OCS Study
MMS 2003-037

Monitoring Beaufort Sea Waterfowl and Marine Birds

Prepared for
U.S. Department of Interior
Minerals Management Service
Alaska OCS Region
949 East 36th Street
Anchorage, Alaska 99508

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By

Paul L. Flint[1], John A. Reed[1], J. Christian Franson[2], Tuula E. Hollmén[3], James B. Grand[4], Mark D. Howell[4], Richard B. Lanctot[5], Deborah L. Lacroix[1], and Christian P. Dau[5]

[1]U.S. Geological Survey, Alaska Science Center, Biological Science Office,
1011 E. Tudor Road, Anchorage, Alaska 99503
[2]U.S. Geological Survey, National Wildlife Health Center, 6006 Schroeder Road,
Madison, Wisconsin 53711
[3]Alaska Sea Life Center, P.O. Box 1329, Seward, Alaska 99664
[4]Alabama Cooperative Fisheries and Wildlife Research Unit,
108 M. White Smith Hall, Auburn University, Auburn, Alabama 36849
[5]U.S. Fish and Wildlife Service, Migratory Bird Management, Waterfowl Branch,
1011 E. Tudor Road, Anchorage, AK 99503

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PROJECT ORGANIZATION PAGE

Dirk V. Derksen, Project Manager, Chief, Wetlands and Terrestrial Ecology Branch, USGS, Alaska Science Center, 1011 East Tudor Road, Anchorage, AK 99503

Paul L. Flint, Principal Investigator, Wildlife Biologist, USGS, Alaska Science Center, 1011 East Tudor Road, Anchorage, AK 99503

John Reed, Crew Leader, Wildlife Biologist, USGS, Alaska Science Center, 1011 East Tudor Road, Anchorage, AK 99503

J. Chris Franson, Co-Principal Investigator for Contaminants, National Wildlife Health Center, 6006 Schroeder Road, Madison, Wisconsin 53711

Tuula E. Hollmen, Co-Principal Investigator for Diseases, Alaska Sea Life Center, P.O. Box 1329, Seward, Alaska 99664

James B. Grand, Co-Principal Investigator for Body Composition of Long-tailed Ducks, Alabama Cooperative Fisheries and Wildlife Research Unit, 108 M. White Smith Hall, Auburn University, Auburn, Alabama 36849

Mark D. Howell, Graduate Student studying Body Composition of Long-tailed Ducks, Alabama Cooperative Fisheries and Wildlife Research Unit, 108 M. White Smith Hall, Auburn University, Auburn, Alabama 36849

Richard B. Lanctot, Co-Principal investigator for 2 years, Alaska Science Center, Biological Science Office, 1011 E. Tudor Road, Anchorage, Alaska 99503

Deborah L. Lacroix, Crew Leader, Wildlife Biologist, Alaska Science Center, Biological Science Office, 1011 E. Tudor Road, Anchorage, Alaska 99503

Christian P. Dau, Pilot/Wildlife Biologist, U.S. Fish and Wildlife Service, Migratory Bird Management, Waterfowl Branch, 1011 E. Tudor Road, Anchorage, AK 99503

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U.S. Geological Survey
Alaska Science Center
1011 East Tudor Road
Anchorage, Alaska 99503

Telephone (907)-786-3512

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TABLE OF CONTENTS

SECTION II. BREEDING ECOLOGY OF COMMON EIDERS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

We present the results from four seasons of a multifaceted research program designed to assess the breeding ecology of Pacific Common Eiders (*Somateria mollissima v-nigra*) and molting ecology of Long-tailed Ducks (*Clangula hyemalis*) along the Beaufort Sea coast of Alaska. An aerial survey component of this study was completed in 2000 and presented as a separate report (Fischer et al 2002). Our study area was split into an Industrial Area adjacent to current oilfield development to the west of Prudhoe Bay and an undeveloped Control Area around Flaxman Island.

Long-tailed ducks congregate in the lagoon system of the Beaufort Sea for a post-breeding molt period from mid-July through mid-September. During this time the lagoons host 10-30,000 flightless Long-tailed Ducks. The combination of their large numbers, limited mobility, nutritional demands along with a declining population trend has led to concern for this species. In 1999 and 2000, we collected ducks through the molt period for a study of body condition, molt timing, and flight parameters. The dynamics of body composition during the molt period act to minimize the flightless period for Long-tailed Ducks. These ducks meet their nutritional demands by foraging during the molt period, but there is no indication that they are resource limited. Body condition was not affected by experimental boat disturbances or proximity to industrial development. During 2000-2002, we studied aspects of movement, site fidelity, habitat use, and foraging using radio telemetry. In general, Long-tailed Ducks forage in the lagoons by day and roost along the barrier islands at night. Movement patterns of Long-tailed Ducks among years and areas are highly variable with some individuals showing a great deal of mobility. We have not seen effects of disturbance (including underwater seismic gunning) on movement, habitat use, or foraging; rather weather (esp., wind) appears to be the primary influence on these behaviors. To examine the role of disease and contaminants on Long-tailed Ducks, we have analyzed blood and cloacal samples taken from live ducks and tissue samples from carcasses. Blood levels of lead were low and there were no major differences in concentrations of trace elements between the Industrial and Control Areas. We identified an adenovirus outbreak as the cause of poor body condition and mortality of Long-tailed Ducks in the Control Area in 2000. Our data suggest that molting Long-tailed Ducks are more influenced by natural phenomena such as wind and disease than human disturbance.

There is concern for the Common Eiders of the Beaufort Sea due to recent dramatic population declines. Along the arctic coast of Alaska, the greatest concentration of breeding Common Eiders is in the central Beaufort Sea where they nest almost exclusively on barrier islands. We used aerial surveys and ground based nest monitoring to assess the breeding ecology of Common Eiders in our study areas. Both aerial surveys and ground based nest searches show a continued decline in nesting effort since 1999. This decline parallels increasingly late sea ice breakup and we believe that it is in part due to eiders forgoing nesting because of poor conditions on breeding grounds. All of our measures of productivity (nesting effort, clutch size, hatch success, and fledging success) are low and substantially below those of Pacific Common Eiders nesting on the Yukon-Kuskokwim Delta. Predation by Arctic Foxes and Glaucous Gulls is the greatest contributor to nest failure. Of 52 broods followed in 2000 and 2001, none were known to survive until fledging. A reovirus, similar to one responsible for a major die-off in Finland, was isolated from two duckling carcasses collected in 2000. Disease and predation may be responsible for poor duckling survival. Concentrations of lead and mercury in blood and eggs were lower than on the Yukon-Kuskokwim Delta. Our data do not show an effect of industrial development on Common Eiders, with the possible exception of an increased risk of predation for eiders breeding near the oilfields. With the breeding success that we have documented since 2000, this population will not persist on its own. We see three possible scenarios for this population: 1) the population may be declining rapidly, 2) the population is maintained by recruitment from other populations, or 3) the population is maintained by infrequent years of high recruitment. Regardless, there is cause for significant concern about the long-term viability of this population.

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INTRODUCTION

The Alaskan Arctic Coastal Plain is home to the largest oil and natural gas discovery in North America (Gilders and Cronin 2000). Located primarily between the Colville and Sagavanirktok rivers on the North Slope of Alaska, this development spans an area approximately 30 x 100 km in size, with facilities occupying some 8,793 ha (Gilders and Cronin 2000). Recent expansion of oil and gas development into the near shore waters of the Beaufort Sea has raised concerns that wildlife using these waters (and the nearby barrier islands) may be at risk to disturbance and oil spills (US Army Corps of Engineers 1998). Of particular concern are more than one hundred thousand sea ducks and other marine birds that use the Beaufort Sea each summer (Johnson and Herter 1989, USFWS 1999). Impacts on sea ducks may be especially important given their recent declines in Alaska and along the Arctic Coastal Plain (Goudie et al. 1994, Suydam et al. 2000, USFWS 1999).

To address the potential threats to wildlife resources, the Outer Continental Shelf Lands Act and its amendments include provisions for post-lease monitoring studies to identify environmental changes, establish trends in marine bird populations, and design experiments to identify causes of any changes (Johnson and Gazey 1992). In 1999, the Minerals Management Service, in collaboration with the U.S. Geological Survey, began studies to describe the abundance and distribution of Long-tailed Ducks (*Clangula hyemalis*), eiders (*Somateria* spp.), and other marine birds in lagoons and offshore areas located adjacent to and away from industrial development. This study consisted of nearshore and offshore aerial surveys, and intensive ground-based studies focused on breeding Common Eiders (*Somateria mollissima v-nigra*) and molting Long-tailed Ducks. These latter studies monitor eiders and Long-tailed Ducks in more detail, and evaluate how species utilizing the lagoons during different stages of their breeding cycle may be affected differentially by industrialization.

The specific objectives of this study were:

1. Monitor Oldsquaw and other species within and among *industrial* and *control* areas in a manner that will allow comparison with earlier surveys using Johnson and Gazeys' (1992) study design.
    a) Perform replicate aerial surveys of five previously established transects based on existing protocol (OCS-MMS 92-0060).
    b) Expand the area from original surveys to include near-shore areas along Beaufort Sea coastline between the original "*industrial*" (Jones-Return Islands) and "*control*" (Stockton-Maguire-Flaxman Islands) areas.

   c) Define the range of variation for area waterfowl and marine bird populations. Correlate this variation with environmental factors and oil and gas exploration, development, and production activities.

2. Expand aerial monitoring approximately 50 km offshore. Surveys will target Spectacled, Common and King eiders. The goal is to sample areas potentially impacted by oil spills from the Liberty, Northstar, and/or Sandpiper Units.
3. Locate and determine the species, number of individuals, density, flock size, direction of movement, habitat/water depth, and behavior of eiders along transect lines. Record the species, location, numbers, and flock size of other seabirds and loons encountered during the surveys.
4. Determine the timing of staging/migrating flock occurrence including the range of dates and peak period dates, the occurrence of eider consistent use areas and areas where generally higher densities of eiders would be expected.
5. Develop a monitoring protocol for birds breeding on barrier islands, particularly Common Eiders. These data will be compared to historic data summarized by Schamel (1977) and Moitoret (1998).
6. Examine relationships between life-history parameters (e.g., fidelity, annual survival, productivity) and ranges of variation in Oldsquaw and Common Eider distribution and abundance to enhance interpretation of cross-seasonal effects of disturbance. That is, the combination of aerial and ground based work has the potential to both document changes in abundance/distribution and describe those changes in terms of movements of marked individuals. Parameters will be examined in relation to disturbance using the two-tiered approach (i.e., within and among lagoons) developed by Johnson and Gazey (1992).
7. Recommend cost-effective and feasible options for future monitoring programs to evaluate numbers and species of birds potentially impacted by oil spills involving ice-free and ice periods in both inshore and offshore waters.

To accomplish objectives 1-4 the USGS-BRD collaborated with the Waterfowl Branch of the USFWS Migratory Bird Management Division to conduct near-shore aerial surveys using existing MMS protocol (OCS-MMS-92-0060). This protocol was designed to measure effects of near shore industrialization on marine bird abundance and distribution (Johnson and Gazey 1992). Rather than test for industrial effects on all species, the protocol identified the Long-tailed Duck as a focal species because of its relative abundance and distribution within the area of interest. We used this protocol to collect density and distribution data on Long-tailed Ducks in 1999-2000 to compare relative densities between 'industrial' and 'control' areas. These areas were delineated in the early 1990's at a time when human activity was concentrated in the 'industrial' area (Johnson and Gazey 1992).

Although human disturbance may have indirect effects on marine birds, an oil spill would likely cause direct mortality of some individuals of certain species (Stehn and Platte 2000). The probability and relative severity of oil spill impacts on population status depends on the temporal and spatial distribution of marine birds in the region. To understand marine bird distribution, we expanded aerial surveys throughout the near-shore environment between Oliktok and Brownlow Point.

The near-shore aerial survey protocol provides a means to monitor trends and distribution patterns of bird populations close to shore, but bird use of offshore waters is poorly documented. Previous studies demonstrated that Spectacled Eiders (*Somateria fischeri*), a threatened species, use offshore waters extensively (Petersen et al. 1999). Surveys in the Canadian Beaufort Sea revealed that eiders used waters as far as 115 km from shore (Searing et al. 1975). Thus, we designed an Offshore survey to delineate concentrations of eiders and other marine birds that use waters within and beyond the barrier island lagoons between Cape Halkett and Brownlow Point. In contrast to the near-shore survey that was designed to detect small-scale distribution patterns within the barrier island lagoons, the offshore survey covered a much larger area. Consequently, inferences drawn from the offshore survey are not limited to small-scale localized patterns of distribution. Results of the aerial survey portion of this study, relative to objectives 1-4 and 7, are summarized and reported by Fischer et al. (2002).

Because molting Long-tailed Ducks and breeding Common Eiders are using the Beaufort Sea lagoons during different portions of their respective annual cycles, the USGS-BRD developed a multifaceted research program designed to address objective 6.

MOLTING ECOLOGY OF LONG-TAILED DUCKS

Between mid-July and mid-September 10-30,000 Long-tailed Ducks use the lagoons along the Beaufort Sea for a post-nuptial molt (Johnson and Richardson 1981, Bartels et al. 1983, Wilbor 1999). At this time, Long-tailed Ducks are the most abundant and widespread waterbird in the nearshore areas of the Beaufort Sea (Schroger 1947, Gollop and Richardson 1974, Johnson and Richardson 1981, Johnson and Herter

1989). During this molt period, birds are flightless for 3-4 weeks, making them vulnerable to human disturbance, weather events, and predation (Johnson and Richardson 1982). Within the lagoons invertebrates (esp., mysids and amphipods) are an abundant food source for sea ducks during an energetically costly time (Johnson 1984).

Industrial development associated with oil and gas exploration and extraction has resulted in increased industrial activity in the Beaufort Sea lagoons. These activities include increased sea and air traffic, and changes in habitat due to development of temporary and permanent structures. Offshore industrial development in the Northstar Unit of the Beaufort Sea began during the winter of 1999. In addition, underwater seismic activity, conducted in 2001, may continue in other areas. The additional air and boat traffic may result in increased levels of stress during a time of energetic demand. Additionally, there is at least a 15% chance of $\geq$ 1,000 barrel oil spill during the expected 15-year lifespan of the industrial developments (U.S. Army Corps of Engineers 1998). Long-tailed Ducks may be especially vulnerable to these disturbances during the flightless period.

Knowledge of the distribution, movements, and residence times of ducks within the lagoons, as well as their behavior, is important to predict potential effects of pollution and disturbance from oil exploration on Long-tailed Ducks using the coastal lagoon system. Effects of disturbance could be as subtle as changes in behavior, or as major as mortality and abandonment of molting sites. Understanding the patterns body composition dynamics is essential to interpreting the potential effects of disturbance. Birds in poor condition are likely to be more susceptible to alteration of behavior patterns or displacement from preferred feeding locations. Disease and exposure to contaminants have been shown to have negative effects on populations of sea-ducks. Therefore, it is essential to assess the prevalence of these potentially confounding factors.

The specific objectives of our molting Long-tailed Duck studies include:

1. Examine within season site-fidelity, local movement and feeding patterns of Long-tailed Ducks in relation to time of day, weather, disturbance and industrial activity.
2. Compare the dynamics of muscle mass and body composition of molting Long-tailed Ducks in relation to the use of exogenous resources and examine the effects of disturbance on body composition dynamics.
3. Determine the prevalence of viruses and concentrations of selected contaminants in molting Long-tailed Ducks and evaluate these parameters in relation to proximity of oil development and potential for influencing population dynamics.

BREEDING ECOLOGY OF COMMON EIDERS

The Pacific race of Common Eiders (*Somateria mollissima v-nigra*) is of particular interest to resource managers because of their recent population declines (Hodges et al. 1996, Suydam et al. 2000). Indices to the number of Common Eiders migrating past Barrow, Alaska, have dropped dramatically in recent years (Suydam et al. 2000). Further, recent satellite telemetry data suggest that the North Slope breeding population is largely isolated from other populations of this subspecies (Petersen and Flint 2002). Reasons for this apparent decline are unknown, but may be related to poor productivity, low adult survival, or contaminants and disease.

Along the North Slope of Alaska, Common Eiders nest and raise their broods almost exclusively on barrier islands (Johnson 2000). Loss of island habitat, either from natural events or industrial development, would likely have negative effects on local segments of the Beaufort Sea population. Two of the primary nesting islands, Egg and Stump, are bisected by an underwater oil pipeline or lie adjacent to the Northstar oil production facility (Schamel 1977, Johnson and Richardson 1980, Johnson 1984, Noel et al 2002). Accordingly, an understanding of the distribution of Common Eider nests across islands is essential to evaluate the potential impacts of an oil spill and to lessen the effects of future offshore oil development on the local nesting population.

The specific objectives of the Common Eider studies include:

1. Document nesting activity by birds on barrier islands and compare these data to historic data summarized by Noel and Johnson (2000).
2. Examine life-history parameters (e.g., annual survival, productivity, and site fidelity) of Common Eiders in relation to proximity to oil development and in comparison with eiders breeding in other locations.
3. Develop a model of population dynamics, incorporating levels of productivity and annual survival.
4. Determine the prevalence of viruses and concentrations of selected contaminants in blood and eggs of nesting Common Eiders, and evaluate these parameters in relation to proximity of oil development and potential for influencing population dynamics.

STUDY AREA

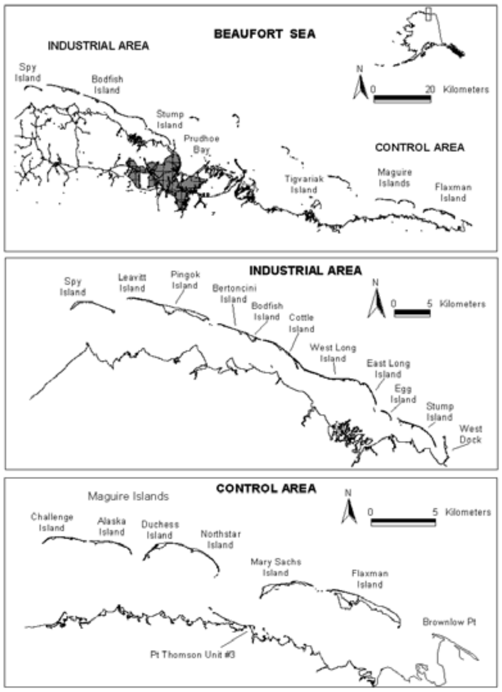


Figure 1. Location of Long-tailed Duck and Common Eider study area along the Beaufort Sea, Alaska, 1999-2002.

This study was conducted at Simpson Lagoon (formed by the barrier island complex between Spy and Stump Islands) and an unnamed lagoon to the east (formed by the Maguire, and Flaxman Island complex) (Figure 1). Simpson lagoon lies adjacent to oilfield production facilities (including Milne Point and Northstar) and is thus considered the Industrial Area. The lagoon to the east is considered to be a comparable Control Area. The study area includes the barrier islands and the adjacent waters of the lagoons and Beaufort Sea. This follows the design proposed by Johnson and Gazey (1992) for monitoring waterfowl and marine birds in the Beaufort Sea. Our Control Area is not a true control in the sense that some limited development has occurred in the area. However, with active coastal and off-shore facilities at F-Pad, Milne Point, West Dock, and Northstar the magnitude of development and activity is much greater in the Industrial Area.

Chapter 1
Effects of Disturbance on Condition of Molting Long-tailed Ducks

INTRODUCTION

We hypothesized that disturbance similar to that caused by industrial activity would have negative impacts on the body condition of molting Long-tailed Ducks. Feather replacement requires large amounts of protein (Hohman et al. 1992, Murphy and King 1992). These nutritional requirements can be satisfied by increasing foraging time, reducing other nutrient costly processes (e.g., shortened periods of activity, roosting close to feeding sites, limiting activities to foraging and resting), or catabolizing stored nutrients (Ankney 1979). Most waterfowl have the ability to store nutrients that can be used to meet the demands of molt if environmental factors prevent them from obtaining necessary nutrients from exogenous sources (Ankney 1979, Hohman et al. 1992). Thompson and Drobney (1996) found that the nutritional reserves of molting Canvasbacks (*Aythya valisineria*), a species that dives readily, remained stable during feather growth after the wing molt. Thus, they concluded the nutritional requirements of feather growth were not derived from endogenous stores of nutrients. However, Goudie and Ankney (1986) examined diets and activity budgets of co-existing sea ducks and found that smaller species fed on higher energy prey items and spent more time feeding. They suggested that smaller species, such as Long-tailed Ducks, had relatively higher metabolic rates and stored less energy than larger species. Therefore, Long-tailed Ducks may have fewer endogenous reserves available to satisfy the nutritional demands of molt if foraging time is reduced due to increased disturbance. Thus, if disturbance reduces foraging time or increases time spent in energy costly behaviors, patterns of nutrient reserve dynamics may be good indicators of the impact of disturbance on molting small-bodied waterfowl. Our objectives were to describe the dynamics and effects of disturbance on nutrient reserves of Long-tailed Ducks during wing molt.

METHODS

In 1999 and 2000, we collected Long-tailed Ducks through the molt period in both the Industrial and Control Areas. During 1999, we attempted to obtain comparable samples of birds from each study area representing all stages of the wing molt from just prior to flight feather loss through feather growth and re-attainment of flight. We also collected birds prior to wing molt for comparative analysis. In 2000, we further divided each area into experimentally disturbed and undisturbed areas to assess the potential effects of disturbance on Long-tailed Duck nutritional status. For this study, our experimental disturbance consisted of boat traffic through the treatment areas. We chose boat traffic because it represented one of the causes of disturbance within the lagoons and has been linked to changes in foraging behavior of water birds (Galicia and Baldassarre 1997). Two transects were established approximately 50 m and 150 m from shore. Each transect was driven in an 18 ft skiff with a 40 hp outboard motor once every other day after the initial collections were taken at all sites. We planned to collect birds from each area within each site during three collection periods: initiation of molt, feather regrowth half-completed, and as birds began to regain flight. However, adverse weather conditions disrupted the experiment and the final collection of birds was not completed. Disturbance was applied from 4-11 August after which weather conditions interrupted the study.

All specimens were collected by euthanizing birds captured during banding operations or by shooting in accordance with Auburn University animal care and use committee guidelines. We recorded culmen width from freshly euthanized specimens. Birds were then frozen and transported to Auburn University for laboratory analysis. Laboratory analyses were similar to procedures described by Dobush et al. (1985) and Thompson and Drobney (1996). We plucked each bird, removed all contents from the digestive tract, and weighed the carcass (see Bailey 1985, Thompson and Drobney 1996, and Brown and Saunders 1998). We also measured the length of the keel as an index of skeletal size.

Specimens were ground to a homogenized mixture with a Hobart meat grinder. A homogenized subsample weighing approximately 100 g was removed and oven-dried for 72 hrs at 90°C. The dried sample was further ground up in a food processor; after which, an ~8 g subsample of dried homogenate was used to determine lipid, protein, and ash content. Subsamples were placed in cellulose thimbles and placed in a Soxhlet apparatus with petroleum ether for 8 hr to remove lipids. The remaining lipid-free material was dried and re-weighed to determine lipid content. The dried lipid free subsample was placed in an aluminum dish and combusted in a muffle-furnace at 550°C for 3 hr and the remainder weighed to determine protein and ash content.

For our analysis, we used nutrient levels based on dry mass to minimize variation in moisture content due to storage conditions. We also used dry carcass mass, rather than whole bird mass, to minimize variation due to body molt and undigested carcass contents. To describe body composition dynamics during wing molt and subsequent feather regrowth in 1999, we used 20 linear models with each of the dependent variables: carcass mass, protein, lipid, and ash (on a dry weight basis); and the independent variables: keel length (KEELEN), bill width (BILLWID), collection date (DATE), length of the ninth primary (NINTH) and squared length of the ninth primary (SQNINTH). Keel length and bill width were included in all models to control for variation due to size. Length of ninth primary was measured from the tip of the feather to its insertion on the proximal side of the feather. We examined potential differences among sites by including site (SITE) and an interaction between site and length of ninth primary (SITENINTH) as independent variables. We selected the models that best fit our data based on $\Delta AIC \leq 2.0$ (Burnham and Anderson 1998). We included KEELEN and BILLWID in all models to control for differences in structural size among individuals. Thus, for 1999 analyses we report the difference in R^2 for each model in comparison to a model containing only keel length and bill width. We assumed that the factors influencing condition each year would be similar. Therefore, to examine the effects of disturbance on body composition in 2000, we used only models from the analysis of 1999 data with $\Delta AIC \leq 2.0$, and added the independent variables treatment (TRT), an interaction between treatment and ninth primary (TRTNINTH), and a site by treatment interaction (SITTRT). Date was included in all lipid and carcass models, and excluded in all protein and ash models based on 1999 analyses. Thus, 20 models were considered.

RESULTS

Patterns of Nutrient Use

Between 28 July and 14 August 1999, we collected 97 males, of which 4 had not molted (length of ninth primary = 144-156mm) and 93 were in the process of molt and feather growth (length of ninth primary = 0-136mm). NINTH appeared in all models with $\Delta AIC \leq 2.0$ for carcass, lipid, and protein mass (Table 1-1). Thus, molt stage was related to mass and nutritional status. As indicated by low R^2, there was little variation in ash content in relation to molt stage (Table 1-1).

Long-tailed Duck carcass mass and lipid levels declined during molt (Table 1-2, Figure 1-1). We also found a strong relationship between carcass mass and DATE after controlling for molt stage (Table 1-2). Further, the relative importance of the SQNINTH parameter suggested moderate support for a decrease in the rate of decline in mass, but weak support for a change in rate of decline in lipid use through feather regrowth (Table 1-2, Figure 1-1). Mass and lipid levels also differed between sites (Table 1-2). We found little support for the interaction term SITENINTH indicating little or no difference in the rate of decline in either carcass mass or lipid levels between sites (Table 1-2).

Long-tailed duck protein levels declined during early stages of wing molt (Table 1-2, Figure 1-1). However, we found strong evidence for an increase in protein levels to levels comparable with pre-molt birds near the end of feather regrowth (Table 1-2), and a difference in protein levels or rate of protein use between sites was only weakly supported (Table 1-2). DATE also had minimal effect on protein levels (Table 1-2).

Table 1-1. General linear models describing variation in body condition of male Long-tailed Ducks during molt and feather regrowth in 1999. The models best fit by our data, and those with substantial support (i.e., with ΔAIC $\leq$ 2.0), are presented. Keel length and bill width were included in all models to control for body size.

Response variable	Model	Explanatory variables[ab]	Number of parameters	ΔAIC_c	AIC_c weight	R^2 Total	R^2 Partial[c]
DRY CARCASS	1	NINTH SQNINTH DATE	7	0.00	0.25	0.56	0.43
	2	SITE NINTH SQNINTH DATE	8	0.34	0.21	0.57	0.44
	3	SITE NINTH SITENINTH SQNINTH DATE	9	0.86	0.16	0.57	0.45
LIPID	1	SITE NINTH DATE	7	0.00	0.30	0.60	0.50
	2	SITE NINTH SITENINTH DATE	8	0.45	0.24	0.61	0.51
	3	NINTH DATE	6	1.29	0.16	0.59	0.49
PROTEIN	1	NINTH SQNINTH	6	0.00	0.45	0.33	0.23
	2	SITE NINTH SQNINTH	7	1.31	0.23	0.34	0.23
ASH	1	SITE NINTH SQNINTH	7	0.00	0.11	0.10	0.07
	2	--[d]	4	0.06	0.10	0.03	0.00
	3	NINTH SQNINTH	6	0.20	0.10	0.07	0.04
	4	SITE	5	0.27	0.09	0.05	0.02
	5	NINTH	5	0.37	0.09	0.05	0.02
	6	SITE NINTH	6	0.90	0.07	0.07	0.04
	7	SITE NINTH SITENINTH SQNINTH	8	1.24	0.06	0.11	0.08
	8	SQNINTH	5	1.27	0.06	0.04	0.01
	9	SITE SQNINTH	6	1.80	0.04	0.06	0.03

[a] NINTH - length of ninth primary, SITE - study site, SQNINTH - squared ninth primary, SITENINTH - interaction term between site and length of ninth primary, DATE - collection date (Julian),

[b] Culmen width and keel length were included in all models to control for size variation among individuals.

[c] Improvement in R^2 with addition of specified explanatory variables.

[d] Model including only culmen width and keel length.

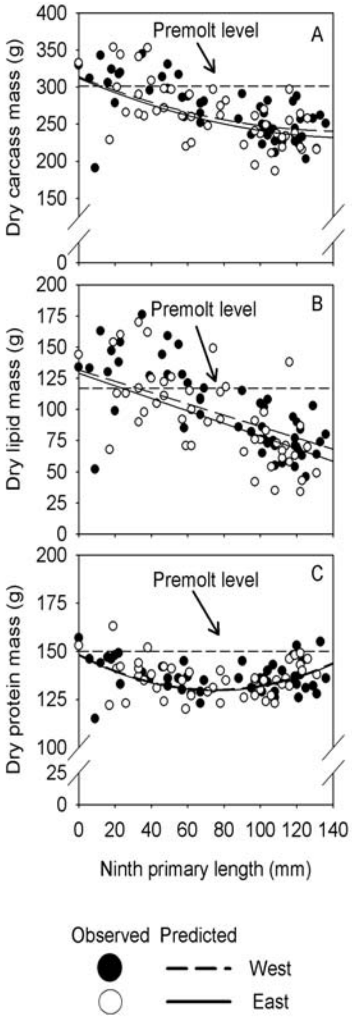


Figure 1-1. Dynamics of (A) dry carcass mass, (B) lipid, and (C) protein levels during molt compared to pre-molt levels for male Long-tailed Ducks collected in Control (East) and Industrial (West) Areas in 1999. Curves are based on results of weighted model averaging.

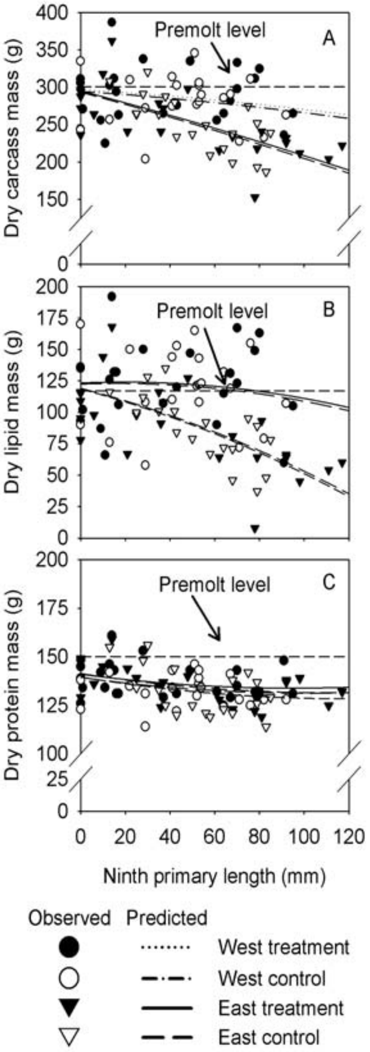


Figure 1-2. Dynamics of dry (A) carcass mass, (B) lipid, and (C) protein levels during molt compared to pre-molt levels for male Long-tailed Ducks collected from experimentally disturbed (treatment) and undisturbed (control) sites in 2000. Ducks were collected from both the Control (East) and Industrial (West) Areas. Curves are based on results of weighted model averaging.

TABLE 1-2. Parameter estimates from general linear models describing variation in Long-tailed Duck body condition during molt and subsequent feather regrowth in 1999. Parameter likelihoods, i.e. AICc weights summed across all considered models that included a given variable, indicate the importance of that variable. Parameter estimates are weighted averages (based on model AICc weights) from all candidate models and SE's are based on unconditional variances over the suite of models considered. Parameter likelihoods are not given for parameters that were included in all models.

Response variable	Explanatory variable[a]	Parameter likelihood	Parameter estimate	SE
DRY	INTERCEP	--	322.5255	275.550
CARCASS	KEELEN	--	2.5275	0.750
	BILLWID	--	5.8411	3.766
	NINTH	0.9964	-0.9939	0.401
	DATE	0.8392	-1.7806	0.828
	SQNINTH	0.6861	0.0033	0.002
	SITE	0.6446	-1.7910	7.104
	SITENINTH	0.2674	-0.0484	0.050
LIPID	INTERCEP	--	334.6773	201.890
	KEELEN	--	1.3831	0.636
	BILLWID	--	4.6972	3.187
	DATE	0.9692	-2.0104	0.670
	NINTH	0.9429	-0.4533	0.134
	SITE	0.7667	-2.5415	7.264
	SITENINTH	0.3229	-0.0508	0.051
	SQNINTH	0.3008	<0.0001	0.001
PROTEIN	INTERCEP	--	48.2950	38.024
	KEELEN	--	0.9371	0.208
	BILLWID	--	0.1587	1.019
	NINTH	0.9999	-0.4900	0.090
	SQNINTH	0.9999	0.0033	0.001
	SITE	0.4069	-0.5898	0.889
	DATE	0.2462	-0.0139	0.060
	SITENINTH	0.0965	0.0001	0.004

[a] KEELEN - keel length, BILLWID - culmen width, NINTH - length of ninth primary, SITE - study site, SQNINTH - squared ninth primary, SITENINTH - interaction term between site and length of ninth primary, DATE - collection date (Julian).

TABLE 1-3. General linear models describing variation in body condition of male Long-tailed Ducks during molt and feather regrowth in 2000. The models best fit by our data, and those with substantial support (i.e., with ΔAIC $\leq$ 2.0), are presented. Keel length and bill width were included for all models to control for body size, site and ninth primary length were included in all models, and date was included in models of lipid and dry carcass mass based on 1999 results.

Response variable	Model	Explanatory variables[a]	Number of parameters	ΔAIC_c	AIC_c weight	R^2	
						Total	Partial [b]
CARCASS [c]	1	SITENINTH	8	0.00	0.39	0.41	0.05
	2	SITENINTH TRT	9	1.82	0.16	0.41	0.06
LIPID [c]	1	SITENINTH	8	0.00	0.36	0.40	0.06
	2	SITENINTH SQNINTH	9	0.91	0.23	0.41	0.07
PROTEIN [d]	1	TRT	7	0.00	0.15	0.33	0.03
	2	SQNINTH	7	0.43	0.12	0.32	0.03
	3	SQNINTH TRT	8	0.92	0.09	0.34	0.04
	4	SITENINTH SQNINTH	8	0.93	0.09	0.34	0.04
	5	SITENINTH TRT	8	1.54	0.07	0.33	0.04
	6	--[e]	6	1.53	0.07	0.30	0.00
	7	SITENINTH SQNINTH TRT	9	1.75	0.06	0.35	0.05
	8	TRT TRTNINTH	8	1.78	0.06	0.33	0.03
ASH [d]	1	--[e]	6	0.00	0.31	0.08	<0.01
	2	SITENINTH	7	1.89	0.12	0.09	<0.01
	3	TRT	7	1.94	0.12	0.09	<0.01

[a] Parameters added to baseline model. SQNINTH - squared ninth primary, SITENINTH - interaction term between site and length of ninth primary, TRT - treatment, TRTNINTH - interaction term between treatment and ninth primary length.

[b] Improvement in R^2 with addition of specified explanatory variables.

[c] Site, keel length, culmen width, length of ninth primary, and collection date were included in all models.

[d] Site, keel length, culmen width, and length of ninth primary were included in all models.

[e] Model included only site, keel length, culmen width, and length of ninth primary.

TABLE 1-4. Parameter estimates from general linear model analyses describing variation in Long-tailed Duck body condition during molt and subsequent feather regrowth in 2000. Parameter likelihoods, i.e. AICc weights summed across all considered models that included a given variable, indicate the importance of that variable. Parameter estimates are weighted averages (based on model AICc weights) from all candidate models and SE are based on unconditional variances over the suite of models considered. Parameter likelihoods are not given for parameters that were included in all models.

Response variable	Explanatory variable[a]	Parameter likelihood	Parameter estimate	SE
DRY CARCASS	INTERCEP	--	-232.6521	325.616
	NSITE	--	-1.1368	16.917
	KEELEN	--	1.0253	1.226
	BILLWID	--	8.0976	5.064
	NINTH	--	-0.2002	0.310
	DATE	--	1.2212	7.275
	SITENINTH	0.91	-0.6006	0.239
	TRT	0.44	2.3221	5.454
	SQNINTH	0.28	0.0009	0.001
	TRTNINTH	0.11	0.0209	0.039
	SITTRT	0.10	-0.6022	1.715
LIPID	INTERCEP	--	-103.6680	268.570
	SITE	--	-3.9026	13.855
	KEELEN	--	0.4647	1.020
	BILLWID	--	2.2555	4.195
	NINTH	--	0.0652	0.330
	DATE	--	0.6159	0.953
	SITENINTH	0.93	-0.5359	0.204
	SQNINTH	0.43	0.0020	0.002
	TRT	0.38	0.8734	3.903
	TRTNINTH	0.10	0.01485	0.028
	SITTRT	0.09	-0.3454	1.216
PROTEIN	INTERCEP	--	15.2135	37.222
	SITE	--	0.1558	3.169
	KEELEN	--	0.4080	0.306
	BILLWID	--	4.2220	1.205
	NINTH	--	-0.1625	0.106
	TRT	0.69	1.5782	2.094
	SQNINTH	0.50	0.0008	0.001
	SITENINTH	0.37	-0.0268	0.030
	TRTNINTH	0.20	0.0111	0.017
	SITTRT	0.17	0.1796	0.658

[a] SITE - study site, KEELEN - keel length, BILLWID - bill width, NINTH - length of ninth primary, SQNINTH - squared ninth primary, SITENINTH - interaction term between site and length of ninth primary, DATE - collection date (Julian), TRT - treatment, TRTNINTH - interaction term between treatment and ninth primary length, SITTRT - interaction term between site and treatment.

Effects of Disturbance on Nutrient Use

From 21 July to 10 August 2000, we collected an additional 9 males prior to molt (length of ninth primary = 141-161mm) and another 88 males that had molted and were in the process of regrowing new feathers (length of ninth primary = 0-117mm).

Differences in the rate of nutrient use (parameters SITENINTH and TRT) were important in explaining the variation in condition of Long-tailed Ducks in 2000 (Table 1-3). We found some indication of a treatment effect on carcass mass and lipid levels (Tables 1-3 and 1-4, Figure 1-2), as well as a change in rate of decline in carcass mass through feather regrowth in 2000 (i.e., SQNINTH term; Table 1-4). However, improvement in model fit related to treatment effects, as indicated by the partial correlation coefficients (Table 1-3) was relatively small, and the rate of decline in carcass mass and lipid levels differed between sites (Table 1-4).

There was marginal support for a treatment effect on protein levels in Long-tailed Ducks (Table 1-4, Figure 1-2). Marginal support was also given for a change in the rate of protein use through feather regrowth as indicated by the squared ninth term (Table 1-4). The best models only explained <10% of the variation in ash levels (Table 1-3).

DISCUSSION

Wing molt is a nutritionally costly process for Long-tailed Ducks in the Beaufort Sea region, as indicated by declining carcass mass and lipid levels throughout this study. Declines in lipid reserves explained a large portion of the declines we saw in body mass. Lipids are a readily catabolized source of energy (Blem 1976, Peterson and Ellarson 1979). Thus, declines in lipids could be explained by energetic demands, reduced foraging, or cost of feather growth (Blem 1976, Peterson and Ellarson 1979). Our findings are similar to Peterson and Ellarson's (1979) study of Long-tailed Ducks wintering on Lake Michigan, in which most of the decrease in body weight was due to a decline in lipid reserves. Cursory observations of fat deposits showed that, similar to Musacchia's (1953) findings, during the early molt Long-tailed Ducks had high amounts of subcutaneous fat, which are the primary depots for storage (Johnston 1964).

In contrast, protein levels decreased and then rose to levels similar to those of pre-molt birds as feathers were grown. The decrease in protein levels during molt indicated that Long-tailed Ducks initially used endogenous reserves to meet increased demands for protein. Although feathers are composed primarily of protein and molt increases the daily requirement of this nutrient, muscles were a store of labile protein for energy and feather growth (Kendall et al. 1973, Swick and Benevenga 1977, Murphy and King 1982). The rise in protein levels we observed suggested that Long-tailed Ducks were able to meet the demands of feather development in the latter stages of molt through nutrients obtained from foods. Additionally, the return to protein levels similar to that of pre-molt birds resulted from the development of breast muscle necessary to regain flight.

Long-tailed Ducks are similar to other waterfowl in not catabolizing minerals stored in bone tissue (Ankney 1979, Thompson and Drobney 1996). Our analysis failed to explain the small, observed variation in mineral content. Consequently, it would appear that Long-tailed Ducks did not experience any shortages in mineral availability and were able to meet demands from exogenous sources.

We suggest that nutrient dynamics provide a clearer picture of the adaptive strategies employed by ducks during wing molt. The decline in carcass mass slowed during the later stages of wing molt, because protein levels increased even though lipid levels declined at a constant rate. Continued mass loss during a period of muscle building suggested that the dynamics of condition during molt were related to flight attainment as well as a use/disuse of locomotion muscles (Ankney 1979, Thompson and Drobney 1996, Brown and Saunders 1998). Increases in muscle mass were likely due to changes in behavior and wing surface area (e.g., wing flapping and use while diving) and the resulting recovery of flight muscle from disuse. The concurrent continual decline in lipid levels allowed birds to attain lower body mass while rebuilding muscle necessary for flight. This decreased mass effectively lowered the wing load (ratio of body mass to wing area) for Long-tailed Ducks, given a reduced wing area during molt, thereby shortening the period of flightlessness (see Chapter 3 for further discussion of mass and flight dynamics).

Our results suggest that limited disturbance had little or no effect on the nutritional status of molting Long-tailed Ducks. Males molting in disturbed areas were in slightly better condition than males in undisturbed areas. Although we found limited support for a treatment effect in our models, the difference in condition of birds between disturbed and undisturbed areas as reflected by the improvement in model fit was trivial. Thus, this result is more likely due to experimental error than any real difference in condition between treatments. Additionally, if Long-tailed Ducks experience losses in mass as a strategy to shorten the flightless period, additional losses in mass may be negligible. However, our inability to detect a disturbance effect may have been due to the limitations of our study design. Due to a major storm event in 2000, we were unable to subject birds to disturbance for the duration of the molt period and make the final planned collection. Additionally, our disturbance experiment was restricted to limited boat traffic. Alternate sources, more frequent, or intense disturbance may have produced an effect on Long-tailed Duck nutritional dynamics.

Moreover, we measured changes in carcass and nutrient mass with respect to the length of the ninth primary. Our assumption was that changes in behavior related to disturbance would affect the rate of nutrient use during molt. Thus, we would have been unable to discern an effect if nutrient limitation during molt only influenced feather growth rates. Such an effect would be impossible to detect unless repeated measures of feather lengths on individuals could be included in the analysis.

Finally, the observed difference in carcass mass and nutrient composition dynamics between sites, in 2000, may be due to an epizootic during this study (see Chapter 7). In 2000 there was a much higher (44%) incidence of exposure to a previously unknown adenovirus in the Control Area. This disease caused an undocumented number of mortalities among Long-tailed Ducks using the Control study site, and may account for nutrient levels being lower in those birds.

MANAGEMENT IMPLICATIONS

Use by large numbers of birds and the high nutritional costs associated with molt suggest that Beaufort Sea lagoons provide resources that are important to the ecology of Long-tailed Ducks. These lagoons offer shelter from winds and provide calmer waters in which molt can occur. Long-tailed Ducks are a small sea duck and likely spend more time foraging relative to larger sea ducks (Goudie and Ankney 1986). The ability of Long-tailed Ducks to meet the demands of molt depends upon their maintenance requirement, nutrient supply, and ability to compensate through metabolic and behavioral plasticity (King and Murphy 1985). It appears that during the early stages of molt Long-tailed Ducks rely heavily upon lipid and protein stores. Although lipid reserves decreased throughout the study period, during the latter stages of molt, muscle mass increased presumably using protein attained from food resources. This strategy allowed Long-tailed Ducks to lose mass quickly, but regain muscle (protein) in order to regain flight. Protein deficiencies during this period could have resulted in the prolonged duration of molt (i.e. slower feather growth) or the malformation of growing feathers (Murphy and King 1987). Thus, an abundant protein source that was readily available during late July and early August appeared vital to rapid re-attainment of flight and feather regrowth.

Similar rates of nutrient use during 1999, suggested that individuals were able to meet nutritional demands of molt equally well at both sites. Additionally, natural variation in condition due to stage of molt, site, and disease appears greater than any effects of disturbance for birds molting in near-shore waters. However, differences in body condition between Control and Industrial Areas in 2000 suggested that these populations are somewhat segregated. Molting and wintering sea ducks have been shown to exhibit high site fidelity (Flint et. al. 2000 and Robertson et. al. 2000), which may be advantageous to locating food resources and areas with low predation pressure (Robertson et al. 2000). Therefore, we suggest that it is important to maintain the integrity of the entire complex of lagoons, and that further investigations of molt site fidelity and population structure of Long-tailed Ducks are warranted.

Chapter 2
Body Molt Of Male Long-Tailed Ducks

INTRODUCTION

Whereas the molting regimes of most species of waterfowl consist of one or two molting cycles per year (i.e., pre-alternate and pre-basic), Long-tailed Ducks are unique in that they carry out an additional third, supplemental molt (Salomonsen 1949, Humphrey and Parks 1959, and Palmer 1976). The supplemental molt occurs from approximately September through mid-October, between the pre-basic and pre-alternate molts, and involves replacement of the head, neck, and scapular regions (Palmer 1976). Subsequently, pre-alternate molt occurs gradually from some time in September through November or December. This molt involves the replacement of all feathering except the tail, wing, and posterior under-parts of the bird (Palmer 1976). Pre-basic molt occurs in two periods. In the spring (commonly April; Palmer 1976) areas including the head down to the breast and much of the mantle are shed. Pre-basic molt resumes in late summer (July) and continues into fall when Long-tailed Ducks molt the remaining body regions as well as remiges. During this molt Long-tailed Ducks are flightless for approximately three to four weeks (Palmer 1976).

Molt can be a useful indicator of the physiological status, habitat requirements, and probable fitness of migratory waterfowl (Lovvorn and Barzen 1988). Understanding the timing of pre-basic molt is important since it may occur simultaneous with the wing molt, a period that leaves waterfowl vulnerable to disturbance and predation. During this period, birds may lose as much as 25% of their total body mass (Chilgren 1977, King 1980). Nutrient demands increase for the synthesis of new feathers, increased amino acid metabolism, increased cardiovascular activity to supply feather regrowth, daily changes in protein levels, and an increased need for iron to produce red blood cells and for calcium associated with bone formation (Murphy and King 1992). Birds can cope with the added costs of molt by increasing foraging effort, reducing other nutrient costly activities, catabolizing stored nutrients, or a combination of the three (Ankney 1979, Murphy and King 1982). Catabolized reserves often play an important role in supplying the necessary nutrients to carry out feather replacement (Ankney 1979). Therefore, characterizing the body molt as it relates to remige growth provides a measure of the intensity of molting pressures and, when compared to historical information on condition and timing of molt, indicates whether the ability to meet the demands of molt have been threatened. Our objective was to describe the timing and intensity of body molt in relation to the stage of remige molt as it occurs in male Long-tailed Ducks.

METHODS

We collected molting Long-tailed Ducks through the molt period in 1999 and 2000 (see Chapter 1). Stage of wing molt was determined by measuring the length of the ninth primary from the tip of the feather to its insertion on the proximal side of the feather. To measure the intensity of body molt, we assigned feather tracts into eight regions: 1) head and neck (crown, facial, chin/throat, and neck), 2) back and rump (upper and lower back, scapulars, rump), 3) breast (chest), 4) belly, 5) greater coverts, 6) lesser coverts, 7) side (flank and side), and 8) tail (retrices), based on Taylor (1995). Each region was sampled four times by estimating the proportion of blood quills and missing feathers along a 1 inch dissecting probe inserted between feathers. We defined a blood quill as any growing feather containing blue color within the shaft or any feather with feather sheath present at or above the skin surface. We categorized molt intensity into five levels based on the estimated portion of blood quills and missing feathers in each sample: 0 (0%), 1 (1-24%), 2 (25-49%), 3 (50-74%), and 4 (>75%). Samples were averaged and the corresponding score was recorded for that region.

We were interested in estimating the intensity and duration of molt for each feather tract with respect to the stage of wing molt. Therefore, we used nonlinear regression (Sigmaplot 2001 v7.0, SPSS, Inc.) to fit the Gaussian three-parameter model

$$y = ae^{-0.5\left(\frac{x-x_0}{b}\right)^2}$$

where the estimated parameter *a* corresponds to the function maxima, *b* determines the width of the bell curve, *x* is the dependent variable, x_0 is the estimated value of the independent variable at the corresponding function maxima, and *y* is the independent variable. Thus, for a given feather tract and individual, *y* and *x* are the observed molt score and length of the ninth primary (i.e., molt stage). It follows then, that the population parameters estimated for each feather tract are, *a* – peak molt intensity, *b* – variation in molt intensity with respect to molt stage, and x_0 – length of ninth primary at which molt intensity peaks. A high degree of synchrony in molt among individuals resulted in good model fit as indicated by a large R^2. Large variability in timing of peak molt intensity with respect to molt stage was indicated by a relatively large *b*. Thus, a small R^2 in concert with a large value for *b* suggested a low degree of synchrony in feather molt at the population level. Conversely, a large R^2 indicated a high degree of synchrony among individuals.

RESULTS

Specimens were collected (n = 187) from 28 July to 14 August 1999, and from 21 July to 10 August in 2000. Long-tailed Ducks molted each body region during our study except head and neck (Table 2-1, Figure 2-1). Although we found evidence of feather regrowth, only six males (3%) showed any degree of molt in the head and neck (Figure 2-1A).

During our study, molt intensity achieved the highest levels in the lesser coverts, greater coverts, tail, and back and rump regions. Non-linear models explained over 60% of the variation in molt scores for lesser and greater coverts. Lesser coverts appeared to reach the highest molt intensity slightly earlier than greater coverts (Figures 2-1B and 2-1C). Retrices were the next feathers to reach peak molt intensity (Figure 2-1D). The back and rump region also reached highest molt intensity during mid-molt of the remiges (Figure 2-1E). Both the lesser and greater coverts appeared to complete the process of molt before remige regrowth was complete, while the back and rump regions were nearly completed during the same time period. Molt of retrices appeared to have continued into the latter stages of remige regrowth.

Table 2-1. Parameter estimates, standard errors (SE), and coefficients of multiple determination (R^2) for three-parameter Gaussian models of molt intensity for male Long-tailed Ducks in Beaufort Sea lagoons, 1999-2000.

Region		Maximum Intensity (*a*)	Variance in intensity with respect to stage of wing molt (*b*)	Wing molt stage at peak intensity (x_0)	R^2
Head and Neck	Estimate	0.43	0.38	15.40	0.30
	SE	1.32	0.85	0.47	
Back and Rump	Estimate	3.30	45.53	81.59	0.53
	SE	0.10	2.35	1.89	
Breast	Estimate	2.49	35.73	101.70	0.52
	SE	0.13	3.40	3.35	
Flank	Estimate	8.37	306.61	-550.31	0.06
	SE	119.14	1374.08	5218.59	
Greater Coverts	Estimate	4.25	36.44	59.81	0.63
	SE	0.12	1.43	1.30	
Lesser Coverts	Estimate	4.25	30.74	53.35	0.65
	SE	0.15	1.36	1.30	
Tail	Estimate	4.06	42.84	101.94	0.60
	SE	0.15	3.42	3.49	
Belly	Estimate	2.49	37.63	108.52	0.59
	SE	0.11	3.55	3.96	

Our models explained nearly 60% of the variation in molt scores for the breast region and over 50% for the belly region (Table 2-1). We found that the breast and belly regions started molt later than the greater and lesser coverts, retrices, and back and rump regions and attained maximum molt intensity during the latter half of molt. The breast region attained maximum intensity slightly ahead of the belly region (Figures 2-1F&G). However, the figures indicate that the latter stages of feather growth for the breast and belly regions did not occur within our study period and probably continued until and perhaps beyond full remige regrowth.

Molt in the side and flank region occurred throughout our study (Figure 2-1H). Values for molt intensity in this region were also highly variable as indicated by the high value of *b* for this feather tract (Table 2-1).

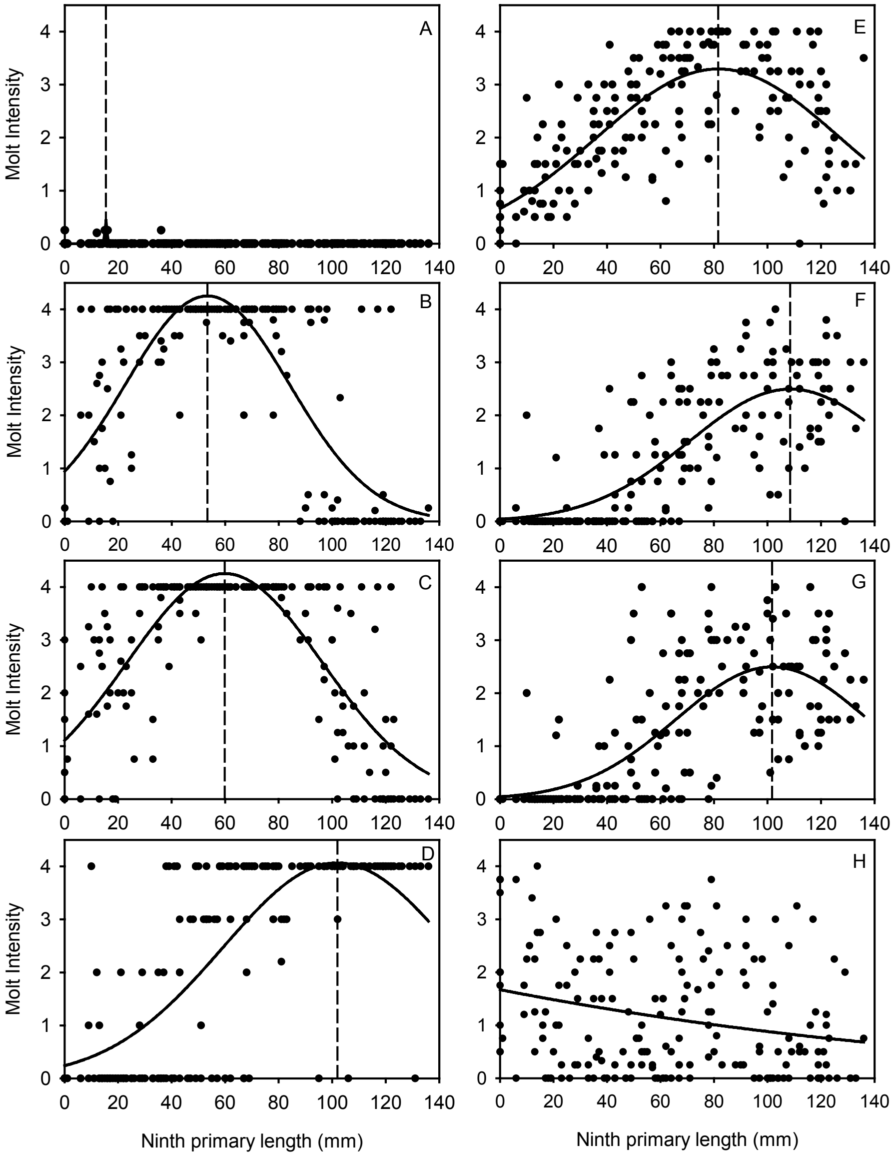


Figure 2-1. Molt intensity in each feather tract through ninth primary growth for male Long-tailed Ducks. (A) Head and neck, (B) lesser coverts, (C) greater coverts, (D) tail, (E) back and rump, (F) belly, (G) breast, and (H) flank and side. Dotted lines indicate the estimated molt stage of wing molt (i.e., ninth primary length) corresponding to peak molt intensity.

DISCUSSION

All feather tracts, except head and neck and flank and side, increased in molt intensity as wing molt progressed. Our research substantiated Palmer's (1976) characterization that molt occurs in the head and neck region prior to all other feather tracts during the pre-basic molt. Molt in the flank and side region appear to be more variable throughout the wing molt and the lack of a discernable "peak" is probably indicative of a slower rate of molt in these areas. Both the greater and lesser coverts, and back and rump regions began molting concurrent with the loss of remiges and were re-grown by the time remige regrowth was complete.

Long-tailed Ducks may reduce the nutritional demands of molt by staggering the molt of various feather regions over time or by undergoing molt during periods when molt does not overlap with other nutrient costly activities such as migration (Heitmeyer 1987). Our data indicate that greater and lesser coverts and back and rump regions likely completed molt prior to additional post-breeding movements, which may reduce costs associated with the initiation of the supplemental molt as it begins in September (Palmer 1976). However, King and Murphy (1985) advise that nutritional status should be considered in the context of the life history of a species with regard to nutritional requirements and accessibility, as well as the repertoire of adjustments available to avert or minimize discrepancies between the two. Additionally, Lovvorn and Barzen (1988) caution the interpretation of molt patterns in terms of staggered costs and found that timing of molt was associated with a photoperiodic response for Canvasbacks. Leafloor and Ankney (1991) also suggest that among unsuccessful nesting female Mallards (*Anas platyrhynchos*) social environment appears to influence the timing of molt. For Long-tailed Ducks molting in the cold waters of the Beaufort Sea, a less synchronous pattern of body molt may also lessen the thermal costs associated with reduced insulatory qualities.

Additionally, completion of the covert molt prior to full remige regrowth may be indicative of an adaptive strategy to minimize the flightless period. Many species of waterfowl regain flight before remige regrowth is complete (Hohman et al. 1992). Brown and Saunders (1998), showed that body mass dynamics and wing surface area played a significant role in enabling Blue-winged Teal (*Anas discors*) to re-attain flight capability before remige growth was complete. However, smoothness and shape of the wing are also important in reducing wing drag and maximizing lift (Pennycuick 1989). We suggest that while the overall timing of molt in Long-tailed Ducks may be controlled by ultimate factors such as photoperiod, the order of molt among specific feather tracts, specifically the molt of wing coverts, is timed to reduce the period of flightlessness. Further, the staggered timing of molt among feather tracts may serve to spread the nutritional demands of feather growth and reduce the energetic costs associated with thermoregulation in cold-water environments.

Chapter 3
Mass Dynamics in Relation to Flight Parameters Following Remige Molt of Male Long-tailed Ducks

INTRODUCTION

Unlike most bird species, waterfowl undergo synchronous wing molt and lose the ability to fly for approximately three weeks. During this flightless period, waterfowl experience physiological changes as well as changes in behavior. Physiological changes include shifts in body mass and the mass of muscle groups associated with locomotion during wing molt and feather re-growth (Ankney 1979, Thompson and Drobney 1996, Brown and Saunders 1998), which have been attributed to energetic costs of molt and use-disuse (i.e., behavioral) adaptations to the loss of flight capabilities (Brown and Saunders 1998). Swimming and diving become the primary modes of travel, as well as means of predator avoidance. These behavioral changes result in changes in the use of muscle groups and may cause shifts in the mass associated with each group of muscles.

Physiological changes associated with wing molt can also have a direct influence on flight capability. Body mass, wing area, wingspan, and flight muscle and leg muscle mass can all be affected during wing molt and influence the ability to regain flight capability. Whether changes in mass are the result of stressful conditions in which nutrient demands exceed nutrient ingestion and cause a catabolization of endogenous reserves is debatable (Ankney 1979). Brown and Saunders (1998) hypothesized that changes in mass during molt are regulated to facilitate a quicker return to flight rather, than the result of nutritional and energetic costs associated with molt. These regulated changes may be an innately programmed process in which endogenous reserves are drawn on even under optimal conditions (King and Murphy 1985). Changes in body composition have been studied in other species and may be normal adaptative changes rather than changes caused by nutritional stress (Freed 1981, Baldassarre et. al. 1986). Swaddle and Witter (1997) found that artificial loss of wing feathers alone was enough to cause European Starlings (*Sturnus vulgaris*) to lose body mass. This loss indicated that a loss of flight performance alone could cause an adaptive response of loss in body mass. In the case of molting Long-tailed Ducks, changes in body condition and muscle mass may also be normal regulated changes to facilitate a shorter flightless period and early return to flight.

We examined four factors related to the physiological changes that occur subsequent to the wing molt that may affect Long-tailed Duck flight and swimming abilities. Wing loading (body mass/wing area) is a measure of the load supported by the wings and influences the amount of power necessary to attain flight. Power loading (body mass/pectoral muscle mass) is a measure of the ratio of flight muscle power given the amount of body mass. Wing-power loading (pectoral muscle mass/wing area) is a measure of the power available to generate lift. All three of these factors directly influence dynamics of flight and consequently affect the ability to attain flight. Leg-power loading (body mass/leg muscle mass) is a measure of power available for swimming given the amount of body mass and may provide flightless birds with the power necessary to reach higher swimming and diving speeds necessary for survival during the flightless period (Brown and Saunders 1998). Hence, we examined changes in nutrient levels, body mass, flight muscle mass, leg muscle mass, and changes in wing area that Long-tailed Ducks undergo during molt and how those changes affect flight and swimming capabilities. Our objective was to describe changes in body mass, muscle mass, and nutrient composition as they relate to the ability of Long-tailed Ducks to regain flight after the wing molt.

METHODS

We collected molting Long-tailed ducks through the molt period in 1999 and 2000 (see Chapter 1). We recorded culmen length and width, tarsus length, and total weight from freshly collected specimens. Keel length was recorded as an additional index to size during later laboratory analysis. Birds were then frozen and transported to Auburn University for laboratory analysis. Prior to dissection, we measured morphological features pertaining to flight dynamics. Each bird was placed ventrally on a flat surface and the right wing was traced (Pennycuick 1989). We then scanned each tracing and determined the area of each wing ($\pm$ 0.01cm) using image analysis in MATLAB (Mathworks, Inc).

We plucked each bird and removed and weighed ($\pm$ 0.01g) the right breast muscles (*M. pectoralis* and *M. supracoracoideus*), right leg muscles (*Gastrocnemius*, *Iliotibialis cranalis*, *Peroneus longus*, and *Tibialis cranialis*), heart, empty gizzard, and empty digestive tract (Bailey 1985, Thompson and Drobney 1996, and Brown and Saunders 1998). After weighing, organs were returned to the carcass and the carcass was weighed again to determine the plucked/digesta free wet carcass mass ($\pm$ 1g) (CARC). A small portion of the heart muscle ($\leq$ 1g) was removed and preserved for DNA analysis.

We examined the dynamics of flight parameters (wing load, power loading, etc.) using simple linear and polynomial regressions versus wing area. Wing load (g/cm^2) was CARC divided by area of the right wing. Power load (g/g) was CARC divided by the mass of the right pectoral muscle. Wing power (g/cm^2) was calculated by dividing the right wing area by the right pectoral muscle. Leg power (g/g) was calculated by dividing CARC by the total mass of right leg muscles.

We examined changes in pectoral muscle and leg muscle masses with respect to stage of molt using general linear models. We used 26 linear models with the dependent variables: breast muscle mass, and right leg muscle mass; and independent variables: keel length (KEELEN), bill width (BILLWID), date (DATE), length of the ninth primary (NINTH), and squared length of the ninth primary (SQNINTH). Keel length and bill width were included as independent variables in all models to control for variation due to size. We also examined potential differences among sites (SITE), and an interaction between site and length of ninth primary as (SITENINTH). Potential differences among years (YEAR) and a year/site interaction (YRSITE) were also analyzed. We selected the models that best fit our data based on ΔAIC ≤ 2.0 (Burnham and Anderson 1998). For comparative purposes, we included mean values for birds collected prior to wing molt, and birds collected in 1999 that were capable of flight during the latter stage of feather re-growth.

For wing loading analysis involving nutrient composition, we used dry weights obtained from compositional analysis. Contributions of each nutrient to wing loading were calculated using linear regression. Dry weights were used for the nutritional analysis to avoid biases resulting from dessication during laboratory procedures.

RESULTS

We used data from 186 birds collected during the summers of 1999 and 2000, including 12 premolting males and 12 males in the latter stage of feather re-growth, capable of flight, as a reference to flight dynamic conditions prior to flightlessness. As expected, wing load was negatively correlated with wing area (Figure 3-1), and the rate of decline in wing load decreased until premolt levels were reached.

TABLE 3-1. General linear models describing variation muscle mass of male Long-tailed Ducks during molt and feather regrowth. The models best fit by my data, and those with substantial support (i.e., with ΔAIC ≤ 2.0), are presented. Keel length and bill width were included for all models to control for body size. Excludes treatment birds from 2000.

Response variable	Model	Explanatory variables[a]	Number of parameters	AIC_c	AIC_c weight	R^2
Pectoralis Muscle	1	SITE NINTH SQNINTH	6	0	0.293	0.522
	2	SITENINTH SQNINTH	5	0.26	0.257	0.515
	3	SITE NINTH SQNINTH YEAR	7	1.62	0.130	0.523
	4	NINTH SQNINTH YEAR	6	1.94	0.111	0.516
Leg Muscles	1	NINTH SQNINTH	5	0.000	0.236	0.278
	2	SITE NINTH SQNINTH	6	0.697	0.167	0.285
	3	SITE NINTH SITENINTH SQNINTH	7	1.357	0.120	0.291

[a] NINTH - length of ninth primary, SITE - study site, SQNINTH - squared ninth primary, SITENINTH - interaction term between site and length of ninth primary, YEAR - collection year.

Fifty-two percent of the variation in pectoral muscle mass was explained by best-fit models versus molt stage (i.e., ninth primary length, Table 3-1). There was unequivocal support in our data for a change in the relationship between pectoral mass and ninth primary length during feather re-growth (i.e., inclusion of SQNINTH, Table 3-2). There also was strong support for a difference in pectoral mass between sites. Pectoral mass declined initially and then increased during feather re-growth (Figure 3-2). The relationship between wing-power load and wing area was similar to the relation between wing load and wing area (Figure 3-3). Pectoral mass only explained a small portion of the variation in body mass (R^2 = 0.16). Power load increased initially and then decreased, but only 30% of the variation was explained by molt stage (Figure 3-4).

Nearly thirty percent (range = 0.28-0.29) of the variation in leg mass was also explained by best-fit models versus molt stage (i.e., ninth primary length, Table 3-1). There was unequivocal support for a change in the relationship between leg mass and ninth primary length during feather regrowth (i.e., inclusion of SQNINTH, Table 3-2). There was moderate support in the data for differences between sites and years; however, neither parameter was present in the best models. Leg mass increased slightly and then decreased during feather re-growth (Figure 3-2). There was little variation in leg power load through feather re-growth ($R^2 \leq 0.01$, Figure 3-5). Leg mass explained relatively little variation in body mass ($R^2 = 0.30$) and pectoral mass ($R^2 = 0.01$).

TABLE 3-2. Parameter estimates from general linear model analyses describing variation in Long-tailed Duck pectoral muscle and leg muscle mass during molt and subsequent feather re-growth. Parameter likelihoods, i.e. AICc weights summed across all considered models that included a given variable, indicate the importance of that variable. Parameter estimates are weighted averages (based on model AICc weights) from all candidate models and SE are based on unconditional variances over the suite of models considered. Parameter likelihoods are not given for parameters that were included in all models or summed to 1. Excludes treatment birds from 2000.

Response variable	Explanatory variable[a]	Parameter likelihood	Parameter estimate	SE
Pectoralis Muscle	INTERCEP	--	-10.9480	10.845
	KEELEN	--	0.3356	0.082
	BILLWID	--	1.1828	0.375
	NINTH	--	-0.2695	0.027
	SQNINTH	--	0.0023	0.000
	SITE	0.63	0.5321	0.518
	YEAR	0.35	-0.1642	0.282
	SITENINTH	0.16	0.0007	0.003
	YRSITE	0.06	-0.0183	0.076
Leg Muscles	INTERCEP	--	-12.4725	6.565
	KEELEN	--	0.2640	0.050
	BILLWID	--	0.7796	0.228
	SQNINTH	0.92	0.0266	0.016
	NINTH	0.81	0.3692	0.334
	SITE	0.57	-0.0020	0.002
	YEAR	0.31	-0.0573	0.153
	SITENINTH	0.19	-0.0003	0.000
	YRSITE	0.06	0.0312	0.054

[a] KEELEN - keel length, BILLWID - bill width, NINTH - length of ninth primary, SITE - study site, SQNINTH - squared ninth primary, SITENINTH - interaction term between site and length of ninth primary, YEAR - collection year, YRSITE - interaction term between year and study site.

The dynamics of nutrient composition and wing load indicated that protein was the greatest factor contributing to wing load through molt and feather re-growth (Figure 3-6). Contributions of protein to wing load decreased initially and then increased largely due to changes in pectoral mass. Contributions of lipid levels to wing load declined constantly through feather re-growth, while contributions of mineral levels remained constant. Wing load due to each nutrient was relatively constant until the latter stage of feather re-growth when protein levels increased (Figure 3-7). Once Long-tailed Ducks were capable of flying, the relative contribution of lipid to wing load decreased rapidly.

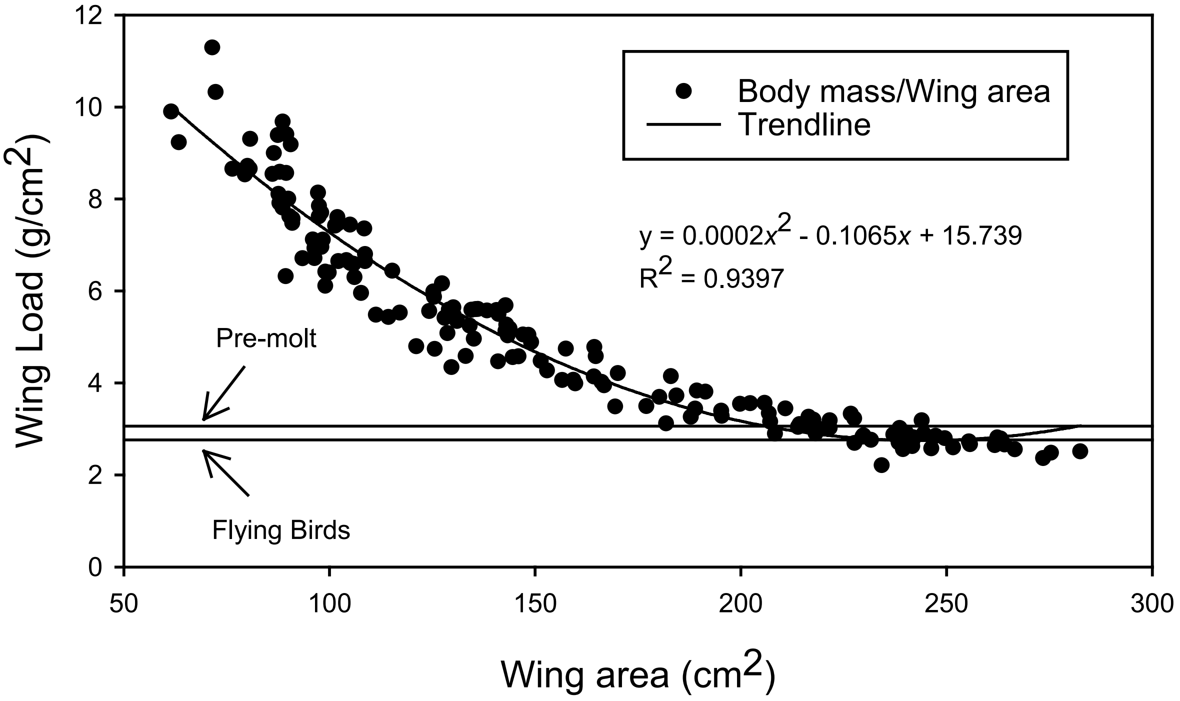


Figure 3-1. Dynamics of wing load for molting male Long-tailed Ducks 1999-2000 (wing loads are based on wet weights). Reference lines for pre-molting and individuals that had re-attained flight included for comparison.

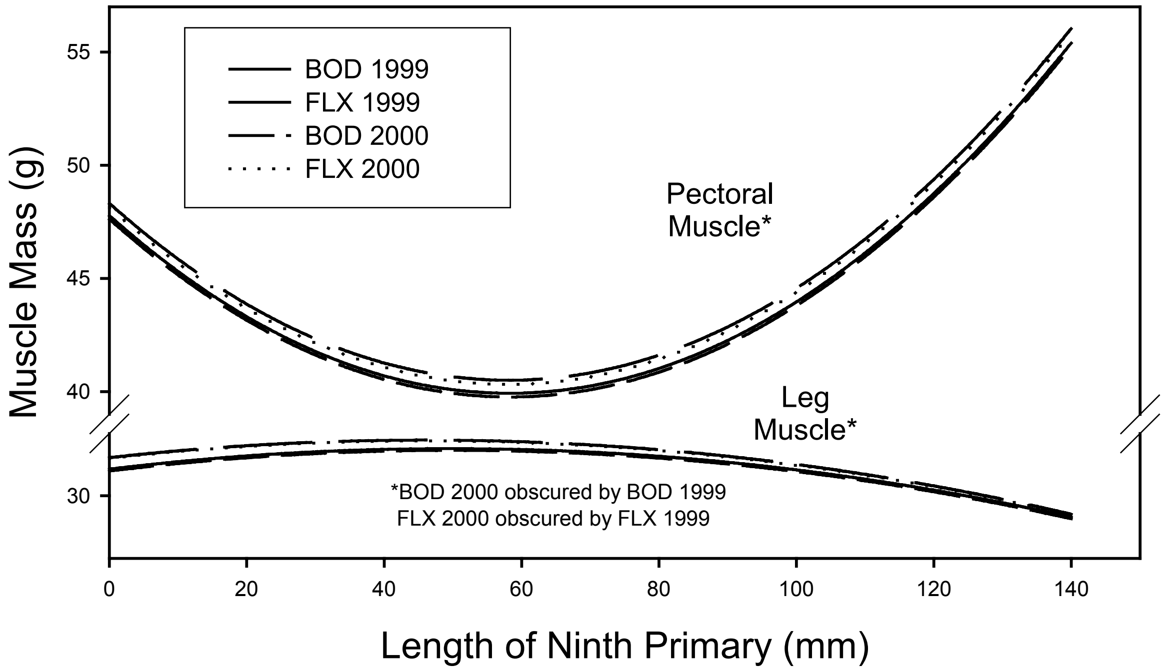


Figure 3-2. Changes in pectoral and leg muscle mass in relation to molt stage for molting male Long-tailed Ducks 1999-2000.

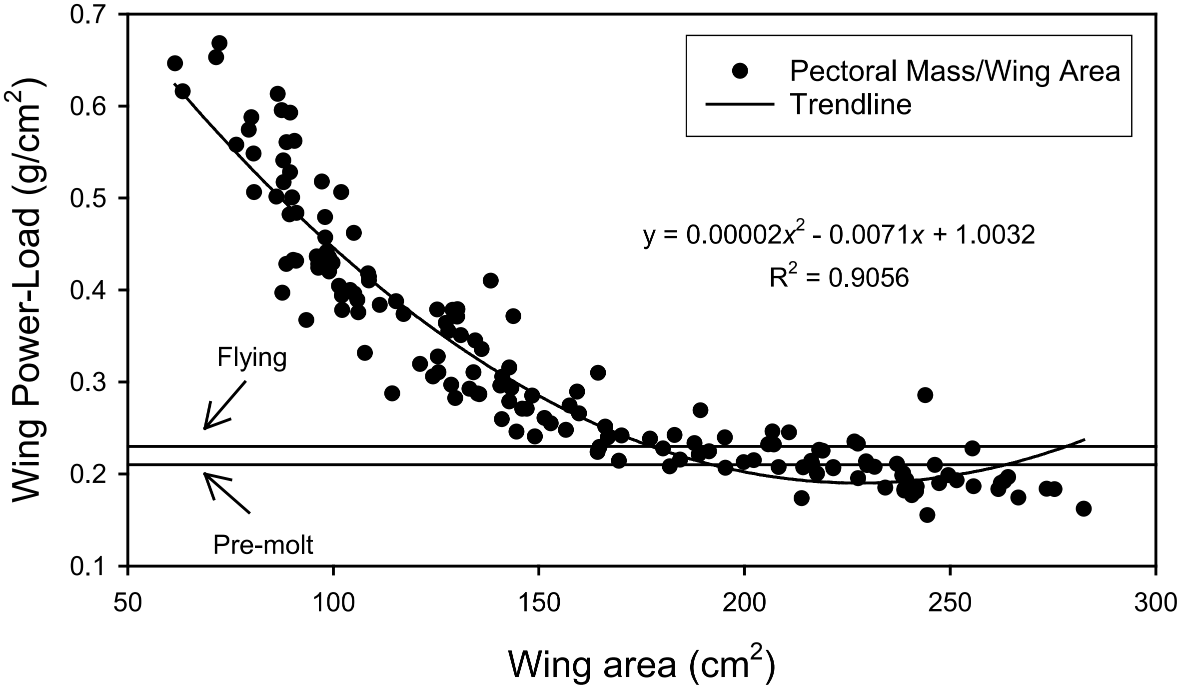


Figure 3-3. Wing power load (pectoral muscle mass/wing area) in relation to molt stage for molting male Long-tailed Ducks 1999-2000. Reference lines for pre-molting and individuals that had re-attained flight included for comparison.

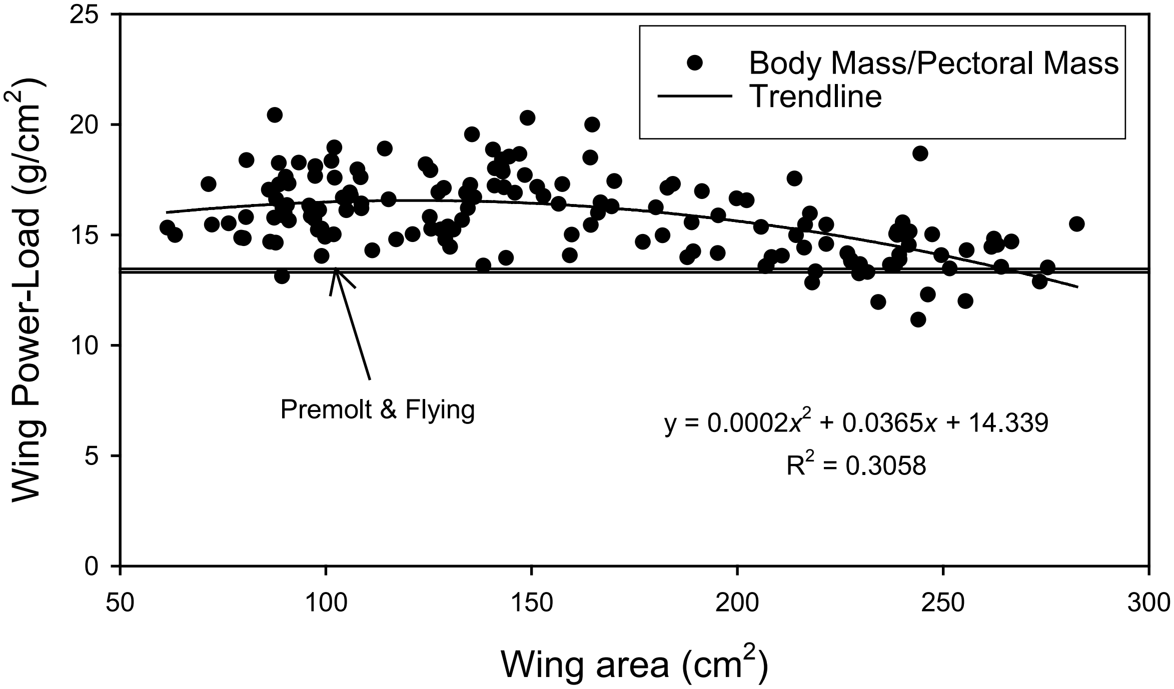


Figure 3-4. Power load (carcass mass/right pectoral muscle mass) in relation to molt stage for molting male Long-tailed Ducks 1999-2000. Reference lines for pre-molting and individuals that had re-attained flight included for comparison.

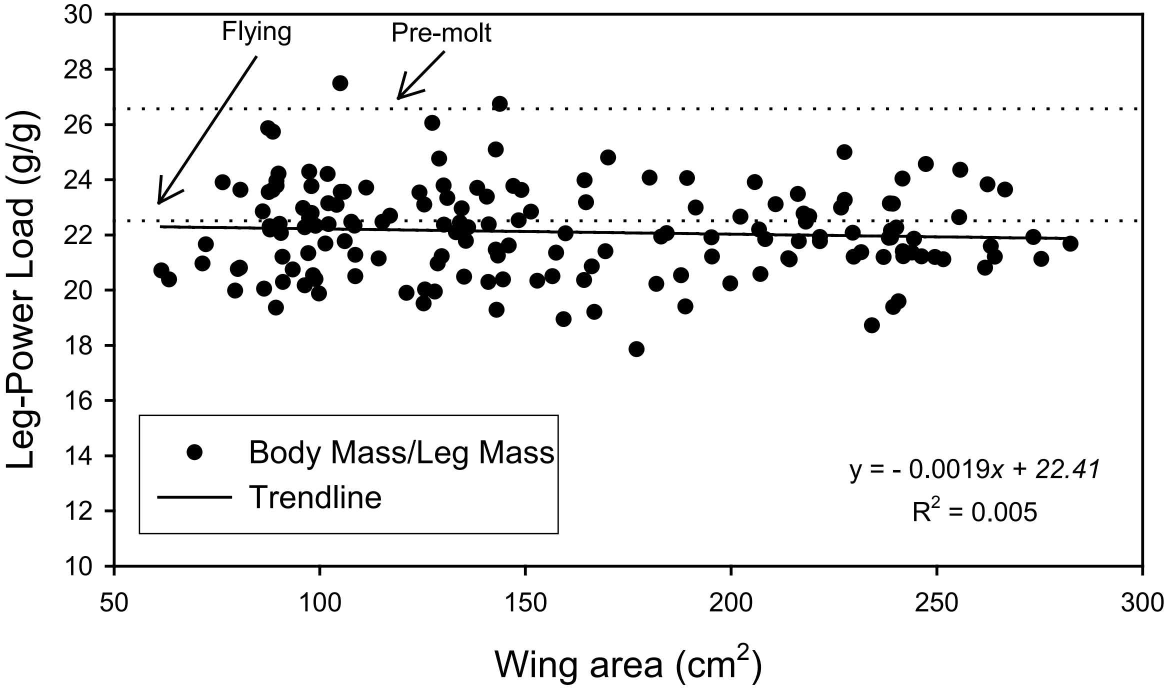


Figure 3-5. Leg-power load (carcass mass/leg muscle) in relation to molt stage for molting male Long-tailed Ducks 1999-2000. Reference lines for pre-molting and individuals that had re-attained flight included for comparison.

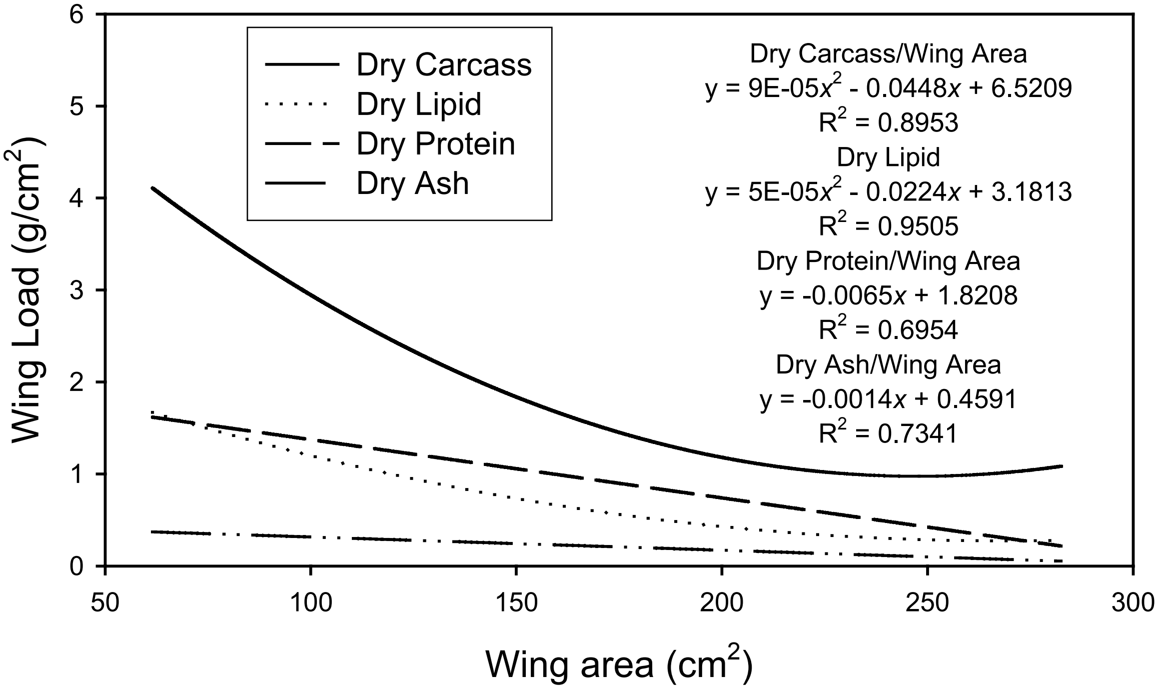


Figure 3-6. Wing loading based on nutrient composition (dry weight values) in relation to molt stage for molting male Long-tailed Ducks 1999-2000.

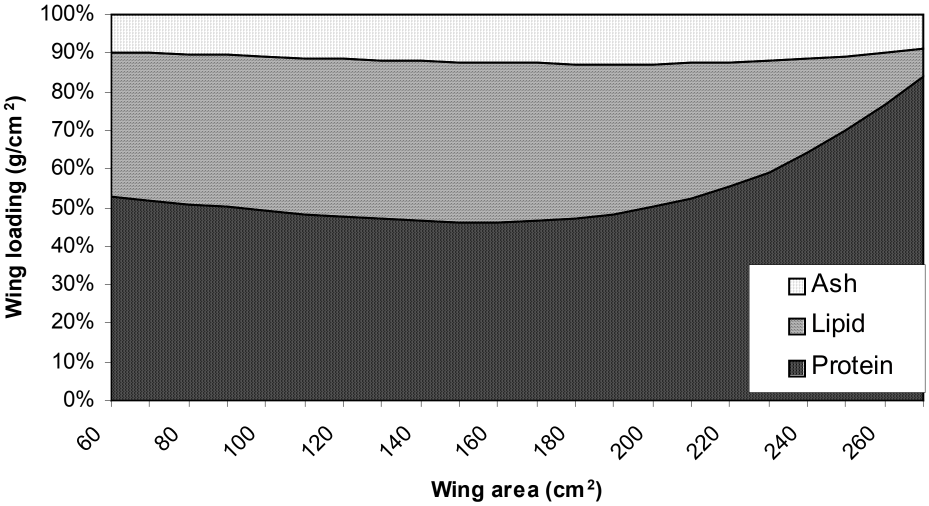


Figure 3-7. Percent of nutrients contributing to wing load in relation to molt stage for molting male Long-tailed Ducks 1999-2000

DISCUSSION

Male Long-tailed Ducks experienced changes in parameters affecting flight performance similar to those found by Brown and Saunders (1998) for Blue-winged Teal. Wing-power loading increased and wing load more than tripled over pre-molt levels with the loss of flight feathers. These results were expected given the sudden drop in wing area experienced during synchronous wing molt. Power loading, the ratio of body mass to pectoral mass, also increased initially and subsequently returned to pre-molt levels indicating a return to levels necessary for flight.

In contrast to flight parameters, we found that leg-power loading remained relatively constant throughout molt. This result differed from that of Brown and Saunders (1998). This was expected given the different ecological adaptations of Long-tailed Ducks and Blue-winged Teal. Long-tailed Ducks have been reported to depend on wing power for diving and therefore should not experience an increased dependence on leg power for foraging or escape (Snell 1985). Similar studies on diving ducks have found little or no change in leg muscle mass with regard to stage of molt. Bailey (1985) found that while male Redheads (*Aythya americana*) experienced losses in mass for breast muscle, these losses were not compensated by increases in leg muscle mass and could not simply be attributed to a use/disuse cause alone, but rather were related to protein reserves, foraging time, and anticipated seasonal use. Similarly, Hohman (1993) found that leg muscle mass was not related to stage of molt in Ruddy Ducks (*Oxyura jamiacensis*). While Thompson and Drobney's study (1996) of molting Canvasbacks indicated a change in leg muscle mass concurrent with an atrophy of breast muscle, the increase was only 12% compared to a greater than 40% increase in leg muscle mass for Blue-winged Teal (Brown and Saunders 1998). Although leg-power loading levels were higher during pre-molt, this was likely due to small sample size.

We suggest that changes in pectoral muscle and nominal changes in leg muscle mass experienced by Long-tailed Ducks are the result of behavioral adaptations (i.e., loss of flight and increased foraging activity to offset costs of molt) and anticipated use (i.e., increased reliance on diving to escape predators). We found little support for the hypothesis that breast muscle mass for Long-tailed Ducks was offset by hypertrophy of leg muscle mass ($R^2 = 0.01$). While flightlessness likely resulted in increased reliance of dabbling ducks on swimming for predator evasion and feeding, Long-tailed Ducks and similar species normally demonstrate more diving and swimming behavior (Hohman 1993). Furthermore, diving ducks have been shown to allocate a greater amount of time to resting during molt than dabbling ducks (Bailey 1985, Thompson and Baldassarre 1991, and Adams et al. 2000). To better clarify whether Long-tailed Ducks experience changes in muscle mass that are normal regulated changes made in anticipation of use, as Bailey (1985) suggested, then studies of mass dynamics should include behavioral observations prior to molt as well as during the flightless period.

Reductions in mass of male Long-tailed Ducks effectively shortened the period during which wing loading levels were too high for flight. Throughout the period of flightlessness Long-tailed Ducks experienced a decrease in carcass mass. Wing area increased as body mass decreased and stabilized as pre-molt levels of wing loading were reached. Thus, pre-molt wing loads were attained before remiges were completely re-grown allowing Long-tailed Ducks to resume flight with less than a complete wing.

We found that mass loss during the initial stages of molt, when wing loading was at its highest, was the result of decreases in the levels of protein, lipid, and ash. As the level of wing loading approached pre-molt levels, the rate of decline in carcass mass decreased and eventually began to stabilize. Protein and lipid levels were greatest and made the largest contribution to overall wing loading. Changes in the levels of these two nutrients also resulted in the greatest fluctuations in wing load. Protein levels also stabilized and ultimately increased as wing loading levels approached those similar to pre-molt. However, lipid levels continued to decrease, offsetting the gain in protein, and thereby allowed wing loading levels to remain at a level similar to that of pre-molt birds.

We suggest that mass dynamics experienced by Long-tailed Ducks cannot be explained by a singular causative factor, but rather a combination of factors. Changes in mass could result from regulated changes, costs associated with molt, and anticipated use. Protein levels may diminish initially due to increased demands for protein during feather development (Murphy and King 1992), as well as a lack of use of flight muscles. Lipid declines may be due to increased energetic demands resulting from a diet higher in protein than lipid content (Murphy and King 1987) or increased energetic demands resulting from a reduction in insulation due to feather loss (Blem 1976). Additionally, if Long-tailed Ducks make frequent stops to feed, lipid reserves may not be necessary during migration (Johnston 1964). While the ultimate cause of mass dynamics are debatable, decreases in mass resulting from decreases in levels of protein and lipid effectively shorten the period of flightlessness.

Chapter 4
Site Tenacity and Movements of Long-Tailed ducks

INTRODUCTION

Flightless Long-tailed Ducks appear to establish a relatively regular diurnal pattern of movement and habitat use (Johnson 1984). Flocks of birds are regularly observed roosting along the barrier islands late in the evening and early in the morning. During mid-day, birds are dispersed throughout the central portions of the lagoons. While flocks of birds are regularly observed in the same locations, it is unknown to what degree this represents consistent use by the same individuals. It has been suggested that patterns of habitat use by flightless Long-tailed Ducks are influenced by wind direction and speed. That is, birds appear to select habitats providing protection from wind-generated waves. Thus, individuals may not actually show site fidelity, but birds are observed in consistent locations simply because of overall patterns of habitat selection. Obviously, flightless birds have limited opportunity to move if conditions change following the onset of molt. Thus, understanding the degree of site fidelity and range of movement by flightless birds is essential to predicting the effect of potential displacement caused by disturbance or habitat loss. Our goal in this study was to measure site fidelity and movement probabilities of radio-equipped Long-tailed Ducks.

METHODS

From 1999 to 2002, we live-captured flocks of flightless Long-tailed Ducks using boats and corral traps set at known roosting locations throughout the Industrial and Control Areas. In 2000 and 2001, a sub-sample of males was marked with subcutaneously anchored radio transmitters (Peitz et al. 1995). Birds were released at the capture site immediately following marking. Presence/absence of marked individuals was recorded using Data Collection Computers (DCC) connected to Yagi antennas on fixed towers. The DCCs are automated data loggers that record the pulse rate of transmitters within the detection range of the antenna tower. Locations for DCC towers were based on logistics, such that data could be retrieved without disturbing birds (Figure 4-1). DCCs were programmed to listen for each radio transmitter for 45 seconds, then switch to the next frequency, and to repeat the cycle once all transmitters were scanned (Table 4-1). In this way, transmitters were monitored 2-3 times per hour continuously through the study period. Our transmitters emitted 60 pluses per minute. Because saltwater attenuates VHF radio signals, we considered records of 40 pulses or less (during a 45 second scan) to indicate a bird that was diving (i.e., feeding); records with 41-50 pulses were considered to represent a roosting duck, and records with more than 50 pulses were discarded as erroneous. High pulse rates may have been caused by competing radio frequencies from two or more ducks close to the radio towers, interference from other radio sources (i.e., marine radio) or low battery voltage effects on the receiver or DCC unit.

Table 4-1. Sampling results for radio-equipped Long-tailed Ducks monitored by Data Collection Computers (DCC) on the Control and Industrial Areas, 2000-2002.

		Industrial Area									Control Area	
Year	DCC sites:	Bodfish Island	Cottle Island	E. West Long Island	W. West Long Island	F-Pad	Oliktok Point	Pingok Island	E. Spy Island	W. Spy Island	Flaxman Island	Maguire Island
2000	Sampling (days)		12								15	8
	Sampling (hours)		272.0								337.7	170.8
	No. radios monitored		20								26	26
	No. radios detected		19								26	24
	Fixes/radio (± SE)		735.9 ± 107.4								1141.3 ± 116.8	493.5 ± 60
	Range of fixes/radio		23 - 1518								12 - 1929	4 - 758
	Total Fixes		13982								29673	11843
2001	Sampling (days)	29	14	4	1	35	31	28	34	32	18	16
	Sampling (hours)	649.7	229.5	61.0	4.5	690.7	659.2	623.6	762.2	654.4	321.8	343.7
	No. radios monitored	40	40	40	40	40	40	40	40	40	63	63
	No. radios detected	18	14	1	1	6	3	28	30	15	36	27
	Fixes/radio (± SE)	132.2 ± 55.1	26.5 ± 11.6	48	6	5.2 ± 1.7	3.3 ± 1.3	215.3 ± 48.2	135.5 ± 34.0	26.1 ± 6.3	144.4 ± 20.8	118 ± 21.9
	Range of fixes/radio	4 - 737	2 - 170			2 – 11	2 - 6	5 – 995	2-699	2-100	2-446	2-395
	Total fixes	2380	371	48	6	31	10	6027	4066	391	5186	3202
2002	Sampling (days)	37	37		34			30	37	6	15	14
	Sampling (hours)	876.7	877.5		796.4			734.7	874.6	114.5	338.5	306.3
	No. radios monitored	59	59		59			59	59	59	59	59
	No. radios detected	39	31		41			21	17	2	9	33
	Fixes/radio (± SE)	62.1 ± 17.5	76.2 ± 16.6		73.5 ± 20.8			21.5 ± 7.6	48.9 ± 25.2	50 ± 24	106.9 ± 21.7	101.6 ± 16.4
	Range of fixes/radio	2 – 645	2 - 430		2 – 755			2 - 130	2-389	26-74	2-186	2-322
	Total fixes	2423	2363		3015			451	831	100	962	3352

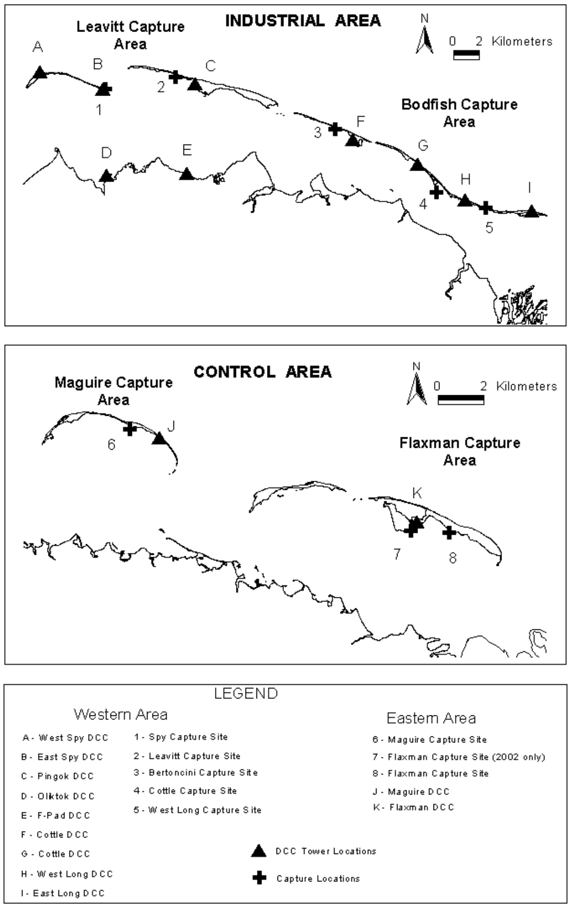


Figure 4-1. Locations of Data Collection Computers (DCC) and Long-tailed Duck capture sites in the Control and Industrial Areas, 2000-2001.

Because DCC antennas were stationary and could only detect the presence of ducks within 2.5 km, we used DCC records to indicate the presence or absence of radio-equipped ducks near the towers. Thus, we defined the area around each tower as a unique area and describe the fidelity of individuals to these areas. We used two approaches to analyze these data. First, we used standard Cormak-Jolly-Seber models to estimate the overall rate of fidelity. These models examine the 'capture history' of individuals and typically estimate two parameters: survival rate and recapture rate. The recapture parameter accounts for the fact that not all marked individuals are typically encountered at every 'observation' and is defined as the probability of recapturing or observing a marked individual given that it is present on the study area. However, in our case, our areas were defined by the coverage of antennas. Thus, the recapture rates account for individuals on the fringe of the antenna range or individuals that left the areas for a period of time then returned (i.e., temporary emigration). The survival parameter is related to the proportion of individuals that disappear from the area and are never re-encountered. These individuals either died or permanently emigrated from the area. Because our study was of a short duration, we assumed that survival was 100% and that the apparent 'mortality' from a mark-recapture model was actually permanent emigration. Hereafter, we refer to this parameter as the emigration rate. We examined models that estimated emigration and recapture probability on a daily basis (i.e., individual days were the period of observation). Unfortunately, we lacked sufficient data to examine if this daily rate varied through time. We fit models that allowed the emigration and recapture rates to differ among areas. This analysis estimates the daily rate of emigration. The probability of emigration for the flightless period was estimated by raising this daily rate to the 21st power (i.e., flightless interval). This represents the probability of leaving a particular monitoring area and moving to any other area. Accordingly, the fidelity rate is one minus the probability of permanent emigration during the flightless period.

The second analysis used multi-state mark-recapture approaches to estimate the transition or movement probabilities among specific areas. Statistically, this approach is similar to the one described above, however it incorporates additional parameters that estimate the probability of individuals changing 'states'. In this case, 'states' were defined as specific monitoring areas. Thus, this model has the ability to estimate the specific probability of individuals moving from one area to another. For this analysis, we lacked sufficient sample size to estimate the emigration and detection probabilities for each area separately. Therefore, we estimated an overall emigration rate and detection probability and fixed these values in subsequent analyses. We then applied multi-state models to estimate the transition probabilities among the different areas. It is important to realize that a single individual can contribute to more than one transition probability. That is, once an individual changes areas, it is subsequently assumed to be a member of the 'new' population and any further movements will contribute to subsequent transition probabilities. Thus, if an individual moves from area A to area B then back to area A, it will contribute to both the probability of movement from A to B and from B to A. Accordingly, the sum of all possible transition probabilities can be greater than one.

RESULTS

Estimates of site fidelity ranged from 1-96%, with considerable variation among locations and within locations among years (Table 4-2). In 2000, radio-marked birds had a very high probability (>85%) of remaining at one site through the flightless period. In 2001, we were only able to estimate probabilities for the Control Area and they were much lower (<50%). In 2002, Control Area estimates were high (72-96%) again, whereas Industrial Area estimates were particularly low (0.5-32%).

Using multi-state analyses, site-specific movement probabilities suggest a general trend of movement to the east. For all but one transition probability, the probability of eastward movement (estimates below the diagonal in table 4-3) exceeded comparable estimates for westward movement (above the diagonal). The probability of movements was negatively related to distance between DCCs. The transitions with the highest probabilities (i.e., Bodfish to Cottle, Cottle to Bodfish, and Cottle to West Long) are between adjacent DCCs (Table 4-3).

Table 4-2. Probability (%) of a bird remaining within the detection zone of a single Data Collection Computer (DCC) for a 21-day sampling period.

	2000	2001[1]	2002
Industrial Area			
West Long			29
Cottle	100		17
Bodfish			22
Pingok			1
East Spy		44	22
Control Area			
Maguire	87	67	<1
Flaxman	64	17	43

[1]Because of sampling gaps caused by equipment malfunction, we could not estimate probabilities for most of the Industrial Area in 2001.

Table 4-3. Daily probability (%) of movement between the detection zone of one DCC and another in the Industrial Area 2002.

From	To				
	West Long	Cottle	Bodfish	Pingok	East Spy
West Long	94.7[1]	5.0[2]	0.07	0	0
Cottle	13.1	91.9	18.0	0	0
Bodfish	10.7	18.3	93.0	1.9	0
Pingok	7.7	0	0	77.8	0
East Spy	0	0	0	0	93.0

[1] Values along the diagonal are the daily probabilities of not *permanently* emigrating from a site. Because some ducks move to other sites and then return (i.e., non-permanent emigration) rows can sum to >100%. Estimates based on Cormak-Jolly-Seber model.

[2]Values off the diagonal were estimated with a multi-state transition model.

DISCUSSION

Our results demonstrate that Long-tailed Ducks move considerably during the molt period in spite of their flightless state. While flocks of birds are consistently observed in the same locations on a daily basis, our results suggest that there is turnover within these aggregations. Unfortunately, we lack sufficient data to assess daily variation in fidelity rate, thus we cannot directly address the effect of wind on site fidelity. The general weather pattern along the Beaufort Sea coast in August is dominated by winds from the northeast. Thus, under normal conditions the barrier islands provide protection from wind generated waves. This likely explains the preference for use of the barrier islands for roosting.

The strong annual variation in site fidelity is likely explained by annual variation in weather conditions. The low site fidelity in 2001 is associated with a period of strong southwesterly winds and likely represents birds moving in search of protected water. Interestingly, the year with the highest probability of ducks remaining at one DCC for the entire flightless period (i.e., 2000) was the year when we experimentally disturbed Long-tailed Ducks with boats at two of the three DCC locations (Cottle and Flaxman Islands – see Chapter 1). In 2002, we collected our largest and most consistent set of DCC data, thus we were able to examine 2002 data in greater detail. Long-tailed Ducks in the Industrial Area appear to move more readily among DCC sites. This lack of site fidelity in the Industrial Area is likely associated with the more contiguous arrangement of islands (Figure 4-1). The islands that form Simpson Lagoon essentially create a uniform strip of habitat. Conversely, the Control Area represents a more fragmented habitat and movements between areas would require crossing a relatively large open channel. Apparently, flightless Long-tailed Ducks are reluctant to make movements across these large channels. Movements between DCC sites were most likely when distances were short. However, this may be an artifact of our sampling design. Because the islands essentially create a linear strip of habitat, our DCC sampling stations are arranged in a linear fashion. Thus, in order to move from one station to a more distant station, birds would likely pass though intermediate stations. The multistate analysis approach, assigns individuals to a ‘population or site’ as soon as they are detected at that site. Consequently, an individual moving from Bodfish to West Long would likely travel through the Cottle DCC area. If this individual were detected in the Cottle area its movement would contribute to both the transition probability from Bodfish to Cottle and from Cottle to West Long. Nonetheless, most individuals only moved to the next nearest sampling location.

Our data demonstrate that even flightless Long-tailed Ducks have the ability to move considerable distances in response to environmental conditions. We found little evidence for displacement of individuals associated with disturbance. We suggest that patterns of site fidelity are predominantly influenced by weather conditions, particularly wind direction. The observations of birds feeding and roosting in consistent locations are supported by our data, however, a considerable proportion of individuals change locations during the flightless period in each year. This movement within years could be interpreted to suggest that foraging conditions are relatively uniformly distributed throughout the lagoon systems and site selection is based on other habitat characteristics.

Chapter 5
Effect of Underwater Seismic Surveys on Molting Long-Tailed Ducks

INTRODUCTION

Environmental disturbances, such as those caused by mineral exploration and development, may compromise the ability of Long-tailed Ducks to access and fully use their molting habitats, and thus successfully complete their molt. An example of such a disturbance is near shore underwater seismic surveys that are commonly used to explore and map mineral resources located below the surface (Richardson et al. 1995). Open water marine seismic surveys use a process by which very intense sound pulses are emitted at regular intervals by an array of underwater airguns (Greene and Richardson 1988). The sound returning from the seabed is processed to locate geological formations that may contain producible quantities of hydrocarbons. In addition to the sound that travels downwards into the seabed, the sound from the airguns also travels sideways through the water, and this noise has been cited as causing environmental effects. The peak noise levels of the seismic blasting frequently exceed those of other industrial activities such as aircraft, ships, dredging, and construction (Richardson et al. 1995). These noise pulses have been found to cause general avoidance reaction, changes in behavior (e.g., dive cycles, respiration), and displacement of marine mammals such as the Common Dolphin (*Delphinus delphis*), Gray Whale (*Eschrichtius robustus*), Sperm Whale (*Physeter macrocephalus*), and Bowhead Whale (*Balaena mysticetus*) (Richardson et al. 1995, Goold 1996). Richardson (2001) indicated that some bowheads may remain as far as 24 km from on-going seismic surveys. Even at 25 km, the sound pulses seem strong and obtrusive to humans listening via hydrophones and sonobuoys (Richardson et al. 1995). Airguns can be fatal to some species at very close range (Warren 1989). This noise may have the potential to disrupt the behavior of Long-tailed Ducks, particularly while diving to feed (Goudie and Ankney 1986).

In August 2001, BP Exploration (Alaska) Inc. (BPXA) contracted Western Geophysical to conduct a 3-dimensional geophysical survey in the Simpson Lagoon of the Beaufort Sea (Richardson 2001). We used this opportunity to evaluate the effects of underwater seismic activity on molting Long-tailed Ducks. Aerial surveys were used to detect changes in the distribution and abundance of molting Long-tailed Ducks before, during, and after seismic activities in a “Seismic Area” and in the adjacent portion on the Industrial Area that had similar habitat features. We also compared changes in the abundance and feeding propensity of individual radio-equipped Long-tailed Ducks located in the Seismic, Industrial, and Control Areas through time. Radio-equipped ducks were monitored with automated Data Collection Computers (DCC) that were capable of detecting the presence and feeding behavior of ducks within 2.5 km distance of each system. We predicted that Long-tailed Ducks would leave the Seismic Area if the activity and associated noises disrupted their normal activities. We did not predict whether Long-tailed Ducks would feed more or less during seismic activities because both options were plausible. We believe that this is the first study to evaluate the effects of underwater seismic surveys on sea ducks.

METHODS

The study area was divided into three areas: 1) a Seismic Area located near Spy and Pingok Islands in the western portion of Simpson Lagoon, 2) the remainder of the Industrial Area near Bodfish and Cottle islands in the central portion of Simpson Lagoon, and 3) the Control Area located along the Maguire and Flaxman islands (Figure 5-1). To clarify, the Seismic Area is a sub-sample of the Industrial Area (as referenced through this report). Because the magnitude of the human activity associated with the seismic survey exceeded the activity in the rest of the Industrial Area and the Control Area, we pooled these areas and treated them as controls to the Seismic Area.

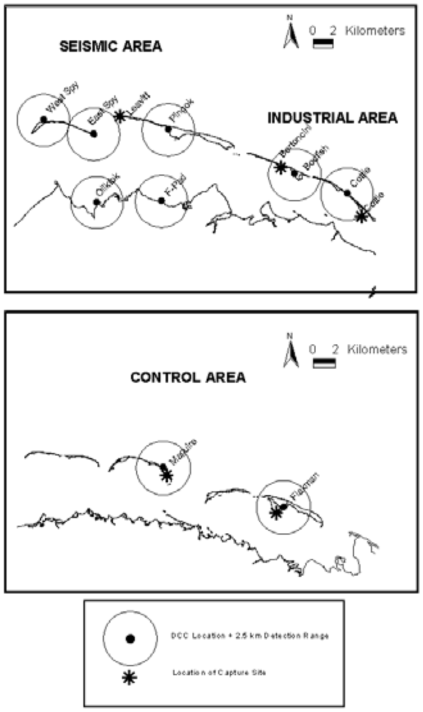


Figure 5-1. Location of the Seismic, Industrial and Control Areas. The location and 2.5 km-radius detection area of nine data collection computer systems (dots with circles) and capture locations (denoted with stars) are presented.

Seismic Survey Protocol

From 4-26 August 2001, Western Geophysical conducted a 3-dimensional reflection survey for hydrocarbon deposits in the nearshore waters of the western portion of the Simpson Lagoon, approximately 48 km from Prudhoe Bay (Richardson 2001). Five vessels, ranging in length from 23-41 m, were used including two source vessels with airguns, two cable deployment vessels, and one multi-use boat. Seismic activities were conducted systematically in discrete sections until the entire area was sampled. Activities included surveying each section to obtain water depth, laying receiving cables (2.54 cm in diameter) along uniformly spaced transect lines on the ocean floor, towing and discharging airgun arrays perpendicular to the cables, and retrieving cables from the ocean floor. Airguns were towed by one of two source vessels depending upon the bathymetry of the area. In shallow water (i.e. within the lagoon), a smaller vessel was used, which deployed two identical clusters of four sleeve-type airguns over the port and starboard sides of the vessel. Each airgun was 1.3 L in size for a total of 10.5 L. After initial calibration only 8 airguns were operated for a total of 5.2 L. The airguns released high pressure underwater air blasts every 8 to 10 sec. On the ocean side of the islands where the water was deeper, a larger vessel was used to tow 12 sleeve-type airguns of various individual volumes (1.3 to 2.5 L for a total of 19.8 L), which discharged every 12 to 24 sec. Clusters of geophones and hydrophones, which were attached to the receiving cables at 50 m intervals, registered the subsurface signals and sound vibrations and transmitted the information along the cable to the recording/telemetry vessel.

The location of all vessels and the time of day when seismic activity occurred were recorded on digital hydrographic charts. We used these charts to classify daily disturbance at each DCC site.

Aerial Surveys

To examine changes in the abundance and distribution of ducks, aerial counts of Long-tailed Ducks were conducted before, during and after seismic activity along the inside and outside edges of barrier islands of the Seismic and Industrial Areas (Thetis to Stump islands). No surveys were conducted in the Control Area. One “before” seismic survey occurred on 24 July 2001, two “during” seismic surveys were conducted on 6 and 15 August 2001, and one “after” seismic survey took place on 7 September 2001. Thetis Island and the ocean side of most of the islands were not surveyed on 15 August, and Thetis Island was not surveyed on 7 September 2001. To standardize surveys we excluded counts from Thetis Island and eliminated the incomplete survey conducted on 15 August 2001 for comparisons of the ocean and lagoon sides of the islands. Surveys were conducted in the mid-afternoon to evening (start times ranged from 12:45 to 20:50). Restricting surveys in this way maximized our ability to count ducks and likely reduced the amount of variation in survey counts (Johnson and Gazey 1992; Fischer et al. 2002).

Long-tailed Ducks were counted from a Cessna 185 airplane, 90 m above ground level at 140 km/hr. For consistency, a single observer counted all ducks within a 400 m strip between the plane and the barrier islands. The data was transcribed into a tape recorder and the locations of all ducks were marked on 1:50,000 maps of the Simpson Lagoon area by a separate observer. Additionally, the second observer photographed flocks when feasible. Later, estimates of flock size were compared to counts of ducks taken from enlarged photographs. We used a 34.7% correction factor for all counts.

We also tallied the number of Long-tailed Ducks located on the lagoon and ocean side of each individual barrier island for each survey.

Capture and Detection of Radio equipped Long-tailed Ducks

We captured molting Long-tailed Ducks with corral traps set at roosting sites on the barrier islands. A sub-sample of males was equipped with 15 g subcutaneously anchored radio transmitters (see Chapter 4). Transmitters were programmed to emit 60 pulses per minute.

Data collection computers (DCCs) connected to fixed antennas were placed near each of the Long-tailed Duck capture sites to maximize detection of the radio marked birds. Five DCC towers were erected within the Seismic Area (three on barrier islands and two on the mainland) and two DCC towers were erected in both the Industrial Area and the Control Area (all on barrier islands, Figure 5-1). DCCs could detect ducks with transmitters within approximately 2.5 km of the towers.

The DCCs recorded the presence and number of pulses of each radio transmitter for a 45 sec period, before switching to the next transmitter frequency. In this way, radio transmitters were monitored 1-3 times per hour, depending upon the number of radio-equipped birds located near a site. We also monitored a reference transmitter at each DCC tower that enabled us to determine if and when the tower was functioning.

Discharged batteries and downloading of data resulted in days with no data or less than 24 hours of data. To determine how the hours of operation per day affected the number of radio-equipped ducks detected by DCCs, we plotted the cumulative proportion of radios detected by hour for each DCC in each day. This analysis was limited to days when DCCs operated a full 24 hours and included only radio-equipped ducks originally captured near a given DCC. We then averaged these proportions across days and DCCs. We found that most radios ($\bar{x}$=84.6% ± 2.5 [SE]) were detected after six hours of DCC operation. Consequently, we eliminated 14 DCC days when less than 6 hours of data were available. The days removed from our analyses were evenly distributed throughout the study period. The remaining DCC data allowed us to determine the proportion of radios in a given DCC area that were present each day. The physical arrangement of the capture sites allowed us to compare the movement of ducks between the Seismic Area and the Industrial Area, and between the western (Maguire Island) and eastern portion (Flaxman Island) of the Control Area (Figure 5-1).

We also investigated the feeding propensity of ducks by classifying them as feeding or not feeding depending upon the number of transmitter pulses recorded during each 45 sec scan. Radio signals are attenuated by saltwater when Long-tailed Ducks dive. Thus, pulse rates below that expected within a 45 sec scan interval can be interpreted as coming from diving (i.e., feeding) birds. We considered radio frequencies with 40 pulses or less to represent ducks feeding, frequencies with 41-50 pulses to be ducks present but not feeding, and frequencies with more than 50 pulses to be erroneous readings (i.e., caused by transmitter interference from other radio sources or when battery power was low).

Statistical Analysis

To examine changes in the proportion of ducks detected near DCCs within the Seismic, Industrial, and Control Areas, we first computed the proportion of ducks present on a given day at each DCC site (observations were summarized for each 24 hr period). We limited these calculations to ducks captured near a given DCC site. Because previous seismic studies indicated the explosion of airguns was the most disturbing to wildlife (Richardson et al. 1995, Goold 1996), we considered 6-26 August to be the "during-seismic" period. This period encompassed all dates when airguns were used somewhere in the Seismic Area. The days in which radio-transmitters were monitored prior to 6 August and after 26 August were considered the "pre-seismic" and "post-seismic" periods, respectively. Although we recognize that each DCC had different patterns of seismic activity exposure, the statistical analyses required us to standardize the "during-seismic" period to investigate changes occurring through the season at each DCC site. This allowed DCC sites to be used as replicates and contrasts could be generated between DCCs located within and outside of Seismic Area. This standardization only applied to the five DCCs located in the Seismic Area, all of which were within 7 km of each other. Prior studies have showed that the noise from airgun explosions typically travels much farther than 7 km (especially in the water column). Finally, we used a modified BACI (before-after-control-impact, Green 1979, McDonald et al. 2000) repeated measures analysis of variance (SAS procedure PROC MIXED, SAS Institute 1996) to compare the difference in mean proportion of ducks in the Seismic Area with the Industrial and Control Areas, during the pre-seismic and during-seismic periods. This comparison was carried out as a single degree of freedom contrast (i.e., the BACI contrast) within the interaction effect of the repeated measures analysis of variance. Even though a few cells were missing data in the repeated measures analysis, the BACI contrast was always estimable. The null hypothesis of the BACI contrast was,

$$H_0: \mu_{pc} - \mu_{dc} - \mu_{ps} + \mu_{ds} = 0$$

where μ_{pc} was the mean proportion of ducks in the pre-seismic period on the Industrial and Control Areas, μ_{dc} was the mean proportion of ducks in the during-seismic period on the Industrial and Control Areas, μ_{ps} was the mean proportion of ducks in the pre-seismic period on the Seismic Area, and μ_{ds} was the mean proportion of ducks in the during-seismic period on the Seismic Area. The alternative hypothesis was that the difference in proportions pre- and during-seismic on the Industrial and Control Areas (i.e., $\mu_{pc} - \mu_{dc}$) was not equal to the difference in proportions pre- and during-seismic in the Seismic Area (i.e., $\mu_{ps} - \mu_{ds}$). Prior to analyses, data were arcsin square root transformed (i.e., $x_i = arcsin(\sqrt{p_i})$ where p_i was the proportion of ducks in an area on day i) and plotted to ensure data met normality assumptions. We also accounted for autocorrelation in the daily transformed values by modeling the variance-covariance matrix with a power function that estimated correlations between observations from the same DCC. Modeling of the variance-covariance structure used the restricted maximum likelihood method (REML; PROC MIXED documentation, SAS Institute 1996). We assumed observations from different DCCs were independent. Finally, from the repeated measures analysis and estimated variance-covariance matrix, we generated estimates of the proportion of ducks detected for each treatment (Seismic Area and the pooled Industrial and Control Areas, and pre- and during-seismic periods). Unfortunately, comparisons to the post-seismic period proved impossible. Ducks were beginning to fly by the time seismic activities ended and several of our DCCs failed to work properly in the Industrial and Control Areas at this time.

A similar analysis was conducted to investigate changes in the proportion of ducks feeding on a daily basis near each DCC within the Seismic Area and the Industrial and Control Areas. We developed an index to feeding activity that controlled for diurnal variation in feeding activity. We determined the proportion of observations indicative of feeding during each hour of each day for each DCC, and then averaged these proportions across a 24 hr period for each DCC. Thus, we removed any weighting based on sample size that would have influenced a daily index. Although it would have been preferable to statistically investigate feeding behavior during each hour of each day, this proved impossible because of compounded autocorrelation problems and large numbers of missing or sparsely populated cells. As above, data were arcsin square root transformed, autocorrelation was accounted for, and estimates of feeding proportions were determined. We used two-tailed tests and an alpha-level of 0.05 in all cases.

RESULTS

Aerial Surveys

Long-tailed Ducks were observed near most of the islands during each of our surveys (Figure 5-2). Particularly large concentrations of ducks occurred near Thetis, Spy, Cottle, and West Long islands. Most ducks were observed on the lagoon side of the barrier islands, although large numbers of ducks occurred on the ocean side of Spy, Cottle, and West Long islands during one or more of the surveys.

The total number of ducks detected (after standardizing data sets) during aerial surveys decreased from a high of 5499 ducks during the first survey to 1981 ducks during the second survey (Figure 5-3A). The number of ducks later increased to 3538 ducks during the last survey (Figure 5-3A). Although this pattern was consistent across islands within the seismic (Spy, Leavitt, West Pingok) and non-seismic areas (East Pingok to Stump islands), the magnitude of the change was greater in the Seismic Area (Figure 5-3A). When the aerial survey data was restricted to only the lagoon side of the barrier islands, a similar pattern was found (Figure 5-3B). The lowest number of ducks occurred during the period with seismic activity (gray shaded areas in Figure 5-3). Whereas the decline in duck numbers in the Seismic Area may be partially due to seismic activities, the concurrent decline in the Industrial Area suggests other factors were affecting duck numbers and distribution.

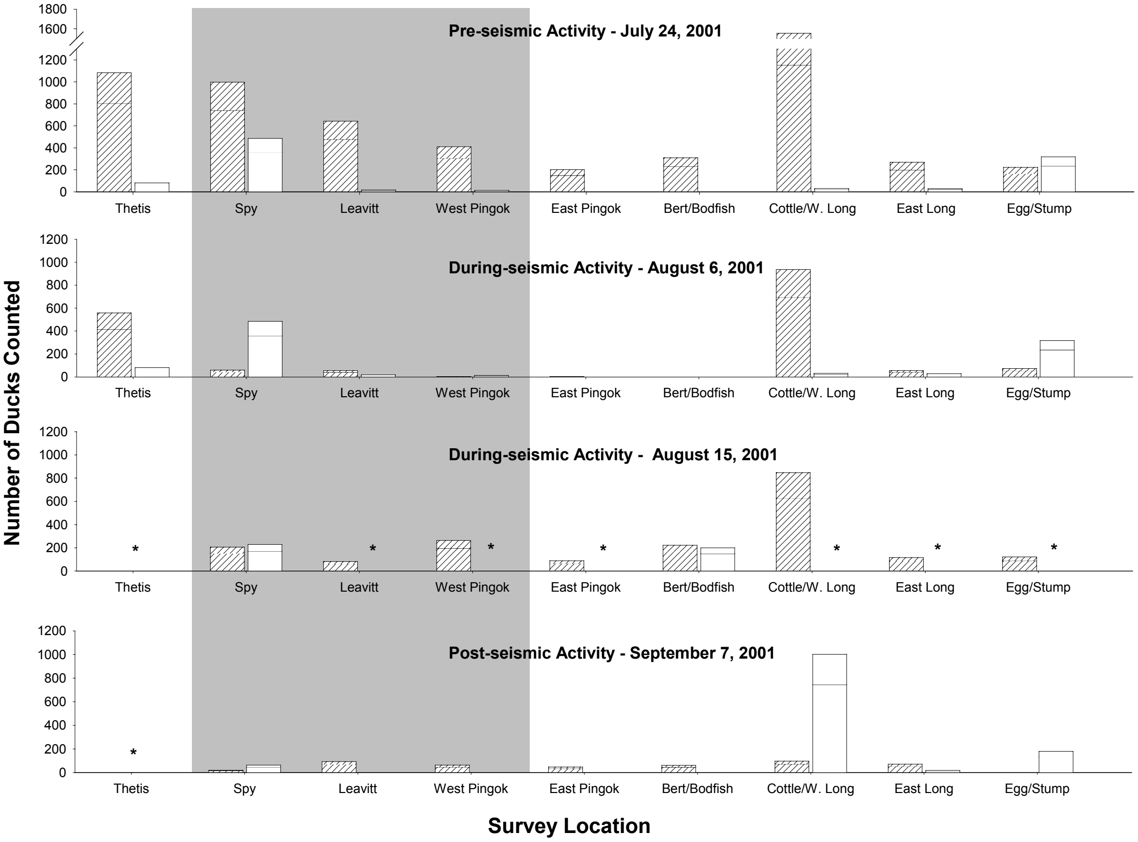


Figure 5-2. Number of Long-tailed Ducks counted from aircraft during the pre-seismic, during-seismic, and post-seismic periods along the lagoon and ocean sides of barrier islands in the Beaufort Sea, Alaska, in 2001. Stacked bars represent observer counts (bottom portion of column) and corrected counts (top portion, see text for methods), and diagonal and open bars represent lagoon and ocean counts, respectively. An “asterisks” (*) indicates where surveys were not conducted on a given island due to weather. Islands where seismic activity occurred nearby are shaded gray.

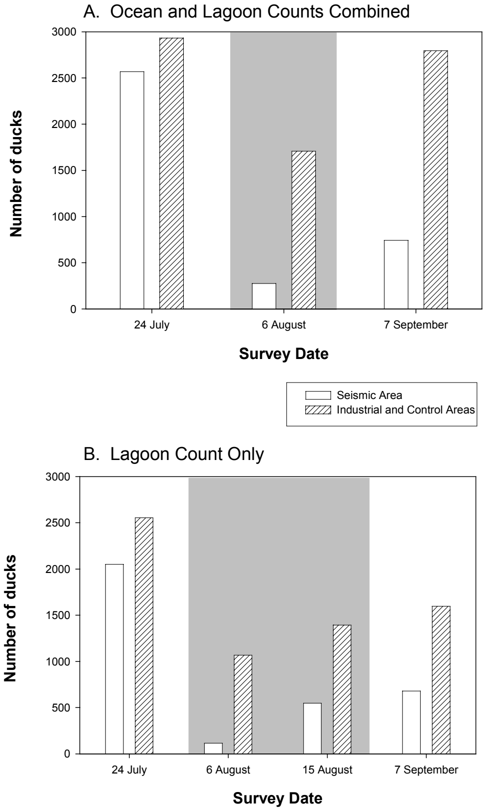


Figure 5-3. Number of Long-tailed Ducks counted (corrected values) on the (A) ocean and lagoon, and (B) lagoon only sides of the barrier islands where seismic activity occurred (i.e., Spy, Leavitt, and West Pingok) and did not occur (i.e., East Pingok, Bertonicini, Bodfish, Cottle, West and East Long, Egg and Stump islands). We excluded data from Thetis Island during all survey dates, and did not include data from the 15 August survey in panel A because information from the ocean side of the islands was not available. Dates with seismic activity are shaded gray.

Capture and Location of Radio equipped Long-tailed Ducks

We trapped a total of 246 Long-tailed Ducks at five different sites; ducks were captured at one site within the Seismic Area and two sites within both the Industrial and Control Areas (Figure 5-1, Table 5-1). All ducks, except seven at Bertoncini, were caught prior to the start of seismic activities and most were males (94.7%, n=246). A total of 102 male Long-tailed Ducks were equipped with radios throughout the five capture areas (Table 5-1). Ducks captured at Bertoncini and Cottle islands were combined to represent ducks from the Industrial Area because these capture locations were within 4 km each other and only one duck was captured at Cottle Island. We did not combine information from the two capture areas in the Control Area because the distance between the two capture sites was large (> 12.7 km).

Table 5-1. Number of Long-tailed Ducks captured and radio-marked at five capture areas on the barrier islands of the Beaufort Sea, Alaska, during 2001.

	Seismic Area	Industrial Area[1]		Control Area	
Capture Area	Leavitt Island	Bertoncini Island	Cottle Island	Maguire Island	Flaxman Island
Number Captured	30	9	1	124	82
Number (%) Males	29 (96.8)	9 (100)	1 (100)	124 (100)	70 (85.4)
Number Radioed	29	9	1	31	32
Capture Dates	Jul 30	Jul 29; Aug 3,9	Aug 1	Jul 28	Jul 30

[1] Ducks captured at Bertoncini and Cottle islands were combined to represent ducks from the Industrial Area.

The DCCs began monitoring radio transmitters at some sites by 31 July, and all sites were active by 4 August (gray areas within Figures 5-4 and 5-5). The first seismic boat moved west past Pingok Island on the 4 August and cables were laid on the same day near the eastern half of Spy Island (see seismic activity symbols, Figure 5-4). Airguns were fired for the first time on the 6 August. Within the Seismic Area, radio-transmitters were monitored for 5 days prior to the start of seismic activities, whereas in the Industrial and Control Areas, radio-transmitters were monitored for 2-6 days prior to the start of airgun activities in the Seismic Area. The during-seismic period lasted was 6-26 August (i.e., 21 consecutive days). Post-seismic monitoring lasted 3-8 days depending upon the DCC.

Each DCC collected data for 13 to 35 days ($\bar{x}$=26.1±8.3[SE]) for a total of 4869 hrs of detection time (Table 5-2). Of the initial sample of radio-equipped ducks, nine (8.8%) radios were not heard by any DCC after capture (all from the Control Area). The radio transmitters on these ducks may have failed or the ducks may have moved out of antenna range. The high number of fixes per radio at DCCs located at Pingok, East Spy, Bodfish, Maguire, and Flaxman islands suggested these sites were used heavily by our radio-equipped Long-tailed Ducks. In contrast, DCCs located at F Pad, Oliktok Point, West Spy Island, and Cottle Island had low fix averages, indicating the radio-equipped ducks seldom used these areas (although a few ducks were heard frequently even at these sites, see “range of fixes/radio” Table 5-2). The total number of fixes at each site also indicated ducks used areas near particular DCCs more (Table 5-2).

Table 5-2. Detection results for radio-equipped Long-tailed Ducks monitored by Data Collection Computers located on the barrier islands and the mainland in 2001. "Local" radios refer to those placed on ducks at the capture site adjacent to the DCC and "foreign" radios refer to those placed on ducks at capture sites away from the DCC.

	Seismic Area					Industrial Area		Control Area	
Parameter	F Pad	Oliktok Point	Pingok island	East Spy Island	West Spy Island	Bodfish island	Cottle Island	Maguire Island	Flaxman Island
Sampling (days)	35	31	28	34	32	28	13	16	18
Sampling (hours)	659.2	659.2	621.3	730.81	654.4	649.7	228.7	343.7	321.8
No. of local radios monitored	29	29	29	29	29	10	10	32	31
Total no. of radios monitored	39	39	39	39	39	39	39	63	63
No. of local radios detected	6	3	28	28	15	10	5	27	27
No. of foreign radios detected	0	0	0	2	0	8	9	0	9
Fixes/radio (±SE)	5.0 ± 1.8	3.3 ± 1.3	214.6 ± 48.2	135.5 ± 34.0	25.7 ± 6.2	132.2 ± 55.1	25.8 ± 11.0	118.6 ± 21.9	144.1 ± 20.8
Range of fixes/radio	1 – 11	2 - 6	4 – 995	2-699	1-99	4 – 737	2 - 160	2-395	2-446
Total fixes	30	10	6009	4066	386	2380	361	3202	5186

Proportion of Ducks Detected and Seismic Activity Effects

Figures 5-4 and 5-5 show the proportion of ducks detected during each day in the Seismic, Industrial, and Control Areas. Of the five DCCs located in the Seismic Area, the highest proportion of ducks were detected at Pingok, followed by East Spy, West Spy, F Pad and Oliktok (Figure 5-4). Only three and six radios were detected at the Oliktok and F Pad DCC sites, respectively, indicating few radio-equipped Long-tailed Ducks moved to the mainland from the barrier islands within the Seismic Area. These two DCCs were excluded from subsequent statistical analyses due to their low detection rate. In the Industrial Area, the Bodfish DCC detected most of the radios, while the Cottle DCC detected less than 40% of the ten radios placed on birds in the area. This is likely due to proximity of DCCs to capture areas in the Industrial Area. In the Control Area, generally over 40% of the radio-equipped ducks were detected each day, and the detection rate remained relatively constant through time.

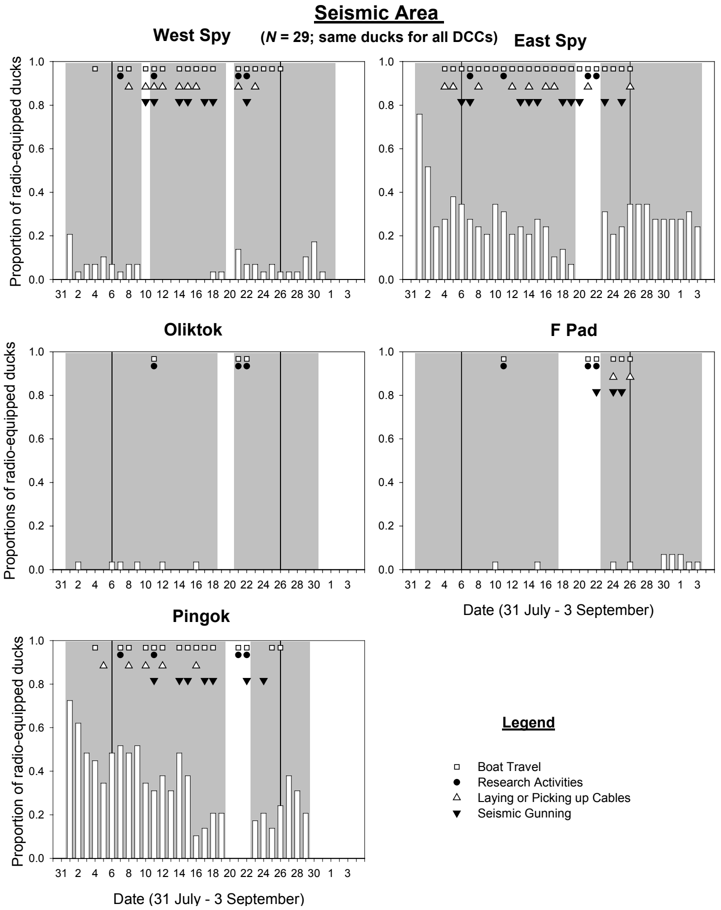


Figure 5-4. The proportion of radio-equipped Long-tailed Ducks detected by DCCs placed in the Seismic Area. The proportion of ducks included only those captured in the Seismic Area. The gray shading indicates when the DCC were recording data. The solid vertical lines represent the first and last days when seismic activity occurred in the general area. The five symbols represent the types of activities occurring within a 2.5 km radius of each DCC.

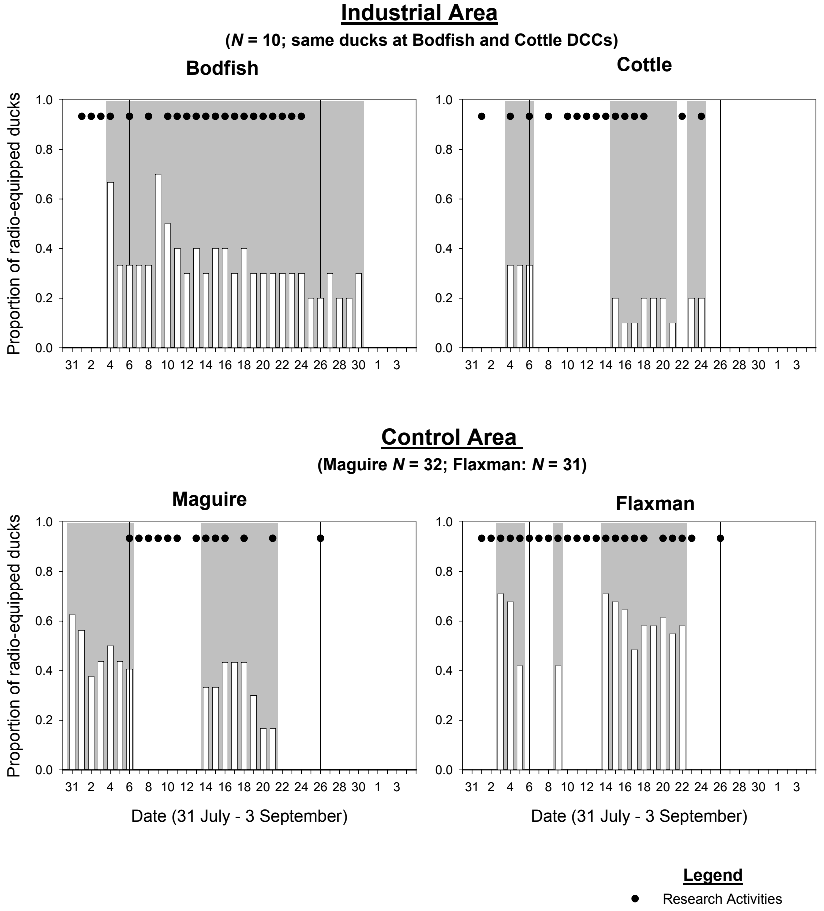


Figure 5-5. The proportion of radio-equipped Long-tailed Ducks detected by the four DCCs located in the Industrial and Control Areas. In the Industrial Area, the number of ducks detected included all those captured near both the Bodfish and Cottle island DCCs. In the Control Area, the number of ducks detected included only those captured near their corresponding DCC site (Table 5-1). The gray shading indicates when the DCCs were recording data. The solid vertical lines represent the first and last days when seismic activity occurred in the seismic area. The "●" symbol represents when researchers conducting this study were boating within a 2.5 km radius of each DCC.

A repeated measures analysis of variance indicated there were no significant differences in the proportion of Long-tailed Ducks detected by DCCs located in the Seismic, and the Industrial and Control Areas (Seismic main effect, Table 5-3). There was a significant date effect, suggesting the proportion of ducks declined through the molting season (Date main effect, Table 5-3). However, the primary effect of interest was not significant (P = 0.94, BACI contrast, Table 5-3), indicating that the difference in proportion of ducks staying near each DCC for the pre- and during-seismic periods was nearly identical in the Industrial and Control Areas and the Seismic Area.

Table 5-3. Repeated measures analysis of variance for proportion of Long-tailed Ducks detected by three and four data collection computers located in the Seismic Area, and the Industrial and Control Areas, respectively.

Source	Numerator DF	Type III F	Pr > F
Seismic	1	3.07	0.140
Date	25	1.92	0.017
Seismic x Date	23	1.23	0.249
Contrast			
BACI-seismic x period	1	0.01	0.939

Seismic Activity Effects on Feeding Activity

Our index to feeding activity varied both among and within areas (Figures 5-6 and 5-7). Generally, 40% or more of our records indicated ‘feeding’ on any given day, although there was noticeable variation among DCC sites. DCCs located at East Spy, Pingok and Maguire had exceptionally high indices of feeding (60-80%), whereas the West Spy DCC was low (20%). Feeding indices were not calculated for the F Pad and Oliktok DCC sites because of the low number of ducks detected. Interestingly, some of the highest feeding indices were detected on days when airguns were fired (note especially East Spy and Pingok, Figure 5-6).

The repeated measures analysis of variance for feeding also failed to find significant differences between the Seismic Area and the Industrial and Control Areas (Seismic main effect, Table 5-4), through the season (Date main effect, Table 5-4), or in the slope through time on the Seismic Area and the Industrial and Control Areas (Seismic x Date effect, Table 5-4). The BACI contrast was also not significant (P = 0.83, BACI contrast, Table 5-4), indicating that the difference in feeding indices for each DCC pre- and during-seismic was nearly identical in the Industrial and Control Areas and the Seismic Area. Estimates of feeding suggest that the highest indices were in the during-seismic period in the Industrial and Control Areas (mean and 95% C.I. across days = 0.50; 0.31 – 0.70), followed by the pre-seismic period in the Industrial and Control Areas (0.46; 0.17 – 0.76), followed by the during-seismic period in the Seismic Area (0.42; 0.22 – 0.63), and finally, by the pre-seismic period in the Seismic Area (0.32; 0.09 – 0.61).

Table 5-4. Repeated measures analysis of variance for proportion of Long-tailed Ducks feeding when detected by three and four data collection computers located in the Seismic Area and the Industrial and Control Areas, respectively.

Source	Numerator DF	Type III F	Pr > F
Seismic	1	0.62	0.468
Date	25	0.84	0.677
Seismic x Date	23	1.25	0.233
Contrast			
BACI-seismic x period	1	0.05	0.829

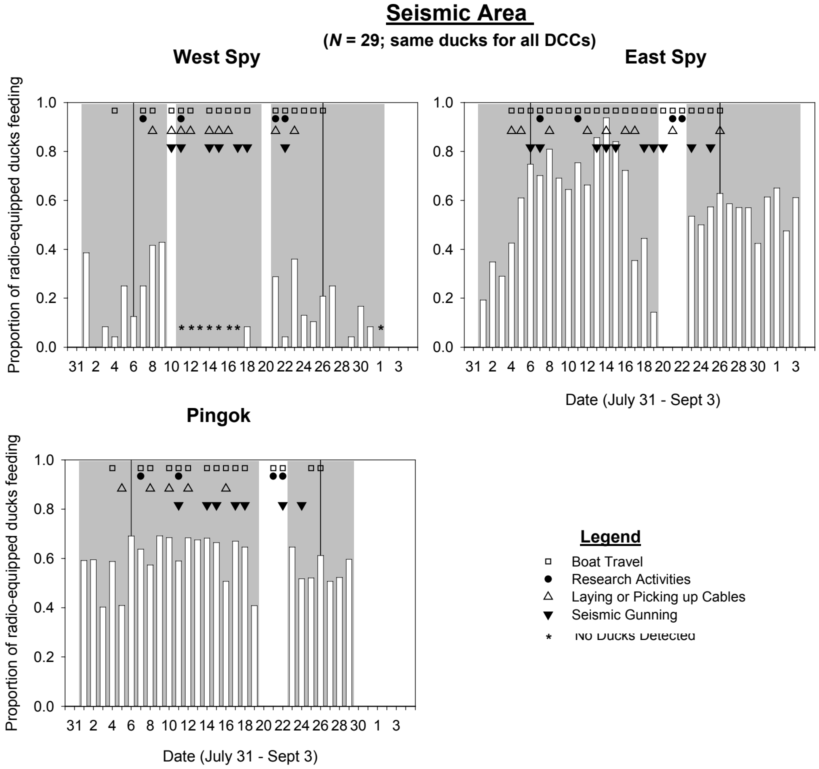


Figure 5-6. The proportion of radio-equipped Long-tailed Ducks detected feeding by DCCs on barrier islands in the Seismic Area. The proportion of ducks included only those captured in the Seismic Area. The gray shading indicates when the DCC were recording data. The solid vertical lines represent the first and last days when seismic activity occurred in the general area. The five symbols represent when and the types of activities occurring within a 2.5 km radius of each DCC.

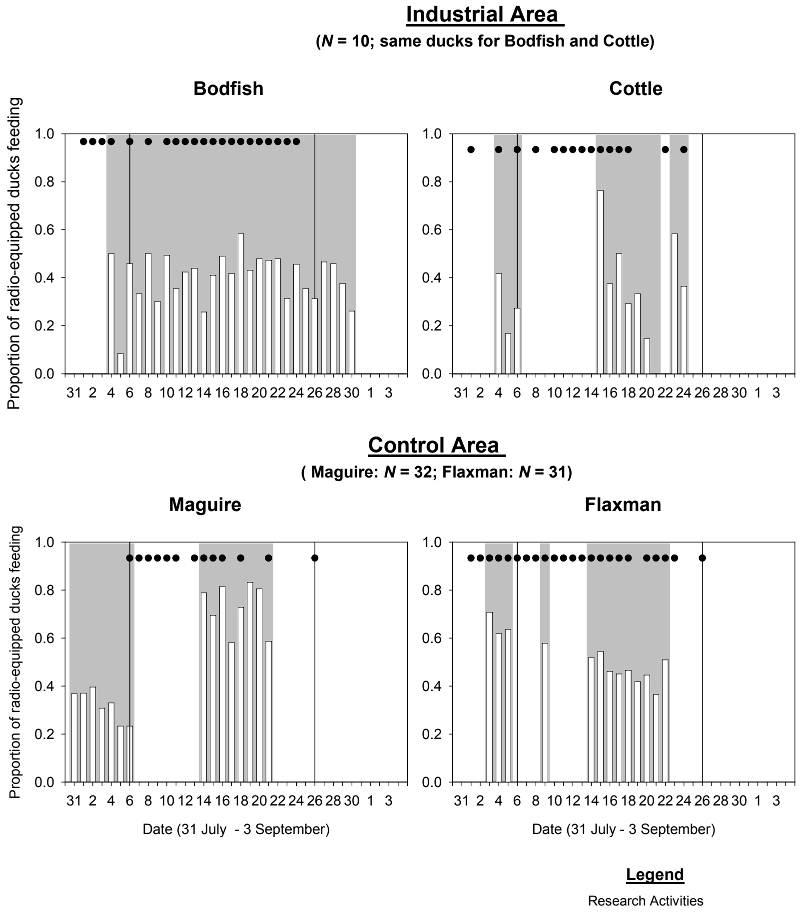


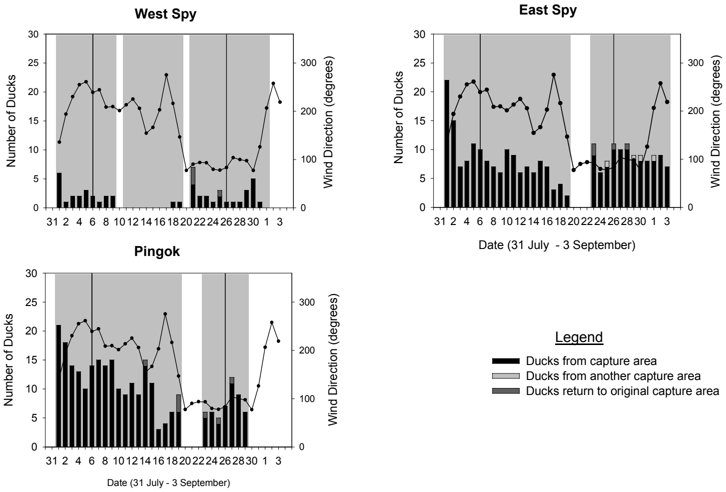
Figure 5-7. The proportion of radio-equipped Long-tailed Ducks detected feeding by DCCs in the Industrial and Control Areas. In the Industrial Area, the number of ducks detected included all those captured near both the Bodfish and Cottle island DCC. In the Control Area, the number of ducks detected included those captured near the corresponding DCC (Table 5-1). The gray shading indicates when the DCCs were recording data. The solid vertical lines represent the first and last days when seismic activity occurred in the seismic area. The "●" symbol represents when researchers conducting this study were boating within a 2.5 km radius around each of the DCC.

Movement of Ducks

The East Spy, Bodfish, Cottle, and Flaxman DCCs detected 2-9 radio-equipped ducks captured at adjacent capture sites (Figure 5-8). In all but the East Spy DCC, this represented ducks moving east from their original capture site. This easterly movement of radio-equipped ducks occurred during the middle and end of seismic activities (Figure 5-8). Easterly movement of this sort, if restricted to the Seismic Area, would support the hypothesis that ducks were moving away from seismic activities. However, this movement was observed in the Seismic, Industrial, and Control Areas. Further, we documented local ducks returning to their initial capture areas before seismic activities ended (e.g., West Spy, East Spy, and Pingok DCCs, Figure 5-8).

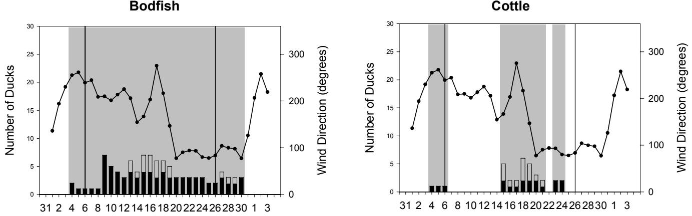
Seismic Area

(*N* = 29; same ducks for all DCCs)



Western Control Area

(*N* = 10 ducks; same ducks for Bodfish and Cottle)



Eastern Control Area

(Maguire: *N* = 32; Flaxman: *N* = 31)

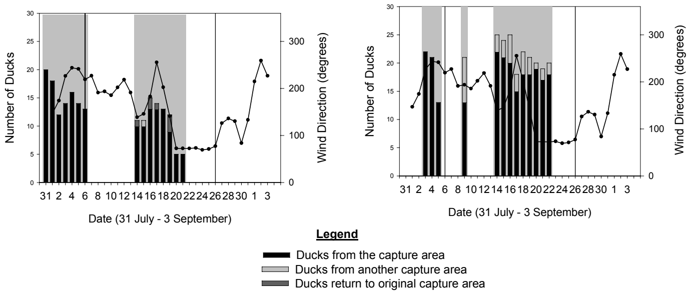


Figure 5-8. The number of radio-equipped Long-tailed Ducks detected by DCCs on the barrier islands in the Seisimic, Industrial, and Control Areas. Black bars represent detections of ducks originally equipped with radio transmitters near the DCCs, light gray bars represent those ducks detected that were captured away from the DCCs, and dark gray bars represents ducks that returned after having departed the area. The gray background shading indicates when the DCCs were recording data. The solid vertical lines represent the first and last days when seismic activity occurred in the seismic area. Wind direction is represented in a line and scatter plot.

DISCUSSION

Both aerial surveys and DCC data show declines in duck numbers in the Seismic Area following the start of seismic activity. However, we detected no concurrent decline in feeding behavior during the seismic period. In fact, high feeding indices were recorded from DCCs on days when seismic activity was near by. An analysis based on a modified Before-After Control-Impact approach (McDonald et al. 2000) found that the difference in proportion of ducks staying near each DCC in the pre- and during-seismic periods was nearly identical in the Industrial and Control Areas and the Seismic Area. Unfortunately, we could not conduct a similar analysis on aerial survey counts and inter-lagoon movements because replicate data were not available. Nonetheless, changes in aerial survey counts and lagoon movements exhibit similar patterns in the Seismic Area and the Industrial and Control Areas.

Although evidence from this study suggests that underwater seismic activity did not cause Long-tailed Ducks to leave the Seismic Area, these results should be viewed cautiously given several statistical and ecological factors that may have reduced our ability to detect changes. First, our study may have lacked statistical power to detect differences between the Seismic Area and the Industrial and Control Areas. We would need additional seismic areas and associated controls to compensate for site variation. Unfortunately, the cost of conducting underwater seismic surveys and monitoring radio-equipped ducks prohibits such a design. Second, our statistical analysis suffered from having treatment periods of unequal duration. The pre-seismic period was rather short and the during-seismic period was relatively long. The long during-seismic activity period precluded comparisons to the post-seismic period because many ducks were completing their molt and beginning to fly. Other researchers have reported Long-tailed Ducks flying in large numbers during late August and leaving the lagoons for the ocean environment (Bartels et al. 1983, Brackney et al. 1985, Johnson and Richardson 1982, Fischer et al. 2002). Third, the parameters measured during our study were rather coarse and unlikely to detect subtle changes in duck distribution. DCCs, while enabling us to collect data continuously over a very large area, are only capable of recording the presence of ducks within a 2.5 km radius. Short distance movements by ducks, as would occur in response to a passing vessel, would not be detected. Further, we did not directly observe the behavior of Long-tailed Ducks in or outside of the Seismic Area. Johnson (1982) documented numerous occasions of Long-tailed Ducks moving from one habitat to another in response to aircraft, boat, and human disturbances. We know from direct observations of Long-tailed Ducks near our research vessels that they frequently dive and swim short distances away. However, we typically travel through an area quickly, allowing them to resurface and return to their previous location. How Long-tailed Ducks respond to slow moving boats and loud airgun explosions is unknown.

There are other factors that may have confounded our comparison among areas all of which contribute to the stochastic nature of duck distribution and numbers. For example, consistent strong southwesterly winds influenced duck distributions in our study and likely caused some birds to move eastward (out of the Seismic Area). Indeed, Dygas (1975) documented a significant correlation (r = 0.73) between wind speed and current velocity in the Simpson Lagoon, and suggested that waves are generated by local winds. By coincidence, strong (averaging 4-9 m/sec) southwesterly winds were present during much of the pre- and during-seismic periods of our study. These winds corresponded with a decrease in duck numbers. Islands located in the Seismic Area are especially exposed to southwesterly winds (Figure 5-1), thus ducks in the area might seek better protected habitats. An abrupt shift in wind direction (i.e., easterly winds) occurred during the 20-30 August also coincided with duck numbers either stabilizing or increasing in the Seismic Area (e.g. East and West Spy, and Pingok, Figures 5-2 and 5-3).

Additional factors that may affect duck abundance and distribution, include seasonal shifts in prey distribution and abundance, lagoon orientation and configuration, bottom configuration, and other weather related phenomenon (Griffiths and Dillinger 1981, Bartels and Doyle 1983, Noel et al. 2001, Fischer et al. 2002). Despite the potential for these factors to affect duck distribution and numbers, other studies have shown that radio-equipped Long-tailed Ducks typically remained within the same lagoon system throughout the molt period (Bartels et al. 1983, Brackney et al. 1985).

How seismic activities affected Long-tailed Duck feeding is less clear. The higher feeding rates, although not significant, observed on days when seismic activities were occurring suggests ducks may need to feed more or have more difficulty obtaining prey during these days. Given that Long-tailed Ducks are heavily dependent on exacting exogenous food resources to successfully complete molt, additional behavioral observations documenting this relationship are needed.

Effects of Seismic Activities on Other Animals

Whereas extensive field studies on the effects of seismic activity on marine mammals have been conducted, very little information on birds is available. Stemp (1985) failed to document any effect of seismic activities on seabirds, although these data were confounded with seasonal changes in bird numbers related to migration. Stemp (1985) insisted that these results not be extrapolated to areas with large concentrations of feeding or migrating birds, or birds that were molting. Most studies of marine mammals have documented general avoidance or behavioral changes, although the overall reaction depends on the species, the strength of the seismic pulses, and whether animals are attracted to an area for feeding or reproduction (Richardson et al. 1986, Richardson et al. 1995, Goold 1996, Richardson 2001). Given the variable reaction of mammals to seismic activity, it is clear that additional studies on other species of birds are needed to fully understand the effects of underwater seismic testing. Accordingly, we suggest several practical guidelines be implemented when conducting seismic surveys in the offshore lagoons. First, we suggest seismic activities be conducted during the winter. If summer surveys are unavoidable, then they should be scheduled around the period of peak concentration of flightless Long-tailed Ducks (late July through mid August). If seismic activity must be conducted, studies should avoid lagoons or shorelines where previous studies have documented large numbers of Long-tailed Duck. These precautions seem especially prudent given the 67% decline in the species' population size documented between 1977 and 1998 (Wilbor 1999).

Chapter 6
Habitat Use and Foraging Patterns of Long-tailed Ducks

INTRODUCTION

One set of possible effects from industrial development on Long-tailed Ducks could be changes in daily activity patterns, including foraging and habitat use. Changes in foraging patterns could be of particular importance because these Long-tailed Ducks meet the nutritional needs by foraging during the molt period (see Chapter 1). Decreased feeding, increased movement, and use of less preferred habitat could lead to diminished body condition. This, in turn, could lead to increased susceptibility to diseases (see chapter 7) or extreme weather.

The problem of human disturbance on molting Long-tailed Ducks has been studied previously. In particular, the effects of helicopter over-flights at Thetis Island (Johnson 1984) and Herschel Island, Yukon Territory (Ward and Sharp 1974). Johnson found no effect on numbers and distribution of birds. Ward and Sharp (1974) saw only brief displacements of ducks immediately following low-level (100m) over-flights. No studies have looked more broadly at possible effects of proximity to oilfield development on molting Long-tailed Ducks.

Previous attempts to characterize patterns of foraging and habitat use by molting Long-tailed Ducks in the Beaufort Sea have relied on aerial surveys (Johnson and Richardson 1980, Johnson and Gazey 1992), observations from islands (Johnson 1982, Ward and Sharp 1974), and aerial telemetry (Brackney et al 1985). All of these studies conclude that molting ducks concentrate in the waters near the barrier islands and that there is a diurnal pattern of habitat use in which ducks approach the islands at night and move offshore into the lagoons during the day. However, these approaches have limitations: 1) aerial surveys and telemetry fail to provide data on diurnal movement and feeding patterns and are frequently limited by poor weather conditions, 2) island based observers can only classify birds within view, ca. 150m (less during periods of fog), and 3) all of these approaches characterize flocks instead of component individuals. To overcome these limitations, in 2000 and 2001 we conducted an intensive study of foraging and habitat use patterns of molting Long-tailed Ducks using radio triangulation.

METHODS

In 2000 and 2001 we erected rotating antenna towers near capture locations at Bodfish, Maguire, and Flaxman Islands (Figure 6-1). We followed the same radio-equipped ducks described in Chapters 4 and 5. Observers monitored each transmitter simultaneously from two or three antenna towers in each area. We used a two-tower approach in 2000 and a three-tower approach in 2001. Once per hour, observers listened for transmitters sequentially until all radios in the area were monitored. For each transmitter, observers recorded two bearings that bracketed the strongest signal, thus incorporating a margin of error around the duck's true location. In addition to directional data, observers recorded foraging activity based on the pattern of radio signals. Long-tailed Ducks feed by diving below the surface of the water where their transmitter signals attenuate. Consequently, signals from foraging ducks are marked by 10-30 second breaks in transmission, whereas signals from roosting ducks are continuous. At least once per day observers monitored the frequencies of birds captured in neighboring areas to investigate larger scale movements of ducks. When new birds were detected, they were added to the list for hourly monitoring.

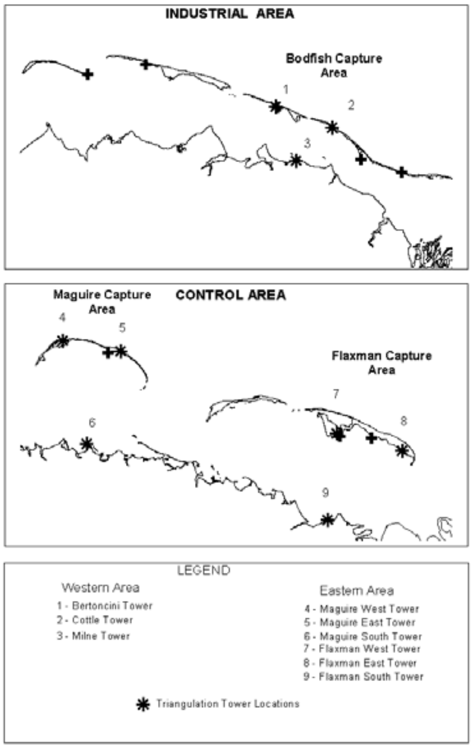


Figure 6-1. Locations of triangulation towers Control and Industrial Areas, 2000-2001.

When a duck was detected from two or three towers in the same hour, the individual's location (X, Y position in UTM coordinates) was calculated by triangulation (White and Garrott 1990). We used two different algorithms to calculate locations; one based on bearings from only two towers and the other based on bearings from three towers. Both algorithms calculate the coordinates and the area of the associated standard error polygon or ellipse. For locations determined from three bearings, we considered those with error polygons larger than the 95th percentile (0.71km^2) to be outliers. Locations determined from two bearings are inherently less precise, thus we set the maximum acceptable error polygon size for two bearing calculations at 1.0 km^2. Although these error polygon cutoff sizes seem large, we believe our locations are sufficiently precise for our analyses. First, the median error polygon size for all locations is only 0.11 km^2. Second, within an error polygon the location with the highest probability of being correct is the calculated location. Third, error polygon size increases with distance from antennas, however our greatest need for precision was for birds in nearshore habitats. Thus the proximity of receivers to the nearshore habitats reduced the likelihood of misclassification. Fourth, error polygons shapes are elongated toward receivers when the calculated location is between the receivers. This elongation parallels the island-lagoon habitat boundary, thus imprecise calculated locations are likely to be correctly categorized. And fifth, inaccurate habitat assignments have equal probability in all habitat types, thus the few inaccurately assigned locations should be unbiased.

In ArcView, we overlaid the calculated Long-tailed Duck locations on a GIS coverage of the coastline and lagoon system. The locations were then subdivided into the following habitat classes: Island (within 300m), Mainland (within 300m), Lagoon (greater than 300 m from Island and Mainland), and Ocean (greater than 300m from Island). We examined diurnal and seasonal patterns of foraging and habitat use patterns at each capture site. In 2000, our triangulation study was terminated early by a major storm on 10 August.

For additional insight into the foraging patterns of molting Long-tailed Ducks we used data gathered from Data Collection Computers (DCCs) placed throughout the lagoon system in 2000-2002. See Chapters 5 and 6 for details of their setup and use.

RESULTS

We recorded locations for Long-tailed Ducks during 1-13 August in 2000 and 1-23 August in 2001. A total of 3316 and 4782 duck locations were recorded in 2000 and 2001, respectively. Table 6-1 summarizes our sampling regime. The majority of locations fell within the Lagoon and Island Habitats. At Bodfish, only 1.5% of locations were within the Mainland Habitat. By contrast, 11.6% of Maguire and 13.8% of Flaxman locations were in the Mainland Habitat. Use of the Mainland Habitat did not differ between Control sites (2000: X^2=0.47 df=1 P=0.49; 2001 X^2=1.35 df=1 P=0.25), but it was significantly different between the Industrial and Control Areas (2000: X^2=17.83 df=1 P<0.0001; 2001: X^2=123.34 df=1 P<0.0001).

A diurnal foraging pattern is evident in all areas in both years. Ducks tend to roost at night and forage during the day (Figure 6-2). Although this pattern is consistently evident, there is a great deal of variation in the exact proportions during each time period, thus Chi-square analyses yielded no significant relationships. Interestingly, this pattern exists even though there is no nighttime dark period until mid-August.

Table 6-1. Sampling effort and results of radio-equipped Long-tailed Ducks monitored by triangulation in the Control and Industrial Areas, 2000-2001

		Industrial Area	Control Area	
		Bodfish	Maguire	Flaxman
2000	Sampling Dates (range)	1-10 August	1-8 August	2-13 August
	Sampling (days)	10	7	10
	Sampling (hours)	129	47	91
	Number of Radios	18	25	25
	Total Fixes	872	492	933
2001	Sampling Dates (range)	10-23 August	6-18 August	1-23 August
	Sampling (days)	14	10	15
	Sampling (hours)	168	87	162
	Number of Radios	39*	31	32
	Total Locations	717	1106	2959

* 10 ducks captured near Bodfish were monitored 10-23 August. Additionally, 29 ducks captured near Leavitt were monitored 16-23 August

A correlated diurnal pattern of habitat use is also evident, though less clearly (Figure 6-3). By and large, a greater proportion of ducks were located in the Lagoon Habitat during the day and a greater proportion were near shore (esp., the islands) at night. This supports observations that ducks tend to forage in the lagoons during the day and roost near shore (esp., islands) at night. The one noteworthy exception was at Flaxman in 2001, where the proportion of locations in each habitat varied little through the day.

To examine foraging and habitat use patterns through the course of the molt period, we divided our data into three week-long sampling periods. As these ducks had little flight feather re-growth when marked (9th primary: $\bar{x}$=23.6mm±1.3 [SE]), the sampling periods represent early, mid, and late molt stage. We suspect that some of our birds attained flight during the third week. Unfortunately for these analyses, a major storm on 10 August cut our sampling short in 2000. We were only able to sample for one day at one location (13 August, Flaxman) after the storm. In 2001, we were able to sample through the three sampling periods.

In all areas except Flaxman in 2001, the proportion of foraging birds increased through the study periods (Figure 6-4). At Flaxman in 2001 the proportion of foraging ducks decreased in the third week, however the majority of locations from this period were recorded between 2100-0800 (72.4%). It is likely that newly flighted ducks were leaving the area during the day and returning at night to roost in the protected lagoons. Foraging data from DCCs show a similar tendency for increased foraging through the molt period (Figure 6-5). In contrast to foraging patterns, there is no clear pattern of habitat use through the molt period (Figure 6-6).

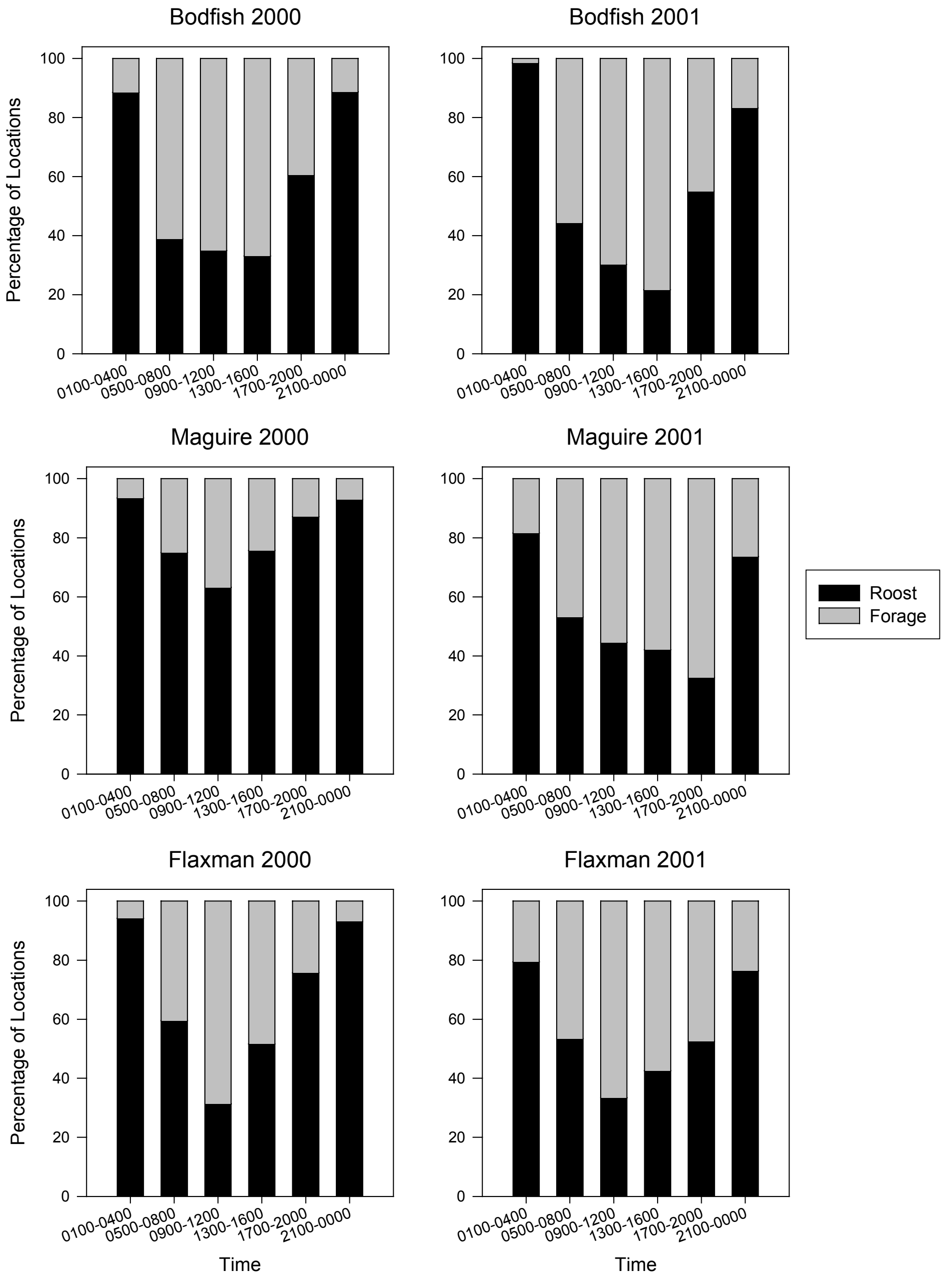


Figure 6-2. Diurnal foraging activity pattern of Long-tailed Ducks determined by radio triangulation in 2000-2001.

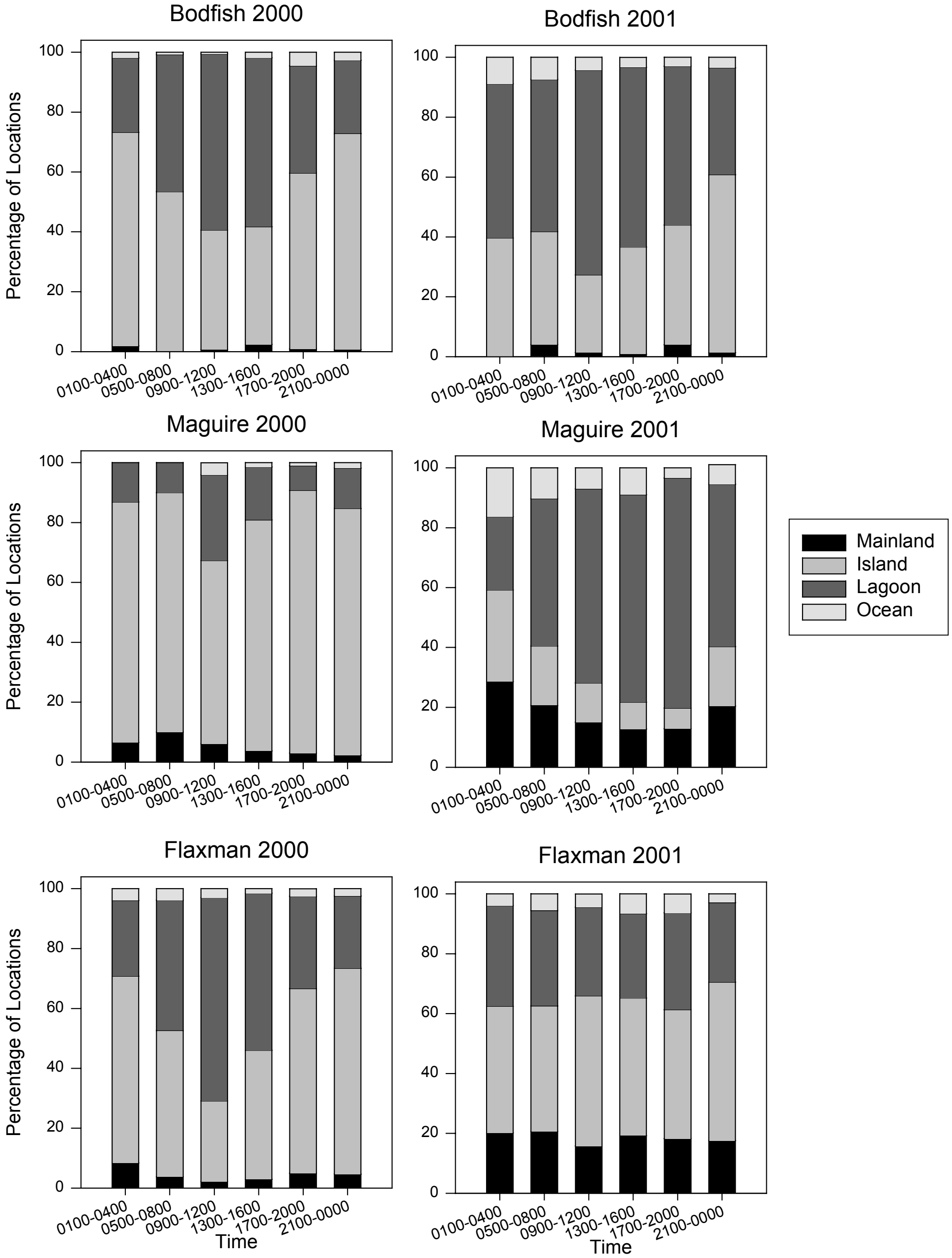


Figure 6-3. Diurnal habitat use patterns of Long-tailed Ducks determined by radio triangulation in 2000-2001.

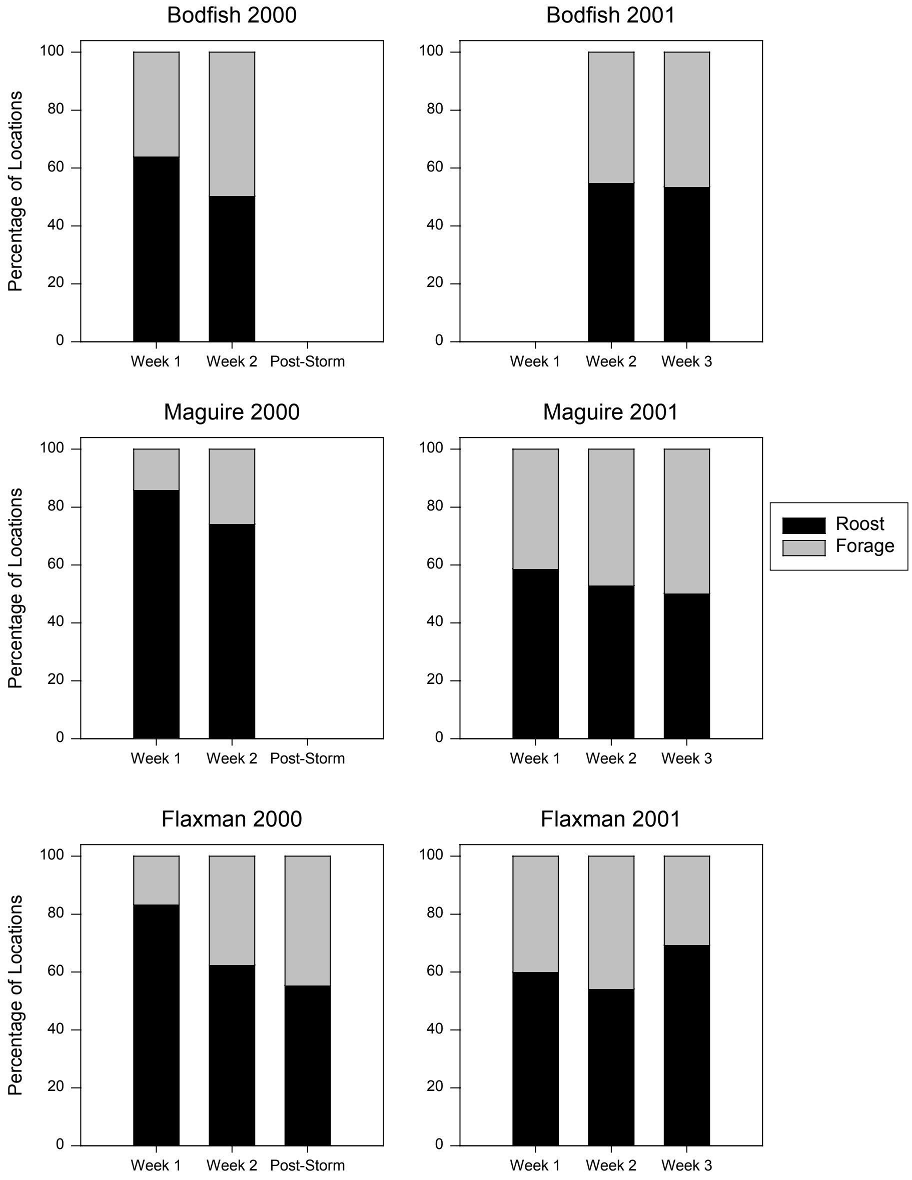


Figure 6-4. Pattern of foraging activity by Long-tailed Ducks through the molt period determined by radio triangulation.

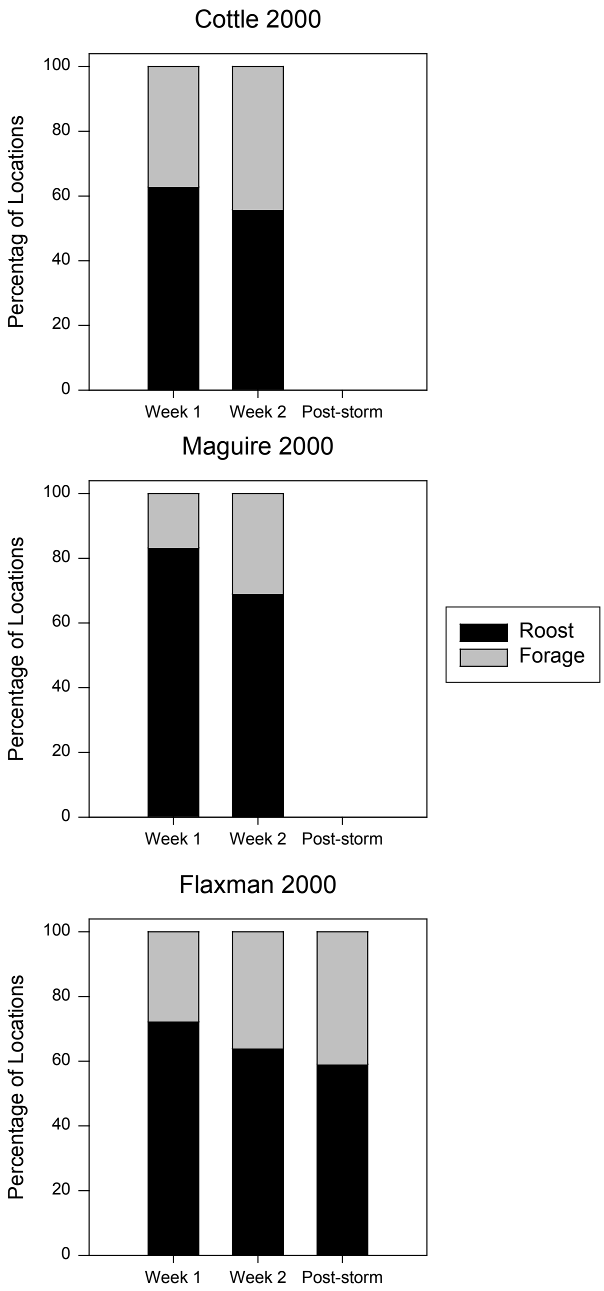


Figure 6-5a. Pattern of foraging activity of Long-tailed Ducks determined by Data Collection Computers in 2000.

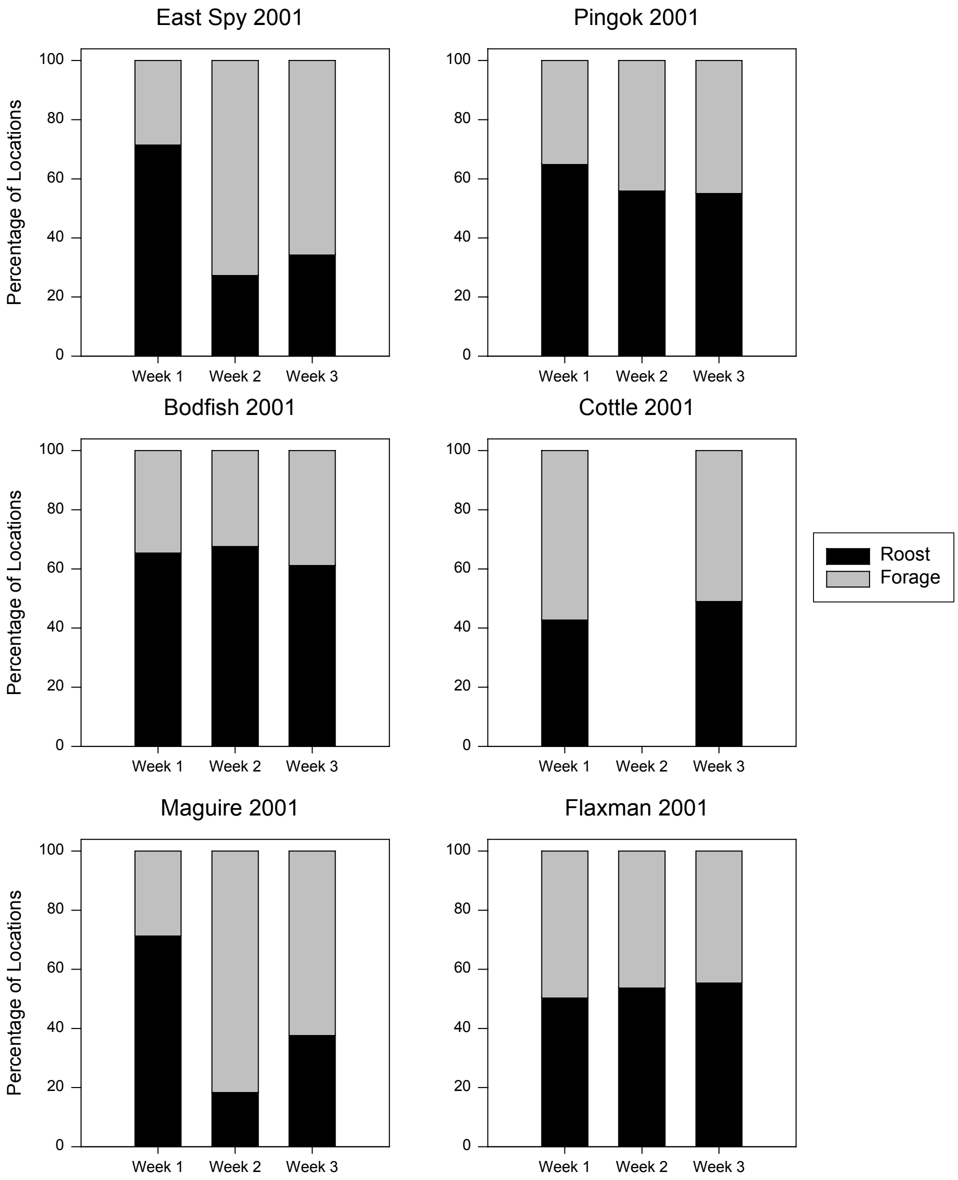


Figure 6-5b. Pattern of foraging activity of Long-tailed Ducks determined by Data Collection Computers in 2001.

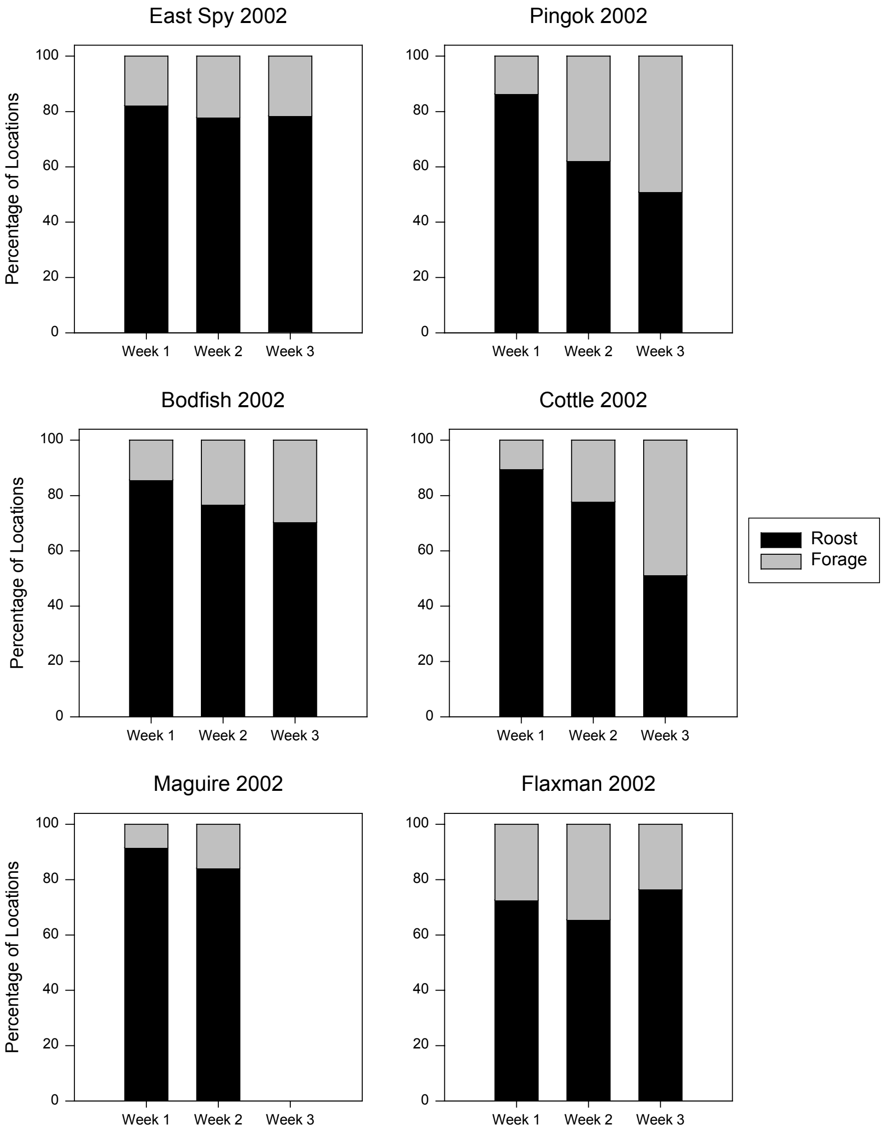


Figure 6-5c. Pattern of foraging activity of Long-tailed Ducks determined by Data Collection Computers in 2002.

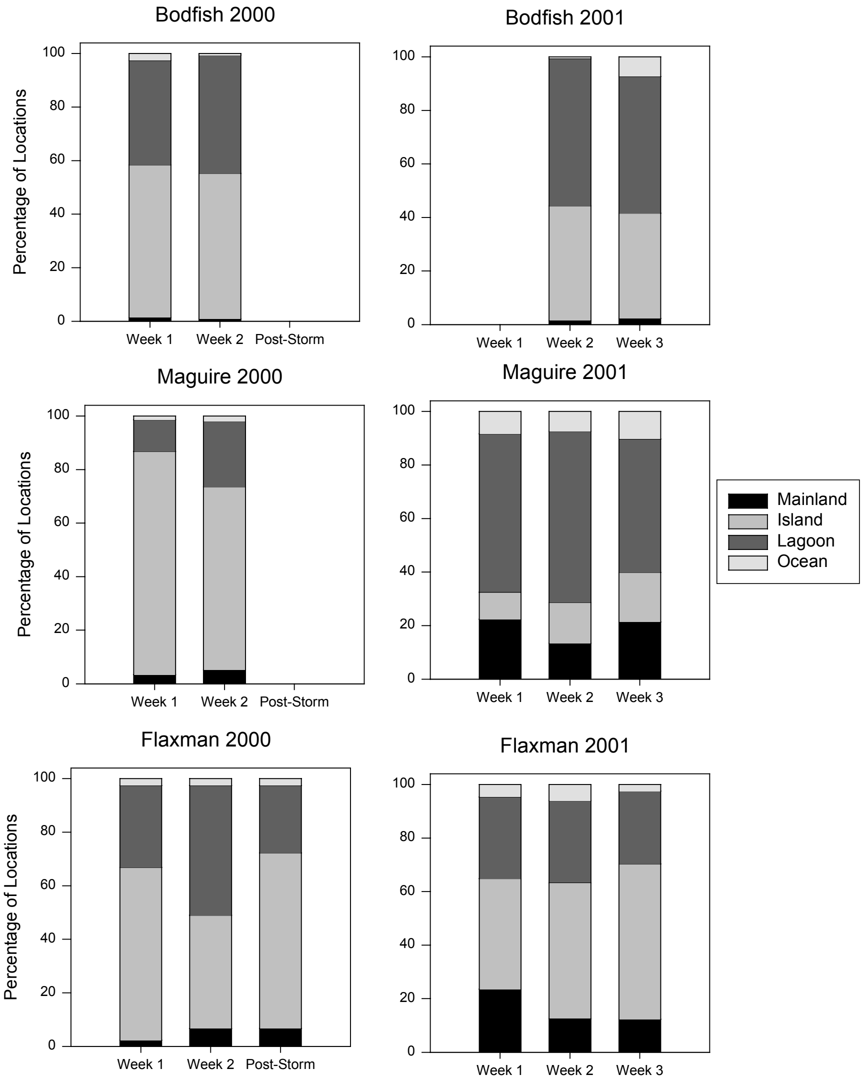


Figure 6-6. Pattern of habitat use by Long-tailed Ducks through the molt period determined by radio triangulation.

DISCUSSION

In order to meet the nutritional demands of molt, the Long-tailed Ducks in our study area must forage during the molt period (see Chapter 1), and we see that foraging accounts for 14-50% of weekly locations by area and year from triangulation data. In the DCC data foraging accounts for 8-81% by area and year. In general, the proportion of foraging ducks as determined by DCCs is lower than from triangulation. This is expected because the detection range of DCCs is only 2.5 km, and it is likely that many ducks foraging in the Lagoon Habitat were beyond the DCC detection range. Our results show substantial variation in the schedule and percentage of time spent foraging. These differences among areas and years may reflect variation in foraging success (i.e., successfully capturing and eating prey) and determinants of success such as prey abundance. Unfortunately, our radio telemetry techniques do not allow us to assess this important component in foraging rates.

Both triangulation and DCC data indicate that foraging rate increased through the molt period. This may be related body composition dynamics and preparation for flight. As seen in Chapters 1 and 2, wing loading is decreased and flight attainment period is shortened by the loss of mass through the molt period. Long-tailed Ducks may follow a strategy of foraging less early in the molt period to lose weight and then increasing foraging and mass as flight is attained.

Although habitat use patterns were highly variable, there was a tendency for ducks to use nearshore habitats more at night and the Lagoon Habitat more during the day. This correlates with our foraging pattern results and is consistent with other studies (Ward and Sharp 1974, Johnson 1982) that found a tendency for Long-tailed Ducks to use nearshore habitats for roosting at night and the Lagoon Habitat for feeding during the day. The notable exception to this (Flaxman Island in 2001) suggests that other environmental conditions (possibly wind protection and prey distribution) strongly influence habitat use.

If proximity to industrial development affects foraging or habitat use, we should see parallel patterns at the Maguire and Flaxman Areas (Control Areas) that contrast with the Bodfish Area (Industrial Area). In these data, only Mainland Habitat use (Figure 6-6) follows this pattern. That is, in both years, we recorded significantly more locations in the Mainland Habitat in the Control Area. This pattern has been documented in aerial surveys (Fischer et al 2002, Noel et al 2002). This difference, however, is likely due to the abundance of protective sand spits along the mainland in both the Maguire and Flaxman Areas and the dearth of sand spits along the mainland of the Industrial Area. In sum, our results do not show an effect on Long-tailed Ducks of proximity to industrial development. This parallels previous studies in which effects of human disturbance on molting Long-tailed Ducks have not been found (Johnson 1984, Ward and Sharp 1974).

While interpreting these findings, however, one should consider that during this study the amount of direct disturbance by industrial activity (e.g., boat and aircraft traffic, construction, or oil spills and response) was low and did not differ among the three areas. Future coastal development projects could have a greater impact on Long-tailed Ducks, especially in the Control Area where Long-tailed Ducks make substantial use of the Mainland Habitat.

Chapter 7

An Adenovirus Linked to Mortality and Disease in Long-tailed Ducks

INTRODUCTION

Apart from renal coccidia, identified in a male Long-tailed Duck found dead near Teshukpuk Lake on the North Slope in the 1970's (Franson and Derksen 1981), little is known about infectious and parasitic diseases in Long-tailed Ducks in Alaska. Elsewhere in North America, Long-tailed Duck populations suffer from mass mortalities caused by diseases. Avian cholera outbreaks have killed significant numbers of Long-tailed Ducks on at least two occasions in Chesapeake Bay (Locke et al. 1970, Mashima et al. 1998, Montgomery et al. 1979) and in 2002, several thousand Long-tailed Duck carcasses were collected during a mortality event in the Great Lakes (primarily Lake Erie), which was attributed to avian botulism type E (National Wildlife Health Center, Madison, WI, unpubl. data). Additionally, cestodes have been identified as intestinal parasites (Schiller 1955). Viral diseases have not been reported as a cause of mortality in Long-tailed Ducks, although viruses have been linked to die-offs in other species of waterfowl, including sea ducks (Converse and Kidd 2001, Hollmén et al. 2002). Viral diseases could be particularly significant when birds congregate in dense flocks during molt, and bird-to-bird contacts allow efficient transmission and perpetuation of an outbreak.

Evaluation of the effects of infectious diseases on populations of wild birds poses difficult challenges. However, recent studies suggest that diseases have significant impacts on species already in decline and, furthermore, that avian populations previously thought to be healthy and stable should be monitored for potential effects of new and rapidly spreading diseases (Friend et al. 2001). Because factors affecting survival of Long-tailed Ducks and the causes of recent population declines among sea ducks in Alaska are not well understood, our objectives were to evaluate Long-tailed Ducks for presence of viruses and viral diseases during molt in the Beaufort Sea. We evaluated viruses as a cause of death in Long-tailed Duck carcasses recovered during a mortality event in 2000, characterized the pathogenicity of a virus isolated from these carcasses in captive Long-tailed Ducks, and compared virus prevalences between live-trapped Long-tailed Ducks at the mortality site and a reference area, where no mortality was observed.

METHODS

Field studies

We collected blood and cloacal samples from Long-tailed Ducks caught during the live-capture drives described in Chapter 4. In 2000, samples were collected from 40 birds in the Control Area and from 30 birds in the Industrial Area. In 2001, samples were collected from 30 and 20 birds at the Control and Industrial Areas, respectively. Cloacal samples were collected with Dacron-tipped swabs, transferred into virus transport media (Hanks' balanced salt solution with 0.5% gelatin and 1500 international units [i.e., IU] penicillin, 1500 µg streptomycin, 100 µg gentamicin, and 100 IU mycostatin per ml), and stored in the gaseous phase of a liquid nitrogen dry shipper (Chart, Inc., New Prague, MN). Blood samples were collected by jugular venipuncture and transferred into Vacuette® (Greiner Meditech, Inc., Bel Air, MD) tubes without anticoagulant. The blood samples were allowed to clot for approximately 2 hrs in a cooler with ice packs and centrifuged at 1500 × g for 10 min. Serum was harvested, and stored in the dry shipper in the field and at -80°C until analyzed.

Field work on other aspects of Long-tailed Duck molting ecology continued through August in 2000 and 2001. In August of 2000, Glaucous Gulls (*Larus hyperboreus*) were observed feeding on Long-tailed Duck carcasses floating on the water surface in the near-shore lagoons of the Control Area. A total of 12 duck carcasses were found by mid-August, however, we were rarely in a position to observe scavenging or discover carcasses. Two intact carcasses were frozen at -20°C in the field and shipped to the National Wildlife Health Center (NWHC) (Madison, Wisconsin, USA).

Diagnostic laboratory analyses

The two carcasses were examined at necropsy and samples of liver, spleen, lung, kidney, small intestine, and cloaca were collected for virus isolation. Moderate autolysis prevented histopathologic evaluation of tissues. Samples of liver and intestine were submitted to the microbiology laboratory of the NWHC for bacteriology and samples of liver were submitted to the chemistry laboratory of the NWHC for heavy metal analyses. Primary cultures of Muscovy Duck (*Cairina moschata*) embryo fibroblasts (MDEF) were used for virus isolation (Docherty and Slota 1988). Approximately 1 g of each tissue sample was homogenized in virus medium, and the homogenates were centrifuged at 800 × g for 30 min at 4°C. The cloacal swabs were mixed by vortexing, and centrifuged at 800 × g for 15 min. Supernatants of each sample were inoculated separately into MDEF monolayers and incubated at 37°C in 5% CO_2. The cell cultures were examined every other day for 7 days for viral cytopathic effects (CPE). When no CPE was observed, samples were freeze-thawed, blind passaged to fresh cell cultures, and monitored for an additional 7 days.

Virus identification

The nucleic acid type of the isolated viruses was determined by evaluating their infectivity to MDEF cells after 5-iodo-2'-deoxyuridine treatment. The presence or absence of lipoprotein envelope was evaluated with a chloroform lability assay (Feldman and Wang 1961). Positive cells cultures were prepared for electron microscopy by slow centrifugation at 800 × g for 30 min, and by ultracentrifugation of the supernatant at 35,000 × g for 150 min. The viral pellets were resuspended in distilled water, placed on grids, negatively stained with 0.5% phosphotungstic acid, and examined with a Hitachi H-500 transmission electron microscope (Hitachi High Technologies, Tokyo, Japan). Representative isolates were tested against avian adenovirus I (serotypes 1, 3, and 5) (Spafas® Inc., Preston, CT), avian adenovirus II (hemorrhagic enteritis virus) (Spafas® Inc.), and avian adenovirus III (egg drop syndrome virus, duck adenovirus serotype 1) (National Veterinary Services Laboratory, Ames, IA) antiserum using a standard virus neutralization assay (Thayer and Beard 1998).

Serology

Serum samples were heat-inactivated at 56°C for 30 min and serial two-fold dilutions were tested with a standard virus neutralization assay (Thayer and Beard 1998) for antibodies against a representative isolate from the Long-tailed Ducks.

Experimental studies.

Three Long-tailed Ducks (Dry Creek Waterfowl, Port Angeles, WA) were received at the NWHC on September 20, 2001 for a pilot virus infectivity trial. Ducks were housed in a biosafety level III room (5.7 m x 3.2 m) equipped with a pond liner and filled with water to a depth of 20 cm (experimental room). Water was exchanged in the pool at a rate of 4 liters/min and the room was kept on a light cycle of 12 hr per day (0600 to 1800). All ducks were fed Mazuri® (PMI Nutrition International, Brentwood, MO) #5681 sea duck diet *ad libitum* throughout the experiment. Feeding stations consisted of two artificial islands per pool with open feeding pans placed on top. On 22 September, two pilot ducks (one male and one female) were inoculated orally with approximately 7×10^4 infectious units (IU) of the virus (as determined by tissue culture infective dose 50 [i.e., $TCID_{50}$]concentrations) isolated from the year 2000 mortality event and the second female was inoculated with approximately 3.5×10^5 IU of the virus to evaluate the dose required in the main experiment. Based on the results of the pilot experiment, thirteen additional Long-tailed Ducks were received on 22 October and placed in an identical biosafety level III room (control room). On 5 November, eight ducks were moved to the experimental room and inoculated with 6.2×10^5 IU of the virus (Figure 7-1). The three ducks from the pilot study were moved into the room with the rest of the infected birds, and the five ducks remaining in the control room were dosed orally with sterile transport media. Pre-inoculation blood samples and cloacal swabs were collected from all ducks. Post-inoculation blood samples were collected at intervals of approximately one week and cloacal samples were collected on the day after inoculation and every three days thereafter from the virus-inoculated ducks and weekly from the control ducks. The weight of each duck was recorded each time a cloacal sample was taken. During the first two weeks postinoculation, the feeding pans of the ducks were periodically swabbed for virus isolation. On 7 December, three experimental ducks (second inoculation) and three controls were inoculated with approximately 1.6×10^6 IU of virus (Figure 7-1). Ducks were euthanized and necropsied 6 to 32 days postinoculation (Figure 7-1), based on weight changes in conjunction with data on virus activity. The three ducks from the pilot study were euthanized on 5 January 2002. Blood samples were collected prior to euthanasia, centrifuged at 1500 g for 10 min, and serum was harvested for antibody testing and serum biochemistries. At necropsy, the following tissues were collected for both virus isolation and histopathology: duodenum, jejunum, ileum, large intestine, cloaca, cecum, liver, spleen, kidney, lung, and gonad. Additionally, heart and skeletal muscle were collected for histopathology. Virus isolation was performed as described for samples collected from the wild birds.

RESULTS

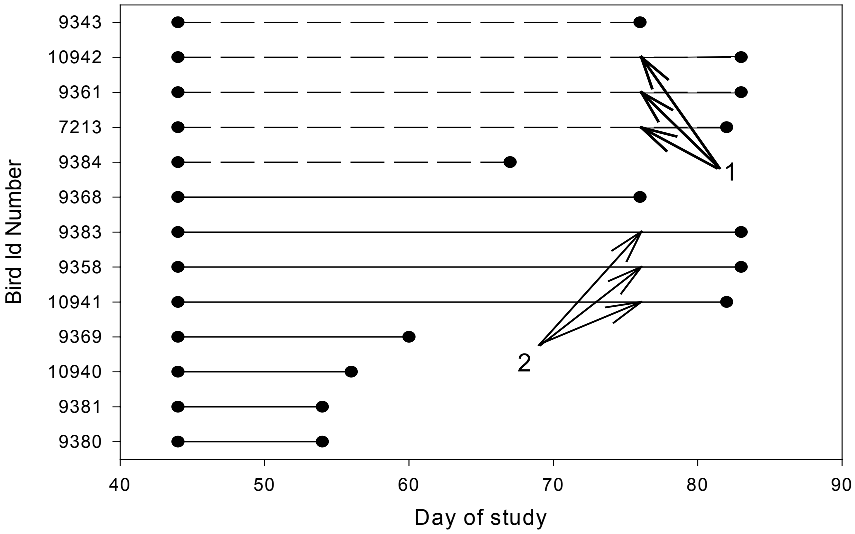


Figure 7-1. Time line indicating when individual birds were inoculated with the adenovirus and necropsied. Solid lines indicate exposed birds and dashed lines indicate control birds. Number 1 identifies the day on which control birds were inoculated with the virus. Number 2 identifies the day on which exposed individuals were re-inoculated with the virus. Three additional "pilot" birds were inoculated on day 1 and necropsied on day 105 (not plotted).

Necropsy findings

Both Long-tailed Ducks collected from the Control Area in 2000 were males and in poor to moderate body condition (reduced pectoral muscles and subcutaneous fat reserves). Gross lesions of enteritis (dilated small intestines, mucoid and hemorrhagic intestinal contents) were observed at necropsy in both individuals. No pathogens were isolated in bacterial cultures and heavy metal levels in liver samples were not considered elevated. Small intestinal and cloacal samples from carcasses were positive in virus cultures, and the isolates were characterized as nonenveloped DNA-viruses. By electron microscopy, the viral capsomeres were arranged in equilateral triangles and the isolates were identified as adenoviruses (Horne et al. 1959). The virus was not neutralized by reference antiserum against avian adenovirus group I, II, or III viruses.

Virus prevalence in the field

In 2000, live virus was isolated from 50% of cloacal swabs collected at the mortality site (Control Area) and from 7% of cloacal swabs from the Industrial Area, where no mortality was observed. Prevalence of serum antibody titers ≥1:64 was 86% in the Control Area and 10% in the Industrial Area. In 2001, no mortality was observed at either of the study areas. Live virus was present in 7% and 0% of the cloacal swabs collected in the Control and Industrial Areas, respectively. Seroprevalence was 20% in the Control Area and 0% in the Industrial Area.

Experimental study

No mortality occurred during the experimental study. Clinical signs indicative of gastrointestinal disease were observed in ducks inoculated with adenovirus and included watery consistency of feces and blood in feces. Serologic testing indicated that all inoculated ducks became infected with the virus. Titers of >1:256 were measured at 7 to 14 days post-inoculation. After three weeks, the circulating antibody levels dropped and exhibited an undulating pattern in the three ducks that were monitored for 3.5 months. Most inoculated birds were shedding viruses from their cloaca for approximately two weeks, and the three ducks that were monitored for 3.5 months were shedding periodically throughout the entire period. In the 11 ducks that were necropsied during days 6-32 post-inoculation, virus was isolated most frequently from the ileum and large intestine (73%), but was also isolated from duodenum (63%), jejunum (55%), cloaca (55%), cecum (55%), liver (36%), kidney (27%), lung (9.1%), testis (14% of males), and ovary (14% of females). At necropsy, pinpoint and paintbrush hemorrhages were noted in the proximal intestine of eight (73%) birds. Histological findings included widespread lymphoid hyperplasia and necrosis (in 91% of the ducks), mild to moderate multifocal non-suppurative enteritis (91%), mild to moderate multifocal non-suppurative typhlocolitis (36%), and multifical non-suppurative hepatitis (36%). Lymphoid and enteric lesions were seen throughout the 6-32 day period, and hepatic lesions were seen in ducks euthanized on days 6, 7, and 12 post-inoculation. Hepatic intranuclear inclusion bodies were found in one duck at 12 days post-inoculation. Virus was re-isolated from the spleen of two of three individuals monitored for 3.5 months. One of these ducks showed lymphoid hyperplasia and necrosis of spleen and small intestine, and had multifocal non-suppurative enteritis. Viruses were also isolated from materials swabbed from the feeding pans during the first two weeks of the study.

DISCUSSION

We isolated an adenovirus from intestinal tissues of Long-tailed Ducks found dead in the Beaufort Sea in Alaska in 2000. The virus was not neutralized by antisera against previously known avian group I, II, or III adenoviruses and probably represents a new duck serotype. Although no mortality occurred during the inoculation study, the virus was infectious for Long-tailed Ducks under experimental conditions and resulted in lesions previously described for avian adenovirus infections, including intestinal hemorrhage, inclusion body hepatitis, and lymphoid tissue pathology (McFerran 1997a, McFerran and Adair 1977, Pierson and Domermuth 1997). Based on the pathology observed in Long-tailed Ducks, the newly isolated adenovirus appears to share some characteristics with both group I and II avian adenoviruses. Inclusion body hepatitis has been previously reported in chickens, pigeons, and some species of raptors, with the etiologic adenovirus belonging to group I. Hemorrhagic enteritis virus has been previously reported from turkeys, is classified as a group II adenovirus, and has also been associated with immune system pathology. Reproductive pathology has been linked to group III avian adenoviruses and virus-associated effects include reductions in egg production rate and egg abnormalities (Mcferran 1997b, McFerran and Adair 1977). In our experimental study, the adenovirus was isolated from gonad tissues of one male and one female Long-tailed Duck, but the potential of the newly isolated virus to affect reproductive parameters was not studied in Long-tailed Ducks.

The carcasses collected from the original die-off in the Beaufort Sea showed lesions indicative of enteric pathology. Because the tissues were not suitable for a histological evaluation, we were unable to determine if liver inflammation and hepatic intranuclear inclusion bodies were present. Based on the serology and virus isolation results from live-trapped Long-tailed Ducks, high prevalence of both serum antibodies and live viruses in cloacal samples was strongly linked to the mortality event in 2000. The prevalence of antibodies and live viruses was significantly lower in birds trapped at the reference site 100 km away, where no mortality was observed in 2000. Furthermore, in 2001, the year following the die-off when no mortality was observed, virus prevalences were also very low. These results support the hypothesis that the virus was either responsible for or a significant contributing factor in the mortality event in 2000.

Experimentally infected Long-tailed Ducks were shedding viruses from their cloaca for approximately two weeks post-inoculation and intermittently for at least an additional four months. Viruses were isolated from feeding pans of the experimental pools for two weeks post-inoculation. Because all ducks were shedding viruses and virus persisted in the feeding pans, transmission via a fecal-oral route seems likely for the Long-tailed Duck adenovirus. In the wild, molting Long-tailed Ducks roost in dense flocks on shore during the nights allowing for close bird-to-bird and bird-to-feces contacts, and thus, potential virus transmission.

Animals inoculated with viruses and housed under experimental conditions often exhibit less severe disease than that which occurs in natural infections (Turpin et al. 2002), and a similar scenario may explain our experimental results in captive birds that were fed *ad libitum* and not stressed by other environmental factors. The virus caused moderate intestinal, hepatic, and lymphoid pathology in Long-tailed Ducks under experimental conditions, and effects on organs can be more significant in the wild because birds undergoing molt may be nutritionally stressed due to energy demands of feather growth and decreased insulation (Hohman et al. 1992, Murphy and King 1992). Indeed, Howell (2002) documented declines in body mass and lipid levels in Long-tailed Ducks undergoing wing molt in the Beaufort Sea during the same time when our study was conducted. Additionally, birds in the Control Area, where the prevalence of virus was higher, were in poorer condition than birds in the Industrial Area. Birds that experience nutritional stress during molt may be more susceptible to viral infection and therefore, the molt may have been a contributing factor to the mortality event in 2000. Furthermore, an infectious agent interfering with intestinal function could increase the level of nutritional stress and lead to a cycle of deteriorating body condition during molt. Both carcasses that were examined in 2000 were in relatively poor body condition, suggesting that interactions between nutrition and intestinal adenovirus infections contributed to the mortality.

Additional indirect health effects of Long-tailed Duck adenoviruses may relate to immunopathology and reproductive disorders. If the adenovirus induces immunosuppression as a consequence of the lymphoid depletion and necrosis noted in our experimental study, interactions between the virus and other pathogens or environmental contaminants may be important. Other than gonadotropism, we have no evidence for the potential of Long-tailed Duck adenoviruses to cause reproductive problems in their host, but because previously reported strains of adenoviruses associated with ducks have been linked to decreased egg production and egg abnormalities, the possibility of reproductive consequences should be evaluated in Long-tailed Ducks during nesting. If the newly isolated adenovirus is associated with impaired nutrition, reproduction, and immunocompetence in addition to causing direct mortality, its overall effects may be more subtle but result in a long-term reduction in population size and viability.

Chapter 8
Trace Elements in Long-tailed Ducks

INTRODUCTION

Metals and trace elements enter the marine environment from natural geologic sources and from discharges of anthropogenic materials (Law 1996). In marine ecosystems, the highest concentrations of trace elements often occur in coastal regions (Harrison and Peak 1995), where they bind to and accumulate in sediments. From sediments, contaminants may bioaccumulate in the food chain, a species-dependent process associated with feeding ecology, potentially resulting in toxicity (Barron 1995). Contaminants also may enter arctic environments through releases associated with mining and the use and transport of oil and gas resources. Findings of the Minerals Management Service's Beaufort Sea Monitoring Program indicated that concentrations of some trace elements, particularly barium and chromium, were higher in sediments from the Beaufort Sea in comparison to other outer continental shelf sediments (Beohm et al. 1990). The National Oceanic and Atmospheric Administration's National Status and Trends Program found that sediment concentrations of arsenic, mercury, nickel, and silver were higher at Oliktok Point on the Beaufort Sea than at the reference area, Lutak Inlet in southeast Alaska (Meador et al. 1994). In the western Beaufort Sea, concentrations of arsenic and nickel were higher than the average for U.S. sediments (Valette-Silver et al. 1997).

Lead exposure from ingested shot is a problem that has been identified for the threatened Spectacled Eider (*Somateria fischeri*) in western Alaska, where populations of this species have undergone a dramatic decline. Since 1992, lead poisoning has been diagnosed as the cause of death of several Spectacled Eiders on the breeding grounds (Franson et al. 1995). Lead poisoning and predation were the only two identified causes of mortality for adult female eiders followed by radiotelemetry during a 3-yr study of survival during the brood rearing period (Flint and Grand 1997). Flint et al. (1997) studied exposure of diving ducks to lead in western Alaska and reported that nearly 12% of the Spectacled Eiders radiographed had ingested shot and that up to 36% of Spectacled Eider hens, about 12% of Spectacled Eider ducklings, and over 20% of Long-tailed Ducks sampled on the breeding grounds had blood lead concentrations of ≥0.20 ppm wet weight. Blood lead concentrations of ≥0.20 ppm were associated with reduced survival rates of immature Canvasbacks (*Aythya valisineria*) (Hohman et al. 1995) and a lower survival index was associated with elevated blood lead concentrations in American Black Ducks (*Anas rubripes*) (Samuel et al. 1992). The factors contributing to reduced long-term survival of waterfowl exposed to lead may be those that are sublethal in the short term, such as anemia and other hematologic effects, reduced body condition, and immunosuppression (Pain 1989, Hohman et al. 1990, Rocke and Samuel 1991).

High levels of cadmium and selenium have been reported from sea ducks in several areas of Alaska. Cadmium is not biologically essential, is toxic at high concentrations, and is present in some ores and in various anthropogenic sources, including wastes from mining, smelting, and the incineration of cadmium-bearing materials (Eisler 2000). Reported cadmium concentrations in kidneys of sea ducks from Alaska have been as high as 353 ppm dry weight in Spectacled Eiders and 375 ppm dry weight in White-winged Scoters (*Melanitta fusca*) (Henny et al. 1995, Stout et al. 2002). Although marine birds may tolerate higher cadmium levels than other species, Furness (1996) proposed a threshold level of 100 ppm wet weight (about 333 ppm dry weight) in kidneys of birds, above which cadmium poisoning could be expected. Selenium is an essential trace element for birds and other animals, but it bioaccumulates through the food chain and can be toxic (Eisler 2000). Selenium enters the environment from a variety of anthropogenic sources, but it is also a natural component of the earth's crust and the major source of environmental selenium is the weathering of rock (Eisler 2000). Selenium concentrations in sediments at remote coastal Alaska sites, including Oliktok Point on the Beaufort Sea, Dutch Harbor on the near Aleutian Islands, and Boca de Quadra in southeast Alaska are higher than at many other sampling sites along the Pacific coast from southern California northward (Meador et al. 1994). High selenium concentrations also have been found in waterfowl in Alaska. Spectacled Eiders, most of which were collected at St. Lawrence Island and the Yukon-Kuskokwim Delta (YKD), had selenium concentrations in their livers that ranged from 4.98 ppm to 401 ppm dry weight, with means of 43 ppm dry weight in females and 124 ppm dry weight in males (Trust et al. 2000, Stout et al. 2002). In livers of Steller's Eiders (*Polysticta stelleri*), most of which were collected near Barrow, Kotzebue, and Togiak, selenium concentrations ranged from 8.18 ppm to 56.8 ppm dry weight (Stout et al. 2002). Mean selenium concentrations of 19.26 and 12.79 ppm wet weight were found in blood of male and female Spectacled Eiders, respectively, sampled during the incubation period on nesting grounds in the YKD (Grand et al. 2002). Marine birds apparently tolerate higher selenium exposure than freshwater species, as levels above 10 ppm wet weight (about 33 ppm dry weight) in liver are considered harmful in the latter group (Heinz 1996).

Little is known about trace element exposure in Long-tailed Ducks. Our objectives were to measure and compare trace elements and delta-aminolevulinic acid dehydratase (ALAD), an enzyme inhibited by lead, in blood of Long-tailed Ducks molting at the Control and Industrial Areas.

METHODS

In 2000, whole blood samples for trace element analysis were collected from 20 male Long-tailed Ducks at each of the two study areas (Control and Industrial). Samples were frozen in the field in a liquid nitrogen vapor shipper and transported to the National Wildlife Health Center, where they were stored at –75°C until shipment to RTI International, Research Triangle Park, NC, for analysis of the following trace elements: Al, As, B, Ba, Be, Cd, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pb, Se, Sr, V, and Zn. Samples were weighed, freeze dried (percent moisture determined by the difference in the wet and dry weights), and digested in nitric acid. Analysis was done by inductively coupled plasma/mass spectrometry (ICP/MS), except mercury was analyzed by cold vapor atomic absorption (CVAA) and selenium by graphite furnace/atomic absorption spectrophotometry (GF/AAS). The ALAD activity was measured colorimetrically in whole blood (Burch and Siegel 1971). One unit of enzyme activity is defined as an increase in absorbance at 555 nm of 0.100, with a 1.0 cm light path, per ml of erythrocytes per hour, at 38°C. Kruskal-Wallis tests were used to compare contaminant residues and ALAD activity between the Control and Industrial Areas. Spearman correlation was used to evaluate the relationship of Se and Hg concentrations in blood. We assigned a concentration of one-half of the lower limit of detection to the samples that contained no residues of a particular contaminant, as long as detectable residues were found in 50% or more of the samples. If residues of a particular contaminant were found in less than 50% of the samples, no median was calculated and the data were not used in statistical comparisons. Trace element residues in blood are reported on wet weight basis.

RESULTS

Table 8-1. Frequency of detection, median, and minimum-maximum concentrations (ppm wet weight) of 11 trace elements[1] in blood of Long-tailed Ducks at the Control and Industrial Aeas (n = 40).

Trace element		% detected[2]	Median	Min-max
Al	Aluminum	7.5	NC[3]	ND[4]-2.64
As	Arsenic	20.0	NC	ND-0.18
B	Boron	62.5	0.08	ND-0.23
Ba	Barium	35.0	NC	ND-0.03
Cd	Cadmium	17.5	NC	ND-0.007
Cu	Copper	100.0	0.31	0.15-0.61
Hg	Mercury	100.0	0.12	0.06-0.28
Mn	Manganese	100.0	0.016	0.005-0.412
Mo	Molybdenum	100.0	0.03	0.007-0.060
Pb	Lead	100.0	0.01	0.006-0.081
Se	Selenium	100.0	11.3	4.20-22.1

[1] Trace elements tested for, but not detected, were Be and Ni.

[2] The percentage of the samples in which the trace element was above the detection limit.

[3] Not calculated when trace element was detected in <50% of samples.

[4] Not detected.

Nickel and Be were not detected in any of the Long-tailed Duck blood samples. Aluminum, Cd, As, and Ba were detected in 7.5% to 35% of the samples. Boron was above detectable limits in 30% of the samples at the Industrial Area and in 95% of the blood samples from the Control Area, for an overall frequency of 62.5%. The remaining trace elements were detected in all samples (Tables 8-1 and 8-2). Concentrations of six trace elements differed significantly ($P < 0.05$) between locations (Table 8-2). Iron, Mg, and Zn were higher in blood samples collected from the Industrial Area, while Cr, Sr, and V were higher in the Control Area. The median blood Pb concentration in Long-tailed Ducks was low (0.01 ppm wet weight) and the ALAD activity was not significantly different between locations (249 units in the Industrial Area and 232 units in the Control Area). Concentrations of Se in blood were high, Hg was low, and the two were not correlated ($n = 40$, $r = -0.04$, $P = 0.80$).

Table 8-2. Median and minimum-maximum concentrations (ppm wet weight) of six trace elements in blood of Long-tailed Ducks at the Control and Industrial Beaufort Sea study areas. All six were detected in all samples at each location and the concentrations were significantly different between locations (Kruskal-Wallis test; P = 0.0066 for Cr, 0.0090 for Fe, 0.0200 for Mg, <0.0001 for Sr, 0.0102 for V, 0.0167 for Zn).

Location	Cr	Fe	Mg	Sr	V	Zn
Control (n = 20)						
Median	0.15	452	68.6	0.11	0.049	4.52
Min-max	0.07-0.40	390-755	63.6-116	0.05-0.22	0.023-0.127	4.00-8.37
Industrial (n = 20)						
Median	0.11	493	71.7	0.05	0.039	4.73
Min-max	0.05-0.40	422-759	60.1-116	0.03-0.11	0.020-0.130	4.30-7.88

DISCUSSION

Apart from several reports in eiders, few published data are available for trace element concentrations in blood of sea ducks. The median Se concentration (11.3 ppm wet weight) in blood of Long-tailed Ducks in this study was greater than in Common Eiders (6.87 ppm wet weight) sampled at the same locations (see Chapter 13). Selenium levels in blood of Long-tailed Ducks in the Beaufort Sea were also greater than most other published reports from sea ducks, except for Spectacled Eiders sampled during the incubation period on the YKD of Alaska, where mean concentrations were 19.26 ppm wet weight in males and 12.79 ppm wet weight in females (Grand et al. 2002). Although marine birds can apparently tolerate higher Se exposure than freshwater species, high Se levels in blood of Emperor Geese (*Chen canagica*) were accompanied by increased glutathione peroxidase in plasma, which is consistent with early oxidative stress (Hoffman 2002, Franson et al. 2002). High levels of Hg may counteract some of the toxic effects of Se (Cuvin-Aralar and Furness 1991), but Hg concentrations in blood of Long-tailed Ducks were low. At 0.01 ppm wet weight, the median lead concentration was much lower than the threshold (0.20 ppm wet weight) for lead exposure (Pain 1996). These results suggest that Long-tailed Ducks sampled at molting areas in the Beaufort Sea have lower concentrations of lead in their blood than the levels that have been reported from Long-tailed Ducks and other sea ducks in some areas of Alaska, such as the YKD (Flint et al. 1997, Grand et al. 2002).

Aluminum was detected in only 7.5% of the blood samples, at a maximum concentration of 2.64 ppm wet weight. Aluminum is poorly absorbed, it's potential for toxicity is low, and soft tissue levels do not necessarily reflect exposure (Scheuhammer 1987). Detectable levels of Cd were found in the blood of 17.5% of Long-tailed Ducks and the maximum concentration was about one-half the maximum found in Common Eiders in this study (see Chapter 13) and considerably lower than in blood of Common Eiders from the Canadian Arctic (Wayland et al. 2001). Boron is not an essential trace element for animals, is distributed widely in the environment, and naturally elevated boron levels are often associated with marine sediments, seawater, and some ground waters (Eisler 2000). Boron was found in 62.5% of the Long-tailed Duck blood samples, at a maximum concentration of 0.23 ppm wet weight. In a study evaluating the uptake and loss of boron, Mallards were fed a diet containing 1600 ppm B for 32 days, at which time the mean B concentration in blood was 67.57 ppm dry weight (about 14 ppm wet weight, assuming 80% moisture for blood) (Pendleton et al. 1995). Thus, the concentrations of B that we found in Long-tailed Ducks are not likely to have adverse impacts. Copper concentrations in Long-tailed Ducks were low and similar to the levels found in Common Eiders (see Chapter 13). Birds and mammals are more resistant to Cu exposure than other animals and interpretive data on the toxicity of Cu are not available for wild birds (Eisler 2000).

Although concentrations of six trace elements in the blood of Long-tailed Ducks differed significantly between the two study areas, they were not consistently greater at one location. Concentrations of three trace elements (Cr, Sr, and V) were greater in the Control Area and three (Fe, Mg, and Zn) were greater in the Industrial Area (Table 8-2). Except for Sr (twice as high at the Control area) and Cr (36% greater at the Control Area), the differences between the median concentrations at the two locations were relatively low (4.5-25%). According to Eisler (2000), presumptive evidence for chromium exposure is based on tissue (type not specified) levels of 4 ppm dry weight or greater. For blood, this is equivalent to approximate 0.8 ppm wet weight, a considerably greater concentration than we found in Long-tailed Ducks. Zinc is an essential trace element, but can be toxic at high concentrations. The concentration of Zn in Long-tailed Ducks was similar to levels found in blood of Trumpeter Swans (*Cygnus buccinator*) in the western United States (Blus et al. 1989). Iron, Mg, and Mn are required trace elements and little information is available about toxic levels. Likewise, few interpretive data for Sr and V in blood of birds are available, but normal levels in mammals are reported to be about 0.07 and 0.02-0.03 ppm wet weight, respectively (Puls 1988). Concentrations of Fe, Mg, Mn, Mo, Cr, V, and Zn were similar to, or somewhat lower than, median concentrations in blood samples from Steller's Eiders from the Alaska Peninsula, while Sr at the Control Area was somewhat greater than the median found in Steller's Eiders (Franson, unpublished data).

The Se concentrations that were found in blood of Long-tailed Ducks in the Beaufort Sea are some of the highest levels yet to be reported in sea ducks. Although Se concentrations did not differ between locations, concentrations of three trace elements were higher in the Control Area and three were higher in the Industrial Area. Strontium levels were relatively low, but the median Sr concentration in the Control Area was about twice as high as in the Industrial Area. The magnitude of difference between medians of the other five trace elements that differed by location was considerably less. Except for Se and Sr, concentrations of other trace elements in blood of Long-tailed Ducks were often similar to, or lower than, trace element levels in other sea ducks.

Chapter 9

Synthesis of Aerial and Ground Based Studies of Molting Long-tailed Ducks

Aerial surveys of Long-tailed Ducks molting in the Beaufort Sea lagoons indicate a long-term population decline (Fischer et al. 2002). This decline in molting populations is occurring coincidentally with declines in breeding population indices (USFWS unpubl. data). Thus, it is unclear if these long-term population declines are related to factors encountered on breeding areas, molting areas, or during other portions of the annual cycle. In fact, the breeding and wintering affiliations for birds molting on our study areas are unknown. Many species of waterfowl undergo substantial migrations away from breeding areas prior to molting. Therefore, the associated breeding affiliations for this molting population could be a considerable distance away. However, recent satellite telemetry data from the Yukon-Kuskokwim Delta suggests that birds breeding in western Alaska do not migrate to the North Slope. Thus, it is most likely that birds molting along the Beaufort Sea are from breeding areas in arctic Alaska and Canada. There is essentially nothing known about the biology of Long-tailed Ducks breeding in the arctic making it impossible to define potential causes of the broad scale population decline.

While aerial surveys indicate a population decline, there has been little change in overall patterns of distribution of molting birds within our study areas (Fischer et al. 2002). Thus, it does not appear that there has been localized extinction or displacement of birds from historic range. The overall patterns of distribution observed during aerial surveys are supported by our ground based observations and radio telemetry data. Generally, Long-tailed Ducks roost along the barrier islands in the morning and evening, and feed in open water areas, mid-day.

Our data suggest that body condition dynamics are adapted to minimize the flightless period. Several factors suggest that forage quality and/or availability are not limiting. First, the relative energetic costs of feather production are thought to be relatively constant throughout the period of feather regrowth. While molting Long-tailed Ducks initially lose weight, they re-gain weight during the latter half of the feather growth period. If costs are constant, then the fact that individuals can increase in condition suggests that exogenous resources are not limiting. Second, Long-tailed ducks are simultaneously molting body feathers during the flightless period. This body molt incurs additional costs in two ways. First, there is the additional direct cost of replacing these feathers. Second, there may be additional metabolic maintenance costs caused by a reduction in plumage insulation during body molt. Other species of waterfowl delay body molt until well after wing molt is complete thereby extending the overall period of molt, but minimizing immediate costs. If foraging were limiting, we would not expect flightless Long-tailed Ducks to be simultaneously molting body feathers during the flightless period. Finally, our data indicate that individual birds are quite mobile even during the flightless period. While we documented considerable movements of individuals, we did not see complete abandonment of specific areas. If birds were moving in response to inadequate foraging conditions, we would expect to see directional movement away from specific areas resulting in localized reductions in density and abandonment of these areas. However, our data suggest that individuals are moving in multiple directions and that a significant fraction of the observed movements are ‘temporary’ and many birds ultimately returned to previously used areas.

We found little evidence for displacement of birds as a direct result of disturbance. Levels of disturbance varied from our boating activity to an underwater 3-D seismic survey using airguns. In neither case did we detect substantial changes in distribution, behavior, or body condition of Long-tailed Ducks. Importantly, our study of individual behavior started with a major disturbance event (i.e., the capture and marking of individuals), yet we did not see substantial movements immediately following marking. Obviously, we have no measure of behavior prior to marking and thus, we cannot assess potential changes in behavior as a result of our marking activities. However, we conclude that wind and weather patterns have a stronger influence on movements and patterns of habitat use than disturbance.

The strongest negative effect on molting Long-tailed Ducks that we observed was caused by the adenovirus outbreak we identified in 2000. The exposure rate to this virus was highest in the area with the greatest density. This was likely caused by greater bird-to-bird transmission in high-density situations. Aside from causing direct mortality, exposure to the virus likely had a major influence on body condition dynamics during the flightless period. This virus was detected in subsequent years, but was not widespread and did not cause any observed mortality. The factors related to outbreaks of this virus and frequencies of mortality events are unknown. However, disease agents that influence large concentrations of birds would certainly have the potential to influence population dynamics.

While our studies have yielded useful information regarding behaviors, patterns of habitat use, and effects of disturbance, several major questions still remain. Foremost, it is unclear what factors influence variation in density within and among lagoons. Densities have historically been higher in the Control Area than the Industrial Area. Associated with these differences in densities we also observed variation in behavior, and habitat use among lagoons. However, this variation in habitat use and behavior apparently was not of sufficient magnitude to influence body condition. The disease outbreak we observed in 2000, may have been related to overall density of birds; however, if this were occurring regularly, we would expect relatively uniform, low densities of birds throughout the lagoon systems. Birds in the Control Area also tended to use the mainland shoreline more frequently than those in the Industrial Area. Certainly this could be a direct influence of the existing development in place along the mainland in the Industrial Area. However, an alternative explanation of this variation among lagoons is related to the topography of the lagoons and relative protection from wind generated waves. The mainland shoreline along the Control Area has a series of protected estuaries and small islands. Additionally, the prevailing winds are from the northeast. Thus, the limited fetch in the far eastern portion of the lagoon limits the overall magnitude of the waves. Conversely, in the Industrial Area, the mainland shoreline lacks protective structure and is exposed to considerable fetch and associated larger waves. Thus, it appears that the primary factors influencing overall variation in density are related to habitat selection in relation to topography and protection from prevailing winds.

A second major, unanswered, question is relative to the use of the Beaufort Sea outside the barrier islands. Flightless birds were regularly observed on the Beaufort Sea side of the barrier islands and several of our radio-equipped birds moved outside of the islands during the flightless period. Aerial survey data suggest that a significant proportion of Long-tailed Ducks move offshore after regaining flight, where they stage prior to the initiation of fall migration. Thus, on the larger scale, off-shore areas may be preferred habitat for Long-tailed Ducks. These areas may be unsuitable for molting because they lack protection from waves and ice. However, previously we suggested that our data support the conclusion that potential forage was not limiting molting birds. While forage may not be limiting birds during the flightless period, it may be inadequate to allow birds to gain sufficient condition to undertake fall migration. Thus, the preference of the Beaufort Sea lagoons for molting Long-tailed Ducks may be related to the proximity of post-molt staging habitats offshore.

Chapter 10
Aerial Population Surveys of Common Eiders Along the Coastline and Barrier Islands of the Arctic Coastal Plain

INTRODUCTION

Pacific Common Eiders (subspecies *v-nigra*) breed along the coast of arctic Alaska and Canada. Indices to the number of Common Eiders migrating past Barrow, Alaska, have dropped dramatically in recent years (Suydam et al. 2000), suggesting that this breeding population is declining. Recent satellite telemetry data suggest that the North Slope breeding population is largely isolated from other populations of this subspecies (Petersen and Flint 2002). This conclusion is supported by recent genetic analyses (Sonsthagen unpubl. data). The factors contributing to this overall population decline are unknown. We designed an aerial survey to assess the population trend on a more localized geographic scale.

We initiated aerial surveys designed to index the breeding population of Common Eiders along the Alaskan Beaufort Sea coast. Here we summarize four years (1999-2002) of aerial surveys during the early incubation period of Common Eiders. We focused on estimates of Common Eider population size, demography, and distribution north and east from Omalik Lagoon on the Chukchi Sea to the Canadian border on the Beaufort Sea. This survey was designed to provide an estimate of the numbers and trends of Alaskan breeding Common Eiders along the Chukchi and Beaufort Seas coastline. These data are useful in interpreting ground based nesting surveys and the migration counts of the combined Alaska and Canadian populations at Point Barrow.

METHODS

The survey was timed to coincide with early incubation while male eiders were in the vicinity of breeding sites. Ground surveys of nesting birds were used to determine breeding phenology and appropriate survey timing. A Cessna 206 amphibian flown at approximately 110 knots and an altitude of 45 meters ASL/AGL was used. Observations were made from both sides of the aircraft and entered directly into laptop computers using remote microphones. Computers interfaced with the aircraft Global Positioning System (GPS) and observations were collected using record and transcribe programs. Meandering flight routes followed mainland and barrier island shorelines and adjacent nearshore waters providing complete coverage from the shore to 1.6 km offshore. Moving map programs on both pilot and observer computers helped ensure coverage of the survey area. Flights were conducted in calm or light winds whenever possible and during mid-day to maximize height of the sun-angle, reduce glare and increase the visibility of birds on the water.

The survey area included 29 shoreline segments and 20 islands or island groups (Figure 10-1). Insular areas along the central Beaufort Sea coast were identified on 1:63,360 scale topographic maps. Maps were consulted primarily to identify segment start and stop points. General observations on habitat and survey conditions were recorded by the pilot and along with sea surface analyses prepared by the National Weather Service, were used to portray ice conditions during the survey. For all waterfowl species, we determined the sex and age of single birds and composition of flocks whenever possible. Observations of Common Eiders and other species were summarized by barrier island and shoreline survey and for the total survey area. The distribution and sex and age composition of Common Eiders and the number of indicated breeding pairs (single males + pairs) throughout the survey area were determined to estimate the proportion of breeding birds and total population size (singles + 2x pairs + flocks).

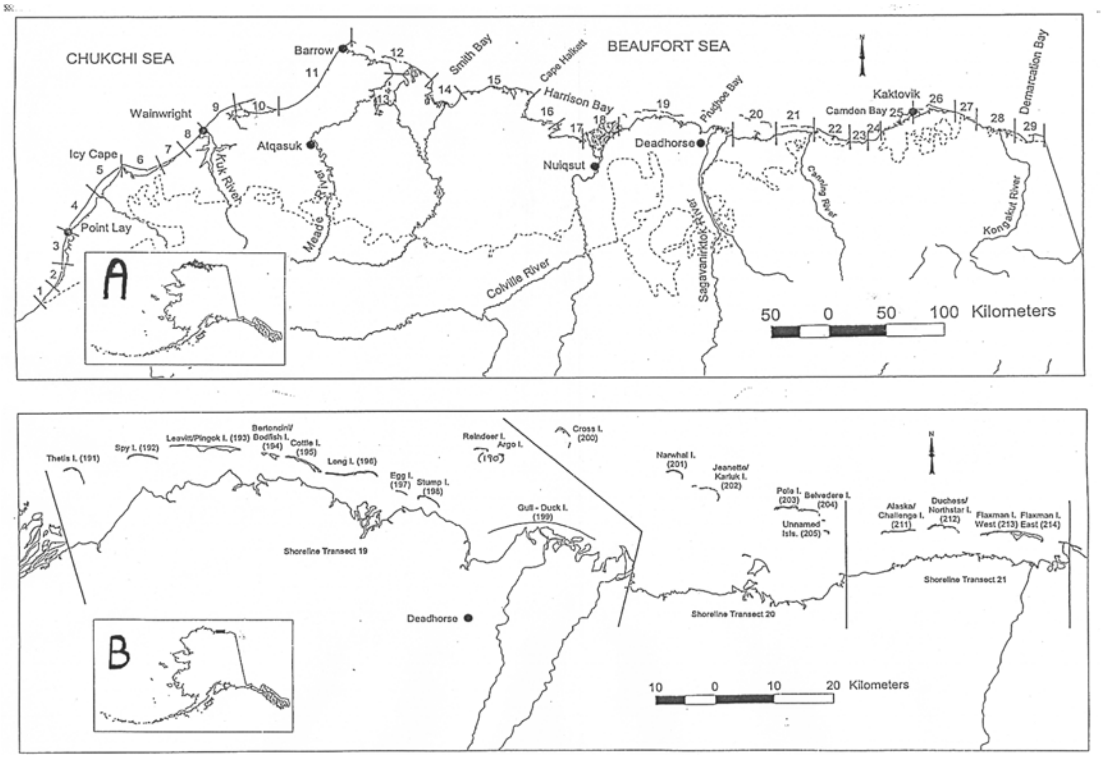


Figure 10-1. Location of aerial survey segments along the Arctic Coastal Plain (A) shoreline and (B) barrier islands.

RESULTS

In 2002, our estimate of indicated breeding pairs and total Common Eider counts were up 56.8% and 24.4%, respectively, from 2001. Total Common Eider counts have increased steadily during this study (Figure10-2, Table 10-1a & b) and have paralleled the increased severity of sea ice conditions during this time. Estimates of indicated breeding pairs across the entire coastline have not increased similarly. However, there is an increasing trend of indicated pairs in all areas excluding the central Beaufort Sea segments (Figure 10-2, Table 10-1b). In all four years, indicated breeding pairs were most numerous along the central Beaufort Sea coast (Figure 10-2,Table 10-1 a & b).

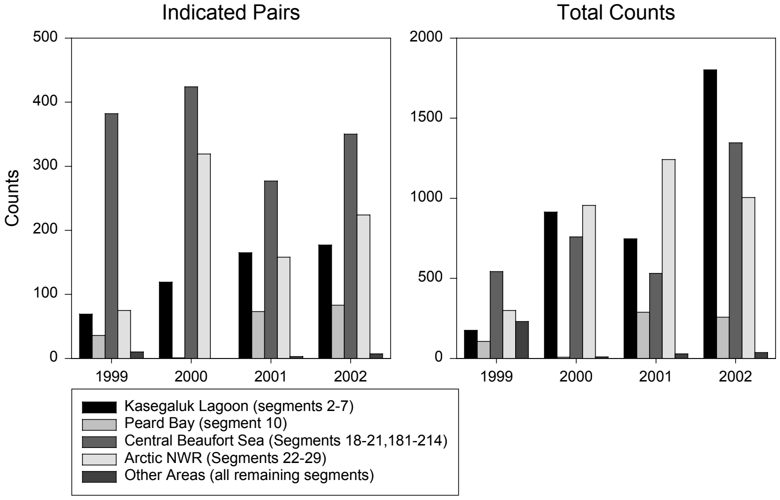


Figure 10-2. Aerial survey counts of Common Eiders at known breeding areas on the Chukchi and Beaufort Seas.

Table 10-1a. Summary of Common Eider counts during aerial surveys of the Arctic Coastal Plain (barrier island segments), 1999-2002.

	1999		2000		2001		2002	
Survey Segment	Indicated Pairs	Total Counts	Indicated Pairs	Total Counts	Indicated Pairs	Total Counts	Indicated Pairs	Total Counts
190	-	-	16	19	4	5	8	16
191	9	14	2	3	16	21	12	20
192	14	18	6	10	3	9	8	18
193	0	0	1	2	0	0	2	5
194	0	0	4	8	0	0	5	7
195	0	0	0	1	0	0	1	2
196	21	26	4	4	24	72	5	19
197	42	45	21	45	7	12	54	205
198	9	12	34	38	49	77	13	22
199	45	71	13	18	30	35	41	541
200	26	49	24	42	25	41	16	24
201	31	45	8	14	12	16	8	18
202	14	17	1	3	4	7	3	6
203	49	64	25	43	11	15	3	6
204	1	1	5	8	2	4	4	7
205	0	0	14	20	4	7	7	14
211	80	104	12	29	18	43	20	31
212	26	33	24	38	27	41	36	85
213	6	12	6	7	8	14	4	7
214	5	11	69	124	3	11	5	8
TOTAL	378	522	289	476	247	430	255	1061

[1] Single males + pairs = Indicated total pairs.

[2] Total = singles + 2 x pairs + flocks

Table 10-1b. Summary of Common Eider counts during aerial surveys of the Arctic Coastal Plain (shoreline segments), 1999-2002.

	1999		2000		2001		2002	
Survey Segment	Indicated Pairs	Total Counts	Indicated Pairs	Total Counts	Indicated Pairs	Total Counts	Indicated Pairs	Total Counts
1	4	5	0	6	1	7	4	5
2	0	10	0	0	18	59	1	13
3	4	14	0	0	10	34	15	24
4	24	48	10	125	72	250	35	337
5	19	51	58	228	32	179	46	163
6	8	16	46	553	27	196	64	1095
7	14	37	5	8	6	26	16	170
8	0	0	0	0	0	0	0	0
9	1	29	0	0	1	2	0	0
10	36	106	1	7	73	288	83	258
11	3	187	0	0	0	10	0	1
12	2	7	0	0	1	12	0	0
13	0	0	0	0	0	0	0	0
14	0	2	0	0	0	1	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	3	31
17	0	0	0	3	0	0	0	0
18	0	0	0	0	0	0	0	0
19	-	-	76	155	5	11	4	4
20	4	5	45	98	21	46	33	60
21	0	15	14	30	4	44	58	222
22	24	65	103	408	53	248	44	174
23	6	39	14	22	6	52	8	14
24	1	2	4	94	6	111	7	19
25	19	135	83	168	10	381	57	253
26	13	34	80	209	31	68	35	107
27	0	0	6	6	5	31	0	0
28	11	22	0	0	37	314	44	316
29	1	2	29	48	10	37	29	122
TOTAL	194	831	574	2168	429	2407	586	3388

[1] Single males + pairs = Indicated total pairs.

[2] Total = singles + 2 x pairs + flocks

The 3083 adults in flocks (69% of total counts) in 2002 represent a nearly threefold increase over the mean counts of flocked adults from the three previous years ($\bar{x}$=1086.7). Within flocks males predominated in 2002 and 2001, but in 2000 the sex ratio was nearly equal, and in 1999 females predominated. Adult males gather in flocks and eventually disperse from breeding areas as incubation proceeds, thus survey timing can affect the estimate of indicated breeding pairs and the sex ratio of flocks. No subadult males were observed in 2002, whereas they comprised 0.3-1.3% of total counts in 1999-2001.

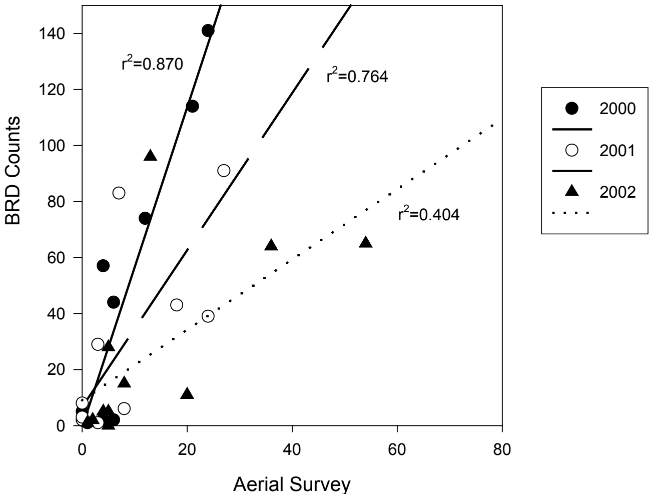


Figure 10-3. Correlation of aerial survey counts (indicated breeding pairs) and ground based nest counts (all successful and failed eider nests).

There is linear relation between indicated breeding pairs estimated by aerial surveys and our and ground based nest searches (R^2= 0.476, Figure 10-3; see chapter 11 for discussion of our ground based nest searches). This relation suggests that aerial surveys can be an efficient mechanism for estimating nesting effort over a large area. Aerial surveys consistently counted fewer pairs than we counted nests from the ground. A correction factor can compensate for this if aerial and ground searches coincide.

DISCUSSION

Primarily, these aerial survey data provide an estimate of Common Eider nesting effort and distribution. As evidenced by these data and our ground based nest searches (see Chapter 11), nesting effort is highly variable by location and year. Nesting effort can be an important indicator of population dynamics and breeding ecology trends, but it does not provide insight into the causes of population change.

Aerial surveys do, however, show aspects of eider biology that ground based surveys cannot. The correlation of ice cover and the dramatic increase in total counts and flocked adults in 2002 may indicate larger scale dynamics of Common Eiders in the Beaufort Sea. Possibly, Canadian breeding eiders briefly delayed their arrival in the Canadian Arctic or a concentration of Alaskan Beaufort Sea eiders chose to forgo nesting due to poor conditions on breeding grounds. This conclusion is supported by the increase in flocked adults. Throughout this study the extent of sea and shorefast ice has increased. Common Eiders typically do not nest until the barrier islands are surrounded by open water. With few ice-free islands many potential breeders likely joined flocks instead of nesting.

Chapter 11
Productivity of Nesting Common Eiders

INTRODUCTION

Clutch size, hatch success, fledging success, and adult survival are important parameters of population dynamics (Johnson et al. 1992, Coulson 1984). Milne (1974) demonstrated considerable annual variation in the proportion of Common Eider ducklings surviving to fledge and linked years of high duckling survival to subsequent increases in population size. Reported estimates of fledging success in other subspecies of Common Eiders vary widely among studies. Estimates of fledglings per female range from 0.47-0.89 (Hilden 1964, Swennen 1983) and duckling survival (hatch to fledge) has varied from 10% to 24% (Milne 1974, Mendenhall and Milne 1985). Brood rearing may be a bottleneck in annual productivity, and low duckling survival may be a major determinant of recruitment. Information on adult annual survival is absent for North America but presumed to be high (Suydam et al. 2000). Estimates of adult mortality in Europe, however, vary from less than 10% to 39% per year (Boyd 1962, Paludan 1962, Swennen 1972).

There have been a variety of studies of Common Eider breeding ecology on the barrier islands of the Beaufort Sea. Schamel (1977) observed breeding on Egg Island before oilfield production began (1971-1973). He was able to measure nesting effort, hatch success, and predation pressure, but lacking marked animals, he did not estimate fledging success or adult survival. Ground based nest searches were used to estimate nesting effort and hatch success (Johnson and Richardson 1980, Johnson 1984), but again no birds were marked. During 1999-2002, biologists from LGL Alaska Research Associates located all Common Eider nests on islands between Thetis and Flaxman Islands during a short period in mid-incubation (Noel et al 2002). While geographically comprehensive, this study was unable to assess hatch success and may have missed nests that failed early or were initiated late. In an attempt to produce a comprehensive population model for Common Eiders in the Beaufort Sea, we implemented a protocol for consistent yearly ground based nest searches, monitoring, and mark-recapture over a large geographic area.

METHODS

During 2000-2002, we searched all islands from Brownlow Point through the Maguire Islands (Control Area) and from Stump Island to Spy Island (Industrial Area). Teams of observers searched islands by systematically examining all potential nesting cover in sufficient detail to detect nests not attended by females. Nest searches began as soon as incubation was detected during spot checks of suitable nesting habitat.

We recorded the exact location (determined by GPS) and habitat information (i.e., landform, distance to water, height above water, density, and size of driftwood within one meter) for all nests. Active nests were marked with a lathe placed 5 m north of the nest bowl. We numbered and candled each egg to determine viability and stage of incubation (Weller 1956). During periodic revisits, we recorded the presence of the female, condition and number of eggs, and stage of incubation. After hatch, we visited nests and determined egg fates from nest contents. We subtracted depredated and unhatched eggs from the number of eggs laid into the nest to determine the number of ducklings produced. We calculated nest initiation dates by subtracting the estimated age of embryos, as determined by candling, plus the number of eggs laid into the nest, from the date of discovery. Alternatively, we back-calculated from known hatching dates to determine nest initiation. We used a 26 day incubation period and assumed one egg was laid each day prior to the start of incubation.

We used only nests with signs of embryonic development in the determination of nest initiation date and clutch size. We defined clutch size as the number of eggs laid into a nest, partial depredation as the number of eggs missing from nests that remained active, and successful nests as those in which at least one egg hatched. For all nests with known fates we determined the number of successful, depredated, abandoned, or destroyed (e.g., by ice, or flooding) nests. We used a Mayfield approach to estimate daily nest survival rates and nest success (Johnson 1979). Analysis of nest success did not include nests that were depredated, destroyed, abandoned, or hatched when first discovered.

We trapped females on nests before hatch using dipnets or string-activated bownets (Sayler 1962). Captured females were weighed, the lengths of the culmen and total tarsus were measured, and blood and cloacal samples were collected. Birds were marked with metal U.S. Fish and Wildlife Service tarsus bands and in most instances with numbered colored tarsal bands. In 2000 and 2001, a sub-sample of females was fitted with 15 g subcutaneously anchored radio transmitters (Pietz et al. 1995). These females were then tracked to determine the fate of broods. Initial brood size was assumed to be equal to the number of eggs present in the nest on the last visit prior to hatch.

The fate of broods was assessed by ground based tracking in 2000 and a combination of aerial and ground based tracking in 2001. Searches were conducted as weather and pilot availability allowed (all females were sought at least four times). Birds detected from the air were subsequently located from the ground to determine brood fate. Aerial searches were conducted along the mainland and barrier islands in the Industrial Area only, as no Common Eiders were equipped with radios in the Control Area in 2001. When a female was located, we determined whether the female had young and if so, how many. Females not detected from the air were assumed to have lost their brood. Our estimate of duckling survival rates is based on all visits combined over the entire study.

Table 11-1. Number of nests found by species and study area in 2000-2002.

Species	Number of nests found					
	Control Area			Industrial Area		
	2000	2001	2002[1]	2000	2001[2]	2002[2]
Common Eider	228	92	52 (33)	218	110 (134)	56 (67)
King Eider	1	0	0	6	2	0 (1)
Unknown Eider[3]	0	49	28 (6)	17	58 (17)	58 (26)
Long-tailed Duck	2	0	0	2	0	0
Northern Pintail	4	0	0	0	0	0
Black Brant	0	0	0	4	5 (3)	2
Canada Goose	2	0	0	0	0	0
White-fronted Goose	0	0	0	0	1	0
Arctic Tern	0	2	0	3	2	1
Glaucous Gull	19	12	0	47	31 (60)	12 (16)
Total	256	155	80 (39)	297	209 (214)	129 (110)

[1] In the Control Area, the search area increased in 2002 to include five, small, sand spit islands adjacent to the mainland. The numbers of additional nests found in the expanded area are enclosed in parentheses.

[2] In the Industrial Area, the search area increased in 2001 to include East Stump Island. The numbers of additional nests found in the expanded area are enclosed in parentheses.

[3] Indicates nests where no eggs or females were observed to help differentiate between eider species. Based on habitat characteristics, the majority of these nests are likely Common Eider.

RESULTS

Through the course of this study, we located a total of 1489 waterbird nests. Of these, 1259 (84%) were eider nests. Among eider nests, less than 1% (n=10) were King Eider (*Somateria spectabilis*), all others were Common Eider (n=990, 79%) or unidentified, though likely Common Eider (n=259, 20%). A summary of nest counts by species and year is given in Table 11-1. Each year since the start of the study we have increased the nest search area. In the Control Area, we added the eastern portion of Stump Island to our search in 2001 and 2002. In the Industrial Area, we added five, small, sand spit islands adjacent to the mainland near Point Thomson in 2002. Although we did not systematically search for nests on these sand spit islands prior to 2002, we believe it was the only year during our study in which eiders nested on them; ice break-up was delayed in this year and these islands provided the only nesting habitat with adjacent open water. We report nest counts for areas searched in all years separately from areas added in subsequent years (Table 11-1). When we examine only the areas searched in all three years, we see a steady decrease in the total number of eider nests found in each year of the study (2000: 470, 2001: 301, 2002: 194). Similarly, the number of Glaucous Gull (*Larus hyperboresus*) nests has decreased since 2000 (2000: 66, 2001: 43, 2002: 12).

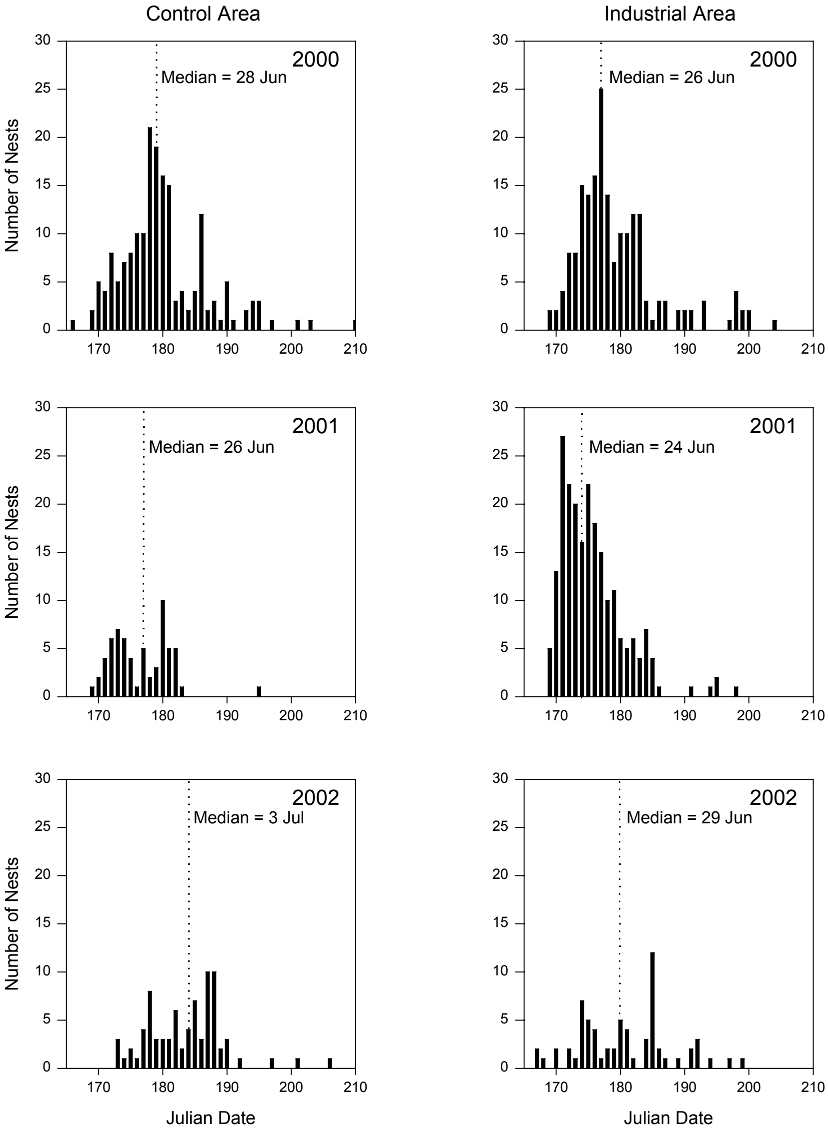


Figure 11-1. Distribution of Common Eider nest initiation dates on the Control and Industrial Areas in 2000-2002.

Of nest site characteristics that we measured (including distance to water, height above water, driftwood density and diameter, and cover height toward the prevailing wind), only cover height shows a significant pattern across years or areas. Cover height has increased across years ($F_{2,1254}$=26.3, P<0.001), however this seems unlikely to be biologically significant.

In 2002 only, the distribution of nest initiation dates differed significantly between the study areas (Wilcoxon Two-Sample Test = 4904, two-sided t approximation P<0.05) with the initiation period earlier and more spread out in the Industrial Area than the

Control Area (Figure 11-1). Initiation dates in 2002 were substantially later than previous years, likely due to the particularly late ice breakup (median initiation date: 2002: 1 July, 2001: 24 June, 2000: 27 June). In all years, mean clutch size declined with nest initiation date in (2002: 0.05 ± 0.02 eggs per day, 2001: 0.04± 0.01, 2000: 0.10± 0.02). Average clutch size showed a significant year by area interaction ($F_{2,688}$=16.35, P<0.001), with clutch size decreasing across years in the Industrial Area and increasing in the Control Area.

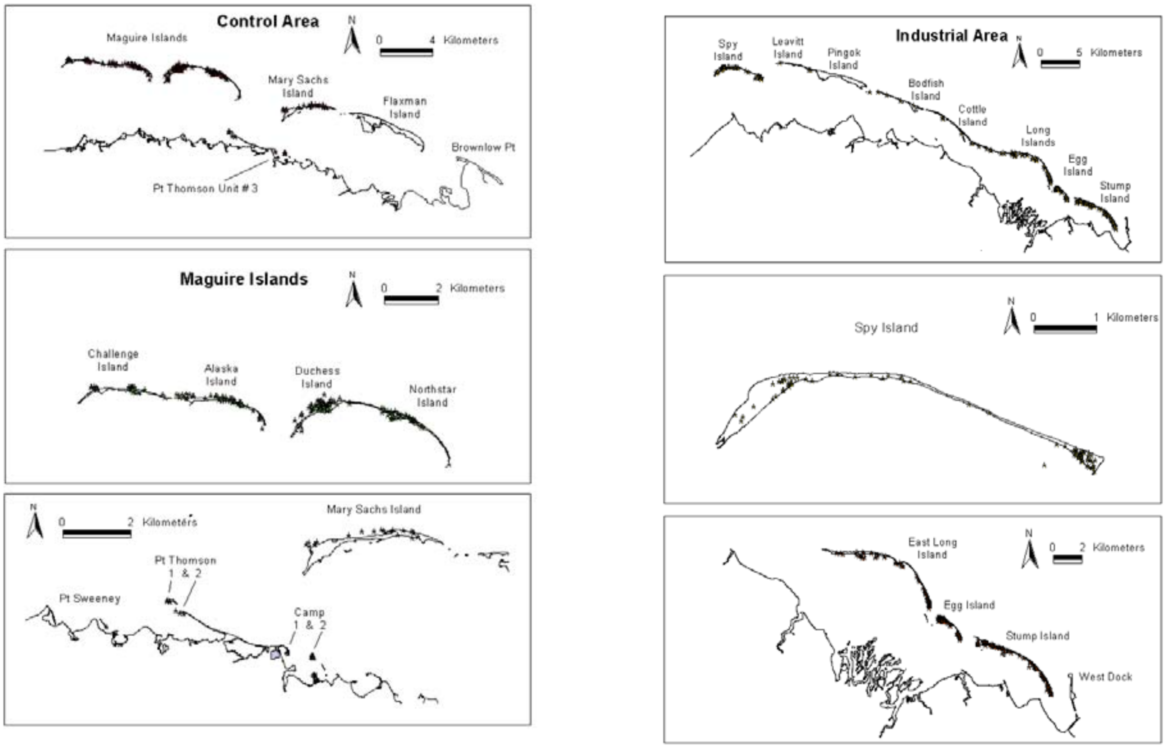


Figure 11-2. Locations of Common Eider nests on the Control and Industrial Areas in 2000-2002.

In all years, the distribution of Common Eider nests was not uniform throughout the study areas (Figures 11-2). Both study areas had small areas of high nesting densities, especially on Spy, Egg, Stump, and Duchess Islands. In all three years, the concentration of Glaucous Gull nests was greater in the Industrial Area and tended to occur where large colonies of eiders were present. In 2002, we located no gull nests in the Control Area. This is likely due to the overall lower nesting effort seen in 2002 (Table 11-1).

Common Eider hatch success, though substantially variable among years, has been particularly low in our study areas (1-31%, Table 11-2). The primary cause of nest failure has been predation by Arctic foxes (*Alopex lagopus*) and Glaucous Gulls (accounting for 58-83% of nest loss). The complete nest failure in the Industrial Area in 2001 and the substantial failure in the Control Area in 2002 were due to fox predation. On 3 July 2002 we observed a fox on West Egg Island. In less than four hours, the single fox, followed closely by many gulls, destroyed every active eider (n=29) and gull (n=6) nest on the island. Stochastic weather related events have also played an important role in nest failure. For example, drifting sand buried 6% of nests in 2000 and 5% of nests in 2002 were flooded.

Table 11-2. Estimates of nesting success for Common Eiders in 2000-2002.

	Control Area			Industrial Area		
	2000	2001	2002	2000	2001	2002
Number of nests	193	67	85	190	220	123
Exposure Days	2385	501	619	2803	2623	1087
No. Hatched	48	0	21	47	90	12
Daily Survival Rate	0.9392	0.8663	0.8966	0.9489	0.9622	0.8979
Hatch success	0.1523	0.0135	0.0379	0.2078	0.3152	0.0395
95% CI	0.11-0.20	0.005-0.04	0.014-0.081	0.15-0.27	0.25-.40	0.019-0.073

Since 2000, we have captured and marked a total of 209 nesting female Common Eiders. Due to particularly poor nesting success in 2001 and 2002, we have only recaptured 13 of these birds. Mean female weight ($\overline{x}$=1732±68 [SE]) has not varied among years or areas. In 2002, two recaptures were females nesting on the sand spit islands near Point Thomson. Those hens were originally captured in 2000, while nesting on the Maguire Islands. Our banding effort is summarized in Table 11-3.

Table 11-3. Banding effort for female Common Eiders in 2000-2002.

	Control Area			Industrial Area		
	2000	2001	2002	2000	2001	2002
Total Captures	47	0	30	66	53	13[1]
First time Captures	47	0	27	66	46	10
Recaptures	-	0	3	-	7	3

[1] Additionally, we banded one nesting King Eider

In 2000 and 2001, we fitted 65 females with subcutaneously anchored VHF transmitters in the Industrial Area (2000: 30; 2001: 35) and 31 females in the Control Area (2000 only, due to total nest failure in 2001). Subsequently, we followed those females to assess fledging success of broods. Because of difficulties with ground-based tracking in 2000, we were only able follow broods in the Control Area, only one brood survived as late as 12 August. In 2001, we conducted five aerial searches for radio-marked females (6 August, 14 August, 15 August, 8 September, and 26 September) on the

Industrial Area. We confirmed brood failure for all but two marked females; the fates of those two broods could not be reliably classified. It is most likely that they failed as well.

DISCUSSION

Nesting Effort

From 2000 to 2002, we observed a steady decline in nesting effort, with particularly low nest numbers in 2002. The reduction in effort between 2000 and 2001 was likely influenced by a major storm event in August 2000. The storm significantly degraded nesting habitat by removing and concentrating the driftwood that eiders use for nest cover. Late ice breakup in 2002 likely contributed to the further diminished nesting effort in 2002. Based on long-term nest census data, it does appear that substantial variation in nesting effort is normal on the barrier islands of the Beaufort Sea (Noel et al 2002). Unfortunately, variability among previous studies has made conclusions about nesting effort difficult. In our study, the methods, duration, and overall effort of nest search has been the same across years, thus we do not have the problem of inconsistent data. In other nest search studies a correlation between low nesting success and the probability of nest detection has been noted (Flint, unpubl. data). Nests destroyed prior to their first discovery, can be difficult to detect and identify as a nest from the current year. Nonetheless, we are confident that there was indeed a reduced nesting effort in 2002.

Nest Initiation and Clutch Size

Nest initiation has been slightly earlier and of a longer duration in the Industrial Area in all three years. Ice breakup has been progressively later through the course of this study, with 2002 being particularly late. Consequently, median initiation date was delayed in 2002 and fewer eiders nested (Figure 11-1). During this study, clutch size has decreased in the Industrial Area while increasing in the Control Area. The trend is consistent with an effect of industrial development, although it may be a result of natural differences (e.g., forage availability) across areas and years. Additional data are needed to test this hypothesis.

Nest Success

During the three years of this study we have seen dramatic variation in daily and nest survival rates (Table 11-2). Our highest hatch success estimates are comparable to historic estimates from Beaufort Sea barrier islands (19.3% on Thetis Island in 1983, Johnson 1984; 33% on Egg Island in 1972, Schamel 1977). Our low estimates have been due largely to catastrophic nest predation by Arctic foxes. Arctic foxes have been implicated in total nest failure on several barrier islands through the years (Johnson and Richardson 1980, Noel et al 2002). While the ice pack is intact foxes can access islands, but typically, as the ice pack begins to break up foxes leave the islands. In years of late breakup, however, eiders may initiate nests while foxes still have access to islands. Artic foxes will eat or cache any egg they discover, and one or two foxes can readily destroy all nests on an island (or island complex). We have observed gulls following a fox during a predation event and depredating eggs as hens flushed. Clearly, the timing of breakup, the presence of foxes, and other natural events all affect the nesting success on each island differently each year. Nonetheless, increased nest predation is a possible indirect effect of industrial development. Fox populations have likely increased in the oilfields (Burgess 2000), due to improved den sites and scavenging opportunities. Glaucous Gull population trends remain unclear, however we have documented greater numbers of gull nests in the Industrial Area throughout this study. Increased numbers of predators in the oilfields is likely to increase the probability of predators accessing the adjacent islands.

Brood Success

Our study of duckling survival in 2000 and 2001 was compromised by methodological problems. Most significantly, persistent fog and wind limited our opportunities to track radio-equipped females from both the air and ground. Additionally, the complete nest failure in the Control Area in 2001 limited the number of females that we could follow. Nonetheless, we found exceptionally low fledging success through the course of the study. In 2000, only one of 31 Control Area broods survived as late as 12 August. In 2001, of 21 Control Area broods, 19 were confirmed failures and the remaining two were suspected failures. The evidence of colossal brood failure is supported (at least anecdotally) by field observations in 2000-2002. Each year we encounter broods shortly after peak hatch, however by the time ducklings should be fledging we no longer encounter broods. We have no direct data explaining duckling loss, however two ducklings collected at Northstar in 2000 were infected with a reovirus similar to one implicated in a massive die-off of Common Eider ducklings in Finland (see Chapter 12).

Adult Survival and Site Fidelity

Nest predation and low nesting effort in 2001 and 2002 have limited our ability to capture and recapture a sufficient number of nesting adult females to make reasonable estimates of adult survival and site fidelity. With one or two more seasons of capture effort we could estimate this important population parameter. In 2002, we made the important discovery of nesting Common Eiders on the sand spit islands near the mainland around Point Thomson. Of particular interest was the confirmation (from recapture data) that at least two of these females nested previous on barrier islands (Duchess Island in 2000). Ice breakup patterns are highly variable; in 2002 breakup was particularly delayed and these sand spit islands provided the only nesting habitat with adjacent open water. We believe that the low nesting effort seen in 2002 was a result of females choosing not to nest on ice-bound barrier islands. Non-breeding in response to ice or other environmental factors has been documented in other eider populations (Bird and Bird 1940, Coulson 1984). That many eiders used the sand spit islands in 2002 suggests that alternative habitats can be important for nesting Common Eiders when environmental conditions prevent nesting in preferred habitats. The apparent lower nesting effort in recent years of delayed break-up may be associated with displacement of birds to alternative nesting areas. Whether displaced females will return in subsequent years, or show fidelity to the new nesting areas, is unknown.

Population Model

To properly develop a population model we need estimates of both fledgling production and adult survival. As indicated above, additional seasons of mark-recapture data are needed for survival estimates.

Status of Breeding Common Eiders in the Beaufort Sea

During the three years of this study, Common Eiders breeding in our study area have shown exceptionally poor success in all components of production (i.e., nesting effort, clutch size, hatch success, and fledging success). In contrast, Pacific Common Eiders breeding at two sites on the Yukon-Kuskokwim Delta (YKD), Alaska had consistently higher productivity (H. Wilson, unpub. data). Average clutch sizes on YKD sites, in 2002, were 5.2 and 4.9, or approximately two eggs/nest more than average clutch sizes in our study. Hatch success estimates on the YKD sites were 53.7% and 45.2%. During our study hatch success estimates have ranged from 31.5% to 1.4% (3.8% in 2002). In a 1997 study, fledging success was 27.1% on the YKD (Flint et al. 1998). North Slope brood success has been essentially zero during our study. Using these data to calculate a rough index of productivity, we estimate that production on the YKD ranges from 0.63 to 0.73 fledglings/nest/year. In contrast, using maximum estimates, North Slope production is 0.09 fledglings/nest/year.

Common Eiders are long-lived birds that breed and over-winter in particularly harsh and variable environments. It is certainly possible that this study has spanned a particularly poor breeding period. Only through additional years of study could we determine this. Regardless, our data strongly suggest a need to be concerned for the future of this population.

Chapter 12
Isolation and Characterization of a Reovirus from Nesting Common Eiders

INTRODUCTION

The reasons for Common Eider population declines are not well understood. As part of our study of the breeding ecology of Common Eiders in the Beaufort Sea, we initiated research into viral diseases of eiders in 2000. We collected serum samples from nesting Common Eiders and conducted postmortem studies on carcasses to determine causes of death. In 2000, a mortality event was documented in molting Long-tailed Ducks (see Chapter 7), and two Common Eider ducklings were found dead at our study areas.

Apart from serologic evidence of exposure to the infectious bursal disease virus or a related virus (Hollmén et al. 2000), little is known about the prevalence of viruses in eiders in Alaska or potential effects of viral diseases on eider duckling survival. Reoviruses have been linked to mortality of Common Eider ducklings in the Baltic Sea (Hollmén et al. 2002), but little is otherwise known of viral diseases of free-ranging eider ducklings. Tissues were collected from the two eider duckling carcasses and evaluated for the presence and potential involvement of viruses in duckling mortality in the Beaufort Sea nesting areas. We also tested serum samples from Common Eider hens to evaluate the prevalence of isolated viruses in the local breeding population.

METHODS

To screen for diseases and to determine causes of mortality in the population, necropsies were conducted on eider carcasses located at our study areas during the course of the breeding ecology study. Carcasses were weighed, gross lesions recorded, and tissues collected for further laboratory analyses. Specimens of liver, spleen, heart, lung, kidney, small intestine, large intestine, pancreas, bursa of Fabricius, and thymus were preserved in 10% buffered formalin and processed for histopathology evaluation. Approximately 1 g of brain, intestine, liver, lung, spleen, and bursa of Fabricius were collected for virus isolation. In the laboratory, the samples were homogenized in media and the homogenates were centrifuged at 800 × g for 30 min at 4°C. Virus isolation was attempted in specific pathogen-free chicken embryos (Spafas® Inc., Preston, CT) and Muscovy Duck (*Cairina moschata*) embryo fibroblasts (MSDEF). Supernatants from the homogenized samples of intestine, liver, and lung were filtered through a cellulose acetate membrane filter (Corning Glass Works, Corning, NY) before the inoculations. Samples of all supernatants were inoculated separately into MSDEF monolayers, and subsamples of supernatants of brain, intestine, and lung suspensions were also inoculated into the chorioallantoic chamber of 9-day-old embryonated chicken eggs. Embryonic viability was monitored daily for 5 days. Eggs were removed from the incubator and refrigerated at 4°C when embryo mortality was observed and all eggs remaining after 5 days of incubation were refrigerated at 4°C. Chorioallantoic fluid from each egg was tested for the presence of viruses with hemagglutination activity using chicken red blood cells. The cell cultures were examined every other day for 7 days for viral cytopathic effect (CPE) using an inverted stereoscopic microscope. After 7 days (or when viral CPE had destroyed 100% of the cell monolayer) the flasks were frozen at -80°C. Cell cultures that were negative for CPE were thawed, harvested, and blind passaged twice before being diagnosed negative.

Virus isolates were tested with 5-iodo-2'-deoxyuridine and chloroform treatments to evaluate their nucleic acid type and presence of a lipid envelope (Feldman and Wang 1961, Docherty et al. 1994). A constant virus varying serum neutralization assay (Thayer and Beard 1998) was performed on a 96-well microplate with reference antisera to avian arthritis reovirus (Spafas® Inc., Preston, CT) using MSDEF as an indicator system.

To determine the prevalence of neutralizing antibodies in adult hens to the reovirus that was isolated from the ducklings, a virus neutralization assay was performed in a 96-well plate according to standard procedures (Thayer and Beard 1998) using MSDEF as an indicator system. The serum samples were heated at 56°C for 30 min before use and run in duplicates. The titer of the serum was determined as the highest dilution at which viral activity was inhibited on cell monolayers of both test wells. Titers of 1:128 or greater were considered positive (Giambrone 1980).

RESULTS

Two Common Eider ducklings were found dead on August 3, 2000 on the Northstar Unit. Both were females in poor body condition and weighed 110 and 116 grams. One of the ducklings had multifocal hemorrhages of the liver and microscopic evidence of liver necrosis.

No embryonic mortality was observed in the chicken eggs inoculated with tissue homogenates, and the chorioallantoic fluids from all embryos were negative in the hemaglutination test. We observed CPE and syncytia formation on the third day of incubation after the first blind passage in MSDEF inoculated with bursal samples. The isolated viruses were resistant to 5-iodo-2'-deoxyuridine and chloroform treatments and were characterized as nonenveloped RNA-viruses. Tissue culture fluids from positive flasks were inoculated into the chorioallantoic chambers of 9-day-old embryonated chicken eggs. All embryos died 4 or 5 days post inoculation but chorioallantoic fluids were negative in the hemaglutination test. The particles showed icosahedral symmetry by electron microscopy, consistent with the family Reoviridae (McNulty 1993). The virus was stable at pH 3.0 indicating that it belongs to the genus *Orthoreovirus* (McNulty 1993). Growth of the virus in cell cultures was not inhibited by avian arthritis reovirus antiserum.

Serum samples were collected from 20 Common Eider hens nesting in the Industrial Area and 19 hens in the Control Area. Antibodies to the duckling reovirus were detected in adult females at both study areas, with a prevalence of 20% in the Industrial Area and 16% in Control Area.

DISCUSSION

The virus isolated from Common Eider ducklings was compatible with the genus *Orthoreovirus*. The virus did not hemaglutinate chicken red blood cells, which is characteristic of most avian reovirus isolates, in contrast to the mammalian reoviruses (McNulty 1993). The eider reovirus probably represents a different subtype of avian reovirus than that found in domestic poultry, based on the lack of serological cross-reactivity with the avian arthritis virus of poultry origin.

Reoviruses have been found in chickens and turkeys worldwide and may also be prevalent in other avian species (McNulty 1993, van der Heide 2000). Reoviruses have been associated with a variety of disease conditions, including arthrititis/tenosynovitis, growth retardation, pericarditis, myocarditis, hydropericarditis, enteritis, hepatitis, bursal and thymic atrophy, osteoporosis, respiratory syndromes, and sudden death (Robertson and Wilcox 1986, McNulty 1993, Rosenberger and Olson 1997). Furthermore, reoviruses have been associated with immune system compromise (Rinehart and Rosenberger 1983, Montgomery et al. 1986), and the pathogenicity of some reoviruses has been shown to increase as a result of co-infection by parasites (Ruff and Rosenberger 1985a, Ruff and Rosenberger 1985b). Reoviruses have been reported to cause severe disease with high morbidity and up to 50% mortality in young Muscovy Ducks (Malkinson et al. 1981, Heffels-Redmann et al. 1992) and they also have been associated with mortality in wild birds, including Common Eiders (Docherty et al. 1994, Hollmén et al. 2002).

Our postmortem findings of poor body condition and necrosis of the liver in virus-positive ducklings suggest similarities with reovirus infections in chickens and Muscovy Ducks and those described for Common Eider ducklings in the Baltic Sea (Malkinson et al. 1981, Heffels-Redmann et al. 1992, Rosenberger and Olson 1997, Hollmén et al. 2002). Therefore, we suggest that the virus found in eiders could affect duckling survival either directly or through immunosuppressive effects. The results of the seroprevalence studies indicate that at least 16-20% of Common Eiders nesting at our study areas in the Beaufort Sea have been exposed to this or a closely related virus. One interpretation of our data is that some fraction of the adult females are carriers of the virus, which is then transmitted to their ducklings. Common Eiders may be particularly succeptable to virus transmission from adults to ducklings because of their brood rearing behavior. Common Eiders typically form creches shortly after hatch. These creches are frequently attended by multiple females, some of whom may not have any offspring in the creche. Thus, even though only a small percentage of the adult females appear to have been exposed to the virus, a large number of offspring could be exposed to a virus from a single female. Additionally, transient females may move among creches and serve as a vector for the spread of the virus. Thus, viral infections could affect demographics by lowering offspring survival, but further research on pathogenicity and epidemiology will be needed to evaluate the significance of neonatal reoviruses on Common Eider populations in Alaska.

Chapter 13
Trace Elements and Persistent Organic Pollutants in Common Eiders

INTRODUCTION

Chlorinated hydrocarbons and trace metals are known to be widely distributed in arctic and subarctic ecosystems that have previously been considered pristine (Anthony et al. 1999, Henny et al. 1995, Hargrave et al. 1992). Organochlorine compounds are resistant to degradation and are distributed to the poles through the atmosphere after evaporation or sublimation from points of release, aided by heat currents from equatorial regions (Ottar 1981). Metals enter the marine environment from natural geologic sources and from discharges of anthropogenic sources. In marine ecosystems, the highest concentrations of contaminants occur in coastal regions (Harrison and Peak 1995), where trace elements and organics bind to and accumulate in sediments. The availability and uptake of persistent contaminants from sediments by forage species can lead to bioaccumulation, a species-dependent process associated with feeding ecology, potentially resulting in toxicity (Barron 1995).

Contaminants may also enter arctic environments through releases associated with mining and the use and transport of oil and gas resources. Several monitoring studies have reported the presence of contaminants in the Beaufort Sea. Findings of the Minerals Management Service's Beaufort Sea Monitoring Program indicated that concentrations of some trace elements, particularly barium and chromium, as well as levels of saturated and aromatic hydrocarbons, were higher in sediments from the Beaufort Sea in comparison to other outer continental shelf sediments (Beohm et al. 1990). Concentrations of polycyclic aromatic hydrocarbons (PAHs) in Beaufort Sea sediments are higher than expected for a pristine area, making the region particularly sensitive to additional anthropogenic inputs of PAHs (Yunker and MacDonald 1995). The National Oceanic and Atmospheric Administration's National Status and Trends Program found that sediment concentrations of arsenic, mercury, nickel, and silver were higher at Oliktok Point on the Beaufort Sea than at a reference area, Lutak Inlet in southeast Alaska (Meador et al. 1994). In the Industrial Beaufort Sea, concentrations of arsenic and nickel were higher than the average for U.S. sediments and the occurrence of certain naphthalenes indicated the presence of crude oil (Valette-Silver et al. 1997).

Although regulations requiring the use of nontoxic shot for hunting waterfowl have been in effect at scattered locations in the United States since the 1970s and were instituted nationwide in 1991, waterfowl continue to be exposed to lead shot in some areas, including Alaska. Lead poisoning was first diagnosed in a Spectacled Eider (*Somateria fischeri*) found dead on the Yukon-Kuskokwim Delta (YKD) in 1992 (Franson et al. 1995). Since that time, lead exposure and poisoning has been reported in additional studies of eiders (Flint and Grand 1997, Flint et al. 1997). The factors contributing to reduced long-term survival of waterfowl exposed to lead may be those that are sublethal in the short term, such as anemia and other hematologic effects, reduced body condition, and immunosuppression (Pain 1989, Hohman et al. 1990, Rocke and Samuel 1991).

Selenium is an essential trace element for birds and other animals, but it bioaccumulates through the food chain and can be toxic at higher exposure levels (Eisler 2000). Surveys indicate that high selenium concentrations occur in sediments and biota of the marine environment of Alaska. Selenium concentrations in sediments at remote coastal Alaska sites, including Oliktok Point on the Beaufort Sea, are higher than at many other sampling sites along the Pacific coast from southern California northward (Meador et al. 1994). High selenium concentrations also have been found in tissues of waterfowl, including Spectacled and Steller's Eiders (*Polysticta stelleri*), in Alaska (Trust et al. 2000, Stout et al. 2002). Mean selenium concentrations of up to 19.3 ppm and 7.3 ppm wet weight were found in blood of Spectacled Eiders and Common Eiders, respectively, sampled on nesting grounds in the YKD (Grand et al. 2002). Steller's Eiders captured at molting (Izembek Lagoon) and wintering (Dutch Harbor) areas in Alaska had mean selenium concentrations of 5-10 ppm wet weight in their blood (Franson, unpublished data). Tissue concentrations of mercury in these studies were low, thus the potential counteractive effect of mercury (Cuvin-Aralar and Furness 1991) was absent, making the high selenium levels all the more significant. Selenium exposure may cause oxidative stress, leading to adverse effects on immunocompetence, inflammation, and other defense systems (Sies 1985).

Our objectives were to measure and compare contaminants in blood and eggs of Common Eiders nesting in our Control and Industrial Areas. Few studies of trace elements in blood of sea ducks are available, particularly from this area of Alaska, and little has been published about organic contaminants in eggs of birds nesting in Alaska, apart from a survey of seabirds done in the 1970s (Ohlendorf et al. 1982) and a report of contaminants in eggs of Bald Eagles (*Haliaeetus leucocephalus*) collected from the Aleutian archipelago in the 1990s (Anthony et al. 1999).

METHODS

In 2000, whole blood samples for trace element analysis were collected from 20 female Common Eiders at each of the two study areas (Control and Industrial). Samples were frozen in the field in a liquid nitrogen vapor shipper and transported to the National Wildlife Health Center, where they were stored at –75°C until shipment to RTI International, Research Triangle Park, NC, for analysis. The following trace elements were tested: Al, As, B, Ba, Be, Cd, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pb, Se, Sr, V, and Zn. Blood samples were weighed, freeze dried (percent moisture determined by the difference in the wet and dry weights), and digested in nitric acid. Analysis was done by inductively coupled plasma/mass spectrometry (ICP/MS), except for mercury, which was analyzed by cold vapor atomic absorption (CVAA) and selenium by graphite furnace/atomic absorption spectrophotometry (GF/AAS). The activity of delta-aminolevulinic acid dehydratase (ALAD), an enzyme inhibited by lead, was measured colorimetrically in whole blood (Burch and Siegel 1971). One unit of enzyme activity is defined as an increase in absorbance at 555 nm of 0.100, with a 1.0 cm light path, per ml of erythrocytes per hour, at 38°C.

Also in 2000, eggs were collected from nests of 20 (n = 9 from the Control Area and n = 11 from the Industrial Area) of the same females from which blood samples were collected. Eggs were wrapped in aluminum foil and kept cool until they were returned to the USGS National Wildlife Health Center (Madison, WI). The surface of each egg was washed with distilled deionized water, scored around the equator with a stainless steel scalpel blade, and the contents were emptied into pre-cleaned glass jars (I-Chem, Nalge Nunc International, Rochester, NY) and frozen at –20°C. Eggs were submitted to En Chem, Inc. (Madison, WI) for contaminants analysis by inductively-coupled plasma/mass spectrometry (ICP/MS) emission spectroscopy, cold vapor atomic absorption spectrometry (CVAA), and gas chromatography/mass spectrometry (GC/MS). Twenty eggs were individually analyzed for trace elements (Al, Sb, As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Sr, Tl, V, and Zn), a suite of 30 organochlorines, and total polychlorinated biphenyls (209 congeners). A subset of 10 eggs was analyzed for 18 polycyclic aromatic hydrocarbons, and four eggs were composited for quality assurance/quality control spikes and duplicates. Kruskal-Wallis tests were used to compare medians of contaminant residues and ALAD activity between the Control and Industrial Areas. Spearman correlation was used to evaluate relationships between concentrations of Se and Hg in blood and eggs. We assigned a concentration of one-half of the lower limit of detection to the samples that contained no residues of a particular contaminant, as long as detectable residues were found in 50% or more of the samples. If residues of a particular contaminant were found in less than 50% of the samples, no median was calculated and the data were not used in statistical comparisons. Residues in blood and eggs are reported on wet weight basis. Total polychlorinated biphenyls were corrected for percent recovery; results for the remaining analytes were not.

RESULTS

Nickel and Be were not detected in any of the eider blood samples. Aluminum, As, B, Ba, Cd, and Mo were detected in 2.5% to 95% of the eiders and all other trace elements were detected in 100% of the ducks (Tables 13-1, 13-2). Although median concentrations were low, blood Pb was significantly greater in the Control Area and Hg was significantly greater at the Industrial area (Table 13-2). The median ALAD activity was not significantly different (178 units at the Industrial area versus 168 at the Control area). The median Se concentration in the blood of the 40 Common Eiders was 6.87 ppm wet weight. Neither Se, nor any of the remaining trace elements, differed between areas. Concentrations of Se and Hg in blood were not correlated (n = 40, r = -0.06, P = 0.73).

Table 13-1. Frequency of detection, median, and minimum-maximum concentrations (ppm wet weight) of 15 trace elements[1] in blood of Common Eiders in the Control and Industrial Areas (n = 40).

Trace element		% detected[2]	Median	Min-Max
Al	Aluminum	7.5	NC[3]	ND[4]-0.97
As	Arsenic	2.5	NC	ND-0.07
B	Boron	30.0	NC	ND-0.22
Ba	Barium	42.5	NC	ND-0.04
Cd	Cadmium	95.0	0.006	ND-0.015
Cr	Chromium	100.0	0.19	0.10-0.44
Cu	Copper	100.0	0.38	0.29-0.60
Fe	Iron	100.0	416	322-675
Mg	Magnesium	100.0	61.8	52.6-104
Mn	Manganese	100.0	0.013	0.007-0.037
Mo	Molybdenum	87.5	0.009	ND-0.016
Se	Selenium	100.0	6.87	4.14-18.0
Sr	Strontium	100.0	0.06	0.03-0.57
V	Vanadium	100.0	0.06	0.04-0.14
Zn	Zinc	100.0	5.16	3.90-8.74

[1] Trace elements tested for, but not detected, were Be and Ni.

[2] The percentage of the samples in which the trace element was above the detection limit.

[3] Not calculated when trace element was detected in <50% of samples.

[4] Not detected.

Table 13-2. Median and minimum-maximum concentrations (ppm wet weight) of Lead (Pb) and Mercury (Hg) in blood of Common Eiders of the Control and Industrial Areas. Both were detected in all samples at each location and the concentrations were significantly different between locations (Kruskal-Wallis test; P = 0.0360 for Pb, P = 0.0265 for Hg).

Location	Pb	Hg
Control (n = 20)		
Median	0.05	0.15
Min-Max	0.02-0.14	0.09-0.22
Industrial (n = 20)		
Median	0.04	0.17
Min-Max	0.02-0.10	0.12-0.25

Table 13-3. Frequency of detection, median, and minimum-maximum concentrations (ppm wet weight) of 14 trace elements[1] in eggs of Common Eiders in the Control and Industrial Areas (n=20).

Trace element	% detected[2]	Median	Min-Max
Al	95	0.87	ND[3]-2.30
As	100	0.09	0.05-0.15
Ba	100	0.33	0.21-1.30
Cd	30	NC[4]	ND-0.02
Cr	100	0.08	0.07-0.25
Cu	100	1.20	0.67-16.0
Fe	100	40.5	30.0-46.0
Pb	35	NC	ND-0.60
Mg	100	125	86.0-160
Hg	100	0.20	0.13-0.28
Se	100	0.79	0.55-1.00
Sr	100	9.10	3.90-19.0
V	100	0.12	0.10-0.14
Zn	100	16.0	12.0-31.0

[1] Trace elements tested for, but not detected, were Sb, Be, Co, Ag, and Tl.

[2] The percentage of the samples in which the trace element was above the detection limit.

[3] Not detected.

[4] Not calculated when trace element was detected in <50% of samples.

Table 13-4. Median and minimum-maximum concentrations (ppm wet weight) of Manganese (Mn) and Nickel (Ni) in eggs of Common Eiders of the Control and Industrial Areas. Mn was detected in all eggs and Ni was detected in all 11 from the Industrial Area and in 8 of 9 from the Control Area. Concentrations were significantly different between locations (Kruskal-Wallis test; P = 0.0479 for Mn, P = 0.0183 for Ni).

Location	Mn	Ni
Control (n = 9)		
Median	0.51	0.064
Min-Max	0.30-0.69	0.029-0.078
Industrial (n = 11)		
Median	0.66	0.077
Min-Max	0.44-1.00	0.063-0.180

Table 13-5. Frequency of detection, median, and minimum-maximum concentrations (ppb wet weight) of 11 chlorinated hydrocarbon pesticides[1] and total polychlorinated biphenyls (PCBs) in eggs of Common Eiders from the Control and Industrial Areas (n=20).

Compound	% detected[2]	Median	Min-Max
4,4' DDE	100	7.45	2.80-17.0
alpha-BHC	5	-[3]	2.2
beta-BHC	90	5.85	ND[4]-11.0
cis-nonachlor	100	2.80	1.10-5.30
dieldrin	100	2.35	1.20-4.10
gamma-chlordane	5	-	2.2
heptachlor epoxide	95	2.65	ND-6.80
hexachlorobenzene	100	6.85	3.60-11.0
mirex	5	-	1.5
oxychlordane	100	3.35	1.90-6.60
trans-nonachlor	100	4.05	1.80-8.40
total PCBs	100	16.6	7.45-32.7

[1] Pesticides tested for, but not detected, were 2,4'-DDD, 2,4'-DDE, 2,4'-DDT, 4,4'-DDD, 4,4'-DDT, aldrin, alpha-chlordane, delta BHC, endosulfan I and II, endosulfan sulfate, endrin, endrin aldehyde, endrin ketone, lindane, heptachlor, methoxychlor, pentachloroanisole, and toxaphene.

[2] The percentage of the samples in which the trace element was above the detection limit.

[3] Compound was detected in one sample.

[4] Not detected.

Table 13-6. Frequency of detection, median, and minimum-maximum concentrations (ppb wet weight) of nine polychlorinated aromatic hydrocarbons (PAHs)[1] in eggs of Common Eiders from the Control and Industrial Areas (n=10).

Compound	% detected[2]	Median	Min-Max
1-methylnaphthalene	100	0.36	0.24-0.56
2-methylnaphthalene	100	0.48	0.36-0.64
benz[a]anthracene	10	-[3]	0.42
benzo[a]pyrene	10	-	0.31
benzo[b]fluoranthene	40	NC[4]	ND[5]-0.36
fluoranthene	50	0.24	ND-0.97
naphthalene	100	0.88	0.68-1.10
phenanthrene	70	0.44	ND-1.10
pyrene	30	NC	ND-0.54

[1] PAHs tested for, but not detected, were acenaphthene, acenaphthylene, anthracene, benzo[g,h,i]perylene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, fluorene, and indeno[1,2,3-cd]pyrene.

[2] The percentage of the samples in which the trace element was above the detection limit.

[3] Compound was detected in one sample.

[4] Not calculated when trace element was detected in <50% of samples.

[5] Not detected.

Silver, Be, Co, Sb, and Tl were not detected in any of the Common Eider eggs. Cadmium and Pb were found in about one-third of the eggs, Al and Ni in 95%, and the remaining trace elements were found in all eggs (Table 13-3). The median concentrations of Mn and Ni were greater in the Industrial Area (Table 13-4). Median Se concentrations in eggs did not differ between locations, and the overall median for 20 eggs was 0.79 ppm wet weight. Concentrations of Se in eggs were not correlated with blood levels (n = 20, r = -0.16, P = 0.50), but concentrations of Hg in eggs were positively correlated with blood Hg (n = 20, r = 0.70, P = 0.0006). Concentrations of Se and Hg in eggs were not correlated (n = 20, r = 0.30, P = 0.20). Organochlorine pesticides detected in each egg included 4,4'-DDE, cis-nonachlor, dieldrin, hexachlorobenzene, oxychlordane, and trans-nonachlor (Table 13-5). Nineteen of the 30 organochlorines that were tested for were not found in any of the eggs. PCBs and three of the PAHs (1- and 2-methylnaphthalene and naphthalene) were found in all eggs (Tables 13-5, 13-6). Nine of the PAHs tested for in eggs were below detection limits (Table 13-6). No differences in concentrations of persistent organic pollutants were detected between the two locations.

DISCUSSION

Except for Se, trace element concentrations in blood were relatively low. The median Se concentration (6.87 ppm wet weight) that we found in Common Eiders nesting in the Beaufort Sea is considerably higher than levels found in fresh water birds, and may be a natural finding in many marine species (Ohlendorf 1993, USDI 1998). Concentrations of Se in Common Eiders sampled in the Beaufort Sea were similar to those found in the blood of Common Eiders, but lower than those found in Spectacled Eiders, on the YKD during incubation and hatch (Grand et al. 2002). However, concentrations of Se in blood of Common Eiders from the Beaufort Sea were higher than concentrations reported in Common Eiders from Canada and Finland (Franson et al. 2000, Wayland et al. 2001). Blood Cd levels in our study were much lower than concentrations reported for Common Eiders in Canada, and Hg concentrations were somewhat lower than the Canadian study but similar to levels found in eiders from the YKD (Wayland et al. 2001, Grand et al. 2002). Mercury concentrations in eiders in our study were low enough at both areas, even though significantly greater in the Industrial Area, to reduce the potential of any protective effect against Se (Cuvin-Aralar and Furness 1991). Although the median concentration of Pb in the blood of Common Eiders was significantly greater in the Control Area, concentrations at both locations were well below 0.2 ppm wet weight, the commonly accepted threshold for lead exposure (Pain 1996). Furthermore, the blood ALAD activity, a sensitive indicator of lead exposure, was not significantly different between locations. Our results suggest that Common Eiders sampled at nesting areas in the Beaufort Sea have lower concentrations of lead in their blood than the levels that have been reported from sea ducks in some other areas of Alaska, such as the YKD (Flint et al. 1997, Grand et al. 2002). Concentrations of Fe, Mg, Sr, V, and Zn in blood of Common Eiders were similar to, or lower than, concentrations in Steller's Eiders from the Alaska Peninsula (Franson, unpublished data). Concentrations of Cu and Mn in Common Eiders were low, but were greater than the levels in Steller's Eiders.

Based on the moisture content of the Common Eider eggs, 9.10 ppm wet weight of Sr (Table 13-3) is equivalent to 23.6 ppm dry weight. This is about twice as high as Cochrane and Trust (1996) reported in Spectacled Eider eggs from the YKD and about 10 times higher than in eggs of Lesser Snow Geese (*Anser c. caerulescens*) from Wrangel Island, Russia (Hui et al. 1998). Custer et al. (2001) reported Sr of 14 and 23 ppm dry weight in eggs of House Wrens (*Troglodytes aedon*) at two study sites in Wyoming, considering those levels to be elevated. According to Puls (1988), normal concentrations of Sr in chicken eggs are about 2.2 ppm dry weight. Selenium concentrations in eggs of Common Eiders nesting on the Beaufort Sea were somewhat higher than those found in eggs of Common Eiders in the Baltic Sea and in one report from Spectacled Eiders on the YKD, but were still below toxic levels (Heinz 1996, Franson et al. 2000, Grand et al. 2002). In another study of contaminants in Spectacled Eider eggs from the YKD, Cockrane and Trust (1996) reported a mean Se concentration of 3.55 ppm dry weight, which is about 50% higher than the median (0.79 ppm wet weight, or 2.18 ppm dry weight) that we found in Common Eider eggs. Although our results suggest that relatively little selenium is transferred from the blood of Common Eider females nesting in the Beaufort Sea to their eggs, the effects of selenium on sea duck physiology and reproduction deserves further study. The median Hg concentration in Common Eider eggs from the Beaufort Sea was somewhat higher than in previous reports from eiders, but below levels that have been reported to cause adverse effects in several species of birds (Cochrane and Trust 1996, Eisler 2000, Franson et al. 2000, Grand et al. 2002).

Cadmium and Pb were detected at low levels in about one-third of the Common Eider eggs, which is consistent with reports indicating that eggs are not particularly useful for evaluating exposure of birds to these two trace elements (Ohlendorf 1993). Cadmium and Ni concentrations were lower in eggs of Common Eiders in the Beaufort Sea than in Common Eider eggs collected in Norway in 1972-1973 (Lande 1977). The maximum Cd concentration in Common Eider eggs was 0.02 ppm wet weight; normal levels in chicken egg yolk are reported to be 0.02 to 0.10 ppm wet weight (Puls 1988). Concentrations of As, Cu, Fe, Mg, and Zn were similar to those found in Spectacled Eider eggs from the YKD (Cochrane and Trust 1996, Grand et al. 2002). Concentrations of Mn in Common Eider eggs were slightly higher than Mn in Spectacled Eider eggs from the YKD, and similar to concentrations in Lesser Snow Goose eggs from Russia (Cochrane and Trust 1996, Hui et al. 1998). Concentrations of Mn and Ni in Common Eider eggs were more than 20% greater in the Industrial than the Control Area.

Based on residues in eggs, we found evidence of exposure to a variety of persistent organic pollutants in Common Eiders nesting in the Beaufort Sea, which is consistent with literature reporting the global distribution of these compounds. However, the concentrations that we found in eider eggs were often below those reported in comparable studies and lower than levels generally considered harmful. For example, although DDE was detected in each egg, the median concentration of 7.45 ppb wet weight compares with 13-29 ppb in Common Eider eggs collected in the Gulf of Finland in the late 1990s, 230 ppb in Common Eider eggs collected off the coast of Maine in 1977, and is well below levels that have affected even the most sensitive species (Szaro et al. 1979, Blus 1996, Franson et al. 2000). Similarly, Szaro et al. (1979) reported 100 times more total PCBs in Common Eider eggs from 1977 than we found in eider eggs from the Beaufort Sea (median = 16.6 ppb wet weight). In field studies with fish-eating birds, adverse effects were associated with total PCB concentrations that were, in most cases, well over 1 ppm (1000 ppb) (Hoffman et al. 1996). Mean concentrations of PCBs in eggs of several species of seabirds collected in Alaska in the mid-1970s ranged from 0.09-3.41 ppm (90-3410 ppb) (Ohlendorf et al. 1982). We found a greater percentage of Common Eider eggs with detectable residues of dieldrin, hepatchlor epoxide, oxychlordane, cis-nonachlor, and hexachlorobenzene residues than Ohlendorf et al. (1982) found in Alaska seabird eggs, but concentrations in eider eggs were generally lower. In the seabird egg study, Ohlendorf et al. (1982) found greater frequencies of detectable residues of DDD, DDT, mirex, and toxaphene than we did in eider eggs.

Egg injection studies have demonstrated that PAHs are embryotoxic for birds, including Common Eiders. When a mixture of 18 PAHs was injected into Common Eider eggs at concentrations of 0.2 and 2.0 mg/kg of egg (i.e., 200 and 2000 ppb), the embryo mortality rate was 18% and 94%, respectively (Brunström et al. 1990). At the 200 ppb level, each of the 18 PAHs in the mixture was present in concentrations of about 9-13 ppb. We tested Common Eider eggs for 11 of the 18 PAHs in the Brunström et al. (1990) mixture, finding detectable residues of five compounds in 10% to 70% of the eggs, with maximum concentrations of 0.31 ppb to 1.10 ppb. Brunström et al. (1991) reported the LD_{50} of the four most toxic PAHs that they tested in chicken embryos. Of those four, we analyzed eggs for three: benz[a]anthracene, dibenz[a,h]anthracene, and benzo(k)fluoranthene. One Common Eider egg had a detectable residue of benz[a]anthracene (0.42 ppb wet weight), but the other two compounds were not detected in any of the eggs. According to Brunström et al. (1991), the LD_{50} for benz[a]anthracene in chicken embryos is 79 ppb, about 188 times the concentration that we found in the eider egg. Common Tern (*Sterna hirundo*) eggs from the Netherlands had maximum concentrations of phenanthrene, fluoranthene, and pyrene of 7.0, 2.0, and 4.0 ppb wet weight, respectively and the authors considered those levels to be low (Stronkhorst et al. 1993). The maximum concentrations of phenanthrene, fluoranthene, and pyrene that we found in Common Eider eggs were 1.1, 0.97, and 0.54 ppb wet weight. Brunström et al. (1991) observed no mortality in chicken embryos when those three PAHs were injected into eggs at a concentration of 0.3 ppm (300 ppb).

Overall, concentrations of persistent organic pollutants in eggs of Common Eiders were low and there were no differences between the two locations. We found few differences in trace element concentrations in blood and eggs of Common Eiders between the two study areas. Although concentrations of Hg in blood, and Mn and Ni in eggs, were greater in the Industrial Area, and blood Pb was greater in the Control Area, concentrations at both locations were relatively low. Selenium was high in blood and low in eggs of Common Eiders, as has been previously reported in Spectacled Eiders.

No location differences occurred for Sr, but Sr levels in eggs of Common Eiders were higher than those reported for Spectacled Eiders and Lesser Snow Geese. Little information on Sr levels in sea ducks is available. Concentrations of Sr in eggs of wild waterfowl that may be associated with adverse effects have not been determined.

Chapter 14
Synthesis of Aerial and Ground Based Studies of Nesting Common Eiders

The dramatic decline in the Common Eider population apparently breeding across the arctic (Suydam et al. 2002) coupled with the particularly poor breeding success that we documented since 2000, strongly indicate the need for continued efforts to understand the population dynamics of this local population. Certainly our data suggest that consistent reproductive failure is likely contributing to the observed overall population decline.

The relationship between aerial survey counts and ground based nest searches indicates that aerial surveys can be an efficient mechanism for estimating nesting effort over a large area. However, we caution that aerial survey data must be interpreted carefully. Aerial survey indices indicated increasing trends during the same period that our ground based indices indicated a population decline. The combination of aerial and ground based surveys appears to enhance the interpretation of both indices. Aerial surveys can show aspects of eider biology that ground based surveys cannot. The correlation of ice cover and total eider counts may show larger scale dynamics of Common Eider in the Beaufort Sea. Canadian breeding eiders may have briefly delayed their arrival in the Canadian Arctic or a concentration of Alaskan breeding eiders may have chosen to forgo nesting due to poor conditions on breeding grounds.

Nesting effort, estimated by aerial surveys, single pass nest searches, or nest searches and monitoring, is an essential component of population dynamics. However, nesting effort alone does not provide a sufficient understanding of population changes or reproductive success. Timing of aerial surveys and single pass nest searches can significantly affect counts, especially when predation levels are high (as they were in our study area).

Our results show that Common Eiders in our study area are doing poorly in all stages of breeding (i.e., low nesting effort, small clutch sizes, poor hatch success, and extremely poor fledging success). Nesting effort and clutch size are affected by initiation date, which is related to the timing of ice breakup. Thus, we expect improvements in these parameters in years with early breakup. Hatch success in our study is strongly influenced by predation, which, although stochastic in nature, may be indirectly linked to oilfield development via enhanced predator populations. We have no conclusive data to explain the poor fledging success of Common Eiders in our study. Due to their low levels in eggs, contaminants are not implicated. Gull predation certainly plays a role (our observers have seen a few ducklings eaten by gulls), but the extent is unknown, as the probability of seeing predation events is low even when predation is high. Disease (i.e., viruses) may be important, unfortunately the probability of encountering duckling carcasses is very low, especially in the presence of scavengers such as gulls, making it difficult to assess the relative mortality due to disease. Adult survival is a key parameter to population dynamics that, to date, we are unable to estimate. Only with additional years of mark-recapture can we estimate to this parameter.

On its own, the local Common Eider population of the central Beaufort Sea can not continue to exist for long given the poor breeding success that we have documented since 2000. However, Common Eiders are long-lived, and therefore have multiple lifetime opportunities to breed. Accordingly, we see three possible scenarios that may explain the dynamics of this population. First, the study population may be declining as indicated by the migration counts. Second, this population is not self-sustaining and the population is maintained by recruitment from other populations. Third, this population may be maintained by infrequent years of high recruitment. That is, 2000-2002 have been poor years and these years of little or no recruitment will be offset by a series of years with high recruitment. Continued monitoring of this population will be necessary to distinguish between these three possible explanations. Nonetheless, there is cause for significant concern about the long-term viability of this population.

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