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ORIGINAL PAPER

International importance of the eastern Chukchi Sea as a staging area for migrating king eiders

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Abstract The evaluation of habitats used by arctic birds on migration is crucial for their conservation. We explored the importance of the eastern Chukchi Sea (ECS) as a staging area for king eiders (*Somateria spectabilis*) migrating between breeding areas in Siberia and western North America and wintering areas in the Bering Sea. We tracked 190 king eiders with satellite transmitters between 1997 and 2007. In late summer, 74% of satellite-tracked king eiders migrating south staged in the ECS for 13 ± 13 (SD) days between late June and early November. During spring migration, king eiders staged in the ECS between mid-April and early June for 21 ± 10 days. All instrumented birds migrating to breeding grounds in western North America ($n = 62$), and 6 of 11 males migrating to breeding grounds in Siberia, used this area for at least 1 week during spring migration. The importance of this staging area renders it possible that industrial development could adversely affect king eider populations in both Siberia and North America.

Keywords Industrial development · King eider · Migration · Satellite telemetry · Staging · *Somateria spectabilis*

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Introduction

Migratory birds depend on a variety of habitats throughout their annual life cycle, and recent evidence suggests that there are strong seasonal interactions between different life-history stages that affect the fitness of individuals and the demography of migratory populations (Newton 2006; Norris and Marra 2007). Rapid changes to an environment used by migratory birds during one season may therefore affect the fitness of individuals in subsequent seasons. In staging areas, where birds accumulate body reserves for migration and other energetically costly life-history events, changes in habitat quality may result in reduced body condition of migrants, which in turn may decrease reproductive output or overwinter survival (Klaassen et al. 2006b; Drent et al. 2007).

Many sea duck populations migrate from arctic breeding grounds to sub-arctic or temperate wintering areas at sea. For large sea ducks, like eiders (*Somateria* spp.), seasonal carry-over effects are assumed to be relatively strong (Parker and Holm 1990; Meijer and Drent 1999). Changes to habitats on wintering grounds or along migration routes are therefore believed to be a potential cause of recent population declines for some species (Lovvorn et al. 2003; Grebmeier et al. 2006b). King eiders (*Somateria spectabilis*) are large sea ducks breeding around the circumpolar arctic. The population breeding in western North America declined between the 1970s and the 1990s (Suydam et al. 2000). King eiders in western North America migrate from breeding grounds in Alaska and western Canada through the Beaufort and Chukchi Seas to wintering areas in the Bering Sea (Suydam 2000; Oppel et al. 2008). While the distribution and habitat use of king eiders in the western Beaufort Sea has been analyzed (Phillips et al. 2007), there is currently little information on king eider distribution and use of the Chukchi Sea.

The Chukchi Sea is a shallow sea with a broad continental shelf that supports a high abundance of benthic organisms due to the influx of nutrients from the Bering Sea (Feder et al. 1994; Dunton et al. 2005). The high abundance of both plankton and benthic organisms provides a reliable food source for consumers at higher trophic levels, which renders the eastern Chukchi Sea an important habitat for large populations of sea birds (Springer et al. 1984) and marine mammals (Miller et al. 1986; Gilbert 1989).

The Chukchi Sea has been of interest for oil and gas exploration since the 1980s (Dees 1991). The shelf regions of the Chukchi Sea are estimated to hold between 1 and 14 billion barrels (Bbbl) of crude oil (Dees 1991; Sherwood et al. 2001), with 1 Bbbl currently being considered as a minimum threshold for economically feasible development (Minerals Management Service 2007). In recent years, receding sea ice cover and decreasing sea ice thickness as well as technological advances have facilitated exploration of arctic seas, including the Chukchi Sea (Kerr 2002; Khain and Polyakova 2006). In February 2008, the Minerals Management Service, the federal institution that regulates offshore oil exploration in the USA, sold 1.1 million hectares of lease area in the Chukchi Sea to oil companies (Minerals Management Service 2008). The final environmental impact statement (EIS) for the Chukchi Sea planning area highlighted that a lack of knowledge of natural resources in the area limited the credibility of any potential effects assessment (Minerals Management Service 2007). It conceded that there "is a high potential for marine and coastal birds to experience disturbance and habitat alteration. However, little recent site-specific data are available on habitat and use patterns, routes, and timing of specific species using the arctic environment" (Minerals Management Service 2007, p. ES-4).

In this study, we estimate the proportion of king eiders tracked to wintering areas in the Bering Sea that uses the eastern Chukchi Sea as a staging area during spring and fall migration. We further delineate core areas and annual windows during which the area is used by king eiders, and thus provide data that can be used to estimate the potential effects of oil and gas exploration activities on migratory eiders.

Materials and methods

Study area

We defined the eastern Chukchi Sea (ECS) as the part of the Chukchi Sea between Cape Thompson and Barrow, Alaska, within approximately 300 km from the shoreline. We chose this distance based on prior information from satellite telemetry which indicated few locations outside this area (Oppel et al. 2008). We included all locations from satellite tracked king eiders that fell into an area bounded by 68.09°N in the south, 72.05°N in the north, 169.84°W in the west, and 156.65°W in the east. The area included all active lease blocks currently being leased for exploration and future development (Minerals Management Service 2008).

Satellite telemetry

Between 1997 and 2007, we trapped 208 King Eiders: 103 adult and 51 juvenile king eiders in Alaska, USA (50 adult females, 53 adult males, 27 juvenile females, 18 juvenile males, 6 juveniles of unknown sex), and 54 adults (25 females, 29 males) in Northwest Territories, Canada (Table 1). We captured birds just prior to the breeding season (June) from 1997 to 2005, and during brood-rearing in late August 2006 and 2007. The 13 adult females captured in late August while accompanying young presumably nested successfully in the year of capture, and we refer to those birds as 'successful females' throughout the remainder of this paper.

Each bird was equipped with an intra-abdominal satellite transmitter (38 g PTT with external whip antenna, Microwave Telemetry Inc., USA) following standard surgical methods (Korschgen et al. 1996; Mulcahy and Esler 1999). We released the birds where they were caught two hours after surgery. Transmitters before 2006 were

Table 1 Locations in western North America where king eiders were captured and equipped with satellite transmitters

Site	*n* birds	Latitude	Longitude	Capture years
Victoria Island, Canada	44	70°21′N	110°30′W	1997, 1998, 2003, 2004
Prudhoe Bay, Alaska	10	70°10′N	148°35′W	1999
Banks Island, Canada	10	72°23′N	125°05′W	2000
Kuparuk Oilfield, Alaska	74	70°20′N	149°45′W	2002–2006
Teshekpuk Lake, Alaska	20	70° 26′N	153° 08′W	2003–2005
Trap Lake, Alaska	50	70° 26′N	152° 34′W	2007

Birds were captured before nesting in June from 1997 to 2005 and during brood-rearing in late August 2006 and 2007 programmed to different duty cycles throughout the year, with shorter duty cycles (4–6 h of transmission every 1–4 days) during fall migration, and longer duty cycles (6 h every 3–7 days) during spring migration (see Oppel et al. 2008 for details). In 2006 and 2007 we programmed transmitters to 6 h on and 5 days off throughout their lifetime. All birds were handled under the Institutional Animal Care and Use Committee protocol #05-29 of the University of Alaska Fairbanks, and Canadian Wildlife Service Animal Care Committee permit #PNR007.

We received location data from Service ARGOS and filtered them for unreasonable locations using the SAS ARGOS Filter algorithm using a maximum redundancy distance of 10 km and a travel rate of 60 km/h (Douglas 2006). This algorithm selected the best location per duty cycle based on the location class provided by ARGOS, and the distance, angle, and rate to previous and subsequent locations (Kenow et al. 2002). Further details on capture and tracking methods are presented elsewhere (Phillips et al. 2006; Oppel et al. 2008). Due to transmitter failure and mortality we lost 18 birds (nine adult males, five adult females, four juvenile females) prior to fall migration. We had information from 83 adult king eiders during spring migration, of which 15 did not provide reliable information to calculate staging times.

Calculations of staging pattern and spatial distribution

We calculated spatial distribution, arrival, departure, and residency times (hereafter referred to as staging pattern) separately for two seasons. Those two seasons were the southward migration in summer and fall, and the northward spring migration. We refer to the southward migration to molting and wintering areas as fall migration. We considered a king eider to be staging in the ECS if the bird was recorded at least once in the study area during the respective season. For each season, we calculated the residency time in the ECS for each individual bird by calculating the difference between the first and the last location in the study area. As the exact arrival and departure times are unknown, we added the length of one duty cycle to the residency time to account for uncertainty in arrival and departure times (Petersen et al. 2006). If a transmission period before or after locations in the ECS did not provide a reliable location, we added the length of half a duty cycle for each skipped transmission period to the residency time. If there was a gap of 10 days or more between the first or last location in the ECS and the previous or subsequent location outside the ECS, we excluded that bird from calculations of staging patterns in the ECS (7 birds during fall, 15 during spring migration).

We calculated the average arrival, departure, and residency times separately for males and females in both seasons, and for adult and juvenile birds during fall migration. We calculated the proportion of individuals with at least one location in the study area based on the total number of live birds with active transmitters during each season. This represents a minimum estimate of birds using the ECS, as staging periods shorter than one duty cycle could have gone undetected. For fall migration we analyzed birds captured in Alaska and Canada separately. During spring migration, we divided the actively transmitting birds into those that migrated to breeding grounds in Canada, Alaska, and Siberia, and calculated staging parameters for each group separately. Because female king eiders were captured only on North American breeding areas and females show high breeding site fidelity (Phillips and Powell 2006), we were unable to track females to breeding grounds in Siberia. King eiders form pair bonds in winter or early spring and the pair migrates north together (Rohwer and Anderson 1988; Suydam et al. 2000). Male migration patterns can therefore be assumed to reflect the migration patterns of the females they accompany. We calculated the distance flown to breeding grounds as the cumulative distance of all travel steps along the migration route from the last location in the ECS until the bird was recorded on land or reversed its heading to migrate south.

To describe the spatial distribution of king eiders staging in the ECS we estimated core use areas using fixed kernel density home ranges. We used Hawth's Tools for GIS v. 3.27 (Beyer 2004) to calculate 50% volume contours with a single parameter smoothing factor of $h = 10{,}000$, a grid cell size of 10,000 m, and a bivariate normal kernel function (Laver and Kelly 2008). We plotted king eider locations in ArcGIS 9.2 and calculated the distance of each recorded location ($n = 623$ for fall, and $n = 371$ for spring migration) to the coastline, as well as the proportion of locations within the area currently being leased for industrial development (Minerals Management Service 2007). Further, we used available bathymetry maps (National Ocean Service 1997) to describe water depths used by king eiders during staging.

We report all times, distances, and depths as mean ($\bar{x}$) ± SD. We compared times, distances, and depths among age, sex, and geographic groups using two-tailed non-parametric Mann–Whitney U tests or Kruskal–Wallis tests with $\alpha = 0.05$.

Results

Fall migration

King eiders migrated southward through the ECS from 21 June through 8 November (Table 2; Fig. 1), with the exception of one adult non-breeding male which arrived on

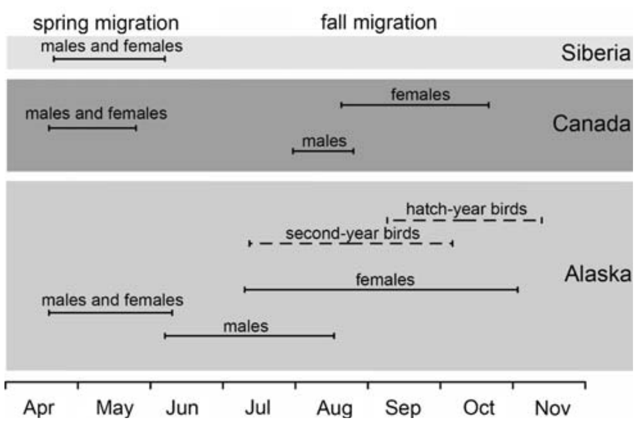

Fig. 1 Time ranges during which adult (*solid lines*) and young (*broken lines*) king eiders are present in the Eastern Chukchi Sea. Each *shaded box* summarizes data of birds migrating to (spring migration) or from (fall migration) one of three geographic breeding areas (Alaska, Canada, or Siberia). During spring migration both sexes migrate together; during fall migration sexes migrate at different times as indicated. Time ranges encompass periods between arrival of first and departure of last individual tracked with satellite transmitter; for sample sizes see Tables 2 and 3

5 June. Of a total of 190 king eiders alive and transmitting during fall migration we recorded 140 (74%) in the ECS between June and November. Staging in the ECS was more common among adults (79%, $n = 143$) than juveniles (59%, $n = 47$), and slightly more common for Canadian (81%, $n = 43$) than Alaskan birds (71%, $n = 147$). Most of the adult females equipped with a satellite transmitter in June did not nest successfully in the year they were tracked. Of the 13 successful females only two (15%) used the ECS on fall migration.

The staging pattern in fall differed between birds migrating from Alaska and western Canada, with adult males from Canada arriving later ($U = 15.0$, $P < 0.001$, $n = 60$) and staging for a shorter period ($U = 166.0$, $P = 0.006$, $n = 60$) than those from Alaska (Table 2). Adult females from Canada also arrived later than those from Alaska ($U = 90.5$, $P = 0.001$, $n = 48$), but females from both regions staged for similar periods in the ECS ($U = 184.0$, $P = 0.2$, $n = 48$). For adults, males migrated through the ECS earlier than females (Canada: $U = 2.0$, $P = 0.001$, $n = 28$; Alaska: $U = 5.0$, $P < 0.001$, $n = 80$). Males from Alaska remained in the ECS on average more than twice as long as all females ($U = 187.5$, $P < 0.001$, $n = 80$), but males from Canada remained on average only a day longer than all females ($U = 61.5$, $P = 0.1$, $n = 28$, Table 2). We did not record any adult king eider that moved <20 km in 3 weeks in the ECS. Such restricted movement would be indicative of flight feather molt (Phillips et al. 2006; Guillemette et al. 2007).

Juveniles were tracked only from Alaskan breeding grounds, and they migrated later than all adult females from Alaska ($U = 31.0$, $P < 0.001$, $n = 62$, Table 2). The majority (75%) of juveniles arrived in the ECS after successful females departed from the ECS (20 September, $n = 2$). Arrival, departure, and residency times were the same for male and female juveniles (all $P > 0.4$, $n = 24$). Juveniles of both sexes remained in the ECS on average 2 weeks longer than adult females ($U = 150.0$, $P < 0.001$, $n = 62$), and only slightly longer than adult males ($U = 577.5$, $P = 0.46$, $n = 74$) from Alaska.

Within the ECS, king eiders occurred in highest concentrations near Point Lay, Icy Cape, and Peard Bay (Fig. 2). Adults staged at an average distance of 13.7 ± 11.4 km from the shoreline in waters 20 ± 10 m deep ($n = 499$ bird locations), and farther offshore and in deeper water than juveniles (distance 5.3 ± 10.1 km,

Table 2 King eider staging times during fall migration in the eastern Chukchi Sea as revealed by satellite telemetry from adult birds captured on breeding grounds in Alaska or Canada, and hatch year birds captured in Alaska

	Adult				Hatch year					
	Male		Female		Male		Female		Unknown	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Alaska	(*n* = 46)		(*n* = 34)		(*n* = 12)		(*n* = 12)		(*n* = 4)	
Arrival	9 July	12	19 Aug	17	23 Sept	15	27 Sept	11	22 Sept	5
Departure	24 July	7	22 Aug	16	10 Oct	15	14 Oct	12	5 Oct	19
Residency time (days)	17	10	6	11	22	20	23	15	18	16
Canada	(*n* = 14)		(*n* = 14)							
Arrival	4 Aug	8	30 Aug	14						
Departure	9 Aug	7	3 Sept	15						
Residency time (days)	9	4	6	4						

Arrival is the first recorded location of a bird after migration from the Beaufort Sea, departure is the last recorded location prior to migration towards the Bering Sea, and residency time is the difference between the arrival and departure dates plus the time of one complete duty cycle of the satellite transmitter. All times are given ±SD (in days)

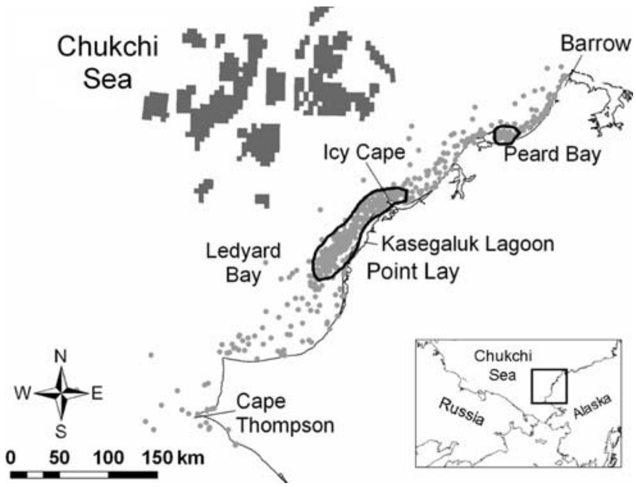

Fig. 2 Spatial distribution of king eiders in the eastern Chukchi Sea during fall migration from 5 June through 8 November. *Bold black lines* indicate high use areas (50% fixed kernel volume contours), *light gray points* represent king eider locations ($n = 623$) as recorded by satellite transmitters, and *dark gray blocks* are active leases for oil and gas exploration and development. *Inset* map shows general location of study area

depth: 10 ± 7 m, $n = 124$; both $P < 0.001$). Among juveniles, males and females were on average the same distance from the coast ($P = 0.51$, $n = 101$), and in waters equally deep ($P = 0.40$, $n = 101$). Among adults, females were farther offshore (16.7 ± 13.6 km) than adult males (12.4 ± 10.1 km, $P < 0.001$, $n = 499$), but not in deeper water (21 ± 9 m) than adult males (20 ± 11 m, $P = 0.30$, $n = 499$). We recorded no king eider locations within the area recently leased for oil and gas exploration and possible future development (Fig. 2).

Spring migration

Adult king eiders returned to the ECS in mid-April and remained through early June before continuing migration to their breeding grounds (Table 3; Fig. 1). In addition, 4 of the 25 first-year birds we tracked through spring and summer in the year after capture returned to the Chukchi Sea in their second summer. These second-year birds did not arrive in the ECS until July, and remained from 15 July through 2 October (Fig. 1).

We tracked 11 adult males to breeding grounds in Siberia, of which 6 (55%) used the ECS for an average of 24 days (Table 3). All of the 56 birds migrating to North American breeding grounds used the ECS. We excluded 15 birds from calculations of residency and departure times because the transmitter failed during staging in the ECS. One adult male left the ECS but did not migrate to a breeding area, and returned to the ECS after 2 weeks in the Beaufort Sea. Three birds (two males, one female) flew from the ECS >250 km into the Beaufort Sea in May, returned to the ECS less than a week later for a second staging period, and then continued spring migration. We subtracted the time spent in the Beaufort Sea from the spring staging time of these birds, but used the last location date in the ECS as departure date.

There were no differences in timing or duration of staging between males and females migrating to Alaska and Canada (all $P > 0.1$). All adult females returned to the breeding area where they had been caught initially, and we did not track any females migrating to Siberia. Thus, all king eiders tracked to Russian breeding areas (Table 3) were paired males that were presumably following unmarked females philopatric to their breeding areas.

The timing of spring migration differed among birds depending on their final breeding destination (Table 3). Birds subsequently migrating to all three regions (Alaska, Canada, Siberia) arrived in the ECS at similar times ($\chi^2_2 = 3.23$, $P = 0.2$, $n = 62$). Birds migrating from the ECS to Canada departed earliest ($\chi^2_2 = 8.53$, $P = 0.01$, $n = 62$), and had the shortest residency time in the ECS ($\chi^2_2 = 6.83$, $P = 0.03$, $n = 62$). The residency time was highly variable, ranging from 3 days to 6 weeks, and was longest for birds migrating to Alaska (Table 3).

Table 3 King eider staging times during spring migration in the eastern Chukchi Sea as revealed by satellite telemetry from adult birds

	Alaska (n = 23)			Canada (n = 33)			Russia (n = 6)		
	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD
Arrival	*23*	4 May	10	*33*	30 April	6	*6*	28 April	5
Departure	*23*	24 May	11	*33*	14 May	6	*6*	18 May	11
Residency time (days)	*23*	25	13	*33*	18	5	*6*	24	9
Distance to breeding site (km)	*20*	697	387	*16*	1,553	420	*5*	2,969	638

Birds are grouped into geographic regions of their final destination on spring migration, and average distance to breeding site is given for birds where the final destination of spring migration could be determined. Arrival date represents the first recorded location of a bird after migration north from the Bering Sea, departure date represents the last recorded location prior to migration towards the breeding grounds, and residency time is the difference between the arrival and departure dates plus the time of one complete duty cycle of the satellite transmitter. All times are given ±SD (in days)

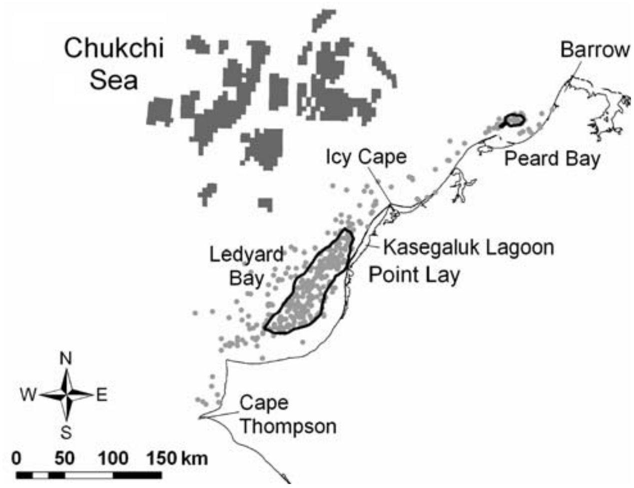

Fig. 3 Spatial distribution of king eiders in the eastern Chukchi Sea during spring migration from 18 April through 8 June. *Bold black lines* indicate high use areas (50% fixed kernel volume contours), *light gray points* represent king eider locations ($n = 371$) as recorded by satellite transmitters, and *dark gray blocks* are active leases for oil and gas exploration and development

The distance to the final breeding destination for birds migrating to Siberia was much longer than for birds migrating to Alaska or Canada ($\chi^2_2 = 27.03$, $P < 0.001$, $n = 41$, Table 3).

In spring, king eiders occurred in highest concentrations in Ledyard Bay near Point Lay, and offshore near Kasegaluk Lagoon and Peard Bay (Fig. 3). Both adult males and females staged farther offshore (28.6 ± 16.7 km) in spring than during fall migration ($U = 38837.0$, $P < 0.001$, $n = 870$ bird locations), and in deeper water (23 ± 7 m; $U = 68843.5$, $P < 0.001$, $n = 870$). In spring, there was no difference between sexes in either distance to coast ($P = 0.77$) or water depth ($P = 0.43$, $n = 371$). There was annual variation in the distance from shore ($\chi^2_2 = 24.63$, $P < 0.001$, $n = 366$), ranging from 22.6 ± 13.7 km (95% confidence interval 20.0–25.2 km) in 2003 ($n = 111$) to 32.3 ± 18.9 km (95% CI 28.8–35.7 km) in 2005 ($n = 117$). We recorded no king eider locations within the area recently leased for oil and gas exploration and possible future development (Fig. 3).

Discussion

The eastern Chukchi Sea is a crucial staging area for king eiders on both fall and spring migration. During spring migration the area served as a staging ground for all marked birds migrating to North American breeding grounds and more than half of the marked birds migrating to Siberian breeding areas. The ECS is therefore important to king eiders that breed over half of the circumpolar range. The ECS was used by king eiders continuously from mid-April through early November, with fall migration of some (presumably non-breeding) males starting before spring migration was fully completed, and first-year birds using the area during summer (Fig. 1).

Fall migration

Fall migration occurred over a 5-month period with marked differences among age and sex classes. Despite some long staging times by adults, king eiders do not appear to molt in the ECS. This pattern is in contrast to the congeneric spectacled eider (*S. fischeri*), which uses the ECS as a regular molting area (Petersen et al. 1999). The king eiders we tracked molted mainly along the Chukotka Peninsula and farther south in the Bering Sea (Phillips et al. 2006). In late summer, the ECS is probably used for staging and foraging to accumulate energy for molting and further migration. During this time, males seem to rely on resources in the ECS to a greater extent than females, as they remained longer on average. Among females, successful breeders departed from nesting areas later and used the ECS in much lower proportion than unsuccessful females.

Females from breeding areas in northern Alaska primarily use the Beaufort Sea as a pre-migratory staging area in late summer (Phillips et al. 2007). Similarly, adult males from Canadian breeding areas stopover in the Amundsen Gulf and the Beaufort Sea (Dickson and Gilchrist 2001), and thus arrive later and remain for shorter periods in the ECS than adult males from Alaska. The advantages of high quality molting areas may exert selective pressure on adult birds migrating to molting areas (Hohman et al. 1992). This could reduce stopover times to a minimum required to successfully complete migration, and explain the shorter residency time of later migrating adults. Juveniles, which do not molt flight feathers in their first summer (Suydam 2000), migrated later than adults, but showed the longest staging times in the ECS.

Spring migration

We did not find different migration schedules for male and female king eiders during spring migration in the ECS. King eiders are assumed to pair on wintering grounds or during spring migration, and migrate mostly in pairs from the Chukchi into the Beaufort Sea in spring (Suydam et al. 2000). It is therefore unlikely that sexes migrate on different schedules after pair formation has occurred. Phillips et al. (2007) reported that female king eiders migrated through the Beaufort Sea later in spring than males. However, most of the males in that study migrated to breeding areas in Canada, while all females returned to breeding areas in Alaska (Phillips and Powell 2006). Our study shows that birds of both sexes migrating to breeding grounds in Canada left the ECS about 10 days earlier than birds migrating to breeding grounds in Alaska. We thus believe that the different staging pattern described by Phillips et al. (2007) was an effect of breeding destination rather than sex. King eiders nesting in Canada use the eastern Beaufort Sea as an important staging area in spring (Alexander et al. 1997; Dickson and Gilchrist 2001). This additional staging area may reduce their need to accumulate reserves in the ECS, thus allowing them to shorten their staging time there. Birds migrating to Siberia left the ECS later than birds migrating to Canada, despite a considerably longer distance to breeding grounds. Due to the lack of consistent polynyas in the East Siberian Sea (Barber and Massom 2007) few other reliable staging areas may be available between the ECS and breeding areas in Siberia. Thus, king eiders migrating west from the ECS may have to acquire sufficient reserves prior to departure from the ECS to complete spring migration.

King eiders require body reserves not only for migration but also for successful reproduction (Kellett 1999; Kellett and Alisauskas 2000). The ECS is the closest staging area to Alaskan nesting areas and thus the most likely area where body reserves are accumulated (Klaassen et al. 2006a). While we were able to track only males to Siberian nesting areas, it is highly likely that those males accompanied females (Rohwer and Anderson 1988). Hence, our study suggests that females breeding in Siberia may also depend on body reserves accumulated in the ECS. Alteration of this habitat and disturbances of king eider spring migration schedules could have negative consequences for reproductive success and population dynamics of this species, not only in North American but also in Siberian populations.

The spatial distribution of king eiders in the ECS differed slightly between fall and spring migration, with most spring locations being farther offshore and slightly farther south. During spring migration coastal ice prevents king eider foraging in nearshore areas, and open water exists only in polynyas in the pack ice. The location of the polynya depends on ocean currents and wind conditions, and varies among years (Ahlnäs and Garrison 1984). Variation in sea ice probably accounts for annual variation in the distance from shore that king eiders use for staging during spring migration.

Importance of the ECS and potential threats to eiders

Besides king eiders, the ECS is also a crucial staging area for common (*S. mollissima*) and spectacled eiders (M. Petersen, US Geological Survey, Anchorage, personal communication). It is an important molting area for the North American spectacled eider population (Petersen et al. 1999). Some of the Steller's eiders (*Polysticta stelleri*) nesting in Alaska also use the region during fall migration (P. Martin, US Fish and Wildlife Service, Fairbanks, personal communication). Thus, the area is important for all four eider species, and alteration of habitat and increases in disturbance levels may have negative consequences for several species of sea ducks, including two species (Steller's and spectacled eider) listed as 'Threatened' under the US Endangered Species Act.

The international importance of the ECS to eiders requires consideration when evaluating proposals for industrial development. The current EIS estimates that over the life of development and production of oil and gas facilities in the Chukchi Sea, the chance of a large spill $\geq$1,000 barrels ($\approx$140 tons) of oil is within a range of 33–51% (Minerals Management Service 2007). An oil spill in the ECS could potentially cause high mortality of eiders and have long-term adverse effects on eider populations (Peterson et al. 2003). The areas already leased for oil and gas exploration and possible development in the ECS are >70 km offshore (Minerals Management Service 2008), and production facilities would thus be unlikely to fall within the areas most heavily used by eiders for foraging. However, king eiders use the entire area between the coast and the offshore development area, and will potentially be affected by air and ship traffic connecting land-based and offshore facilities (Mosbech and Boertmann 1999). Man-made structures and activities at sea may also affect sea birds during migratory flights (Wiese et al. 2001; Garthe and Hüppop 2004; Fox et al. 2006). Eiders are generally heavy ducks with high wing loading and poor maneuverability (Raikow 1973). They tend to avoid man-made structures at sea, but fatal collisions occur in low visibility during peak migration (Mallory et al. 2001; Larsen and Guillemette 2007). Development of industrial facilities near major flyways of eiders could lead to additional mortality or costly detours resulting in negative fitness consequences, especially when those structures provide sources of light in an otherwise unlit environment (Wiese et al. 2001; Montevecchi 2006). While many North American eiders may migrate close enough to the coast to bypass structures in the current lease sale area, king eiders flying from the ECS to Siberia may have to cross the currently leased areas and are thus potentially affected by industrial structures.

Another potential threat to eiders in the ECS is environmental change. Sea ice is receding from Arctic seas due to increases in water temperature. Elevated water temperatures facilitate northward range expansion of some species (Vermeij and Roopnarine 2008) and may lead to changes in benthic invertebrate community structure and abundance (Dunton et al. 2005; Grebmeier et al. 2006a; Bluhm and

Gradinger 2008). Such changes have occurred in food sources for eiders in the Bering Sea (Lovvorn et al. 2003), and may in the future reduce prey availability for eiders in the ECS. Changes in prey abundance or distribution could be compounded with increasing anthropogenic disturbances to substantially decrease the profitability of the ECS as a staging area on migration. Reductions in sea ice may also enable sea ducks to winter in the ECS in the near future, thus potentially extending their exposure to harmful effects from industrial developments. The potential interactions between climate change and direct anthropogenic impacts have not been adequately addressed in the Chukchi Sea. More research is required to determine current food sources of sea ducks and possible future changes in the abundance of prey organisms. Furthermore, we recommend aerial surveys to assess the total number of eiders using the eastern Chukchi Sea during spring, summer, and fall. This research is essential for predicting and mitigating possible future impacts of industrial development in the region.

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