Further Evidence for Site Fidelity to Wing Molt Locations by King Eiders: Integrating Stable Isotope Analyses and Satellite Telemetry

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Abstract.—Studies using stable-isotope analyses of feathers to determine molt locations in marine birds are increasingly common but generally lack verification through ground-truthing. In this study, we examined the stable isotope compositions of wing feathers from King Eiders (*Somateria spectabilis*) implanted with satellite-transmitters. We compared stable carbon, nitrogen, and hydrogen isotope compositions ($\delta^{13}C$, $\delta^{15}N$, and δD, respectively) of primary feathers with the geographic location of wing molt in the subsequent year. Longitude of molt locations of eiders was highly correlated with $\delta^{13}C$ ($r^2 = 0.69$, N = 12) and δD ($r^2 = 0.90$, N = 12) isotope values from their primary feathers grown in the previous year. There was no relationship between $\delta^{15}N$ and location of wing molt ($r^2 = 0.007$, N = 12). The results of this study provide further evidence for site fidelity during wing molt by King Eiders. *Received 10 March 2006, accepted 2 October 2006.*

Key words.—carbon-13, deuterium, feather, molt, nitrogen-15, satellite telemetry, *Somateria spectabilis,* stable isotope, site fidelity.

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Determining the locations of migratory birds during the non-breeding portion of the annual cycle is increasingly important to their management because events at these locations such as weather, predation, or anthropogenic factors may contribute to mortality (Webster and Marra 2005). In Alaska, sea duck populations, including King Eiders (*Somateria spectabilis*), have been declining for several decades (U.S.F.W.S. 1999; Suydam *et al.* 2000). Sea ducks are difficult to study during the non-breeding period because they are typically located in areas difficult to access (Goudie and Ankney 1988). Thus locations of molt, when ducks are highly vulnerable due to their flightless condition, often remain unknown. Recent use of satellite telemetry has been successful at locating areas used by individual Spectacled (*Somateria fischeri*) and King Eiders during non-breeding (Petersen *et al.* 1999; Dickson *et al.* 2000, respectively), however, whether molt occurs in these areas must be inferred. Furthermore, satellite telemetry generally lacks the ability to make population-scale predictions because of inherent small sample sizes. Unlike extrinsic marking methods, intrinsic markers in the form of naturally occurring stable isotopes have been used to infer origins of feather molt for a variety of bird species. For example, stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope values from albatross feathers in the Indian Ocean enabled researchers to distinguish between their molting and breeding sites (Cherel *et al.* 2000). In recent years, molt latitudes of terrestrial migratory birds have been determined by comparing stable hydrogen isotope (δD) values of continental rainfall with those in feathers (e.g., Chamberlain *et al.* 1997; Hobson and Wassenaar 1997; Wassenaar and Hobson 2000). Stable isotope analyses of feathers provided a powerful tool for interpreting information about life history events (i.e., feather molt) that occurred in remote terrestrial locations (Hobson 1999; Meehan *et al.* 2004), but the applicability of their use in marine systems is not well known because marine isoscapes are poorly understood (Bowen *et al.* 2005).

King Eiders that breed in western Arctic coastal areas molt in the Bering Sea but their spatial distribution during the latter period is not well understood (Dickson *et al.* 2000; Suydam 2000). Satellite telemetry has provided molt locations for a few individual eiders as well as evidence of fidelity to molt locations in subsequent years (Phillips and Powell 2006). Eiders arrive at molt locations in the Bering Sea and presumably become flightless (Suydam 2000). Captive eiders remain flightless for approximately three weeks until new feathers are grown (Arnold Shouten, pers. comm., Dry Creek Waterfowl, Port Townsend, Washington). King Eiders consume benthic invertebrates during the period of feather growth (Frimer 1997). In the Bering Sea, δ^{13}C and δ^{15}N values of invertebrates vary among geographic locations due to differences in primary production, fresh water influences (Schell *et al.* 1998), and trophic interactions (McConnaughey and McRoy 1979; Dunton *et al.* 1989). Marine sediments exhibit increasing (isotopically heavier) δ^{13}C values in an east-west gradient in the Bering Sea (Naidu *et al.* 1993). Because feather stable isotope values reflect assimilated diet at the time of synthesis (Mizutani *et al.* 1992) the isotopic variation in the Bering Sea may allow eiders to be assigned to molt locations from stable isotope values of feathers.

Similar to δ^{13}C and δ^{15}N values, the δD values of feathers reflect diet and drinking water at the time of synthesis (Hobson *et al.* 1999). The δD values of feathers have not been used previously to determine molt location of marine birds (Hobson 1999; Hobson *et al.* 2000; Hobson 2005). This is presumably due to relatively constant δD values fluctuating near 0‰ in marine systems (Hoefs 1980). However, the δD of feathers from birds consuming marine- or terrestrial-based diets are different and so these measurements can be of use in marine systems with terrestrial or freshwater influences (Hobson *et al.* 2000; Lott *et al.* 2003). For example, bird-eating raptors feeding in coastal habitats, determined from stable sulfur isotope (δ^{34}S) measurements, had much higher feather δD values than their inland counterparts (Lott *et al.* 2003). Given the variation in δD between marine and terrestrial systems, the δD values in the Bering Sea could provide information about eider molt locations.

In this study, primary feathers were sampled from King Eiders during capture for implantation with satellite transmitters to determine if isotopic values were related to molt locations in the subsequent year. The objective of this study was to examine the possibility that combining intrinsic and extrinsic tracking methods might allow for population-scale extrapolation of King Eider distribution during wing molt and provide additional support for molt site fidelity. We hypothesized that wing molt location in the Bering Sea and the δ^{13}C values of primary feathers from eiders would be correlated and follow the pattern in δ^{13}C values in sediments and longitude described by Naidu *et al.* (1993). Site fidelity to wing-molt locations is a necessary condition to test this hypothesis because feather isotope values in this study will represent the diet at the time of primary feather synthesis from the molt year preceding transmitter implantation. It follows that if transmittered eiders do not return to the same molt site in the subsequent year (i.e. there is no molt site fidelity) there would be no basis for extrapolating the population distribution during wing molt. Feathers were also analyzed for δD and δ^{15}N values to determine whether these measurements would be useful to determine wing molt locations.

METHODS

Samples were collected in June 2003 from the tips (<1 cm) of the first primary feather (vane material only) from nine male and three female King Eiders captured for implantation with satellite transmitters at Kuparuk, Alaska (70°20'N, 149°45'W) (Phillips and Powell 2006). Feathers were cleaned and rinsed using ethanol to remove surface contaminants and air dried. Samples were weighed to 0.3-0.5 mg then placed in tin boats (Elemental Microanalysis Limited, Devon, UK). The δ^{13}C, δ^{5}N and δD values for each sample were obtained using continuous flow stable isotope-ratio mass spectrometry (CF-SIRMS) at the Alaska Stable Isotope Facility (http://www.uaf.edu/water/ASIF/ASIF.html). To determine the δ^{13}C and δ^{5}N values of the samples they were each combusted in a Carlo Erba NC2500 elemental analyzer interfaced via a Finnigan Conflo III to a Finnigan Delta+XP mass spectrometer. Stable isotope ratios were reported in standard δ notation, as parts per thousand (‰) relative to Vienna Pee Dee Belemnite for carbon and atmospheric Air for nitrogen, using the equation $\delta X = ([R_{sample}/R_{standard}]-1 \times 1000$, where X is ^{13}C or ^{15}N and R is the ratio of ^{13}C:^{12}C or ^{15}N:^{14}N. Analytical precision was determined by conducting multiple analyses of a homogenous peptone standard (N = 29) (δ^{13}C = 7.0‰, C = 44.3%, δ^{15}N = 15.8 ‰, N = 15.8%) during the run of analyses and were < ± 0.4‰ for δ^{13}C, < ± 0.3‰ for δ^{15}N.

For stable hydrogen isotope analysis the methods were consistent with those described by Greenberg *et al.* (in press) where 0.1-0.3 mg of each sample feather was weighed out into silver capsules, and analyzed using a Finnigan ThermoQuest thermochemical reactor elemental analyzer (TCEA) attached via a Conflow III to a Thermo Finnigan Delta Plus XL IRMS. δD results are expressed relative to Vienna Standard Mean Ocean Water (VSMOW). The δD of sample hydrogen was calculated by measurement of HD isotopes (after standard H^{3+} corrections) and comparison to a pulse of reference H_2 gas (research grade 99.999%) (VSMOW). δD values of samples were calibrated relative to international standards (NBS 22, NBS 30 and PEF 1) (measured *vs.* expected r^2 = >0.99). Analytical precision based on the analyses of Benzoic Acid (Fisher Chemical, Fisher Scientific No. 947429) during the run of samples producing a standard deviation of 2.3‰, while the % hydrogen analytical precision was 0.3%. We acknowledge the issues related to hydrogen exchange as described by others (e.g., Wassenaar and Hobson 2002). We adopted a method where samples were "air equilibrated" with ambient laboratory air moisture in the ASIF at room temperature for >96 hours prior to stable hydrogen isotope analysis. Samples and standards were then immediately loaded into the auto sampler carousel of TCEA-IRMS system described above. All samples were analyzed in the same batch. Since the aim of this study was comparative within the sample set it was less crucial to produce non-exchangeable δD values. However, this should be taken into account if the δD data are being considered for comparison with future studies.

Geographic locations of wing molt for satellite-transmittered King Eiders were obtained from Service ARGOS (2001) (see Phillips and Powell 2006). Phillips (2005) defined molt location as the period after molt migration when eiders did not change location for ≥3 weeks. Movements of individuals at their geographic location of wing molt was small (<50 km^2) within the scale of the Bering Sea (2.3 × 10^6 km^2) (Hood and Kelley 1974). The mean values of all coordinates from each individual during the molt period were used as their molt location [for details on telemetry analyses see Phillips and Powell (2006)]. Universal Transverse Mercator (UTM) conversions were not available west of the central meridian 180°, so transmittered eiders occupied both negative and positive longitude during molt in the Bering Sea. Therefore, geographic coordinates were standardized to make all values positive for statistical analyses. Standardized longitude was calculated using UTM Zone 4 False Easting as the origin because the most easterly-molting King Eider molted within this zone. We added 500,000 m to each coordinate of longitude from an individual eider within a zone and then added 500,000 m more for each consecutive zone (i.e., Zone 4 coordinates were not changed, Zone 3 + 500,000 m, Zone 2 + 1,000,000 m, etc.). The SAS (SAS Institute 1996) General Linear Model (GLM) was applied to determine the relationship between wing molt locations of transmittered eiders and stable isotope values from their primary feathers. Means were reported with ±1 standard deviation.

RESULTS

The distribution of transmittered King Eiders during molt in 2003 ranged from Bristol Bay, Alaska, in the east to the west coast of Siberia (Phillips 2005) (Table 1, Fig. 1). Seven males and the three females molted on the east and south coasts of the Chukotka peninsula. δ^{13}C values of primary feathers from eiders sampled ranged from -15.7‰ to -20.5‰. In addition, the δ^{13}C values of feathers from these birds were positively correlated with longitude of wing molt location in

Table 1. Mean location, sex, and δ^{15}N, δ^{13}C, and δD values of feathers from King Eiders molted in fall 2002. Letters correspond with point locations on Figure 1.

Individual	Sex	Lat/Long	δ^{15}N	δ^{13}C	δD
a	M	58.510/-158.305	16.00	-20.5	-100.5
b	M	64.744/-171.966	14.20	-17.8	-88.3
c	M	65.142/-172.995	14.70	-19.2	-96.3
d	F	65.805/-171.995	14.60	-18.7	-95.4
e	F	64.340/-172.810	13.80	-17.9	-95.0
f	M	64.642/-172.352	14.50	-17.9	-87.8
g	M	65.351/-176.425	14.70	-17.6	-82.2
h	M	65.409/-176.691	14.30	-17.7	-84.3
i	M	65.540/-177.027	14.30	-17.1	-84.8
j	M	65.516/-177.177	13.80	-17.6	-86.2
k	F	64.776/179.320	14.60	-18.1	-77.4
l	M	60.851/171.967	15.57	-15.7	-72.3

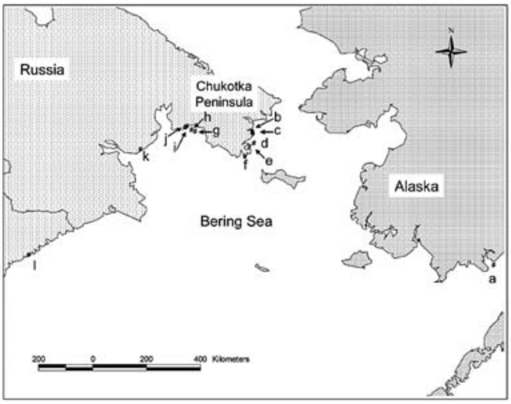

Figure 1. Geographic locations of wing molt in fall 2003 from King Eiders implanted with satellite transmitters in summer 2003. Letters correspond with individuals listed in Table 1.

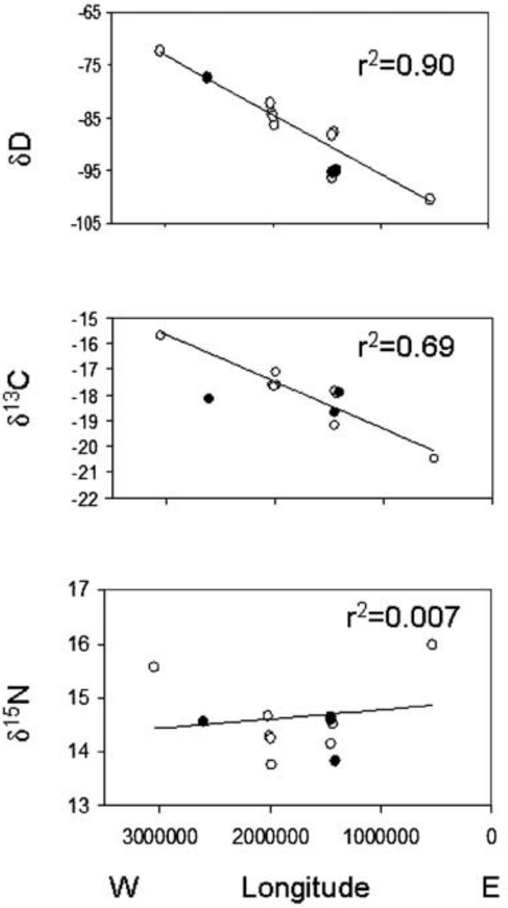

Figure 2. The δ^{15}N, δ^{13}C, and δD values (expressed in ‰ vs. VPDB, atm. nitrogen and VSMOW respectively) of primary feathers from King Eiders molted in fall 2002 in relation to the location of their subsequent molt location in 2003. Males are denoted by open circles, females by closed circles.

the Bering Sea in the subsequent year (r^2 = 0.69, N = 12, Fig. 2), becoming increasingly enriched along an east-west gradient. δD values ranged from -72.3‰ to -100.5‰ and were also highly correlated with longitude of wing molt (r^2 = 0.90, Fig. 2). The δ^{15}N values from these feathers was not correlated with latitude or longitude of known wing molt locations (r^2 = 0.007, Fig. 2).

DISCUSSION

Both δ^{13}C and δD values of primary feathers from King Eiders implanted with satellite transmitters were correlated with longitude of their wing molt locations in the Bering Sea in the subsequent year. Five regions of the Bering Sea were fairly distinguishable based on feather δ^{13}C and δD values. Regions with multiple molting eiders (i.e., eastern and southern Chukotka) had similar within area feather isotope values. Only one feather sample was collected from each individual so we performed no formal analysis of within region isotopic variation. δ^{13}C values of Bering Sea sediments have demonstrated a longitudinal gradient from the Seward Peninsula (isotopically lighter) to the south of the Chukotka Peninsula, Russia (isotopically heavier) by Naidu *et al.* (1993), who suggested freshwater inputs from the Yukon River and an east-west current across the Bering Sea could drive that gradient. Assuming that particulate organic carbon found in sediments is the basic carbon source in marine systems (Fry and Scherr 1984), it is not surprising to encounter the same trend in marine fauna (see Saupe *et al.* 1987; Schell *et al.* 1998), including eiders. Furthermore, Phillips (2005) found that eiders molted flight feathers in areas with lower salinity (i.e., freshwater influence) than random points.

Fresh water flowing from the Yukon River in Alaska would also have isotopically lighter δD values relative to marine systems because Arctic and sub-Arctic rainfall hydrogen values are lower relative to VSMOW (~135-165‰) (Bowen and Revenaugh 2003; Bowen

2005; Bowen *et al.* 2005). Similar to $\delta^{13}C$, the δD gradient observed is likely caused by mixing of fresh and marine waters and the isotopic composition of the water and its various particulate components are reflected in the eider prey base. Thus, the parallel relationship observed between $\delta^{13}C$ and δD probably reflects a common source of these isotopes in the foodweb. The stronger relationship observed between δD values of feathers and location of wing molt may or may not imply that drinking water increased the effect of the correlation between longitude and δD over $\delta^{13}C$ and longitude, but drinking habits of King Eiders are virtually unknown outside the breeding season (Suydam 2000).

$\delta^{15}N$ feather values from eiders in this study exhibited little variation between individuals and represented a trophic position relative to assimilated diet at the time of feather synthesis (Deniro and Epstein 1981; Hobson *et al.* 2002). Thus, the lack of correspondence between $\delta^{15}N$ feather values and molt locations was not surprising because nitrogen isotope content of particulates (i.e., protein sources at the base of the trophic web) are not necessarily influenced by mixing of fresh and marine waters (Owens 1987).

The observed stable carbon and hydrogen isotope correlations provide further evidence of fidelity to wing molt sites by King Eiders. From satellite telemetry data, six male and two female transmittered eiders returned to within seven km and 50 km, respectively, of individual molt sites from the previous year (Phillips and Powell 2006). In this study, primary feathers were grown during molt in the previous fall before the eiders were implanted with transmitters. Feather isotope values corresponded closely to the longitude of the subsequent wing molt; therefore these eiders appear to have returned to nearly the same molt locations as the previous year. Stable isotope values from satellite-transmittered eiders were not extrapolated to non-transmittered eiders because the majority of eiders in this study molted within a small range with only one individual at each extreme of the distribution, thus the entire range was not well represented by our samples. Finally, these results also suggest that hydrogen isotope measurements have potential for examining molt locations in some marine systems, particularly large estuaries or other areas influenced by fresh water.

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