 May for aquaculture birds (Table 3.3). Mean [SE] home range areas used by non-aquaculture birds (1941.1 [53.4] km², $n = 5$) during the winter were not significantly different than areas used by aquaculture birds (1702.1 [126.1] km², $n = 4$) ($t = 1.89$, d.f. = 7, $P = 0.10$).

3.4.3 Fidelity

Breeding site fidelity could only be measured for the 2007 birds. Each of the 9 birds that survived the winter returned to the Georgian Bay area in the spring and visited their capture colony for at least one day. The 3 birds from GB 6 that remained at their capture colony for the full breeding period in 2007 showed site fidelity in 2008 (Table 3.4, Figure 3.4); however, it is unknown if any of them produced a successful clutch. None of the other 6 birds remained for the full 2008 breeding season at their 2007 capture colony; however, 3 of them did show fidelity to their 2007 summer locations (Table 3.4). Bird 74295 returned within 2.7 km of its previous location in North Bay, bird 74297 returned within 20.7 km of the area north of Parry Sound, and bird 74298 returned within 5.3 km of its previous location in North Channel. Each of these locations was where the birds had moved in the previous year after they were disturbed (Chapter 2). The breeding status and success of these birds in 2008 was unknown.

3.5 Discussion

3.5.1 Staging Sites

In both years, there was a pattern of birds funneling through Lake Erie and remaining there for a day or more before continuing their journeys south. Twenty-one of 26 birds spent time in Lake Erie at either Long Point (a major migratory bird stopover site) or around Middle Island (site of a large cormorant breeding colony) between September and November.

Females left the summer areas significantly earlier, and spent significantly more time in the Great Lakes before making the final leg of their migration than did males. Much literature states that staging sites ensure maximum survival of an individual by providing time to regain fat stores (Yosef et al. 2006). This allows individuals to complete their migration without having to stop frequently to forage along the way (Weber et al. 1998). With the energetic demands of producing, incubating, and rearing chicks, one could argue that in many species, females experience more loss of body fat than do males, which would account for the longer time spent by the female cormorants in the staging sites. However, because both male and female cormorants participate equally in most nesting activities except egg-laying (Hatch and Weseloh 1999), the reason for the sex-biased staging times found is not obvious.

Staging sites for colonial species like the cormorant provide opportunities for birds to form social groups for foraging and roosting. These staging sites are generally well known by individuals in a population (Skagen et al. 1998), and in many cases groups will come to these locations and wait for ideal conditions to continue their migration. In Presqu'ile Bay in Lake Ontario, a large flock of cormorants was observed to gather at

mid-morning and circle high into the air in order to cross the large water body (Hatch and Weseloh 1999).

3.5.2 Migration Routes

It has been suggested that a distinct separation in migration routes exists between birds that travel through the Great Lakes and the interior of United States to wintering locations, and those that travel along the Atlantic Coast. Although there are not a lot of observations of this behaviour, it is suggested that cormorants originally breeding east of the Bay of Quinte migrate down the Atlantic coast (the Bay of Quinte is situated roughly 170 km east of Toronto on the north shore of Lake Ontario) and that birds west of this area migrate through the interior (D.T. King, Pers. Comm.). My results support this suggestion. Dorr et al. (2002) found that 77% of 52 satellite tracked birds caught on Little Galloo Island in eastern Lake Ontario migrated east of the Appalachian Mountains and down the east coast to their winter grounds in the Gulf of Mexico.

Studies on Great Cormorants (*Phalacrocorax carbo*) in Europe have discovered some interesting patterns in their migratory behaviour that might be applicable to Double-crested Cormorants. Yesou (1995) observed in roost surveys in France that Great Cormorants tend to follow the same migration routes each year and generally at fixed time schedules. He also found that younger birds were more nomadic and that old birds showed more fidelity to their wintering grounds. This pattern was also observed in satellite-tracked Ospreys (*Pandion haliaetus*). Adults returned to the same wintering ground each year and moved no farther than 10 km from the central range, whereas juvenile birds explored large areas and remained in the wintering range for a full year (Hake et al. 2001). If cormorants behave in a similar fashion, the nomadic behaviour of

juveniles could be related to the wide distribution throughout the southeastern United States as they search for suitable habitat.

Reymond and Zuchuat (1995) found that female Great Cormorants wintered farther south than males in northern Switzerland, and that older birds showed high perch fidelity in roosts possibly due to established relationships with neighbours. These observations were similar to Van Eerden and Munsterman (1995) but they suggested the reason was that the males remained farther north so that they could be closer to the breeding grounds. This would allow the males to return to the breeding colonies first and establish and defend nest sites or to claim complete nests from the year before, which would save time and energy in constructing a new one. Van Eerden and Munsterman (1995) termed this sex difference in distribution the “arrival time hypothesis”. The arrival time hypothesis states that when arrival at breeding grounds is advantageous to any sex or age class then this should favor winter sites as close as possible to breeding areas. As males benefit by achieving good nest sites that attract females, we should expect them to winter further north. In this study however, I found that there was no significant difference between the distances that males and females traveled, or the latitudes at which they wintered, and that both sexes were relatively equally dispersed throughout the wintering grounds (Figure 3.3).

3.5.3 Habitat Selection

The definition of a home range is any area traversed by an individual in its normal activities of food gathering, mating, or caring of young (Laver 2005). Estimated home ranges showed that there was a significant difference between the home ranges of birds wintering on or near aquaculture facilities and birds wintering on natural habitat, with the

mean home range of birds on natural habitat 2.2% the size of those near aquaculture facilities.

The expansion of the aquaculture industry in the Mississippi delta region has enhanced the food supply of cormorants, increased the winter survival, and improved body conditions of returning migrants (Blackwell et al. 2002, Stapanian 2002, Dorr et al. 2004). Due to predation by cormorants, significant economic losses have occurred at aquaculture facilities (Blackwell et al. 2002, Taylor and Dorr 2003) and United States Fish and Wildlife Services (USFWS) has implemented depredation orders that allow aquaculture facilities in 13 states to take unlimited numbers of cormorants if they are found depredating ponds (Stapanian 2002). Management of cormorants at fish ponds includes shooting birds to reduce numbers, frightening them off ponds, and dispensing them from night roosts near ponds (Taylor and Dorr 2003, Dorr et al. 2004). Harassment of night roosts near ponds effectively reduces the predation; however, it moves birds to roosts near other ponds (Dorr et al. 2004). This type of management has likely caused some of the movements I observed throughout the southeastern states, and is likely a key contributor to the size of the home ranges I observed in the birds at these facilities. This harassment may also indicate why only 7 of the birds were observed at aquaculture facilities and the majority in natural habitat instead. Living on natural water bodies likely reduces this dangerous interaction with humans.

My results indicate that perhaps birds foraging at aquaculture farms may not be in as good condition as is generally assumed. These birds exhibited large home ranges, indicating a lot of energy may be spent foraging. The tendency for aquaculture birds to have larger home ranges than birds on natural habitats may explain why I observed no carry over effect or differences in arrival time at the breeding grounds (Marra et al. 1998).

Although the wide distribution of the study birds throughout the six states may be attributed to the development of aquaculture facilities and the harassment associated with them, it may also be a result of the large increases in population that have been observed over the past few decades (Hebert et al. 2008). It is likely that many cormorants still feed at these aquaculture facilities despite management because of the availability of food; however, due to depredation order activities they must continuously move from one to another to avoid harassment. Habitat shift has also been observed in other colonial species like the Pink-footed Goose (*Anser brachyrhynchus*), which winters in the Western Palearctic. These geese have almost completely switched from feeding on natural vegetation to feeding on pastures and agricultural crop because of population increases and availability of these resources. As a result, management measures have been taken to protect crops, including deliberate disturbance of geese, resulting in a range expansion of the geese (Jensen et al. 2008).

3.5.4 Fidelity

Henaux et al. (2007) found that disturbances, such as culling, caused experienced breeding great cormorants to abandon their colonies and relocate to nearby undisturbed colonies. The fidelity of these birds in the following year was reduced as a result of their failed breeding experience and many of them did not return to their original colonies the following year, but rather were re-sighted on nearby colonies to which they had relocated post-disturbance. This has also been observed in other species such as the Yellow-legged Gull (*Larus cachinnans*) (Bosch et al. 2000). My results conform to this pattern. Of 9 birds that returned to Georgian Bay for the 2008 breeding season, only the 3 birds that had remained on their colony in 2007 following disturbance (presumed to have produced

successful clutches) were observed again at their capture colony for the full 2008 breeding season (refer to Chapter 2 for disturbance). Although the other 6 birds visited their 2007 capture colonies in 2008, none of them stayed long enough or consistently enough to allow them to produce a successful clutch. However, 3 of these birds did show fidelity to the locations to which they relocated to in 2007 post-disturbance, which may indicate a permanent dispersal. This can have important implications for local management of colonies in that birds can just relocate and become an issue elsewhere. These observations also show how sensitive this species can be to such disturbances.

3.5.5 Conclusions

This study illustrated the diversity in migration routes and wintering grounds used by a small group of cormorants that shared a common breeding ground. Results suggest an interior route and a coastal route that might be separated by a dividing line through the center of Lake Ontario. Of the four birds that traveled south from east of the Bay of Quinte, three traveled down the Atlantic Coast, which was similar to observations made by Dorr et al. (2002) and D.T. King (Pers. Comm.), who also looked at satellite tracked birds in the eastern end of Lake Ontario. Long Point and Middle Island areas in Lake Erie both act as major staging sites, at which birds spent considerable time before completing their fall migrations. Females left earlier and spent more time in the Great Lakes before initiating the final leg of fall migration and took longer to reach the wintering grounds. Sexes traveled at similar speeds during flight and traveled similar distances to the wintering grounds. This differed from the findings of Van Eerden and Munsterman (1995). They observed that Great Cormorant males wintered in areas closer to the breeding grounds and they proposed an arrival time hypothesis suggesting that

males did so because they would be able to return first in the spring and claim the best nest sites.

The birds were widely dispersed throughout six of the southeastern coastal states, with a plurality of the birds preferring to winter in Florida (Table 3.2). Using band recovery data, Dolbeer (1991) found that birds from a local area in Lake Ontario were similarly quite dispersed throughout the southeastern states from Louisiana to Florida. Contrary to my expectation, very few cormorants from this study wintered near high densities of aquaculture facilities, as was suggested by previous studies. Only seven of the 26 birds wintered on or within 25 km of aquaculture facilities. The dominant winter habitats were inland lakes and coasts. However, the small number of birds observed wintering near aquaculture ponds and their large home ranges may be the result of night roost harassment programs, the purpose of which is to disperse the birds away from these facilities. This, along with population increases, has likely led to the wide distribution of these birds.

Interestingly, a significant difference was found in home range size between birds wintering on aquaculture sites and birds wintering on non-aquaculture sites. There was no relationship between winter habitat type and arrival times as both aquaculture birds and non-aquaculture birds reached the breeding grounds in the spring at similar times. I did not detect the carry-over effect described by Marra et al. (1998) likely because the habitat quality between aquaculture and non-aquaculture birds was similar. Despite the greater abundance of food available at aquaculture facilities, the home ranges of these birds suggest that they must spend more time searching for food than birds foraging in natural habitat likely due to disturbance. Finally, for the 9 birds from 2007 that survived to return to breed in 2008, the 3 birds from GB 6, which was a disturbed colony, showed fidelity

by returning to their capture colony to breed, and 3 others returned to their 2007 summer location they relocated to post-disturbance. This shows that fidelity can also be greatly affected by disturbance (or at least nesting success), suggesting that management activities leading to nest failure may cause these birds to search for new nesting sites in subsequent years.

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3.7 Tables and Figures

Table 3.1. Migration distances traveled by each cormorant to its winter area. The total distance is a sum of the segments of the migration path from the location on the day they left their breeding ground to the location on the day they arrived in what I defined from their later movements as their winter area. Females are indicated by an *. Birds 74290-74303 were captured in 2007, birds 81058-81071 were captured in 2008. Independent t-tests were used to identify differences between males and females.

Bird ID	Total Distance			Distance from Final Staging Area					
	Distance (km)	Distance		Duration (days)	Distance		Arrival Date	Departure Date	Staging Time (days)
		Departure Date	Arrival Date		Distance (km)	Duration (days)			
*74290	1801.7	12-Oct	3-Nov	23	703	24-Oct	3-Nov	11	12
*74292	2018.8	28-Sep	6-Dec	70	1419	22-Nov	6-Dec	15	55
*74298	1999.8	7-Sep	10-Nov	45	1289.8	26-Oct	10-Nov	16	29
*74303	2385.2	13-Sep	29-Oct	47	1579.2	22-Oct	29-Oct	8	39
*81061	4630.5	15-Sep	19-Nov	66	2262	16-Oct	19-Nov	35	31
*81063	1772.9	29-Sep	7-Nov	40	1367	16-Oct	7-Nov	23	17
*81065	1364	3-Sep	5-Oct	33	1004.4	29-Sep	5-Oct	8	25
*81067	2468	1-Sep	7-Dec	98	1815.2	13-Oct	7-Dec	56	42
*81068	1980.5	3-Sep	19-Nov	78	1255.7	12-Nov	19-Nov	8	70
*81071	2218.1	12-Sep	30-Sep	19	1797.6	21-Sep	30-Sep	10	9
Average	2264	12-Sep	7-Nov	52	1449.3	20-Oct	7-Nov	19	33
74291	1358.8	25-Oct	22-Nov	32	846.8	8-Nov	15-Nov	8	24
74293	2618.3	7-Oct	5-Nov	30	1423.5	22-Oct	19-Nov	29	1
74294	1782.6	13-Oct	13-Nov	32	1299.8	29-Oct	13-Nov	15	17
74295	2096.6	28-Sep	16-Oct	19	1025	10-Oct	16-Oct	7	12
74297	2072.9	25-Sep	21-Nov	58	1256.1	4-Nov	21-Nov	18	40
74299	1317.6	10-Oct	29-Oct	51	872.2	22-Oct	29-Oct	8	43
74300	1998.4	10-Oct	15-Oct	6	1998.4	10-Oct	15-Oct	6	0
74301	1481.2	25-Oct	31-Oct	7	999.2	28-Oct	31-Oct	4	3

****Table 3.1 Continued Over

Table 3.1 Continued

Bird ID	Total			Distance from Final Staging Area					
	Distance			Duration (days)	Arrival Date	Departure Date	Distance (km)	Duration (days)	Arrival Date
	Distance (km)	Departure Date	Arrival Date						Staging Time (days)
74302	2378.6	8-Oct	7-Nov	31	7-Nov	8-Oct	2378.6	31	7-Nov
81058	2564.1	27-Sep	12-Nov	46	12-Nov	5-Nov	1601.7	8	12-Nov
81059	1471.8	29-Sep	25-Nov	58	25-Nov	4-Nov	977.5	22	25-Nov
81060	2327.8	5-Oct	11-Oct	7	11-Oct	5-Oct	2295	7	11-Oct
81062	1633.7	22-Oct	5-Nov	15	5-Nov	29-Oct	1487.2	8	5-Nov
81064	2053.7	17-Oct	11-Nov	26	11-Nov	17-Oct	2053.7	26	11-Nov
81066	1557.8	14-Sep	9-Dec	87	-----	-----	-----	-----	-----
81070	2199.6	10-Sep	31-Oct	52	31-Oct	17-Oct	1585.8	15	31-Oct
Average	1932.1	7-Oct	7-Nov	35	7-Nov	22-Oct	1473.4	14	5-Nov
Summary	P = 0.29	P < 0.05	P = 0.94	P = 0.09	P = 0.71	P = 0.90	P = 0.79	P = 0.39	P = 0.04

Table 3.2. Estimated distance/day, winter location and habitat type used. This distance was used to calculate an estimated speed of travel (distance per day). Females are indicated by an *. Birds 74290-74303 were captured in 2007; birds 81058-81071 were captured in 2008.

Bird ID	Longest Distance (km)	Departure Date	Arrival Date	Travel Days	Estimated Dist/Day	Final Destination	Habitat Type
*74290	876.6	24-Oct	27-Oct	4	216.9	Alabama	Aquaculture Pond
*74292	1419	22-Nov	6-Dec	15	94.6	Florida	Lake Aquaculture
*74298	1289.8	26-Oct	10-Nov	16	80.6	Mississippi	Pond
*74303	1579.2	22-Oct	29-Oct	8	197.4	Louisiana	Coast
*81061	1373.2	16-Nov	19-Nov	4	343.3	Florida	Lake
*81063	1264.5	30-Oct	7-Nov	9	140.5	Florida South	Lake
*81065	1004.4	29-Sep	5-Oct	8	125.6	Carolina	River
*81067	1490.9	13-Oct	19-Oct	7	213	Louisiana	Coast Aquaculture
*81068	1255.7	12-Nov	19-Nov	8	157	Alabama	Pond
*81071	1105.8	21-Sep	27-Sep	8	138.2	Louisiana	Coast
Mean	1265.9			9	170.7		
74291	846.8	8-Nov	15-Nov	8	105.9	Alabama	River Aquaculture
74293	1743.2	22-Oct	29-Oct	8	217.9	Mississippi	Pond
74294	1299.8	29-Oct	13-Nov	15	86.7	Florida	Swamp
74295	1066.6	10-Oct	13-Oct	4	266.7	Florida	Lake
74297	1256.1	4-Nov	21-Nov	18	69.8	Florida	Lake Aquaculture
74299	872.2	22-Oct	29-Oct	8	109	Alabama	Pond
74300	1998.4	10-Oct	15-Oct	6	333.1	Florida	Lake Aquaculture
74301	999.2	28-Oct	31-Oct	4	249.8	Georgia	Pond Aquaculture
74302	1048.6	14-Oct	7-Oct	4	262.2	Mississippi	Pond
81058	1602.3	5-Nov	12-Nov	8	200.3	Florida South	Lake
81059	950.8	4-Nov	25-Nov	22	43.2	Carolina	Lake
81060	1316.9	5-Oct	8-Oct	4	329.2	Florida	Oceanic Island
81062	1487.2	29-Oct	5-Nov	8	185.9	Louisiana	Coast
81064	1727.2	17-Oct	4-Nov	19	90.9	Louisiana South	Coast
81066	1351.1	14-Oct	28-Oct	15	90.1	Carolina	Coast
81070	1363.9	17-Oct	24-Oct	8	170.5	Florida	Coast
Mean	1308.1			10	175.7		

Table 3.3. Relationships between habitat type, home range, and spring migration times for surviving birds from 2007. Home ranges are represented minimum convex polygon (MCP) 95%, female birds are denoted by an *. Significant difference between aquaculture home ranges and natural home ranges was found (Mann-Whitney U = 4.0, P = 0.02).

Natural Habitat						
Bird ID	MCP 95% (km²)	Number of Locations	Habitat Type	Spring Migration	Migration Duration (days)	Migration Distance (km)
74292*	3.2	14	Florida Lake	March 23 - April 22	31	1924.7
74294	4.1	19	Florida Swamp	March 26 - April 17	23	1759.4
74295	35.1	23	Florida Lake	March 27 - April 25	30	2090.6
74297	5.3	17	Florida Lake	March 29 - April 26	29	1932.5
74300	216.4	18	Florida Lake	March 8 - April 19	43	1998.3
74303*	144.5	18	Louisiana Coast	-----	-----	-----
Mean						1941.1
[SE]	68.1 [37.1]				31.2 [3.3]	[54.3]
Aquaculture Facilities						
Bird ID	MCP 95% (km²)		Habitat Type	Spring Migration	Duration	Distance
74290*	35.8	25	Alabama Ponds	-----	-----	-----
74293	2857.1	20	Mississippi Ponds	March 18 - April 16	30	1694.4
74298*	884.2	21	Mississippi Ponds	February 5 - May 3	87	2018.8
74299	13523.9	21	Alabama Ponds	-----	-----	-----
74301	1413.8	17	Georgia Ponds	March 28 - April 11	15	1401.4
74302	52	13	Mississippi Ponds	March 14 - April 19	38	1693.6
Mean	3127.8				42.5	1702.1
[SE]	[2122.5]				[15.6]	[126.1]

Table 3.4. Fidelity of the surviving birds from 2007 returning to their previous summer location. Females are denoted with a *. Fidelity was determined by measuring the distance from the centroid of the 2008 summer range to the centroid of the 2007 summer range. If the distance between both points was less than 25 km, then the bird was determined to have fidelity (Hatch and Weseloh 1999).

Bird ID	Spring Migration	2007 Summer Location	2008 Summer Location	Centroid Distance (km)	Fidelity
*74292	March 23 - April 22	GB 6	GB 6	1.4	yes
74293	March 18 - April 16	GB 6	GB 6	10.9	yes
74294	March 26 - April 17	GB 12	Muskoka Lake	45	no
74295	March 27 - April 25	North Bay and North Channel	North Bay and North Channel	2.7	yes
74297	March 29 - April 26	Inland north of Parry Sound	Inland north of Parry Sound	20.1	yes
*74298	February 5 - May 3	North Channel	North Channel	5.3	yes
74300	March 8 - April 19	GB 6	GB 6	3.7	yes
74301	March 28 - April 11	GB 19	Lake Simcoe	63.5	no
74302	March 14 - April 19	Montreal	Southern Georgian Bay	487	no

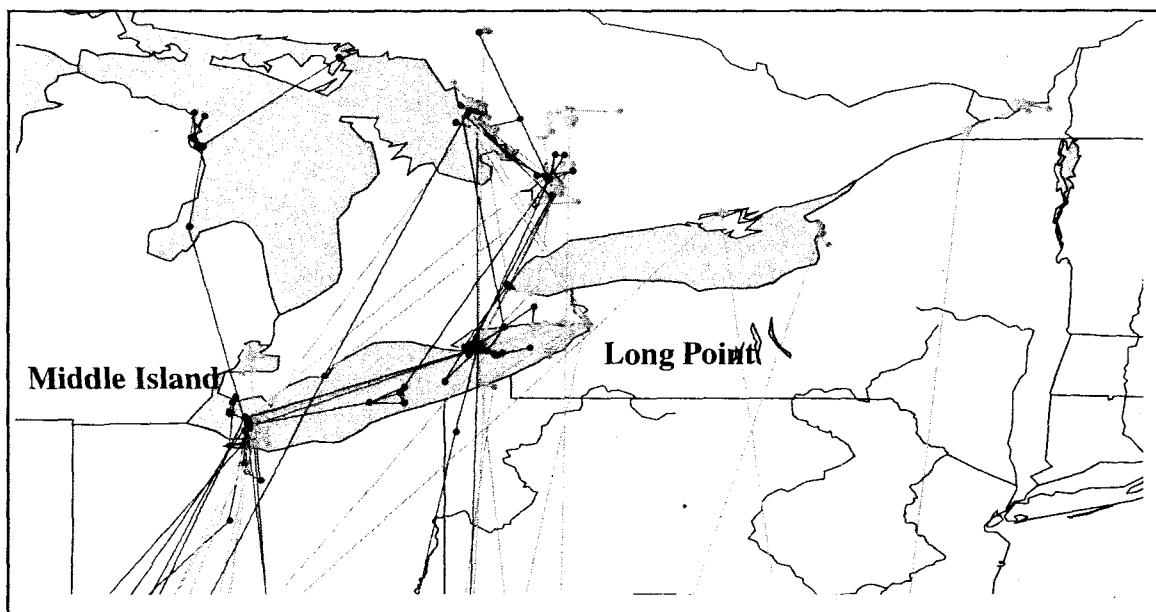


Figure 3.1. An illustration of the “funneling” effect in southern Ontario at the start of fall migration, and the staging areas within Lake Erie (Long Point to the right and Middle Island to the left). Female birds are indicated with black, males with grey.

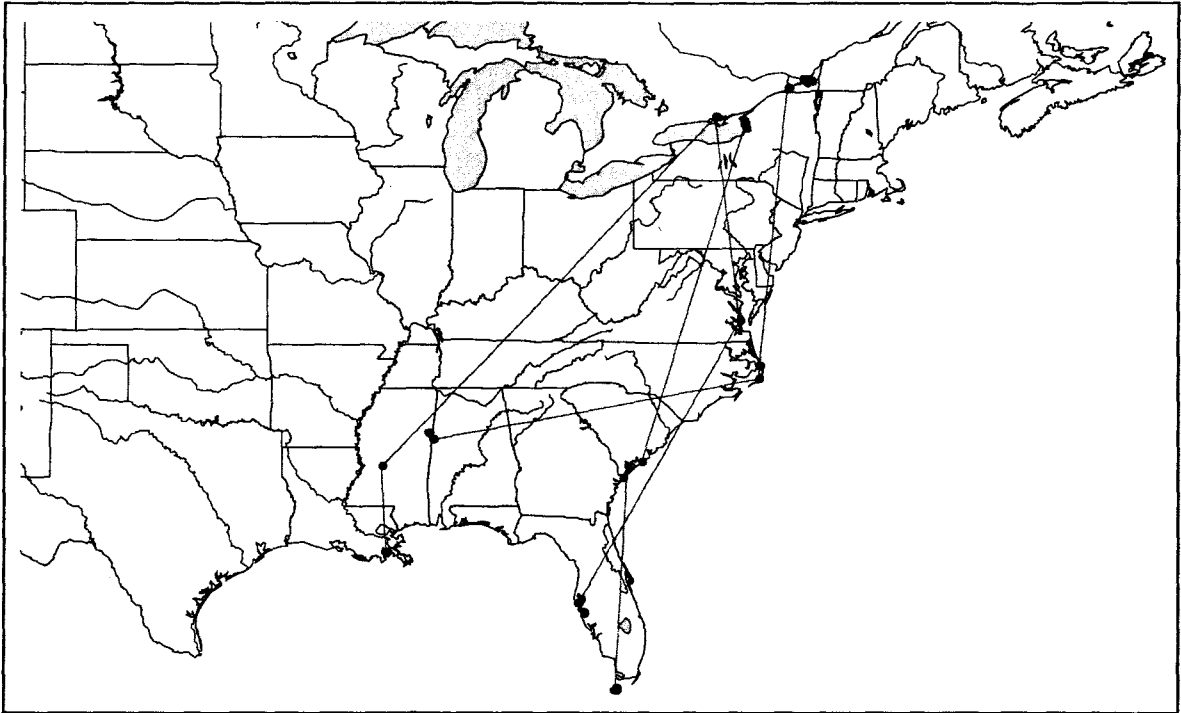


Figure 3.2. Fall migration routes of four birds that moved from Georgian Bay to eastern Lake Ontario or the St. Lawrence River following surgery or disturbance

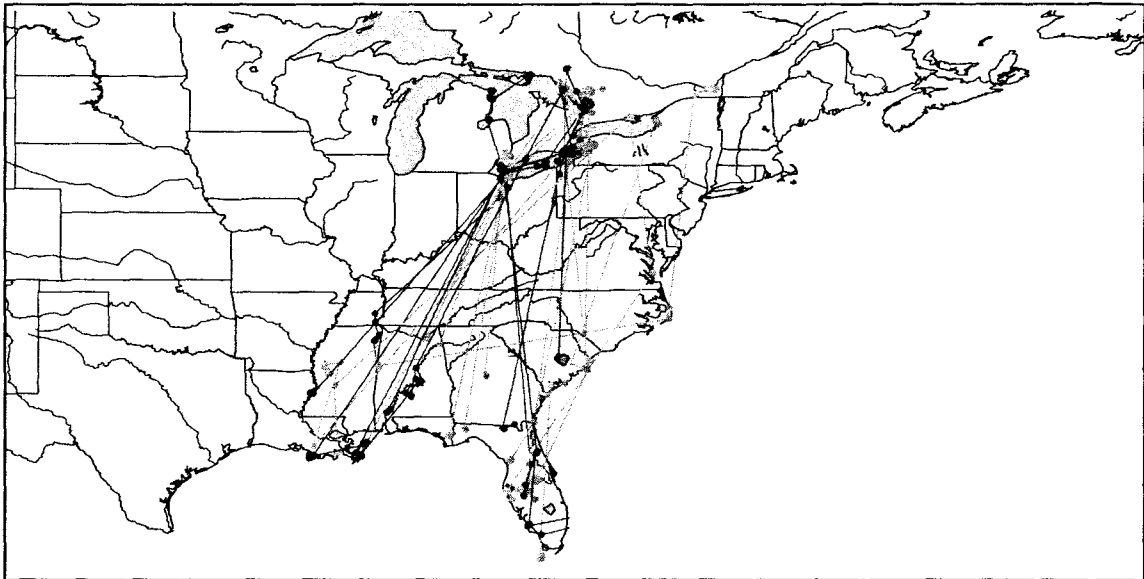


Figure 3.3. Migration routes of all 26 birds from southern Ontario including staging areas in Lake Erie to southeastern United States wintering areas. Females are indicated by black.

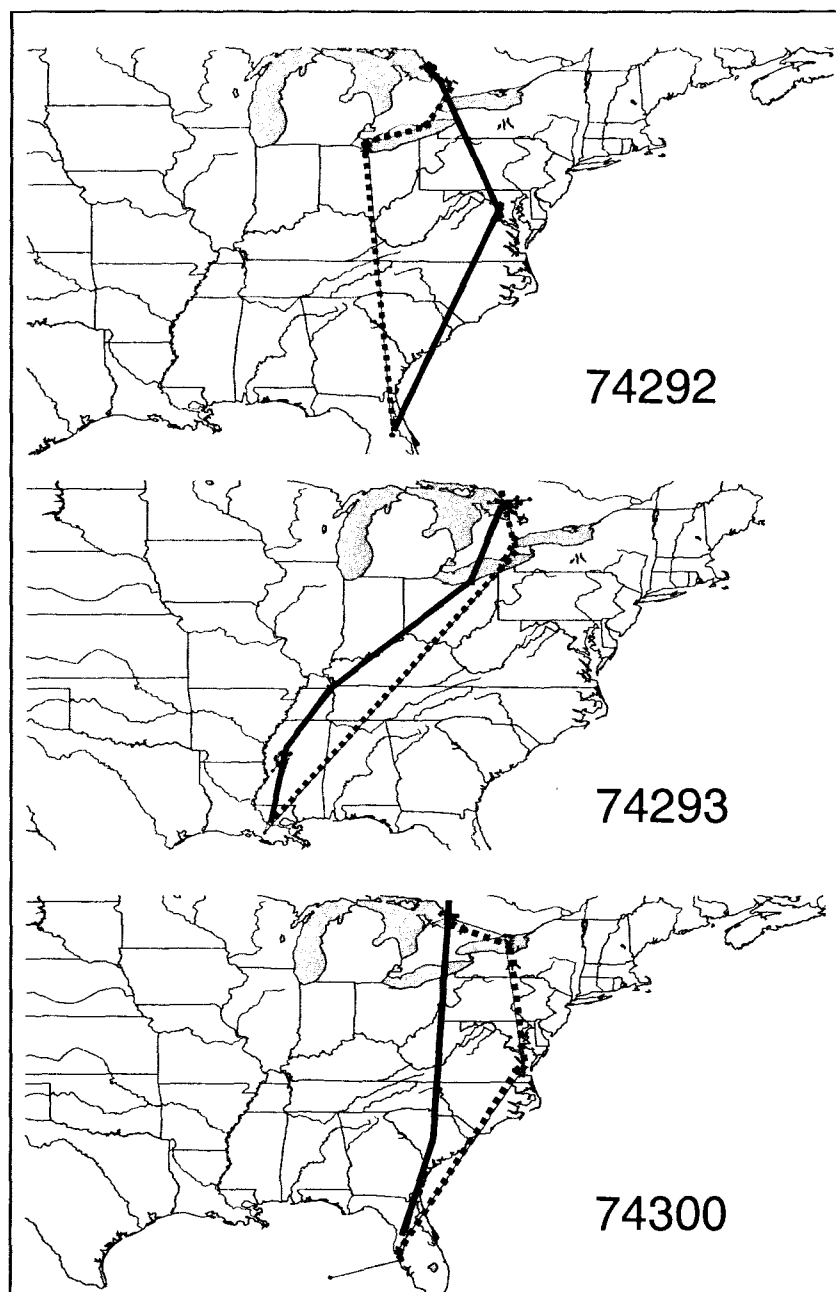


Figure 3.4. Three birds from colony GB 6 that returned to breed in 2008 at their capture colony. All were assumed to be successful breeders in 2007 as they remained at the colony despite the disturbance (Chapter 2). These maps were generated using data points from the beginning of the fall migration (dashed line) to completion of the spring migration (solid line).

Chapter 4: General Conclusions

From this study, some interesting findings were generated regarding the breeding, migrating, and wintering behaviours of the double-crested cormorants breeding in Georgian Bay. In Chapter 2, I looked at the response of breeding cormorants to disturbance, and concluded that the Georgian Bay population could belong to a Great Lakes metapopulation based on the movement of 15 individuals. This hypothesis could only be fully supported if abandoned birds were observed breeding at their new sites post-disturbance (Esler 2000), however the movement clearly indicated that management may be ineffective. At the colony-level, although I was unable to observe directional movement, it was apparent that disturbance increased both abandonment and gull predation, causing these birds to redistribute elsewhere. It was also apparent that the number of gulls on a colony had a great effect on abandonment of nesting cormorants.

In a similar study that looked at the effect that egg oiling had on breeding cormorants, Duerr et al. (2007) found that cormorants were more likely to abandon their colony when their nests were depredated. These birds, based on banding information, were observed to renest on nearby colonies, or relocate as much as 100 km away. Although I was unable to determine where unmarked birds went, or whether they successfully renested, it was clear that these birds were more affected by the combination of disturbance and predation than just disturbance. Duerr et al. (2007) also observed this when they oiled some sub-colonies at night to avoid gull predation and had fewer accounts of birds abandoning their nests.

It also became apparent that the stage of nest development can have an effect on a bird's decision to abandon its colony. In 2007, I observed that birds on colonies with later nest stages and large chicks were less likely to abandon their colony, whereas birds

with eggs or small chicks were more likely to abandon, possibly because predation by gulls was facilitated. However, in 2008 although only eggs were present on the disturbed colonies, high percentages of abandonment were not observed. Ironically, this likely had to do with the fact that I disturbed colonies in 2008 three weeks earlier, while eggs were present. This early stage of loss around the middle of May provided the birds with enough time to return to their colony, re-lay, and attempt to produce a successful clutch.

Finally, the use of implanted PTTs proved to be advantageous in this study, but precautions should be taken by future users of this technology. In this study, abandonment of 11 birds due to surgery was not an issue because I was trying to determine whether disturbance would cause these birds to abandon their colony anyway. Another study has documented problems associated with these devices (Latty 2008) in captive common eiders. In this study, Latty (2008) was able to document specific physiological effects, such as increased lethargy, plumage wetting at incision sites, and decreased dive speeds for up to three months post surgery. Although I am unable to state that the cormorants in this study experienced similar effects, the activity of these birds during the time I monitored them indicates otherwise.

I was able to provide new insight into the migration routes and winter habitat used by this population of cormorants. Staging sites were clearly identified at Long Point and Middle Island areas in Lake Erie, and it was observed that female birds left their breeding areas significantly earlier and spent significantly more time in these staging sites than males. Uncertainty about the cause of this difference suggests an avenue for future research. Otherwise, both sexes were observed to leave the staging sites and arrive in the wintering grounds around the same time, travel similar distances to their wintering grounds, and travel at similar speeds.

The winter habitat types most commonly used were lakes and coasts, with only 7 of the 26 birds foraging for some time at aquaculture facilities. It is unclear whether these birds spent the entire winter at aquaculture sites. Although the expansion of aquaculture facilities throughout the Mississippi river delta region has been identified as the reason for the increase in the number of birds wintering in this area in the last few decades (Werner et al. 2001, Blackwell et al. 2002, Stapanian 2002, Hatch and Weseloh 1999), the recent implementation of the depredation order by United States Fish and Wildlife Service may be pushing many of these birds back to foraging in natural habitat. It was clear that birds that were foraging on aquaculture sites required a significantly larger foraging area than birds foraging in natural habitat. This suggested the possibility that these birds were being harassed and scared off these facilities and were forced to enlarge their foraging area.

Speculation that birds feeding on aquaculture facilities are in better condition than birds feeding in natural habitat (Hebert et al. 2008) due to a greater abundance of food must also be questioned. Although a greater amount of food may be available at these facilities, acquiring it may not be simple, explaining why aquaculture birds in this study required such large foraging areas. My results imply that these birds may be exerting more energy to forage than birds with smaller ranges and thus may not be in better physical condition than birds feeding on natural habitat that may have less food available. This was reflected in the dates these birds returned to their breeding ground in the spring. If birds at aquaculture facilities were in better condition then they should have arrived before non-aquaculture birds (Marra et al. 1998, Norris and Marra 2007); however, no such carry-over effect was noted.

As for fidelity, it was apparent that disturbance and breeding success do have consequences on breeding site fidelity. Of the 9 2007 birds still transmitting data, only 6 individuals showed strong fidelity. Three of these birds were ones that did not abandon their capture colony during the previous breeding season despite the trauma of surgery and disturbance, and were presumed to be successful nesters, and the other three showed fidelity to the sites they relocated to post-disturbance.

In conclusion, this study has shown that disturbance can greatly affect the breeding success and fidelity of cormorants nesting in Georgian Bay, and also can influence their movement to other areas. It is also possible that disturbance can be the factor for the increased movement observed in aquaculture birds, therefore perhaps we cannot assume that these birds are benefiting as much from aquaculture facilities as they once were. On a larger scale, this study shows that even a species that has benefited and adapted so well to human development, can still be greatly affected by our actions. If a species as successful and numerous as cormorants can be disrupted so greatly by disturbance, then we must severely consider our actions if there is a possibility that we could interfere with a more fragile species.

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Chapter 5: Appendix

5.1 Names and locations of Double-crested Cormorant colonies utilized in this study

Colony	Latitude	Longitude	2007 Nest Count	Island Name
GB 4	45.035	-80.335	0	Thumb Rock
GB 5	45.043	-80.33	141	Block Island
GB 6	45.141	-80.134	109	Is. SSE Haystack
GB 7	45.193	-80.196	348	Caleb Island
GB 8	45.194	80.194	0	Is. NE of Caleb
GB 9	45.229	-80.271	111	Tribune Island
GB 10	45.23	80.269	0	North Tribune Island
GB 12.1	45.235	-80.259	68	Rk. W of Chancellor
GB 12.2	45.235	-80.259	22	Chancellor West
GB 15	45.316	-80.293	209	Is. SE Hooper Island
GB 16	45.335	-80.353	11	Snake Island
GB 17	45.382	-80.517	75	Wallis Rock
GB 18	45.386	-80.53	469	S Limestone Island
GB 18.1	45.407	-80.45	99	SE Wallbank
GB 18.2	45.418	80.446	0	Limestone Island 2
GB 18.3	45.416	-80.449	58	Limestone Island 3
GB 19	45.426	-80.447	98	Is. E of Garland
GB 20	45.455	-80.504	51	Southwest Island
GB 22.1	45.46	-80.502	52	SW of Duncan Rock
GB 22	45.467	-80.505	55	Duncan Rock
GB 23	45.514	-80.567	206	Blackbill Rock

5.2 Standard Protocol for Coelomic Implantation of Satellite and Conventional Transmitters (or other devices). Provided by Dr. Graham Crawshaw, Toronto Zoo, Toronto, Ontario.

- 1) Two people are required for the procedure: a surgeon and an anesthetist.
- 2) Standard aseptic surgical technique will be practiced. The surgeon will wear sterile gloves and a surgical mask and hat and the anesthetist will wear a mask. The surgical site will be prepared as for any surgical procedure, including, skin disinfection (using povidone iodine or chlorhexidine) and the use of a sterile drape.
- 3) Transmitters will be packaged and gas-sterilized (peroxide).
- 4) Surgical instruments will be sterilized in an autoclave.
- 5) The bird will be positioned on the surgical table in dorsal recumbency with the legs extended and the wings folded. An insulated cover (towel or disposable absorbent pad) for the surgical table will be used to retard heat loss. Birds will be placed on an elevated platform with a sloped ramp, positioning the bird's head on the ramp so that it is lower than the body.
- 6) Anesthesia:
 - a. Sevoflurane will be used. Sevoflurane is administered to the bird by facemask, the bird intubated once anesthetised. Induction is at 6-8% sevoflurane; maintenance is at 3-4% in oxygen or on a non-rebreathing circuit at a level found necessary for a given species and a given individual. Sevoflurane has similar properties to isoflurane but is less soluble in the tissues resulting in faster induction and recovery times.
 - b. The bird is intubated with a cuffless tube. A protective ointment may be used in the eyes to prevent drying of the cornea. Once the abdominal air sacs of a bird are

opened, respiration can occur partially through the surgical incision, which may require a higher setting on the vaporizer to compensate.

- c. An alternative anesthetic protocol is the intravenous administration of propofol in combination with a local anesthetic block at the incision site (Machin and Caulkett 1998, 2000). A 25 gauge 3/8 in. butterfly catheter is placed into the tibiotarsal vein. The catheter is taped in place. Induction of anesthesia is accomplished by delivering a slow bolus (over 1 min) of 5-10 mg/kg propofol. The induction dose is given to effect, rather than by adhering to a strict dosage. Additional boluses of 2-4 mg may be given to attain induction and to maintain a surgical plane of anesthesia. All birds will be intubated, and ventilated with a bird AMBU bag. The incision site and the antenna exit site are infiltrated with 2 mg/kg of a 0.5% solution of bupivacaine or lidocaine or a combination of bupivacaine and lidocaine (2:1 vol:vol).
- 7) Anesthesia will be monitored by use of a respiratory or cardiac monitor, or both. A heart monitor, such as a pulse oximeter, amplified esophageal stethoscope, or Doppler ultrasound. Body temperature is monitored with an electronic thermometer with the sensor placed either well into the esophagus or into the cloaca. The desired temperature range during anesthesia and surgery is 38-39.5 C. The bird will be warmed or cooled to maintain this range. Additional heat can be supplied to a cold bird by placing bags of warm water on the ventral surfaces of the wings or, ideally, by the use of a radiant heat source located above the bird. Body temperature can be reduced by removal of external heat sources and by wiping the feet with alcohol or cold water.
 - 8) Respiration will be monitored and mechanically supported regardless of visual evidence of spontaneous respiration. At a minimum, four to six ventilations per min are made with a bird AMBU bag or with the ventilation bag.

- 9) The surgical site is between the distal end of the keel and the conjuncture of the distal ends of the pubic bones, palpated through the abdominal wall. Feathers are not plucked from the site. The liquid bandage, Facilitator[®] is applied to the down feathers and massaged in. The feathers around the site are taped back with pieces of microporous tape. A site for the exit of the percutaneous antennae is located by palpating with a finger the intersection of the right pubis bone with the synsacrum. Liquid bandage is also used at this site to move the feathers away from the site. The feathers adjacent to the site are taped back using microporous tape. Both sites are swabbed twice with povidone-iodine or benzalkonium chloride solution. Following site preparation, a sterile gauze pad is placed over the antenna exit site to protect it. A sterile fenestrated drape is placed over the surgical site.
- 10) The skin is incised along the ventral midline with sterile blade. The subcutaneous layer and fat are sharp dissected. Once the muscular abdominal wall is reached, the linea alba is identified. The linea alba is seized with a forceps and lifted to permit penetration of the abdominal wall with a blade. The linea alba is then sharp dissected with blade or scissors, avoiding the viscera, to a length of about 3 cm, or a distance sufficient to pass the transmitter body.
- 11) Using fingers, a space is cleared on the right side of the abdomen, as dorsally (lateral to the ventriculus) as possible.
- 12) The surgeon palpates the site for passage of the antenna through the drape with the right hand and, if necessary, nicks the skin with a blade at the most dorsal position nearest to the intersection of the pubis and synsacrum. Then the surgeon uses a blunt stainless steel trochar to penetrate the abdominal wall, protecting the viscera with his left index finger placed inside the bird. The trochar may be passed through the drape into the

antenna exit site. The drape is then pulled over the hub of the trochar, leaving the trochar entirely below the drape. The trochar is drawn inside the bird full length.

- 13) The surgeon then removes the transmitter from the envelope and places the antenna into the lowest hole in the trochar. With braided wire antennas, such as those used with satellite transmitters, only the end of the antenna can be jammed into the trochar. The surgeon inserts a finger into the incision, along the path of the trochar, to protect the viscera as the trochar is withdrawn. As the surgeon guides the antenna into the incision with his left hand, he uses his right hand to grasp the trochar through the drape and withdraw it from the bird until the end of the antenna can be seen or felt. Frequently there is a detente as the antenna meets and penetrates the body wall.
- 14) Continuing to withdraw the antenna, the surgeon guides the transmitter through the incision, which may need to be slightly stretched to pass the transmitter. The antenna is withdrawn until the collar meets the body wall. The transmitter must be positioned on its narrowest edge and to fit snugly along the dorsal wall, in a "notch" that can be palpated by the surgeon.
- 15) Transmitters may be placed into small birds, in which the body wall aids in holding the transmitter in place, and only a single suture through the antenna collar and body wall is applied. However, if a small transmitter is to be placed into a large bird, covering the transmitter body with a tight-fitting layer of surgical mesh or 100% nylon netting can provide an unlimited number of anchoring points. Two single interrupted sutures may be placed through the mesh and into the body wall well away (dorsally) from the edge of the incision prior to closure. These additional anchoring points contribute greatly to prevent movement of the transmitter body that might cause the antenna to be pulled into the body cavity.

- 16) The surgical incision is closed in two layers using 3-0 braided or monofilament absorbable sutures on a cutting needle. The linea alba is closed using a simple continuous pattern and the skin is closed using either a simple continuous or simple interrupted pattern. A small application of tissue glue "Vet Bond" will be used to seal the incisions.
- 17) A single simple interrupted suture is used to hold the antenna collar to the body wall. The surgeon can reposition the transmitter body by moving the antenna. The surgeon should then place tension on the antenna to allow passage of the needle through the antenna collar. When placing the suture, the needle must penetrate the plastic of the antenna collar to assure stability. To determine that the collar has been penetrated, the antenna can be moved in and out to see if the needle moves with it.
- 18) The drape is removed and the vaporizer is turned to zero. Oxygen supplementation will continue until the bird recovers. The bird will be kept warm by holding it wrapped in a towel until it is fully recovered. If dehydration is a problem, subcutaneous fluids will be administered.
- 19) Following recovery, the bird will be placed in a cage or kennel for at least one hour prior to release. Birds will be released only when they are alert, able to maintain head and body position, and react to human handling. Birds that do not respond will be carefully inspected and given supportive care (heat source, gastric intubation of water and electrolytes, etc.).
- 20) Should euthanasia of a bird become necessary during surgery or during anesthetic recovery, intravenous injection of a T 61 solution will be used.

Birds will be given an injection butorphanol up to 2 mg/kg IM prior to the surgery for intraoperative analgesia and meloxicam 0.03 mg/kg for post-operative analgesia.

5.3 Literature Cited

Machin, K.L. and N.A. Caulkett. 1998. Cardiopulmonary effects of propofol and a medetomidine-midazolam-ketamine combination in mallard ducks. *Amer. J. Vet. Res.* (59): 598-602

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