MIGRATION ECOLOGY AND DISTRIBUTION OF KING EIDERS

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MIGRATION ECOLOGY AND DISTRIBUTION OF KING EIDERS

A

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By

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ABSTRACT

Alaskan-breeding King Eiders (*Somateria spectabilis*) disperse from nesting areas on the Arctic Coastal Plain and move through the Beaufort Sea to wing molt and winter locations in remote areas of the Bering Sea. Knowledge of King Eider distribution outside the breeding period is critical to provide regulatory agencies with opportunities to minimize potential negative impacts of resource development. To characterize the nonbreeding distribution of King Eiders, we collected location data of 60 individuals over two years from satellite telemetry. During post-breeding migration, male King Eiders had much broader use areas in the Alaskan Beaufort Sea than female eiders. Chronology of wing molt was earlier for males than females in all years. Throughout wing molt and winter, eider locations were closer to shore, in shallower water with lower salinity than randomly selected locations. Short residence time of King Eiders in deep water areas suggests the Alaskan Beaufort Sea may not be as critical a staging area for eiders during spring as it is during post-breeding. This study provides some of the first large-scale descriptions of King Eider migration, distribution, and habitat outside the breeding season.

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INTRODUCTION

King Eiders (*Somateria spectabilis*) spend the majority of their annual cycle in remote marine habitats, precluding direct observation and contributing to an incomplete understanding of their life histories. King Eiders perform wing molt, fall, and spring migrations (Suydam 2000), and presumably this migratory behavior has evolved to provide the greatest potential lifetime reproductive success for individuals (Baker 1978). This study was developed with two broad objectives: (1) to determine the use of the Beaufort Sea as a flyway and staging area and the management implications of oil development in the sea, and (2) to provide an initial description of the migration and nonbreeding ecology of King Eiders.

Alaskan-breeding King Eiders disperse from nesting areas on the Arctic Coastal Plain and move through the Beaufort Sea to wing molt and wintering locations in the Bering Sea. Hundreds of thousands of King Eiders use the Alaskan Beaufort Sea as a flyway, staging, or molting area each year (Thomson and Person 1963, Woodby and Divoky 1982, Suydam et al. 2000). Development of offshore oil resources on natural and artificial islands in the Beaufort Sea has prompted managers to fund baseline studies about the distribution of King Eiders in the sea. These data are critical to model potential consequences from oil spills and to provide regulatory agencies with opportunities to modify proposed developments and associated activities to minimize impacts. Potential impacts from oil spills may include displacement of eiders from foraging habitat, contamination of food resources, and mortality from oiling (Flint et al. 1999, Stehn and Platte 2000).

After leaving the Beaufort Sea, King Eiders migrate to marine areas where they congregate in flocks and molt all flight feathers. During this three-to-four week flightless period, movements are constrained, and eiders may be vulnerable to disturbance and predation, and subject to higher energy demands (Salomonsen 1968, King 1974, Hohman et al. 1992). They then move to wintering areas that are characterized by short periods of daylight and extremes in weather conditions, temperature, and ice cover (Systad et al. 2000, Petersen and Douglas 2004). Eiders generally form pair bonds on these wintering areas and migrate as pairs to breeding grounds in the spring (Anderson et al. 1992).

The chronology of waterfowl life-history events during the nonbreeding period may be linked to productivity on the breeding grounds (Heitmeyer and Fredrickson 1981, Hepp 1984, Dugger 1997), and may vary by age, sex, and habitat condition (Heitmeyer 1988). This may be especially true for eider species that rely heavily on endogenous reserves for egg laying (Korschgen 1977, Kellet 1999). Concern regarding apparent population declines in recent decades of all four eider species (Spectacled Eiders [*Somateria fischeri*], Stehn et al. 1993; Steller's Eiders [*Polysicta stelleri*], Kertell 1991; King Eiders and Common Eiders [*Somateria mollissima*], Suydam et al. 2000) has led to increased interest in location and timing of migration, definition of wing molt and wintering areas, and habitat characterization of these sites (U. S. Fish and Wildlife Service 1999, Sea Duck Joint Venture Management Board 2001).

In this study, I obtained location data for the annual cycle of 33 King Eiders in 2002 and 2003. Additionally, I collected wing molt location information for 27 eiders in 2004. Thus, I was able to estimate the areas of the Alaskan Beaufort Sea used by a sample of King Eiders during spring migration and post-breeding and to describe the movements and areas used by King Eiders throughout the nonbreeding period.

This thesis examines two aspects of the annual cycle of King Eiders captured on the North Slope of Alaska and describes the variation in the chronology of life history events between sexes and among years. The first chapter examines the use and distribution of transmittered King Eiders in the Alaskan Beaufort Sea during spring and post-breeding staging and migration and the management implications of those results. The second chapter examines the interrelationship of migratory, wing molt, and wintering periods and provides a description of the habitat characteristics associated with King Eider locations.

The results of this study suggest:

1. King Eiders may not use the Alaskan Beaufort Sea extensively for staging prior to arrival at breeding grounds in Alaska in spring.
2. King Eiders were most concentrated in the areas of Smith Bay and Harrison Bay in the Alaskan Beaufort Sea during post-breeding, supporting the results of previous studies (Stehn and Platte 2000, Dickson et al. 2000, Fischer et al. 2002).
3. Impacts from oil development in the Beaufort Sea may disproportionately affect female King Eiders whose concentrated use and longer residence times in Harrison and Smith Bays suggest they may be less likely to disperse from spill areas to other sites.

4. There was variation in timing of wing molt between sexes and among years which suggests an interrelationship of the breeding and wing molt periods.
5. King Eiders arriving earlier at wing molt sites flew shorter distances on molt migration, potentially incurring lower costs of migration than birds arriving later.
6. Previously undescribed wing molt and wintering locations for King Eiders were located in the Alaskan Beaufort Sea, Olyutor Bay, and the west side of the Kamchatka Peninsula.
7. Throughout the nonbreeding period King Eiders inhabited relatively shallow, nearshore areas characterized by low salinity.

This study provides an initial look at the life history events of King Eiders outside the breeding period and should benefit planning future studies to better understand requirements of eiders during migration, wing molt, and winter. My findings support the idea of an annual cycle of interrelated life history events, but variation in timing and distribution of King Eiders during staging, wing molt, and winter would be better understood with more years of data as well as a sample of successfully breeding females and young of the year. Spring staging locations are likely critical to eiders as refuge from heavy ice and as foraging areas. King Eiders rely on endogenous reserves for egg-laying (Kellet 1999), and disturbance or degradation of staging areas could have a disproportionately large impact on eider productivity. Ledyard Bay should be further investigated as a key stopover site for King Eiders on spring migration. King Eiders have not been studied using direct observations during the nonbreeding period in the Bering Sea. Measuring habitat parameters and observing behavior of King Eiders at some of the major wing molt and wintering locations in the Bering Sea such as Chukotka, Olyutor Bay, Bristol Bay and St. Lawrence Island using ground or aerial observations would add greatly add to our understanding of their nonbreeding ecology.

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CHAPTER 1. USE OF THE BEAUFORT SEA BY KING EIDERS BREEDING ON THE NORTH SLOPE OF ALASKA[1]

Abstract: This study employed the use of satellite telemetry to estimate areas used by king eiders in the Alaskan Beaufort Sea, how distributions of used areas varied, and characteristics that explained variation in the number of days spent in the sea. Sixty king eiders were implanted with satellite transmitters at 2 locations on the North Slope of Alaska in 2002-2004. Distribution of locations did not vary by sex during spring migration. Shorter residence times of eiders and deeper water depths at locations during spring migration suggest the Alaskan Beaufort Sea may not be as critical a staging area for king eiders in spring as it is post-breeding. More than 80 % of our transmittered eiders spent more than 2 weeks staging offshore prior to beginning molt migration, suggesting that the sea is an important migration flyway and staging area for this species. During post-breeding staging and migration, male king eiders had much broader distributions in the Alaskan Beaufort Sea than female eiders, which were concentrated in Harrison and Smith Bays. Significant variation in residence time in the Beaufort Sea was explained by sex, with female king eiders spending more days within the sea than males in spring and during post-breeding. We recommend managers minimize disturbance of

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core use areas in Harrison and Smith Bays during post-breeding and that future studies examine the importance of potential spring staging areas outside the Alaskan Beaufort Sea.

Key Words: Alaska, Beaufort Sea, distribution, king eider, migration, satellite telemetry, *Somateria spectabilis*

INTRODUCTION

In the summer of 1968, a large deposit of oil was discovered beneath the arctic coastal plain of Alaska. Since then, there has been extensive industrial development at Prudhoe Bay and exploration and development of smaller surrounding fields. Thirty-one exploratory wells have been drilled on the Beaufort Sea outer continental shelf since 1981 (Minerals Management Service 2005). The first offshore development project in the sea to use a subsea pipeline to transport oil under the pack ice was the British Petroleum Exploration, Alaska (BPXA) Northstar project, which began oil production in 2001.

Development of offshore oil resources on natural and artificial islands in the Beaufort Sea has important implications for hundreds of thousands of birds that use the sea as a flyway, staging, or molting area. Of these birds, king eiders (*Somateria spectabilis*) are some of the most abundant (Fischer et al. 2002). In spring, they migrate from the Bering Sea, around Point Barrow, and into the Beaufort Sea and to breeding areas on the coastal plain of Alaska and western Canada (Suydam 2000). Woodby and

Divoky (1982) counted over 100,000 king eiders passing Point Barrow within a 30 minute period during spring migration in 1976. After breeding, eiders move back into the Beaufort Sea to stage prior to migrating to wing molt sites in the Bering Sea (Thomson and Person 1963, Woodby and Divoky 1982, Suydam et al. 2000). Migrating king eiders may fly 70 km/h, 12 m above ground level, making them susceptible to collisions with man-made structures (Day et al. 2001, Day et al. 2004). In addition, disturbance from boats and helicopters supporting oil infrastructure could disrupt or displace eiders from foraging areas (Frimer 1994, Mosbech and Boertmann 1999). Potential impacts from oil spills may include displacement of eiders from foraging habitat, contamination of food resources, and mortality from oiling (Flint et al. 1999, Stehn and Platte 2000). Simulated 1580 bbl oil spills in July from the proposed BPXA Liberty development predicted an average of 232 king eiders oiled (Stehn and Platte 2000).

Studies of king eider use of the Beaufort Sea have been limited to coastal migration surveys (Thomson and Person 1963, Johnson and Richardson 1982, Suydam et al. 2000) and aerial transect surveys within 60 km of shore (Fischer et al. 2002). These methods are limited in their scope, with little information gathered about residence time of individual birds or use of sites outside observation areas. Baseline data about the distribution of king eiders in the sea are critical to model potential consequences from oil spills and provide regulatory agencies with opportunities to modify proposed developments and associated activities to minimize impacts. Declining numbers of eiders counted during migration surveys (Suydam et al. 2000), and low capacity for population growth may extend the time necessary for king eider populations to recover from mortality events or cumulative effects (Suydam 2000).

Satellite telemetry is a useful tool to gather location data about an individual's use of specific areas. Coupled with a large sample size, satellite telemetry can give us insight into the distribution of a population of individuals. This study employed the use of 60 satellite transmitters over 3 years to monitor king eiders in the Alaskan Beaufort Sea. Objectives of the study were to: (1) document locations of North Slope-breeding king eiders during spring migration, post-breeding staging, and post-breeding migration in the Alaskan Beaufort Sea; (2) determine whether use areas differed by season, sex, or trapping location, among years, or within season; and (3) determine the residence time of king eiders captured on the North Slope of Alaska in the Beaufort Sea and the characteristics that explained variation in this residence time. Explanatory variables used to explain residence time of eiders within the Beaufort Sea include sex, season, year, Julian date of an individual's first location in the sea each season, and the amount of high (>75 %) ice cover present in the sea at the time of arrival.

STUDY AREA

Capture Locations

We trapped king eiders in early to mid-June 2002, 2003, and 2004 at 2 sites on the North Slope of Alaska: Teshekpuk Lake (70°26'N, 153°08'W) and Kuparuk (70°20'N, 149°45'W). The Kuparuk study site was located between the Colville and Kuparuk rivers. The Teshekpuk Lake study site was added as a trapping location in 2004, and was located about 80 km west of the Kuparuk study area and 10 km inland from the southeast shore of Teshekpuk Lake.

Beaufort Sea

During the post-breeding period (late June through mid-September), Alaskan-breeding king eiders move into the Beaufort Sea where they stage or begin migration to wing molt locations. The Beaufort Sea is part of the Arctic Ocean that lies north of Alaska from Point Barrow eastward to Banks Island north of the Yukon and Northwest Territories of Canada. It has a narrow continental shelf that extends an average of 55 km offshore to the 200 m bathymetric contours (Soluri and Woodson 1990). Sea ice generally covers the entire sea for 9 to 10 months each year. Nearshore ice freezes to the seafloor in winter and ice scouring of benthic habitats nearshore can be severe (Barnes et al. 1984). Primary productivity is low, and food webs are relatively simple with secondary biological productivity peaking during the ice-free summer months of June through October (Norton and Weller 1984).

METHODS

Capture and Telemetry

We obtained locations of king eiders throughout the nonbreeding period using implantable satellite transmitters. We captured king eiders on breeding grounds in early to mid-June using mist net arrays and decoys. Once captured, eiders were placed in a secure, dark kennel and transported to an indoor facility or weatherport equipped for surgery. A 35-g satellite platform transmitting terminal (PTT) transmitter (Microwave Telemetry, Inc., Columbia, Maryland) was surgically implanted into the abdominal cavity of each eider following the techniques of Korschgen et al. (1996). Satellite transmitters were <3% of the average body mass of birds used in this study. Eiders were fitted with a U.S. Fish and Wildlife Service band while still under anesthesia. We held birds until fully awake and recovered from anesthesia (2 - 3 h), and then released them at their capture sites. At Kuparuk, transmitters were implanted into 21 (10 female, 11 male) king eiders in 2002, 12 (3 female, 9 male) in 2003, and 15 (8 female, 7 male) in 2004. We fitted 12 (5 female, 7 male) king eiders with transmitters at Teshekpuk in 2004. All methods and handling of birds were approved by the University of Alaska Institutional Animal Care and Use Committee (IACUC # 02-10).

Transmitters provided location information for 6 h every 48 h from June through September and every 84 h from April through the end of battery life. The expected battery life was 800 h or about 1 year. We received location data from Service Argos (2001). Location data were filtered for accuracy using PC-SAS Argos Filter V5.1 (Dave Douglas, U.S. Geological Survey (USGS), Alaska Science Center, Anchorage, Alaska). The filtering program removed implausible locations based on location redundancy and tracking paths. The best location per transmission period was used for our analyses based on location class. Locations were plotted using ArcView GIS (ESRI 1998).

Due to the variation in the number of locations obtained per individual in the Alaskan Beaufort Sea (range: 1 - 44 locations), we randomly selected a maximum of 10 post-breeding locations (June - September) and 7 spring locations (April - July) per individual to create 2 subsets of eider locations for use in analyses. We created all random subsets using Random Point Generator 1.27 extension (Jennes 2003) in ArcView.

Data Analysis

Distribution and Use Areas.-- Differences in distributions of king eider locations in the Beaufort Sea were examined using multiresponse permutation procedures (MRPP) in BLOSSOM (USGS, Fort Collins, Colorado; Cade and Richards 2001). We examined differences by sex and season (spring migration vs. post-breeding), and among years. We also compared 2004 post-breeding distributions of male and female king eiders transmittered at Kuparuk to those captured at Teshekpuk.

To examine changes over time of male and female spring and post-breeding distributions, we compared 6-day time intervals (spring male: n =6; spring female: n =3; post-breeding male: n =6; post-breeding female: n =9) and combined similar intervals until a significant difference in distribution of intervals was encountered. We eliminated intervals with <5 locations in the very early and very late time periods and did not include locations from birds trapped at Teshekpuk Lake. Alpha levels of multiple comparisons were corrected using the Bonferroni method.

We used fixed kernel analysis (Seaman et al. 1998) to delineate 95% utilization distributions and core use areas of king eiders in the Beaufort Sea. Core use areas represent areas with greater than average observed density of eider locations.

Location Characteristics.-- We used two-way ANOVAs on ranked data to test for differences by sex and season in water depth and distance from shore of eider locations. Water depth at eider locations was calculated using a bathymetric shapefile with 10-m contour intervals compiled by the Alaska Science Center (1997). Distance from shore was calculated using ArcView GIS as the shortest straight-line distance from an eider location to a 1:250,000 polyline shapefile (Soluri and Woodson 1990) of the Alaskan coastline.

Residence Time.-- Variation in the number of days an eider spent in the Alaskan Beaufort Sea was examined using multiple regression. Residence time of a king eider was calculated as the number of days from the first day an eider entered the sea until the date of the last location within the sea. Explanatory variables within the model included sex, season (spring vs. post-breeding), year, standardized Julian date of an individual's first location within Beaufort Sea, and an index of high (>75 %) ice cover present within 100 km of shore when an eider entered the sea. Julian date of an eider's first location within the sea was standardized to allow season to be included in the analysis as a class variable. Ice coverage information was obtained from the National Ice Center (2004). These data ranged from weekly to biweekly shapefiles of percent ice coverage in the Beaufort Sea. We calculated an index of high ice cover concentrations by summing areas with >75 % ice cover within 100 km of shore within the Alaskan Beaufort Sea. We selected 100 km as the cutoff because that was the farthest distance an eider was located from shore. We examined collinearity among variables to exclude highly correlated variables from analyses. Ice cover and standardized date of entry were significantly correlated and negatively ($r_s = -0.36$, $P = 0.001$). We chose to exclude ice cover from further analysis because it was not normally distributed. We included the first order interaction terms sex with season, year, and standardized Julian date. Means are presented $\pm$SE. All statistical analyses were performed using SAS software (SAS Institute 1990).

RESULTS

Distribution and Use Areas

Year.-- Distributions of king eider locations during spring did not differ between years (δ_{149} =-0.70, P =0.16). Distributions of male locations during post-breeding did not differ among years (δ_{258} =-1.54, P =0.079). Post-breeding distribution of female locations in 2003 differed significantly from those in 2002 (δ_{58} =-6.41, P <0.001) and 2004 (δ_{58} =-5.79, P =0.001); however, 2002 and 2004 distributions did not differ (δ_{60} = 0.81, P =0.99).

Sex.-- Distributions of king eider locations in the Alaskan Beaufort Sea differed by sex during the post-breeding period (δ_{516} =-26.38, P <0.001), but not during spring migration (δ_{41} =-1.67, P =0.068). Female locations tended to be concentrated in Harrison Bay and Smith Bay during post-breeding, while male locations were more widely dispersed in the Alaskan Beaufort Sea from Oliktok Point to Point Barrow (Figure 1-1).

Season.-- Spring and post-breeding distributions of eiders differed significantly (δ_{91} =-26.36, P <0.001). Spring locations were scattered from Point Barrow to the Canadian border with over 40% of the locations found >20 km offshore. Core use areas during the post-breeding period were located nearshore and distributed uniformly between the Kuparuk capture site and Point Barrow (Figure 1-2).

Capture Site.-- The post-breeding distributions of male and female king eiders captured at Kuparuk differed significantly from distributions of those captured at Teshekpuk (male δ_{94} =-10.64, P <0.001, female δ_{86} =-17.70, P <0.001). Females from

Kuparuk were concentrated in Harrison Bay while core use areas of Teshekpuk females were located in Smith Bay. Locations of male eiders captured at Teshekpuk Lake were widely dispersed in the Beaufort Sea which resulted in a large core use area that covered the majority of the continental shelf from Point Barrow to Harrison Bay. Males captured at Kuparuk were more concentrated in small areas resulting in scattered dense core use areas off Oliktok Point and in Harrison and Smith Bays (Figure 1-3).

Time Intervals.-- In spring, distributions among 6-day intervals of king eider locations did not differ. Comparisons of 6-day intervals during the post-breeding period reflected a shift in the distribution of male king eiders in late June (16 - 27 June vs. 28 June - 28 July, $\delta_{107} = -13.22$, $P < 0.001$) and female king eiders in late July (24 June - 28 July vs. 29 July - 22 Aug, $\delta_{142} = -27.84$, $P < 0.001$). The locations of both male and female eiders were dispersed more broadly throughout the Beaufort Sea and shifted to the west later in the post-breeding period (Figure 1-4).

Location Characteristics

Water depth at king eider locations differed by sex ($F_{1,548} = 16.68$, $P < 0.001$) and season ($F_{1,548} = 20.12$, $P < 0.001$) with a significant interaction between sex and season ($F_{1,548} = 42.65$, $P < 0.001$). Distance from shore of eider locations differed by sex ($F_{1,560} = 9.96$, $P = 0.002$) but not by season ($F_{1,560} = 0.9$, $P = 0.34$) with a significant interaction between sex and season ($F_{1,560} = 24.37$, $P < 0.001$). In spring, female locations were on average farther from shore (26.5 $\pm$3.6 km) in deeper water (28.8 $\pm$3.1 m) than male locations (distance from shore: 12.0 $\pm$3.5 km; water depth: 11.1 $\pm$1.8), while during the post-breeding period, females were closer to shore (12.8 ±0.6 km) in shallower water (11.7 ±0.8 m) than males (distance from shore: 14.8 ±0.6 km; water depth: 12.6 ±0.4).

Residence Time

Significant variation in residence time of transmittered king eiders within the Beaufort Sea was explained by sex ($t_{1,69}$ =-2.98, P =0.004), season ($t_{1,69}$ =3.66, P < 0.001), and standardized Julian date of first location within the sea ($t_{1,69}$ =-4.89, P < 0.001, Figure 1-5). Year ($t_{1,69}$ =-0.35, P =0.728), sex*year ($t_{1,69}$ =-0.06, P =0.956), sex*season ($t_{1,69}$ =-0.88, P =0.383), and sex*Julian date ($t_{1,69}$ =1.90, P =0.062) explained little variation in residence times. On average, females moved into the Beaufort Sea almost 2 weeks later than males in the spring and 20 days later than males during the post-breeding periods (Table 1-1, Figure 1-6). They spent almost twice as many days on average in the sea than males in spring and more than a week longer than males during post-breeding (Table 1-1, Figure 1-6).

DISCUSSION

Hundreds of thousands of king eiders pass through the Beaufort Sea each year during spring and post-breeding migrations (Suydam et al. 2000). Every king eider we transmittered on the North Slope of Alaska spent at least 1 day in the Alaskan Beaufort Sea after the breeding season. More than 80 % of our transmittered eiders spent more than 2 weeks staging offshore before molt migration, suggesting that the sea is an important migration flyway and staging area for this species.

Spring and post-breeding distributions of king eider locations in the Alaskan Beaufort Sea overlapped very little. Short residence times and deep water at spring locations suggest that king eiders may be using the Alaskan Beaufort Sea as a migration corridor rather than a staging area during this period. Spring staging areas for king eiders in this study were located outside the Alaskan Beaufort Sea in the Chukchi Sea and Canadian Beaufort Sea (L. Phillips, unpublished data). Transmittered eiders returning to the arctic coastal plain of Alaska and Canada in spring staged for 18 days on average in Ledyard Bay in the Chukchi Sea prior to entering the Beaufort Sea. Transmittered female king eiders spent an average of 24 days in Ledyard Bay prior to returning to nesting sites. Female king eiders exhibited fidelity to nesting areas by returning to sites near the capture site. Male king eiders migrated to Russia, Alaska, and Canada in the spring, presumably following females to their breeding grounds. Five of 15 males returning to breeding areas in the spring appeared to forego breeding and staged offshore in the Canadian Beaufort Sea. During spring migration, our transmittered king eiders that returned to breed in Alaska and western Canada did not appear to stage within the Alaskan Beaufort Sea. Ledyard Bay may be a more critical stopover area during spring migration for king eiders.

During spring and post-breeding, we found a negative trend of residence time with date of arrival in the Beaufort Sea for female king eiders and no apparent trend for males. Timing of female staging and migration in the Beaufort Sea may be constrained by subsequent life history events. In spring, early arrival on breeding grounds may provide reproductive advantages to nesting female waterfowl (Johnson et al. 1992), and a short breeding season on Alaska's North Slope may constrain breeding female king eiders to a narrow time period for nest initiation. During post-breeding, female ducks with longer or later reproductive periods may have limited time to replenish diminished fat stores before beginning molt migration, especially in the high arctic where advancing winter weather could reduce forage quality or entrap flightless birds in advancing ice at wing molt sites (Salomonsen 1968, Hohman et al. 1992). Timing of male molt migration appears to be highly synchronized in most waterfowl (Hohman et al. 1992), and this is supported by the behavior of our transmittered male eiders after breeding.

Concentrations of eiders at Harrison Bay and Smith Bay in July were consistent with the findings of Fischer et al. (2002) and Dickson et al. (2000). During post-breeding aerial surveys of the central Beaufort Sea, Fischer et al. (2002) recorded the highest densities of king eiders in deep water (>10 m) areas of Harrison Bay in July. Stehn and Platte (2000) analyzed these same aerial survey data and calculated a density of 3.6 king eiders per km^2 in the deep water (>8 m) area from the Kogru River to Oliktok Point. Dickson et al. (2000) described Harrison and Smith Bays as summer staging areas for king eiders transmittered on breeding grounds at Victoria Island, Northwest Territories and Prudhoe Bay, Alaska.

In this study, Smith Bay was used more heavily by post-breeding female eiders than male eiders. Troy (2003) found the area around Smith Bay to be an important post-breeding area for North Slope-breeding female spectacled eiders (*Somateria fischeri*). After leaving the breeding grounds, 90 % of his tagged females spent over 70 % of their time in and around Smith Bay prior to departing the Beaufort Sea. He speculated that high ice cover in Smith Bay early in the post-breeding period prevented male spectacled eiders from using this area. Severe ice conditions in early summer may have also reduced the amount of time transmittered male king eiders spent in Smith Bay. Shore-fast ice in the Beaufort Sea generally begins to move offshore in early July, creating open water habitat nearshore (Craig et al. 1984). The broad distribution of male locations in the sea after breeding may reflect high (>75 %) ice cover in June which forces male king eiders to dispersed pockets of open water during post-breeding.

The earlier post-breeding movements of male king eiders into the Beaufort Sea relative to females are consistent with previous eider studies (Petersen et al. 1999, Dickson et al. 2000, Troy 2003). Male king eiders disperse from breeding grounds at the onset of incubation, while female timing is probably dependent on breeding success. Post-breeding males spent fewer days staging in the Beaufort Sea than females. Female king eiders may need to remain in the Beaufort Sea longer than males prior to molt migration to replenish fat stores depleted during egg-laying and incubation. Female eiders rely on endogenous reserves for egg-laying and forage very little while incubating (Korschgen 1977, Kellet 1999). King eiders nesting at Karrak Lake, Northwest Territories lost 32 % of their pre-incubation body mass during incubation (Kellet 1999).

MANAGEMENT IMPLICATIONS

This study delineated areas of the Alaskan Beaufort Sea used by king eiders transmittered at 2 locations on the Arctic Coastal Plain of Alaska. Although we can not presume that eiders breeding at these locations represent the population of king eiders nesting in Alaska, we do feel there is enough overlap of use areas by eiders from both capture sites to label areas such as Harrison Bay and Smith Bay as important staging sites. Our results also support previous studies that indicate these areas are used by a relatively high density of king eiders during the post-breeding period (Stehn and Platte 2000, Fischer et al. 2002).

There are currently 64 active leases comprised of over 100,000 ha within federal waters of the Alaskan Beaufort Sea (Minerals Management Service 2005). These leases are within 50 km of shore, and 47 % overlap with the post-breeding distribution of our transmittered king eiders. BPXA Northstar Island is the only offshore development project in the Alaskan Beaufort Sea; however, exploratory wells continue to be drilled and offshore leases offered for purchase. Development of resources in the Beaufort Sea increases the chance of an oil spill occurring, although the likelihood of a large oil spill (>500 barrels) at the proposed BPXA Liberty development was predicted to be very low (<1 %) over the life of a field (Minerals Management Service 2002). According to the final Environmental Impact Statement for this development, a large spill could have some significant adverse impacts on king eider populations if a spill occurred during the 3 – 5 months eiders were present within the Beaufort Sea (Minerals Management Service 2002). This assertion was based primarily on oil spill models created by Stehn and Platte (2000) which predicted a maximum number of 3,102 king eiders oiled during a 6,000 barrel spill at the Liberty project in July. The proposed site for the Liberty development is in an area with relatively low densities of king eiders (0.05 birds per km^2 in July) according to aerial surveys (Stehn and Platte 2000). Numbers of oiled birds could be much higher if a large spill occurred in high use areas such as Harrison Bay and Smith Bay. Impacts may disproportionately affect female king eiders whose concentrated use and longer residence times than males in these areas suggest they may be less likely to disperse from spill areas to other sites. Both of Harrison and Smith Bays currently have areas leased for potential oil development (Minerals Management Service 2005).

The most recent Environmental Assessment of Proposed Oil and Gas Lease Sale 195, Beaufort Sea Planning Area (Minerals Management Service 2004) stated that king eiders were one of the most frequently recorded bird species striking structures on Northstar Island. BPXA recorded 5 king eider mortalities from impacts with Northstar Island since its construction in 2001 (J. Zelenak, U.S. Fish and Wildlife Service, personal communication). The majority of our transmittered eiders moved west of capture sites during the post-breeding period; therefore, the distribution of individuals from our study did not overlap with Northstar Island or the proposed Liberty development after breeding. Our transmittered king eiders migrated on a broad front through the Beaufort Sea from shoreline to >50 km offshore. If king eiders breeding in eastern Alaska and western Canada migrate on a similar front during post-breeding, they could encounter offshore structures. However, eiders averaged about 13 km offshore prior to molt migration and 20 km offshore during spring migration, distances farther from the coast than either the Northstar development (9.5 km) or proposed Liberty project (8 km).

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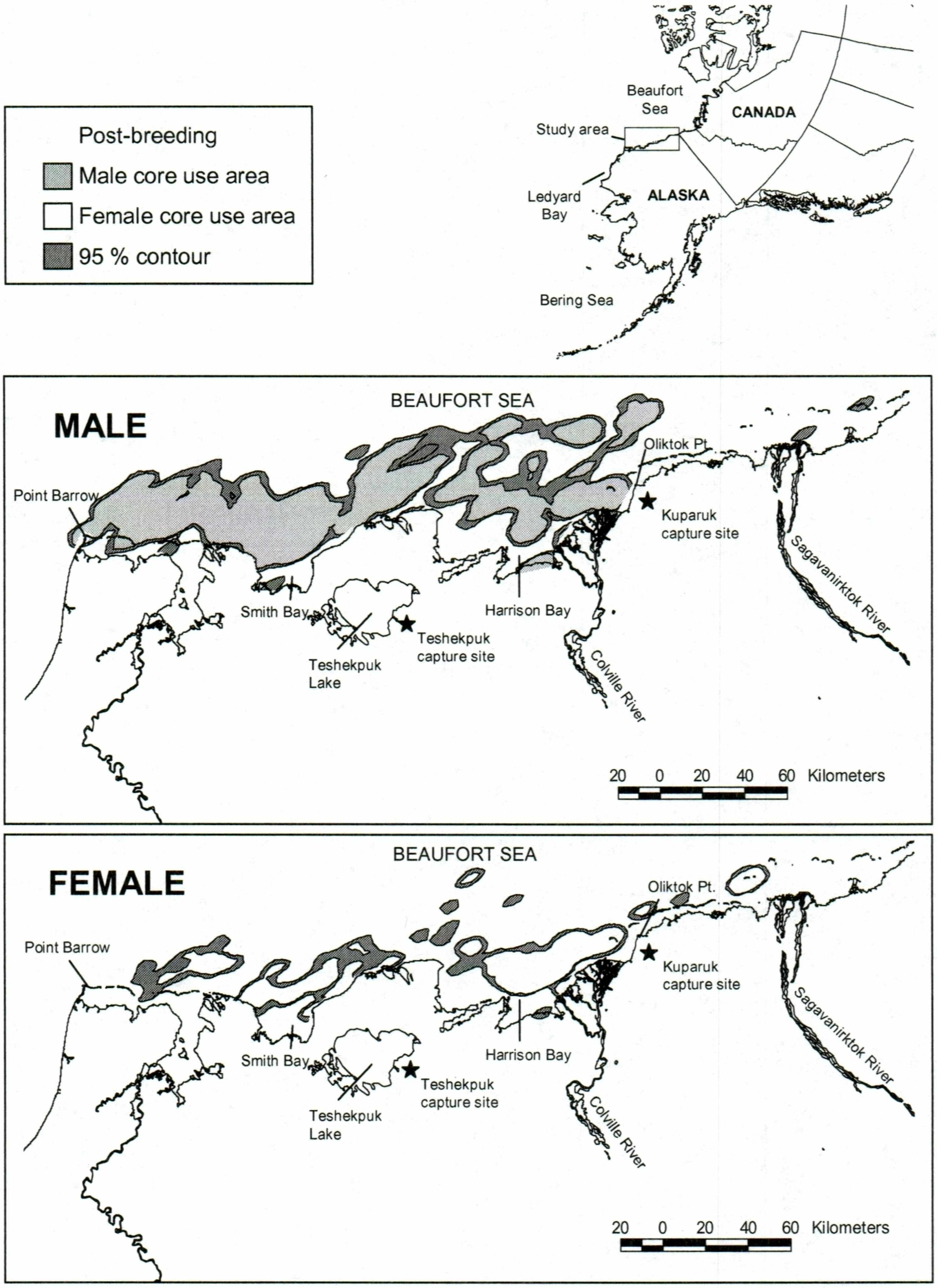

Figure 1-1. Post-breeding distributions of 60 male and female king eiders within the Alaskan Beaufort Sea, 2002-2004.

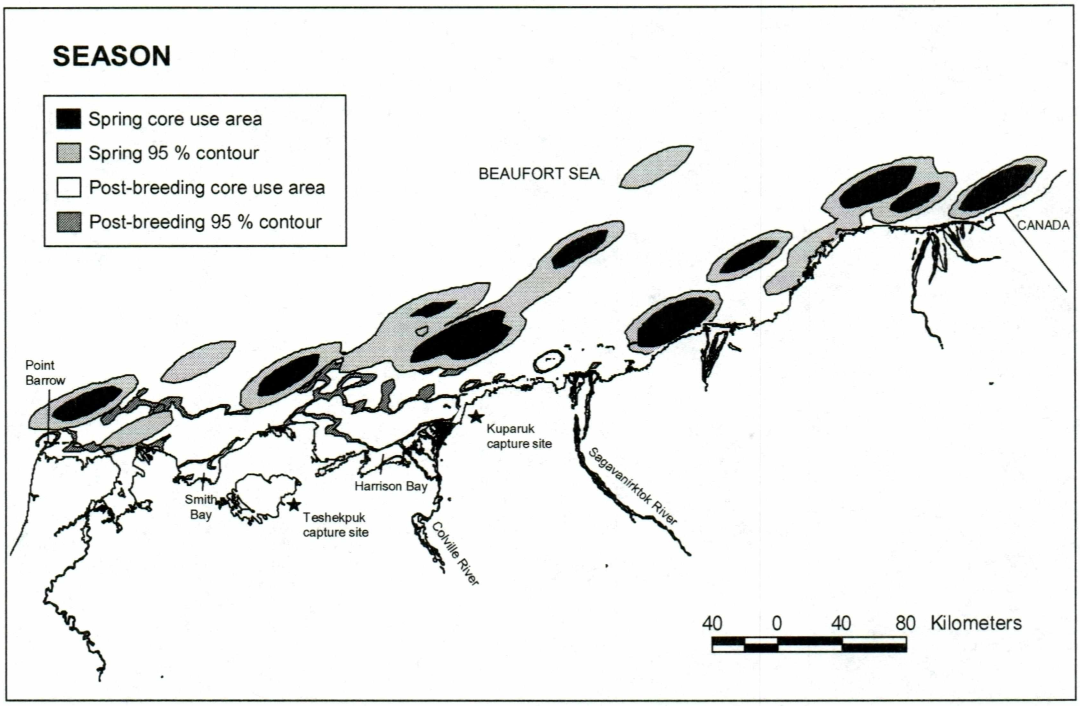

Figure 1-2. Post-breeding and spring distributions of satellite-tagged king eiders in the Alaskan Beaufort Sea, June 2002- September 2004.

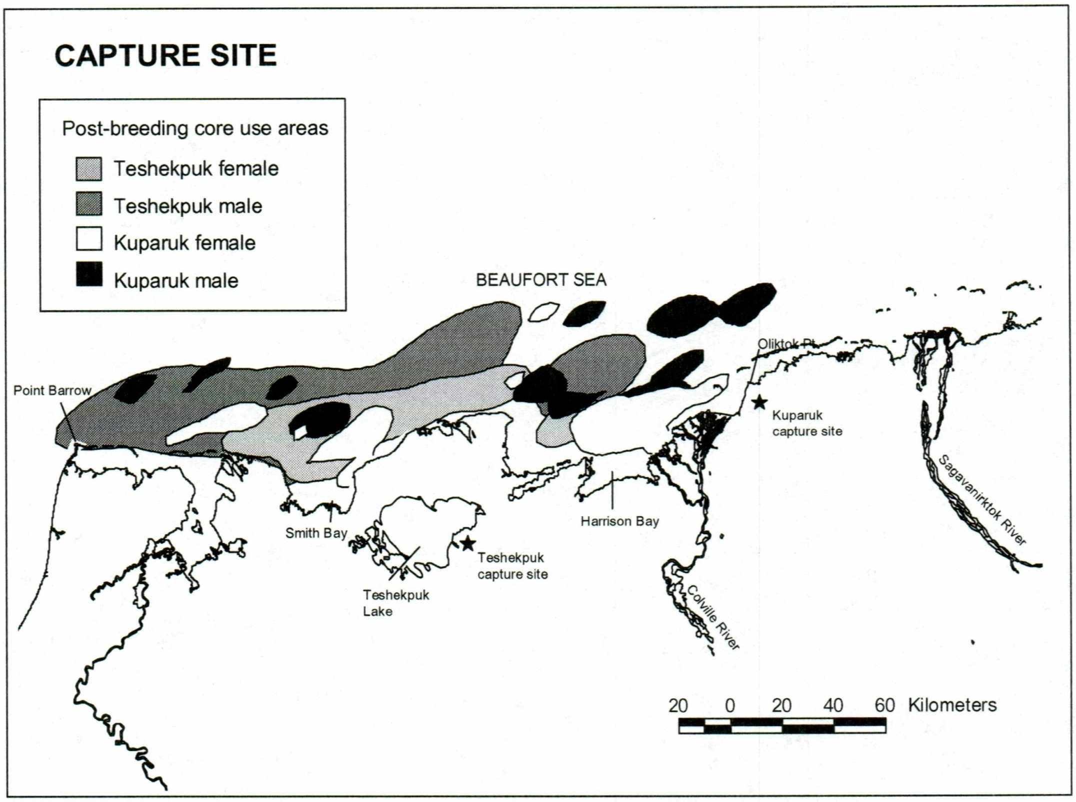

Figure 1-3. 2004 post-breeding distributions within the Alaskan Beaufort Sea of male and female king eiders captured at Kuparuk and Teshekpuk Lake on the North Slope of Alaska.

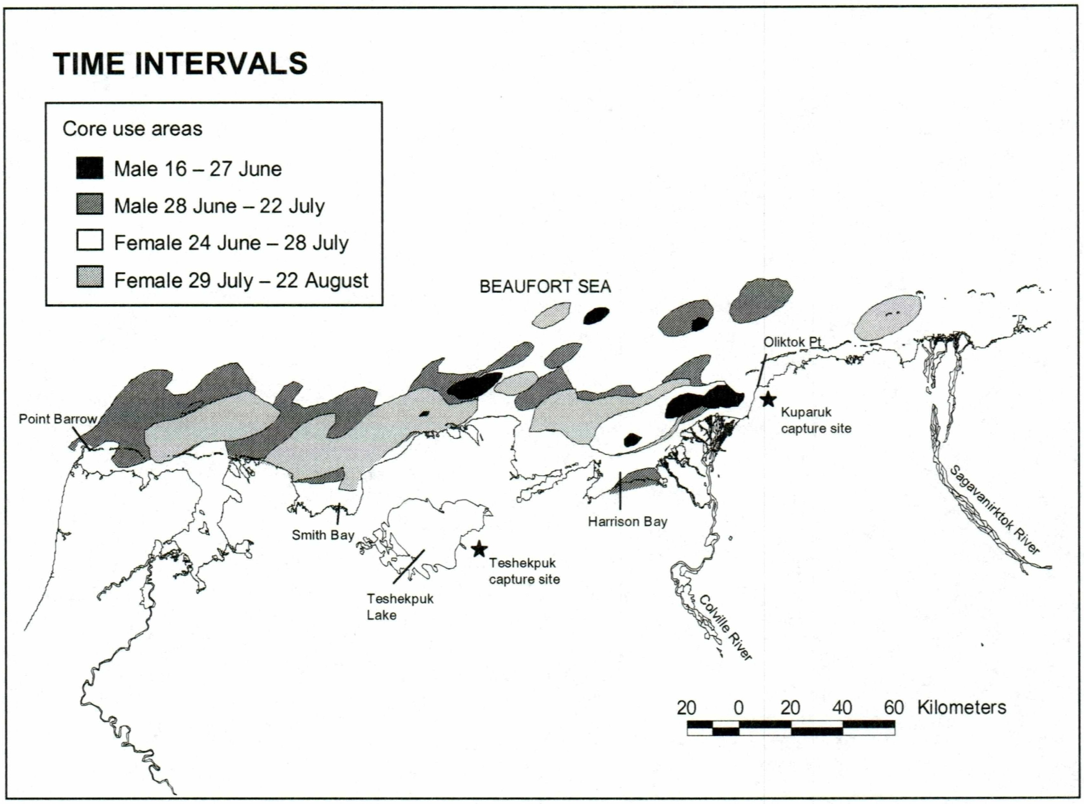

Figure 1-4. Changes in male and female king eider post-breeding distributions over time within the Alaskan Beaufort Sea. 2002-2004 locations of 48 satellite transmittered king eiders captured at Kuparuk, AK were combined to create these distributions.

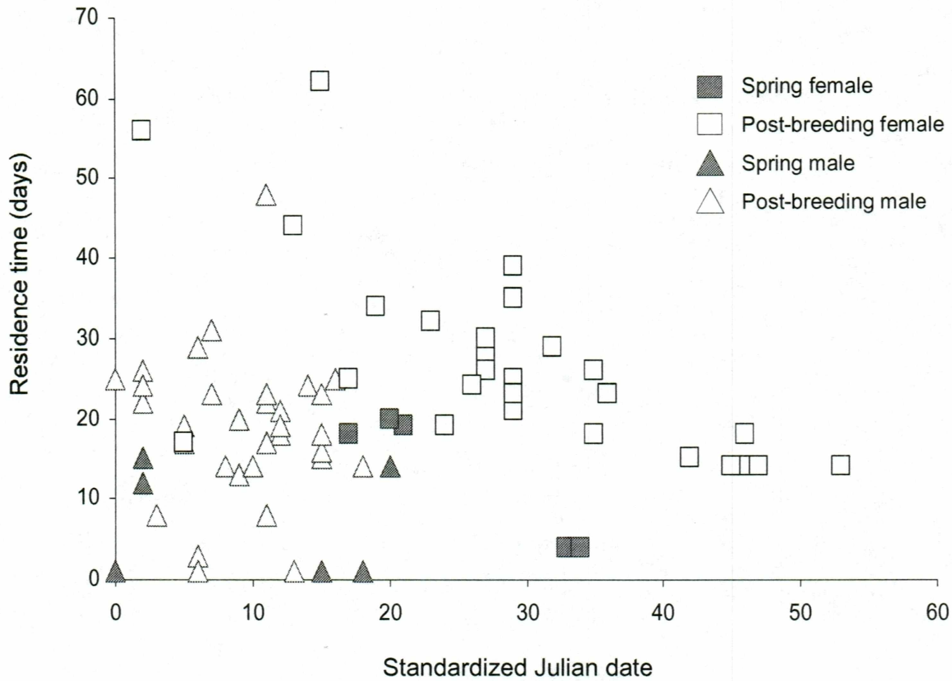

Figure 1-5. Plot of residence time and standardized date of arrival within the Alaskan Beaufort Sea of transmittered male and female king eiders (n = 60) during spring and post-breeding.

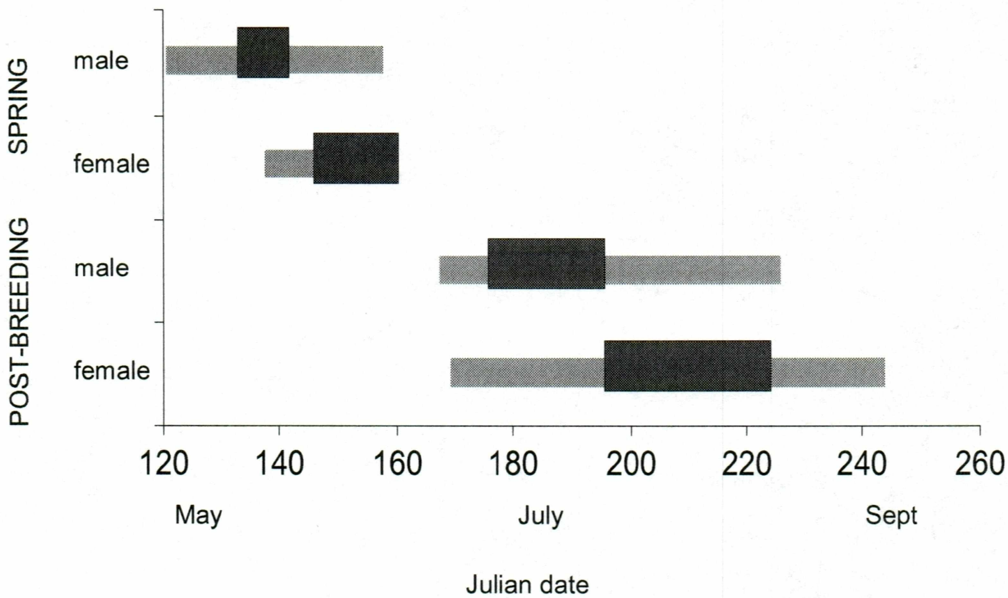

Figure 1-6. Mean residence time (days, black bar) and range (grey bars) of transmittered king eiders located within the Alaskan Beaufort Sea during spring and post-breeding periods.

Table 1. Mean (± SE) residence time and date of first location within the Alaskan Beaufort Sea of male and female transmittered king eiders during post-breeding and spring migration June 2002 - September 2004.

	Male		Female	
	Mean	Range	Mean	Range
RESIDENCE TIME (days)				
Post-breeding	18.2 ± 1.6	1 - 48	26.9 ± 2.4	14 - 62
Spring	7.3 ± 2.9	1 - 15	13 ± 3.7	4 - 20
DATE OF FIRST LOCATION				
Post-breeding	25 Jun	16 Jun - 4 Jul	15 Jul	18 Jun - 8 Aug
Spring	13 May	30 Apr - 20 May	26 May	17 May - 8 Jun

CHAPTER 2. LARGE-SCALE MOVEMENTS AND HABITAT CHARACTERISTICS OF KING EIDERS THROUGHOUT THE NONBREEDING PERIOD[2]

Abstract. Alaskan-breeding King Eiders (*Somateria spectabilis*) molt wing feathers and over-winter in remote areas of the Bering Sea, precluding direct observation. To characterize timing of migration and habitat used by King Eiders during the nonbreeding period, we collected location data of 60 individuals (27 females and 33 males) over three years from satellite telemetry and obtained oceanographic information from remotely-sensed data. Male King Eiders dispersed from breeding areas, arrived at wing molt sites, and dispersed from wing molt sites earlier than females in all years. For males, earlier arrival dates at wing molt sites were correlated with higher latitudes of these sites. Distributions of molt and winter locations did not differ by sex or among years. We suggest that of the variables considered for analysis, distance to shore, water depth, and salinity best describe King Eider habitat throughout the nonbreeding period. King Eiders were located closer to shore, in shallower water with lower salinity than random locations. During the winter, lower ice concentrations were also associated with King Eider locations. This study provides some of the first large-scale descriptions

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of King Eider migration and habitat outside the breeding season.

Key Words: distribution, habitat, migration, satellite telemetry, Somateria spectabilis, *wing molt, wintering.*

INTRODUCTION

Eider species spend most of their annual cycle in remote, inaccessible marine habitats, precluding direct observation and contributing to an incomplete understanding of their life histories. They generally perform a distinct post-breeding migration to marine areas where they congregate in flocks and molt all flight feathers. During this three-to-four week flightless period, movements are constrained, and eiders may be vulnerable to disturbance and predation and subject to higher energy demands (Salomonsen 1968, King 1974, Hohman et al. 1992). They then move to wintering areas that are characterized by short periods of daylight and extremes in weather conditions, temperature, and ice cover (Systad et al. 2000, Petersen and Douglas 2004). Eiders generally form pair bonds on wintering areas and migrate as pairs to breeding grounds in the spring (Anderson et al. 1992). The chronology of these life-history events during the nonbreeding period may be linked to productivity on the breeding grounds (Heitmeyer and Fredrickson 1981, Hepp 1984, Dugger 1997), and may vary by age, sex, and habitat condition (Heitmeyer 1988). Female eiders rely heavily on endogenous reserves for egg laying (Korschgen 1977, Kellet 1999); therefore, body condition upon arrival at breeding grounds can influence clutch size and reproductive potential (Ankney and MacInnes 1978, Raveling 1979). Concern regarding apparent population declines in recent decades of all four eider species

(Stehn et al. 1993, Kertell 1991, Suydam et al. 2000) has led to increased interest in location and timing of migration, delineation of wing molt and wintering areas, and habitat characterization of these sites (U. S. Fish and Wildlife Service 1999, Sea Duck Joint Venture Management Board 2001).

At-sea wing molt and wintering areas of the eastern Alaskan-western Canadian population of King Eiders (*Somateria spectabilis*) are thought to be in marine environments along the shores of the Bering Sea, especially along the Chukotsk Peninsula, south of St. Lawrence Island, and along the Alaska Peninsula and Aleutian Islands (Dickson et al. 2000, Suydam 2000). Aerial observations in Alaska (Larned and Tiplady 1998) have thus far been limited to a few known molt locations at St. Lawrence Island, Kvichak Bay, and Kuskokwim Bay. Dickson et al. (2000) used satellite telemetry to identify wing molt areas, but transmitters did not last beyond mid-winter.

In 2002 and 2003, we obtained location data for the entire annual cycle of 33 King Eiders. Additionally, we collected wing molt location information for 27 eiders in 2004. Thus, we can describe the movements and habitat characteristics of areas used by this sample of King Eiders throughout the entire nonbreeding period. Our objectives were to: (1) determine the timing of migratory movements throughout the annual cycle and variation in timing between the sexes and among years; (2) relate timing of individual movements with distance traveled on migration, latitude of wing molt and wintering areas, and length of time spent at wing molt sites; (3) determine whether individuals were distributed evenly by sex and among years during wing molt and wintering periods; and (4) describe oceanographic and physical characteristics of wing molt and wintering areas.

METHODS

STUDY SITES

Capture locations. We trapped King Eiders in early to mid-June of 2002, 2003, and 2004 at two sites on the North Slope of Alaska: Teshekpuk Lake (70°26'N, 153°08'W) and Kuparuk (70°20'N, 149°45'W). The Kuparuk study site was located between the Colville and Kuparuk rivers. The Teshekpuk Lake study site was added as a trapping location in 2004 and was located about 80 km west of the Kuparuk study area and 10 km inland from the southeast shore of Teshekpuk Lake.

Wing molt and winter locations. During the post-breeding period (late June through mid-September), Alaskan-breeding King Eiders generally move into the Bering Sea. The Bering Sea is characterized by a large, shallow, gently-sloping coastal shelf that is less than 200 m deep and encompasses almost half the sea's total area. This shelf is broad (>500 km) in the northeast along the Alaskan coast and narrow (<100 km) in the southwest along the Siberian coast.

In winter, the Bering Sea is characterized by high winds, frequent storms, and complete ice coverage of its shallow continental shelf region (Niebauer et al. 1999). The seasonal ice pack persists for six to eight months each year and generally reaches its maximum southern extent by March or April (Fay 1974). Major polynyas occur south of the Chukchi Peninsula, St. Lawrence Island, St. Matthew Island, and the Seward

Peninsula (Stringer and Groves 1991). The amount of available daylight in the Bering Sea decreases to between four and six hours in late December and early January.

The Bering Sea is unusually productive for a high latitude body of water. A number of mechanisms are thought to support this high productivity, including the broad shallow coastal shelf, the extensive seasonal ice coverage, and the convergence of current systems rich in nutrients (Walsh et al. 1989, Springer and McRoy 1993). The high density of benthic invertebrates in the Bering Sea is thought to be linked to its high primary productivity (Grebmeier 1993). King Eiders probably forage on benthic and epibenthic invertebrates while in marine systems (Frimer 1997, Suydam 2000).

DESIGNATION OF WING MOLT AND WINTERING AREAS

We obtained locations of King Eiders throughout the nonbreeding period using implantable satellite transmitters. King Eiders were captured on breeding grounds in early to mid-June using mist net arrays and decoys. Once captured, the eiders were placed in a secure, dark kennel and transported to a nearby indoor facility or weatherport equipped for surgery. A 35-g satellite platform transmitting terminal (PTT) transmitter (Microwave Telemetry, Inc., Columbia, MD) was surgically implanted into the abdominal cavity of each eider following the techniques of Korschgen et al. (1996). Satellite transmitters were <3% of the average body mass of birds used in this study. Eiders were fitted with a U.S. Fish and Wildlife Service band while under anesthesia. We held birds until fully awake and recovered from anesthesia (usually about two to three hours), and then released them at capture sites. At Kuparuk, transmitters were implanted into 21 (10 female, 11 male) King Eiders in 2002, 12 (3 female, 9 male) in

2003, and 15 (8 female, 7 male) in 2004. Twelve (5 female, 7 male) King Eiders were fitted with transmitters at Teshekpuk in 2004. All methods and handling of birds were approved by the University of Alaska Institutional Animal Care and Use Committee (IACUC # 02-10).

We programmed transmitters with four duty cycles. Transmitters sent location information to satellites for six hours every 48 h from June through September, every 84 h from October through December, every 168 h from January through March, and every 84 h from April until the end of the battery life. The expected battery life was about one year. Satellite transmitters used in this study had an average life-span of 385 $\pm$15 (SE) days (n = 33, range 99 – 519 days). We received location data from Service Argos (2001). Location data were filtered for accuracy using PC-SAS Argos Filter V5.1 (Dave Douglas, USGS, Alaska Science Center, Anchorage, AK). The filtering program removed implausible locations based on location redundancy and tracking paths. The best location per transmission period was used for our analyses based on location class and number of locations received. Locations were plotted using ArcView GIS (ESRI 1998). Definitions used to categorize events throughout the annual cycle for use in analyses are included in Table 2-1.

HABITAT DATA

We used randomly-selected King Eider locations and computer-generated random locations to investigate habitat characteristics at wing molt and wintering areas. Due to the variation in the number of locations obtained per individual throughout the nonbreeding period, we randomly selected five locations per individual during wing molt and ten locations during the wintering period to create two subsets of eider locations for use in habitat analyses. We created 6500 random points along the coastlines of Alaska and Russia extending from the coast to 80 m water depth to represent habitat available to King Eiders outside the breeding season. These points were generated along coastlines used by King Eiders in this study, including the Bering Sea, Kamchatka Peninsula, Alaska Peninsula, Kodiak Island, and Kenai Peninsula. We created all random subsets using Random Point Generator 1.27 extension (Jennes 2003) in ArcView.

We chose habitat variables based on availability of data and relevance to potential King Eider distribution as suggested by available literature on sea duck wing molt and winter ecology (Guillemette et al. 1993, Frimer 1995, Bustnes and Lonne 1997, Esler et al. 2000, Petersen and Douglas 2004). We used nine variables as potential indices for the food resources and chemical and physical habitat characteristics available at possible wing molt and winter sites. We included phosphate (μM), nitrate (μM), chlorophyll (μg/l), and apparent oxygen utilization (AOU, ml/l) as indices of primary productivity; surface salinity (ppm) and temperature (degrees C) as possible representations of freshwater inputs, upwellings, or polynyas; and water depth (m), distance from shore (km), and ice cover as physical characteristics of habitat. Data for salinity, temperature, phosphate, nitrate, chlorophyll, and AOU were obtained from World Ocean Atlas: 2001 (WOA01, Conkright et al. 2002) as point data with a spatial resolution of 2° latitude by 2° longitude. We used monthly averages of salinity and temperature values and annual averages of all other WOA01 variables. We acquired weekly percent ice cover data from the National Ice Center (2004). Bathymetric data were obtained from ETOP02, a point database with a 0.25° spatial resolution compiled by the National Oceanic and Atmospheric Administration from Smith and Sandwell (1997) and Jakobsson et al. (2001). The depth value nearest a random point or eider location was assigned as the bathymetric value for that location. Distance from shore was calculated using ArcView GIS as the shortest distance from a random point or eider location to a 1:250,000 polyline shapefile (Soluri and Woodson 1990) of the Russian and Alaskan coastlines.

STATISTICAL ANALYSES

We used two-way ANOVA to test for differences by sex and year in the timing of molt migration, residence time at wing molt sites, fall migration, and spring migration. Significant differences among years were further examined using Tukey multiple comparison procedures. We calculated migration distance as the distance between as many subsequent locations that passed filtering requirements as possible per individual and corrected for curvature of the earth. Latitude of wing molt and wintering sites was calculated as the centroid of minimum convex polygons (Hooge and Eichenlaub 1997) at these sites. We then explored relationships among timing of molt, fall, and spring migration with distance of molt migration, number of days spent at wing molt locations, and latitude of wing molt and winter locations using Spearman rank-order correlations.

Differences in distributions of King Eiders during the wing molt and winter periods were examined using multiresponse permutation procedures (MRPP) in BLOSSOM (USGS, Fort Collins, Colorado, Cade and Richards 2001). We used the centriod of the minimum convex polygon (Hooge and Eichenlaub 1997) of the wing molt area and farthest south wintering area of each individual as the sampling unit and compared distributions by sex and among years.

We examined the characteristics of habitats occupied during wing molt and winter periods using logistic regression techniques with candidate model sets. The best model was determined using Akaike's Information Criterion (AIC). For each model, we report AIC value and ΔAIC. We reported coefficients of determination (r^2) for best approximating models to describe variation explained by the model.

We examined collinearity among habitat variables to exclude highly correlated variables from the analyses. Phosphate, nitrate, chlorophyll and apparent oxygen utilization (AOU) were highly correlated, as was chlorophyll with temperature. Of these variables, chlorophyll best reflects primary productivity (Lalli and Parsons 2002); therefore, we chose to retain chlorophyll in the analyses and excluded the other variables. We removed ice cover as a variable in the candidate model set for molt site habitat analyses because ice cover was essentially zero during this period. We included the interactions ice cover and distance from shore, ice cover and water depth, and chlorophyll and salinity.

Means are presented ±SE. All statistical analyses were performed using SAS software (SAS Institute 1990).

RESULTS

VARIATION IN TIMING AND DISTRIBUTION

Wing molt migration. Mean dates of dispersal from breeding areas and arrival at wing molt sites differed by sex (dispersal from breeding: $F_{1,59}$ =75.28, P <0.001; arrival at wing molt site: $F_{1,59}$ =65.79, P <0.001) and among years (dispersal from breeding: $F_{2,59}$ =7.18, P <0.01; arrival at molt site: $F_{2,59}$ =3.98, P =0.02). Female eiders dispersed from breeding areas and arrived at wing molt sites later than males in all years (Table 2-2, Figure 2-1). King Eiders that arrived at wing molt sites earlier flew shorter distances on molt migration (r_s =0.30, P =0.02, Figure 2-2), and male King Eiders that arrived at wing molt sites earlier molted at higher latitudes (r_s =0.42, P =0.01).

Wing molt sites. Average number of days at wing molt areas varied by year ($F_{2,55}$ =4.99, P =0.01) with eiders spending significantly more days at wing molt sites in 2003 (74 ±4 days) than either 2002 (57 ±3 days) or 2004 (53 ±2 days). Number of days at wing molt sites did not vary by sex ($F_{1,55}$ =2.41, P =0.13). Females dispersed from wing molt sites later than males ($F_{1,55}$ =5.57, P =0.02, Table 2-2). Dispersal date from wing molt sites did not vary by year ($F_{2,55}$ =1.57, P =0.22). During wing molt, King Eiders were located in marine areas along the Chukotsk, Kamchatka, and Alaska Peninsulas; St. Lawrence Island, Anadyr, Olyutor, Karagin, Bristol and Kuskokwim Bays; Beaufort Sea; and the coast of Russia near Khatyrka (Table 2-3, Figure 2-3). MRPP did not distinguish differences in distribution of wing molt locations by sex (P = 0.57) or year (P =0.44).

Wintering areas. Eiders wintered along the Chukotsk, Kamchatka, and Alaska Peninsulas, Olyutor and Bristol Bays, and the Gulf of Alaska (Table 2-3, Figure 2-4). MRPP did not distinguish differences in distribution of winter locations by sex (P =0.16) or year (P =0.59).

Spring migration. Arrival date at breeding areas the following year did not vary by sex ($F_{1, 18}$ =1.64, P =0.22) or year ($F_{2, 18}$ =0.01, P =0.92); however, female King Eiders that wintered farther south arrived earlier at breeding locations the following summer (r_s =0.66, P =0.07). Spring arrival date of males was not correlated with wintering latitude (r_s =0.20, P =0.56).

The year/sex interaction term was not significant in all previous two-way ANOVAs (P >0.10).

HABITAT CHARACTERISTICS

Wing molt sites. No one model best described habitat characteristics of King Eider locations during wing molt. The top two models suggested support for the parameters distance to shore, water depth, salinity, chlorophyll, and salinity/chlorophyll interaction (r^2 =0.38, Table 2-4). King Eider wing molt sites were located in shallower areas, closer to shore, and with lower salinity and chlorophyll values than random points (Table 2-5).

Wintering areas. The model with parameters ice cover, distance to shore, water depth, salinity, and ice cover/distance to shore interaction best described wintering habitat (r^2 =0.22, Table 2-4). King Eider wintering locations were in shallower areas, closer to shore, and with lower salinity and percent ice cover than random points (Table 2-5).

DISCUSSION

CHRONOLOGY OF NONBREEDING EVENTS

For Alaskan-breeding King Eiders, differences between sexes in dispersal dates from breeding grounds, arrival dates at wing molt sites, and departure dates from wing molt sites were consistent with those captured in western Canada (Dickson et al. 2000), King Eiders molting flight feathers in Greenland (Frimer 1994a), and with other eider species (Petersen 1981, Petersen et al. 1999). The later chronology of molt migration in 2004 suggested inter-year variation in the timing of King Eider wing molt. The interrelationship of reproductive and wing molt periods in waterfowl has been demonstrated in previous studies. The annual variation in the timing of nesting tends to affect the molt chronology of females more than males (Leafloor and Ankney 1989, Hohman et al. 1992). Postbreeding female waterfowl may have less time for premigratory fattening, potentially leading to a cascading delay in timing of arrival at wing molt, wintering, and breeding sites the following year (Hohman et al. 1992).

Migration is energetically costly, and mortality risks may be proportional to time spent migrating (Ketterson and Nolan 1976). We found that King Eiders arriving earlier at wing molt sites flew shorter distances on molt migration, potentially incurring fewer costs than birds flying farther and arriving later. Intraspecific competition for food resources may be high at molt sites closer to breeding areas, forcing later arrivals to undergo longer migrations (Gauthreaux 1985). Mehl et al. (2004) suggested the flocking nature of King Eiders on migration may allow them to follow other individuals to alternate wintering areas. However, limited data on sequential wing molt sites (n =10) suggests that King Eiders, especially males, may show fidelity to wing molt locations (L. Phillips, unpublished data). This fidelity would be consistent with that seen in Steller's Eiders (*Polysticta stelleri*) which exhibited high return rates to molting areas along the Alaska Peninsula (Flint et al. 2000), and with other waterfowl species (Bowman and

Brown 1992, Bollinger and Derksen 1996). King Eiders may use a combination of strategies with individuals following flocks to molt locations in some years and exhibiting fidelity in others.

DISTRIBUTION OF WING MOLT AND WINTERING AREAS

Male and female King Eiders exhibited no sexual segregation of wing molt sites. There is some evidence that female eiders that successfully raise young to fledging may molt flight feathers closer to the breeding grounds (Petersen et al. 1999), possibly in freshwater wetlands (Knoche 2004). During the course of this study, we found three of our transmittered hens incubating eggs, but their early dispersal from breeding areas suggested none successfully fledged young. The apparent lack of successfully breeding females in this study may explain our inability to detect any sexual segregation. The distribution of wintering sites also did not differ between male and female King Eiders. This lack of sexual segregation would be predicted for waterfowl species that, like King Eider, form pair bonds on wintering grounds (Hepp and Hair 1984) or use marine habitat during winter (Diefenbach et al. 1988).

Wing molt sites for King Eiders in this study were similar to those found by Dickson et al. (2000), with the addition of molting areas located in the Alaskan Beaufort Sea, Olyutor Bay, and on the west side of the Kamchatka Peninsula. We found additional wintering areas in Olyutor Bay, at the southern most tip of the Kamchatka Peninsula, and in Anadyr Bay. Both wing molt and wintering sites for our sample of King Eiders were widely dispersed along the coastlines of the Bering Sea, supporting the results of Pearce et al. (2003) of little population structure within the western population of King Eiders.

HABITAT CHARACTERISTICS

Throughout the nonbreeding period, we found that King Eiders inhabited relatively shallow, nearshore areas that were characterized by low salinity. On average, transmittered King Eiders were located 6 km from shore during wing molt, while post-breeding King Eiders in western Greenland were primarily observed within 1 km of the coast (Mosbech and Boertmann 1999), and molting King Eiders south of St. Lawrence Island and in Kvichak Bay were found >20 km offshore (Larned and Tiplady 1998). While King Eiders foraged predominantly in water 15 – 25 m deep during wing molt in Greenland (Frimer 1995, Bustes and Lonne 1997), eiders generally moved far offshore into deeper water to rest at night (Frimer 1995). Although we did not find salinity to be highly correlated with distance to shore, lower salinity values at King Eider locations may have been a reflection of freshwater inputs, suggesting that King Eiders molted wing feathers near estuaries.

In our habitat models, we intended chlorophyll to reflect the potential food resources at available eider locations and random points. Higher chlorophyll would reflect higher primary productivity and, as a result, higher benthic biomass (Grebmeier 1993). During wing molt, King Eider locations were described by lower chlorophyll values and a chlorophyll/salinity interaction. Benthic biomass in the Bering Sea is unusually high (Grebmeier et al. 1988), and food resources at King Eider wing molt sites may not be limited despite an indication of lower primary productivity in these areas based on chlorophyll values.

King Eiders occupied wintering areas with lower percentage ice cover than random points. Common (*Somateria mollissima*) and Spectacled Eiders have shown a high tolerance for ice obstruction. Common Eiders in the Gulf of St. Lawrence foraged in small openings within areas of >75% ice cover (Guillemette et al. 1993). Petersen and Douglas (2004) found that although population indices of Spectacled Eiders were negatively correlated with extreme ice conditions at core wintering areas, Spectacled Eiders did not move from these areas when ice began to cover them. Multiple wintering locations for birds in our study may reflect that King Eiders are less restricted in their habitat requirements during winter than Spectacled and Common Eiders and may have the ability to move away from areas with high ice concentrations to those with more available foraging habitat.

We did not address a number of habitat characteristics that may influence King Eider use of wing molt and wintering areas in our analyses. Shelter from wind and wave action was thought to be an important habitat characteristic of King Eider wing molt sites in Greenland (Frimer 1994b) and Harlequin Duck (*Histrionicus histrionicus*) wintering areas in Prince William Sound (Esler et al. 2000). Sea ducks may also require protection from human disturbance and predation and the presence of conspecifics at wing molt and wintering areas (Salmonsen 1968, Guillemette et al. 1993, Frimer 1994a, Mosbech and Boertmann 1999).

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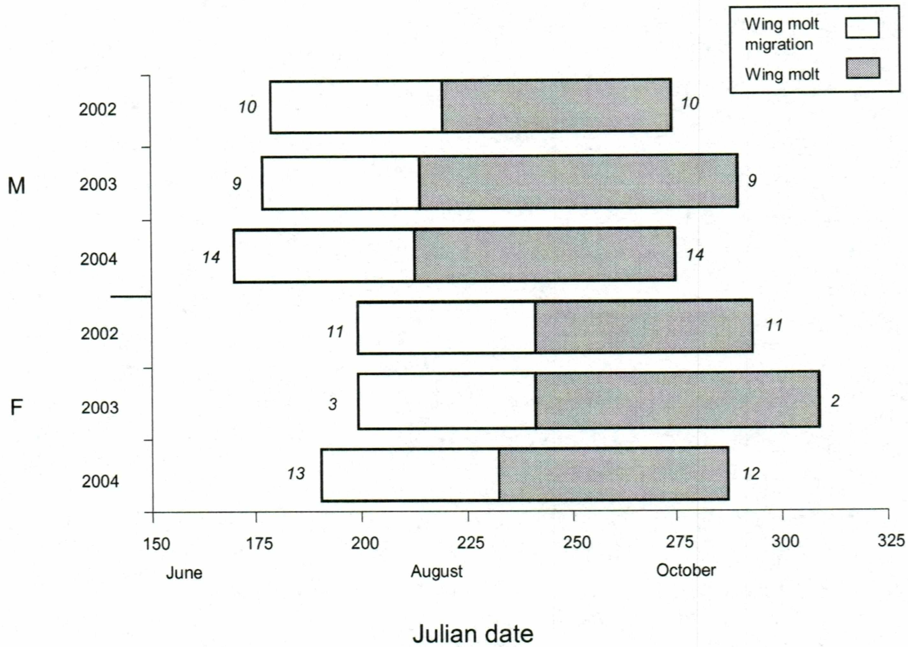

Figure 2-1. Mean number of days spent on wing molt migration and at wing molt sites for male (M) and female (F) satellite-transmittered King Eiders, 2002 – 2004. Sample sizes for the number of individual eiders used to calculate mean days of wing molt migration and duration at wing molt sites are represented by the italicized number before and after the bar graphs, respectively. Ranges associated with dates of dispersal from breeding areas, arrival at wing molt sites, and dispersal from wing molt sites can be found in Table 2.

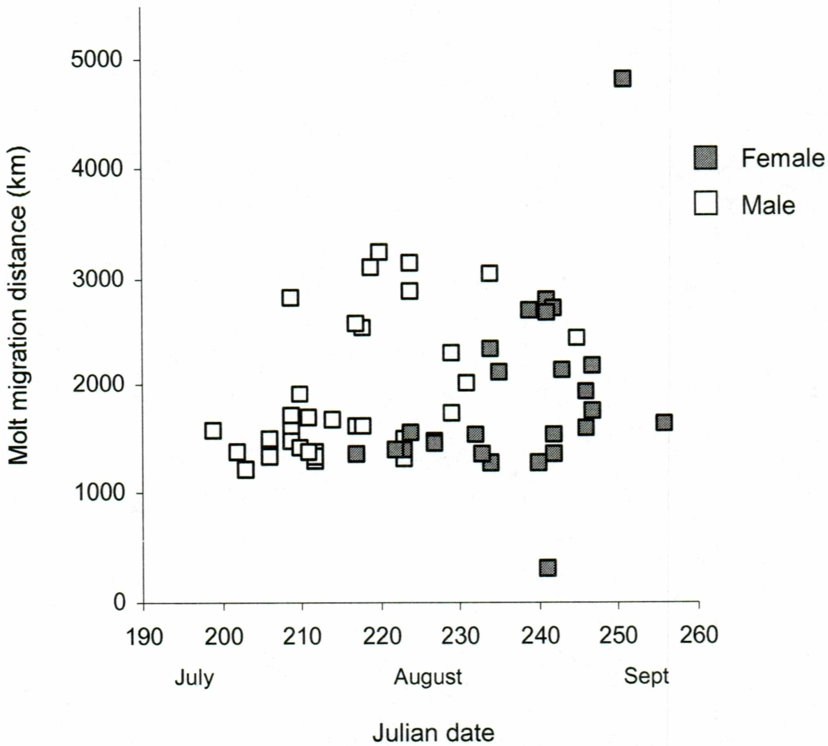

Figure 2-2. Correlation of Julian date of arrival at wing molt site with distance of wing molt migration for male and female satellite-transmittered King Eiders.

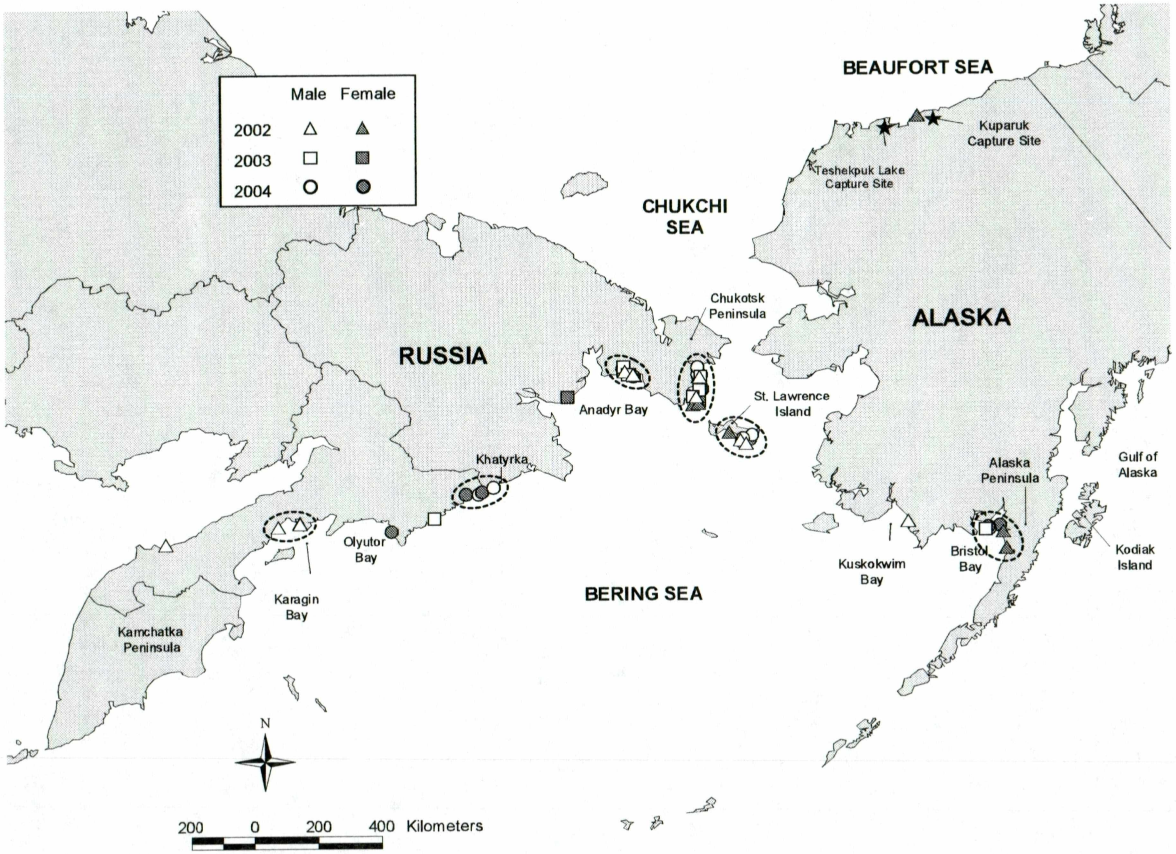

Figure 2-3. Distribution of male and female satellite-transmittered King Eiders during 2002 – 2004 wing molt periods. Areas occupied by two or more eider locations over the three years of the study are outlined by a dashed grey line.

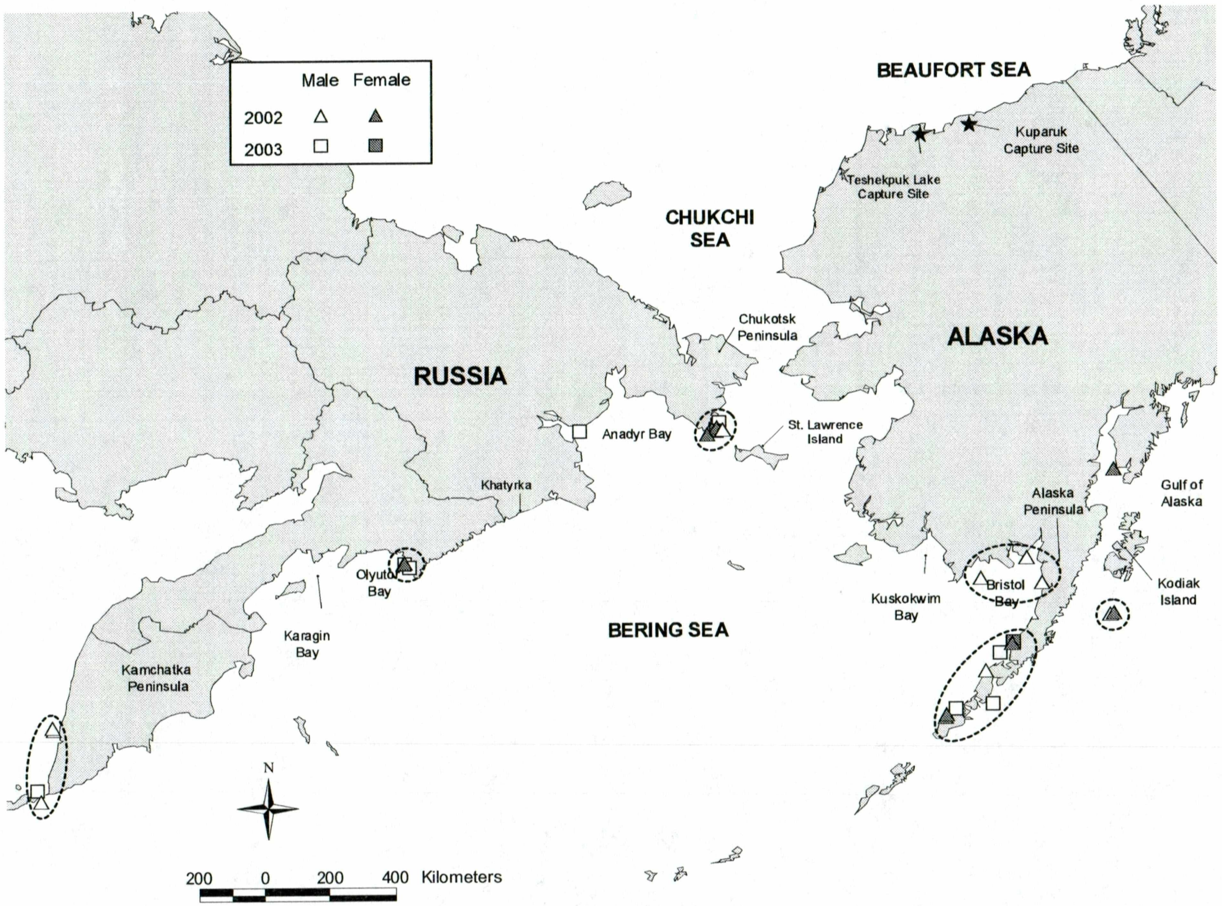

Figure 2-4. Distribution of male and female satellite-transmittered King Eiders during 2002 – 2003 wintering periods.

Areas occupied by two or more eider locations over the two years of the study are outlined by a dashed grey line.

Table 2-1. Definitions of King Eider nonbreeding life history events as defined by satellite telemetry locations.

	Definition
Dispersal	Movement that increases the mean distance between individuals (Baker 1978)
Migration	A set of sequential locations indicating movement in a single direction during which an individual remains in no one area ≥ 1 week (Petersen et al. 1999)
Wing molt migration	The migration period from the last day at the breeding area to the first day at the wing molt location
Wing molt site	An area where an eider spent ≥ 3 weeks with lowest daily movement rates between June and December prior to movement toward wintering areas
Fall migration	The migration period from the last day at the wing molt site to the first day at the farthest south wintering location
Wintering area	An area where an eider spent ≥ 1 week between the end of the wing molt period and spring migration; King Eiders may have multiple wintering areas
Spring migration	The period of migration from the last day at a wintering area to the first day on land at a subsequent breeding location; if there

	were no onshore locations for an eider during the subsequent breeding period, the first location at a June offshore staging area was used
Subsequent breeding area	An area onshore where an individual was located after spring migration and prior to fall migration

Table 2-2. Means and ranges of dates of dispersal from breeding areas, arrival at wing molt sites, dispersal from wing molt sites, and arrival at subsequent breeding areas for male and female King Eiders captured on the North Slope of Alaska in 2002 - 2004.

	Dispersal from breeding (*n*)	Range	Arrival at molt (*n*)	Range	Dispersal from molt (*n*)	Range	Arrival at breeding (*n*)	Range
SEX								
Male	23 Jun (33)	14 Jun - 4 Jul	31 Jul (33)	18 Jul - 2 Sep	2 Oct (33)	13 Sep - 12 Nov	12 Jun (12)	7 - 24 Jun
Female	14 Jul (27)	21 Jun - 8 Aug	28 Aug (27)	5 Aug - 13 Sep	17 Oct (23)	16 Sep - 9 Nov	11 Jun (7)	7 - 12 Jun

YEAR								
2002	29 Jun (21)	14 Jun - 26 Jul	10 Aug (21)	21 Jul – 8 Sep	5 Oct (19)	16 Sep – 9 Nov	11 Jun (12)	7 – 24 Jun
2003	30 Jun (12)	20 Jun – 30 Jul	8 Aug (12)	18 Jul – 4 Sep	15 Oct (11)	23 Sep – 12 Nov	12 Jun (7)	6 – 23 Jun
2004	6 Jul (27)	19 Jun – 7 Aug	16 Aug (27)	27 Jul – 12 Sep	8 Oct (26)	12 Sep – 29 Oct	NA	NA
ALL	3 Jul (60)	14 Jun – 8 Aug	13 Aug (60)	18 Jul – 13 Sep	9 Oct (56)	13 Sep – 12 Nov	12 Jun (19)	7 – 24 Jun

Table 2-3. Proportion of male and female satellite-transmittered King Eiders captured on the North Slope of Alaska located in major wing molt and wintering areas in 2002 – 2004.

	2002		2003		2004	
Location	Male	Female	Male	Female	Male	Female
WING MOLT AREA (*n*)	(11)	(10)	(9)	(2)	(14)	(13)
Russia						
Karagin Bay	0.18	0.10	0	0	0	0
Khatyrka	0	0	0	0	0.14	0.15
Anadyr Bay	0.18	0.10	0.44	0	0.07	0.08
Chukotsk Peninsula	0.18	0.50	0.33	1.00	0.43	0.46
Alaska						
St. Lawrence Island	0.18	0.10	0	0	0.21	0.08
Bristol Bay	0	0.20	0.11	0	0.07	0.15
WINTERING AREA (*n*)	(10)	(8)	(9)	(2)		
Russia						
Kamchatka Peninsula	0.30	0	0.11	0		

Olyutor Bay	0.10	0.38	0.22	0
Chukotsk Peninsula	0.10	0.12	0.22	0.50
Alaska				
Bristol Bay	0.30	0	0	0
Alaska Peninsula	0.10	0.38	0.33	0.50
Gulf of Alaska	0.10	0.12	0	0

Table 2-4. Selection results for models explaining variation in habitat characteristics of wing molt and wintering areas of satellite-transmittered King Eiders captured on the North Slope of Alaska in 2002-2004. Models were evaluated using Akaike's Information Criterion. The four models with the lowest difference in AIC (Δ AIC) from the top model are presented, as well as the null model containing no factors.

Model	AIC Value	Δ AIC
WING MOLT		
Distance shore, salinity, chlorophyll, chlorophyll x salinity	947.43	0
Distance shore, depth, salinity, chlorophyll, chlorophyll x salinity	949.2	1.77
Distance shore, salinity, chlorophyll	949.95	2.53
Distance shore, depth, salinity, chlorophyll	951.47	4.04
Null model	1445.51	498.08
WINTERING		
Ice, distance shore, depth, salinity, ice x distance shore	1785.09	0
Ice, distance shore, depth, salinity, ice x depth	1792.69	7.60
Ice, distance shore, depth, ice x distance shore	1798.36	13.27
Ice, distance shore, depth, salinity, chlorophyll	1798.44	13.35
Null model	2265.99	480.90

Table 2-5. Mean values ± SE of habitat variables associated with locations of King Eiders captured on the North Slope of Alaska in 2002-2004 and random points during wing molt and winter.

	Molt		Winter	
	Eider location	Random point	Eider location	Random Point
Distance to shore (km)	6.1 ± 0.4	68.3 ± 0.7	11.1 ± 0.8	64.3 ± 0.7
Water depth (m)	19.3 ± 2.5	44.1 ± 0.4	37.9 ± 3.2	45.8 ± 0.4
Salinity (ppm)	33.7 ± 0.3	35.2 ± 0.0	34.6 ± 0.1	35.2 ± 0.0
Chlorophyll (µg/l)	0.8 ± 0.1	1.3 ± 0.0	1.2 ± 0.1	1.3 ± 0.0
Ice cover (%)			22 ± 2	32 ± 1

CONCLUSIONS

The apparent decline of the western population of King Eiders (Suydam et al. 2000) has stimulated interest in collecting baseline data of their distribution throughout the annual cycle (U. S. Fish and Wildlife Service 1999, Sea Duck Joint Venture Management Board 2001). Life history events outside the breeding season may be critical to the survival, body condition, and breeding potential of eiders nesting on the North Slope of Alaska. Migration and wing molt are energetically costly events (Salomonsen 1968, King 1974, Ketterson and Nolan 1976, Hohman et al. 1992), and extreme weather or ice conditions on wintering grounds could decrease survival or body condition (Heitmeyer 1988, Petersen and Douglas 2004). Offshore oil and gas exploration in the Alaskan Beaufort Sea also supports the need for distribution information for management agencies to use to modify proposed developments and associated activities to minimize impacts.

Hundreds of thousands of King Eiders pass through the Beaufort Sea each year during spring and post-breeding migrations (Suydam et al. 2000). More than 80 % of our transmittered eiders spent more than 2 weeks staging offshore prior to beginning molt migration, suggesting the Beaufort Sea is an important migration flyway and staging area for King Eiders in this study. Male and female distributions in the Alaskan Beaufort Sea differed during the post-breeding period, with females being more concentrated in Harrison and Smith Bays. Female King Eiders also had longer residence times within the Beaufort Sea prior to molt migration suggesting the Beaufort Sea may be an important area for females to replenish fat stores depleted during incubation and brood rearing

(Kellet 1999). We recommend future oil and gas development be managed to minimize disturbance and potential contamination of Harrison Bay and Smith Bay, especially during the female post-breeding period (late June through August).

Spring and post-breeding distributions of King Eider locations in the Alaskan Beaufort Sea overlapped very little. Short residence times and deep water at spring locations relative to post-breeding locations suggested that during spring eiders were using the Alaskan Beaufort Sea as a migration flyway rather than a staging area. Spring staging areas for eiders in this study were located outside the Alaskan Beaufort Sea, primarily within Ledyard Bay in the Chukchi Sea (L. Phillips, unpublished data). We recommend future studies examine the habitat characteristics of Ledyard Bay and evaluate its importance as a spring stopover site for migrating King Eiders.

Our findings support the idea of an annual cycle of interrelated life history events (Bowman 1987, Hohman et al. 1992). Timing of wing molt migration was influenced by breeding chronology, and latitude of wing molt sites was correlated with arrival date at these sites.

Our sample of King Eiders captured on the North Slope of Alaska was widely dispersed along the coastlines of the Bering Sea during wing molt and winter. The distribution of known wing molt sites was expanded to include areas in the Alaskan Beaufort Sea, Olyutor Bay, and the west coast of the Kamchatka Peninsula. Additional wintering sites were located in Olyutor Bay, Anadyr Bay, and the southern tip of the Kamchatka Peninsula. The broad use of the coastal Bering Sea during the nonbreeding period probably allows for substantial overlap of Alaskan-breeding eiders with those nesting in Russia and supports the results of Pearce et al. (2003) of little population structure within the western population of King Eiders.

On a large spatial scale throughout the nonbreeding period, we found that King Eiders used relatively shallow areas, nearshore, that were characterized by low salinity. Ice cover also seemed to be an important variable describing winter locations of King Eiders with eiders using areas of lower percent ice cover than random points. Multiple wintering locations for birds in this study may reflect the ability of King Eiders to move away from areas with high ice concentrations to those with more available foraging habitat.

This study provides an initial look at the life history events of King Eiders outside the breeding period and should benefit planning future efforts to better understand requirements of eiders during migration, wing molt, and winter. Variation in timing and distribution of eiders during staging, wing molt, and winter would be better explained with more data collected across a longer time period as well as location information from a sample of successfully breeding females and young of the year. Spring staging locations are likely critical to eiders as foraging areas and refugia from heavy ice. King Eiders rely on endogenous reserves for egg laying (Korschgen 1977, Kellet 1999), and disturbance or degradation of staging areas could have a disproportionately large impact on eider productivity. Ledyard Bay should be further investigated as a key stopover site for King Eiders on spring migration.

Habitat requirements were investigated in this study on a very large scale, and models may have lacked some parameters important to eiders during the nonbreeding period. To improve understanding of important habitat characteristics at staging, wing molt and wintering sites, variables such as wave height, current speed, benthic biomass, and substrate type should be examined. As a gregarious species outside the breeding season, King Eider may make habitat choices based on the presence of conspecifics. King Eiders have not been studied using direct observations during the nonbreeding period in the Bering Sea. Measuring habitat parameters and observing behavior of King Eiders at major wing molt and wintering locations in the Bering Sea such as Chukotka, Olyutor Bay, Bristol Bay and St. Lawrence Island using ground or aerial observations would increase our understanding of their nonbreeding biology.

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