

# Spatiotemporal Variation in the Non-Breeding Distribution of Spectacled Eiders



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## **INTRODUCTION**

Global climate change and development of offshore natural resources will likely affect Arctic ecosystems and species in the near future. Rising oceanic temperatures and shrinking Arctic sea ice extent are among the detectable outcomes of our planet's rapid warming in response to elevated atmospheric gases (IPCC 2007). As sub-Arctic ocean temperatures have risen, fish in the Bering Sea are expanding their range northward, a shift that will likely put additional pressure on lower trophic level organisms, including bivalves, crustaceans, and zooplankton (Grebmeier et al. 2006). This might catalyze the northward expansion of the Bering Sea commercial fishery that will likely introduce additional stress on non-target organisms. Furthermore, recent efforts to explore offshore sources of energy in the Arctic have the potential to cause immediate and perhaps severe damage to Arctic ecosystems through disturbance of benthic communities, obstruction of migratory pathways, and potential spills. Arctic ecosystems support a small number of species that have evolved specialized adaptations necessary for year round survival in harsh conditions. With additional and likely abrupt pressure from anthropogenic sources in the future, it becomes imperative to identify those species that occupy Arctic ecosystems and examine aspects of their ecology that might be adversely affected by habitat change.

Spectacled Eiders (*Somateria fischeri*) are large sea ducks that spend 9 to 12 months of the year at sites in the Bering, Chukchi, Beaufort, and East Siberian seas (Petersen et al. 1999). At sea, eiders forage on benthic organisms, including bivalves and polychaete worms (Petersen et al. 1998, Lovvorn et al. 2003). In the fall (August through October), eiders occupy distinct molting sites in Ledyard Bay and eastern Norton Sound, Alaska and Mechigmenski Bay and offshore areas between the Indigirka and Kolyma River Deltas, Russia (Petersen et al. 1999). In winter (November through March), the world population of Spectacled Eiders (370,000 to 380,000 individuals) occupies a single site south of St. Lawrence Island, Alaska, in the northern Bering Sea (Larned and Tiplady 1999, Petersen et al. 1999). Routes and staging areas used during spring migration are unknown.

At the wintering area, eiders depend on an abundant source of prey and perhaps sea ice to balance the energetic costs associated with cold temperatures and winter storms (Lovvorn et al. 2003, Petersen and Douglas 2004, Lovvorn et al. 2009). Although winter food items appear to be abundant, prey diversity is limited to a few benthic organisms of which two bivalve species (*Macoma calcareo* and *Nuculana radiata*) appear to be preferred (Lovvorn et al. 2003). In addition, the distribution and abundance of benthic prey in the northern Bering Sea is spatially and temporally dynamic; a decline in biomass and three major shifts in the composition of benthic bivalves have been detected over the past 40 years (Grebmeier et al. 2006). However, changes in benthic fauna, most likely, did not have a negative effect on the species, as there is no evidence of a substantial population decline occurring across all breeding populations (Petersen and Douglas 2004). Simulations of winter habitat use suggest that loss of sea ice in the northern Bering Sea might decrease the area available for Spectacled Eider roosting, a behavior thought to be key for balancing the energetic costs associated with a cold environment (de Vries and van Eerden 1995, Lovvorn et al. 2009). The importance of sea ice to Spectacled Eider winter survival is however unknown. When modeling eider movement in response to dynamic ice flow, individuals did not experience an energetic loss. This suggests that movement away from historically used areas might be energetically beneficial if the value of those areas decrease (Lovvorn et al. 2009). In addition, eiders might move away from preferred feeding areas in periods of extreme ice conditions or winter weather (Petersen and Douglas 2004). However, there is no evidence to support or reject this hypothesis.

In the summer months, the species is divided into three geographically isolated breeding populations - western and northern Alaska and northern Russia. A majority (> 90%) of adults nest in Russia. Breeding populations appear to be genetically differentiated based on female linked mitochondrial DNA haplotypes; likely influenced by elevated philopatry among female eiders (Scribner et al. 2001). However, a lower degree of differentiation was detected using bi-parentally inherited

nuclear markers, suggesting that spring dispersal of male eiders might, overall, mediate a genetically homogenous species (Scribner et al. 2001). Spectacled Eiders are believed to be seasonally monogamous. However, the site and behavior of pair formation as well as the characteristics of male dispersal, are unknown. Females are likely the selective sex, based on male display patterns and multiple male to single female ratios observed at breeding areas (Johnsgard 1964). Although likely marine, the source of energy required for egg production and nest incubation is also unknown. Male Spectacled Eiders do not care for nests or young and typically return to the sea shortly after nest initiation (Petersen et al. 2000).

As a result of a rapid population decline (96% from 1952 to 1993) within the western Alaska breeding population, the Spectacled Eider was listed as threatened under an amendment to the Endangered Species Act in 1993 (Federal Register 1993, Stehn et al. 1993, Ely et al. 1994). Further, critical habitat was designated throughout the species' North American range in 2001 (Federal Register 2001). Notable threats to Spectacled Eiders at breeding areas include ingestion of contaminants, particularly lead through expended shot (Franson et al. 1995, Flint et al. 1997, Franson et al. 1998, Grand et al. 1998) and predators (Dau 1974, Flint and Grand 1997, Grand and Flint 1997). In addition, a negative relationship has been detected between annual population estimates in western Alaska and extreme winter ice concentration and weather events (Petersen and Douglas 2004).

Unlike other eiders (King (*Somateria spectabilis*), Common (*Somateria mollissima*), and Steller's (*Polysticta stelleri*)), the non-breeding distribution of Spectacled Eiders appears to be restricted to a single wintering area and few molting and spring staging areas. This phenomenon has the potential to create bottlenecks where the effects of environmental change might be detrimental to a significant proportion of the world population or to a single breeding population. However, there is little known about Spectacled Eider habitat use away from breeding areas making it difficult to predict how this threatened species will respond to rapid climate and ecosystem change. Through my dissertation, I will

integrate satellite telemetry data with stable isotope analysis, analyses of migratory connectivity, and spatiotemporal home range modeling to investigate aspects of the non-breeding distribution of Spectacled Eiders that might be affected by rapid change in the Arctic.

#### ***OBJECTIVES AND HYPOTHESES***

- 1) Further define the timing of movement and the non-breeding distribution of Spectacled Eiders, and assess changes, over time, in the fall and winter distribution of eiders from 1993 through 2012.

Current understanding of the non-breeding distribution of Spectacled Eiders is the result of satellite telemetry (Petersen et al. 1999) and aerial surveys (Larned and Tiplady 1999). However, these studies did not identify the distribution of eiders during spring staging. Furthermore, the spring dispersal exhibited by male eiders is unknown. Due to the limitations of satellite telemetry at the time, past satellite telemetry studies did not collect data from a full winter. Within a full winter the distribution of eiders could have shifted in response to sea ice, weather, or benthic prey. As such, Spectacled Eider recovery and conservation efforts would benefit from further investigation of the timing of movement and the non-breeding distribution of Spectacled Eiders, including elucidation of areas used for spring staging and characteristics of male dispersal. In addition, an assessment of long term changes in the fall and winter distribution of eiders from 1993 through 2012 using data from Petersen et al. (1999) might detect decadal variation at molting and wintering sites that could be a response to variable sea ice characteristics, distribution and abundance of benthic prey, and weather. I hypothesize that:

- At core use areas, there will not be significant interannual variation in the fall and winter distribution of eiders from 1993 through 1997 (Petersen et al. 1999), and 2008 through 2012, suggesting the relatively static distribution of benthic prey and weak interannual influence of abiotic variables such as the distribution and concentration of sea ice and severe weather.

- Between and within each winter, marked eiders will occupy a single core wintering area, regardless of sex or prior breeding or molting location.
- Within each winter, the distribution of eiders will be locally dynamic, suggesting that sea ice might ultimately affect winter distribution; assuming that benthic prey are static in distribution. During extreme weather and dense ice conditions, eiders will exhibit a relatively clumped distribution, suggesting potential minimization of heat loss or limited open water.
- Between and within each fall, molting site occupancy will depend on sex and prior breeding location, suggesting connectivity between breeding and molting areas.
- The timing of migratory movement and duration of occupancy will differ by prior breeding and molting locations and sex, and for females, by breeding success.

2) Model individual space use in core non-breeding areas and assess the influence of habitat covariates on behavior related home ranges (staging, molting, and wintering).

Why do Spectacled Eiders predictably occupy geographic areas each fall and winter when conditions are relatively hostile (winter storms, cold temperatures, dynamic ice movement and concentration) and where there appears to be abundant benthic prey at other sites in the north Pacific Ocean, as evident through the non-breeding distribution of other sea ducks including Long-tailed Ducks (Petersen et al. 2003), King Eiders (Oppel et al. 2008), and Common Eiders (Petersen and Flint 2002)? Perhaps habitat or prey related variables constrain the non-breeding distribution of Spectacled Eiders to select areas. Although the diet of Spectacled Eiders at-sea has been well investigated (Petersen et al. 1998, Lovvorn et al. 2003), those habitat characteristics that constrain Spectacled Eiders to certain geographic areas for molting, wintering, and staging are still unknown. Furthermore, it is unclear how modification of those habitat characteristics will affect the distribution, and potentially the survival and recruitment, of Spectacled Eiders in the future. With regard to the characteristics that constrain the non-breeding distribution of Spectacled Eiders, I hypothesize that:

- Wintering home ranges will be independent of sex, prior breeding or molting location, and benthic composition, but will be dependent on bathymetry and weather, and dynamic in response to sea ice concentration.
- Molting and staging home ranges will depend on bathymetry and sea ice concentration. Within occupied sites, there will not be a difference between the home ranges of male and female eiders.
- In areas that are used for both staging and molting, home ranges will be spatially similar, suggesting a preferred or optimal foraging area with a relatively static distribution of benthic prey.

### 3) Assess migratory connectivity and site fidelity.

Spectacled Eider location data from satellite transmitters deployed in the 1990s suggests that molting location might be dependent on prior breeding location and sex (Petersen et al. 1999).

However, an in-depth study of migratory connectivity between breeding, molting, wintering, and staging sites has not been conducted. Site fidelity among waterfowl species has been well documented and is generally exhibited with higher frequency among females (Anderson et al. 1992). This pattern is likely consistent with that exhibited by Spectacled Eiders, although data is lacking (Petersen et al. 2000, Scribner et al. 2001). If Spectacled Eiders exhibit a high rate of site fidelity, and there is connectivity between sites used for molting, wintering, staging, and breeding, it is possible that environmental change at any molting, wintering, or staging site could adversely affect the survival and reproductive success of a breeding population. Therefore, an assessment of migratory connectivity and site fidelity among Spectacled Eiders could, in part, contribute to an explanation of past population declines and future fluctuations in population size. I hypothesize that:

- Among females, fidelity to staging, breeding, and molting sites will be correlated suggesting connectivity.

- Among males, use of staging, breeding, and molting sites will be correlated suggesting connectivity. However, males will not exhibit high rates of seasonal site fidelity between years.
- A significant proportion (> 75%) of marked males will breed in Arctic Russia, regardless of Alaska breeding site, further supporting the current understanding that the majority of the world population breeds in Russia and the hypotheses that females are the selective sex and pair formation likely occurs within flocks consisting of individuals from all breeding sites (Dau 1974, Scribner et al. 2001).

4) Assess current understanding of Spectacled Eider molt chronology and delineate winter and molting locations using stable isotope analysis.

Spectacled Eiders undergo two molts of head and body plumage (late summer and early winter) and a complete molt of flight plumage in fall (Petersen et al. 2000). However, claw growth is likely continuous throughout the annual cycle, with the distal end of claws representing growth from 70 to 170 days prior (Oppel and Powell 2008). For example, claw samples collected in June would provide isotopic information from areas where claws were grown in the previous winter or spring. Through stable isotope analysis, seasonal and location specific isotopic ratios should be detectable, depending on the areas occupied when these tissues are grown.

If a high rate of connectivity between Spectacled Eider molting, wintering, staging, and breeding sites is detected and female fidelity to those sites occurs at a high rate, it might be possible to assign stable isotope ratios to areas by associating isotopic data to data received through satellite telemetry. Similar analyses have been used to investigate aspects of wildlife migration and habitat use, including the winter and molting distribution of King Eiders (Mehl et al. 2005, Knoche et al. 2007, Oppel and Powell 2008). Regardless of capture date and location, stable isotope ratios could then be used to assign an individual to a molting area and potentially associated breeding and staging areas. The ability to easily assign individuals to breeding areas could be a valuable tool for monitoring Spectacled Eider



populations. Furthermore, if connectivity is detected, then it might also be possible to monitor ecosystem change at molting areas and potentially staging areas, by sampling eiders across time (Bump et al. 2007). Ecosystem change at areas specifically used by Spectacled Eiders breeding in Alaska could offer an alternate explanation for the observed population decline over the past 57 years. Through an integrated assessment of satellite telemetry data and stable isotope ratios of various tissue types, I hypothesize that:

- Stable isotope ratios of secondary and tail covert feathers will be similar within, and significantly different between, Spectacled Eider molting areas; and will be useful for assigning isotopic signatures to molting sites, and potentially assigning individuals to connected breeding and staging areas.
- Stable isotope ratios of head and breast feathers will not be significantly different between Spectacled Eider molting areas, suggesting variation in the timing of growth or growth at a single site in winter.
- Stable isotope ratios of claw samples collected at breeding sites will not be significantly different, suggesting that the distal portion of the claw in summer was grown at a single wintering site. However, stable isotope ratios of claw samples collected in winter will be significantly different, suggesting variable timing of growth, or growth in distinct ecosystems at geographically isolated breeding areas.
- Stable isotope ratios of claws, and secondary and tail covert feathers from individuals collected over time will exhibit variation, suggesting ecosystem change at wintering and molting areas in the past, respectively.

#### ***METHODS***

Over 3 years (2008 -2010), I will mark 106 adult Spectacled Eiders with satellite transmitters at breeding sites in Alaska. In 2008, I marked 45 individuals in the Yukon-Kuskokwim Delta, and in 2009 I

marked 21 individuals on the North Slope at Peard Bay and within the Colville River Delta. Thus far, 28 males and 38 females have been marked. In 2010, I will mark up to 40 adult Spectacled Eiders in the Colville River Delta. The final sample size will exceed the minimum recommended for population level inference from satellite telemetry (Lindberg and Walker 2007). However, I will re-evaluate sample size requirements annually, once transmitter loss and mortality are known.

I will capture adults upon their arrival at breeding sites with the use of a large mesh mist net array and decoys. Later in each breeding season, I will capture females on nests with the use of a bow trap or mist net stretched between two crew members. I will also capture females that are assumed to be failed or non-breeders using mist nets and decoys.

Spectacled Eiders will be implanted with a Microwave Telemetry 750 hour, 38g, PTT-100 (Columbia, Maryland 21045). Transmitters will be programmed with an on:off cycle of 5:96 hours, or 5:116 hours to provide at least 2 years of continuous location data and to detect broad spatiotemporal variation. Due to a 4 to 5 day gap between transmission periods, my analysis of migratory movement will be limited to a general characterization of timing and direction, as opposed to the delineation of migratory corridors and home ranges.

Surgical procedures will be conducted in the field by a trained wildlife veterinarian and anesthetist, following the U.S. Geological Survey (USGS) Standard Operating Procedure entitled, "Coelomic Implantation of Satellite and Conventional Transmitters into Birds (USGS Protocol #06SOP03)" (Korschgen et al. 1996, Mulcahy and Esler 1999). During or after surgery, I will collect a variety of tissue samples, including blood, claw tips, and head, breast, secondary, and tail feathers. In addition, cloacal and oral swabs will be collected for avian influenza screening at the USGS National Wildlife Health Center in Madison, Wisconsin. Plasma and subcutaneous adipose tissue will be collected for yolk-precursor and fatty acid analysis, respectively, at the Alaska SeaLife Center (Seward). To minimize the chance of nest abandonment, female eiders that were captured on nests will be released

at nests after administration of Propofol (0.8 to 1.0 mL) via jugular venipuncture (Machin and Caulkett 2000).

In 2008 and 2009, necessary permits were obtained from land owners and borough, state and federal wildlife and land management agencies. In addition, field procedures have been reviewed and approved by the USGS Alaska Science Center Institutional Animal Care and Use Committee (IACUC) (2008-04) for work in 2008 and 2009. Appropriate permits, and USGS and University of Alaska Fairbanks (UAF) IACUC approval, will be sought before work is initiated in 2010.

Location, body temperature, and voltage data will be received from each transmitter through the Argos data collection and location system in Toulouse, France (Service Argos, Inc. 2001). In addition, similar data from satellite transmitters deployed in 1993 through 1999 (Petersen et al. 1999) will be included. Parsing of improbable locations and data conversion will be aided by programs developed by David Douglas (USGS Alaska Science Center). I will then classify the data into spatiotemporal groups (geographical areas), based on distance and time between points, and the assumed behavior in an area as identified by Petersen et al. (1999). I will classify location points as static (molting, wintering, staging, or breeding) if signals are received from the same area in a consecutive transmission cycles. Locations will be classified as migratory if sequential locations indicate broad spatial differences (> 100 km), or if location signals are received between two static locations. I will assume that the first and last transmissions from a static area are indicative of the arrival and departure dates, respectively.

I will use multi-response permutation procedures in BLOSSOM (Cade and Richards 2005) to assess general differences in the distribution of eiders within geographic areas from 2008 through 2012. I will assess the timing of migratory events using Kruskal-Wallis tests. Differences in residence time will be assessed using multiple regression (Phillips et al. 2007). I will use the same procedures to test for annual differences in the fall and winter distribution of eiders, between 1993 through 1999 and 2008 through 2012.

Using location data from non-breeding areas (molting, wintering, and staging), I will develop models of individual home range and habitat use, using the package “adehabitat” (Calenge 2006) as implemented in the R Statistical Package (R Development Core Team 2005). I will then assess models for each individual using an information theoretic approach to identify important, season specific habitat covariates that might influence individual space use (Burnham and Anderson 2002). Habitat covariates that will be used in select models (dependent on season and availability) include bathymetry (The GEBCO\_08 Grid 2008), sea ice distribution and concentration (25-km pixel resolution sea ice concentration maps, Cavalieri et al. 1996, National Snow and Ice Data Center), sea-ice movement (National Oceanic and Atmospheric Administration), benthic prey distribution (Feder et al. 2005, Grebmeier and Cooper pers. comm., Hamazaki et al. 2005), and weather (temperature and precipitation) and day length (National Climatic Data Center).

The satellite telemetry data will provide general information regarding the frequency of seasonal philopatry. Using Mantel correlation coefficients, I will further quantify the connectivity between breeding, molting, wintering, and staging sites for each sex (Ambrosini et al. 2009). When eiders exhibit fidelity to a specific area, I will use the dispersion of individual locations and the central tendency of individual home ranges (previously developed through above modeling) to quantify local shifts in seasonal space use between years. To estimate dispersion, I will calculate the average distance between eider locations and the bivariate median of seasonal home ranges and test for differences between years and sexes using paired and 2-sample *t*-tests, respectively. The distance between the bivariate medians of individual home ranges in year 1 and year 2 will be used to assess differences in central tendency. To test for shifts in central tendency, I will calculate a threshold value for each eider by multiplying the estimate of dispersion for year 1 by 0.8. Threshold values will then be compared to bivariate median distances using a paired *t*-test. A significant *t*-statistic will suggest that there is a

greater than 80% difference between seasonal home ranges used in year 1 and year 2. I will also compare distances between sexes, following appropriate standardization (Plowman et al. 2006).

Claw and feather samples from recent, marked and unmarked eiders will be analyzed for stable carbon and nitrogen isotopes at the Alaska Stable Isotope Facility at UAF. I will then use discriminate function analysis to assess variation in the isotopic composition of each tissue. I will use Kruskal-Wallis tests to compare individual isotope ratios within clusters (Oppel and Powell 2008). Isotopic composition of samples collected at transmitter deployment will be indicative of ecosystems occupied in the year prior to the collection of satellite telemetry data. As such, use of satellite telemetry to assign isotopic ratios to geographic areas requires the assumption that individuals exhibit high rates of site fidelity. I will use samples from marked females to establish baseline assignment as female site fidelity is likely higher than that of males (Scribner et al. 2001). Satellite telemetry results should provide additional support for this assumption. Results from marked males will then be used to test baseline geographic assignment. Tissues from unmarked individuals collected in winter/spring 2009 (Lovvorn pers. comm.) will also be analyzed to test the ability to assign birds from unknown breeding and molting sites using isotopic ratios. If geographic assignment of unmarked eiders is possible, I will apply the technique to samples from museum specimens to assess past ecosystem change at molting areas, and potentially connected staging areas, with the assumption that there has not been a geographic shift in the distribution of eiders over the duration of sample availability.

## GRADUATE PROJECT TIMELINE

- Summer 2008 – Deploy transmitters in western Alaska. (Completed)
- Summer 2009 – Deploy transmitters in northern Alaska. (Completed)
- Fall 2009 – Proposal submission, committee development, and first committee meeting.
- Winter 2010 – Present at the 2010 Alaska Marine Science Symposium, Anchorage.
- Spring 2010
  - Assist with northern Bering Sea benthic sampling.
  - Prepare for 2010 transmitter deployment and Colville River Delta site prep.
- Summer 2010 – Deploy transmitters in northern Alaska.
- Fall 2010
  - Course work at UAA.
  - Present at the World Seabird Conference, Victoria, British Columbia.
  - Present at the MMS Information Transfer Meeting, Anchorage.
  - Proof data from transmitters deployed in Summer 2008.
- Spring 2011
  - Course work at UAF.
- Summer 2011 – Potential deployment of transmitters in juvenile Spectacled Eiders.
- Fall 2011
  - Course work at UAA.
  - Present at the International Sea Duck Conference, Seward.
  - Submit feather and claw samples to the Alaska Stable Isotope Facility for analysis.
  - Proof data from transmitters deployed in Summer 2009.
- Spring 2012
  - Course work at UAF.
  - Comprehensive exams.
- Summer 2012 – Satellite telemetry data collection completed.
- Fall 2012
  - Proof data from transmitters deployed in Summer 2010.
  - Finish analysis of telemetry data.
  - Prepare dissertation, manuscripts, and final report for MMS.
  - Present at the North American Ornithological Conference, Vancouver, British Columbia.
  - Present at the MMS Information Transfer Meeting, Anchorage.
  - Present at the Spectacled Eider recovery team meeting.
- Spring/Summer 2013
  - Defend dissertation and submit to graduate school.
  - Submit manuscripts for internal and journal review.
  - Submit final report to MMS.
  - Graduate.

## LITERATURE CITED

- Ambrosini, R., A.P. Møller, and N. Saino. 2009. A quantitative measure of migratory connectivity. *J. Theoretical Biology* 257:203-211.
- Anderson, M. G., J. M. Rhymer, AND F. C. Rohwer. 1992. Philopatry, dispersal and the genetic structure of waterfowl populations. Pages 365-395 *in* Breeding ecology and management of waterfowl (B. D. J. Batt, A. D. Afton, C. D. Ankney, D. H. Johnson, J. A. Kadlec and G. L. Krapu, Eds.). University of Minnesota Press, Minneapolis.
- Bump, J.K., K. Fox-Dobbs, J.L. Bada, P.L. Koch, R.O. Peterson, and J.A. Vucetich. 2007. Stable isotopes, ecological integration and environmental change: wolves record atmospheric carbon isotope trend better than tree rings. *Proc. Biol. Sci.* 274:2471-2480.
- Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2<sup>nd</sup> ed. Springer-Verlag, New York.
- Cade, B.S., and J.D. Richards. 2005. User manual for Blossom statistical software: U.S. Geological Survey Open-File Report 2005-1353. 124 p.
- Calenge, C. 2006. The package "adehabitat" for the R software: A tool for the analysis of space and habitat use by animals. *Ecological Modelling* 197:516-519.
- Cavaleri, D., C. Parkinson, P. Gloersen, and H. J. Zwally. 1996, updated 2008. Sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I passive microwave data. Boulder, Colorado USA: National Snow and Ice Data Center.
- Dau, C.P. 1974. Nesting biology of the Spectacled Eider *Somateria fischeri* (Brandt) on the Yukon-Kuskokwim Delta, Alaska. M.Sc. thesis, University of Alaska, Fairbanks.
- de Vries, J., and M.R. van Eerden. 1995. Thermal conductance in aquatic birds in relation to the degree of water contact, body mass, and body fat: energetic implications of living in a strong cooling environment. *Physiological Zoology* 68:1143-1163.
- Ely, C.R., C.P. Dau, and C.A. Babcock. 1994. Decline in a population of Spectacled Eiders nesting on the Yukon-Kuskokwim Delta, Alaska. *Northwestern Naturalist* 75:81-87.
- Feder, H. M., Jewett, S. C., and Blanchard, A. 2005. Southeastern Chukuchi Sea (Alaska) epibenthos. *Polar Biology*, 28: 402e421.
- Federal Register. 1993. Final rule to list the Spectacled Eider as threatened. *Federal Register* 58(88):27374-27480.
- Federal Register. 2001. Final determination of critical habitat for the Spectacled Eider. *Federal Register* 66(25):9146-9185.
- Flint, P.L., M.R. Petersen, and J.B. Grand. 1997. Exposure of Spectacled Eiders and other diving ducks to lead in western Alaska. *Canadian Journal of Zoology* 75:439-443.
- Flint, P.L., and J.B. Grand. 1997. Survival of Spectacled Eider adult females and ducklings during brood rearing. *J. Wildl. Manage.* 61:217-221.
- Franson, J.C., M.R. Petersen, C.U. Meteyer, and M.R. Smith. 1995. Lead poisoning of Spectacled Eiders (*Somateria fischeri*) and of a Common Eider (*Somateria mollissima*) in Alaska. *J. Wildlife Diseases* 31:268-271.
- Franson, J.C., M.R. Petersen, L.H. Creekmore, P.L. Flint, and M.R. Smith. 1998. Blood lead concentrations of Spectacled Eiders near the Kashunuk River, Yukon Delta National Wildlife Refuge, Alaska. *Ecotoxicology* 7:175-181.

- Grand, J.B., and P.L. Flint. 1997. Productivity of nesting Spectacled Eiders on the lower Kashunuk River, Alaska. *Condor* 99:926-932.
- Grand, J.B., P.L. Flint, M.R. Petersen, and C.L. Moran. 1998. Effect of lead poisoning on Spectacled Eider survival rates. *J. Wildl. Manag.* 62:1103-1109.
- Grebmeier, J.M., J.E. Overland, S.E. Moore, E.V. Farley, E.C. Carmack, L.W. Cooper, K.E. Frey, J.H. Helle, F.A. McLaughlin, and S.L. McNutt. 2006. A major ecosystem shift in the northern Bering Sea. *Science* 311:1461-1464.
- Hamazaki, T., L. fair, L. Watson, and E. Brennan. 2005. Analyses of Bering Sea bottom-trawl surveys in Norton Sound: absence of regime shift effect on epifauna and demersal fish. *J. Marine Science* 62:1597-1602.
- IPCC. 2007. Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Johnsgard, P.A. 1964. Comparative behavior and relationships of the eiders. *Condor* 66:113-129.
- Knoche, M.J., A.N. Powell, L.T. Quakenbush, M.J. Woller, L.M. Phillips. 2007. Further evidence for site fidelity to wing molt locations by King Eiders: integrating stable isotope analyses and satellite telemetry. *Waterbirds* 30:52-57.
- Korschgen, C.E., K. P. Kenow, A. Gendron-Fitzpatrick, W. L. Green and F. J. Dein. 1996. Implanting intra-abdominal radiotransmitters with external whip antennas in ducks. *J. Wildl. Manage.* 60:132-137.
- Larned, W.W., and T. Tiplady. 1999. Late winter population and distribution of Spectacled Eiders (*Somateria fischeri*) in the Bering Sea, 1998. U.S. Fish and Wildlife Service, Anchorage, Alaska (unpublished report).
- Lindberg, M.S., and J. Walker. 2007. Satellite telemetry in avian research and management: sample size considerations. *J. Wildl. Manage.* 71:1002-1009.
- Lovvorn, J.R., S.E. Richman, J.M. Grebmeier, and L.W. Cooper. 2003. Diet and body condition of Spectacled Eiders wintering in pack ice of the Bering Sea. *Polar Biology* 26:259-267.
- Lovvorn, J.R., J.M. Grebmeier, L.W. Cooper, J.K. Bump, and S.E. Richman. 2009. Modeling marine protected areas for threatened eiders in a climatically changing Bering Sea. *Ecological Applications* 19:1596-1613.
- Machin, K.L., and N.A. Caulkett. 2000. Evaluation of isoflurane and propofol anesthesia for intraabdominal transmitter placement in nesting female Canvasback ducks. *J. Wildlife Diseases* 26:324-334.
- Mehl, K.R., R.T. Alisauskas, K.A. Hobson, and F.R. Merkel. 2005. Linking breeding and wintering areas of King eiders: making use of polar isotopic gradients. *J. Wildl. Manage.* 69:1297-1304.
- Mulcahy, D. M., and D. Esler. 1999. Surgical and immediate postrelease mortality of Harlequin Ducks implanted with abdominal radio transmitters with percutaneous antennae. *J. Zoo and Wildlife Medicine* 30:397-401.
- Oppel, S. and A.N. Powell. 2008. Assigning King Eiders to wintering regions in the Bering Sea using stable isotopes of feathers and claws. *Mar. Ecol. Prog. Ser.* 373:149-156.
- Oppel, S., A.N. Powell, D.L. Dickson. 2008. Timing and distance of King Eider migration and winter movements. *Condor* 110:296-305.



- Petersen, M.R., J.F. Piatt, and K.A. Trust. 1998. Foods of Spectacled Eiders *Somateria fischeri* in the Bering Sea, Alaska. *Wildfowl* 49:124-128.
- Petersen, M.R., W.W. Larned, and D.C. Douglas. 1999. At-sea distribution of Spectacled Eiders: a 120-year-old mystery resolved. *Auk* 116:1009-1020.
- Petersen, M.R., J.B. Grand, and C.P. Dau. 2000. Spectacled Eider (*Somateria fischeri*). In *The Birds of North America*, No. 547 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.
- Petersen, M.R. and P.L. Flint. 2002. Population structure of Pacific Common eiders breeding in Alaska. *Condor* 104:780-787.
- Petersen, M.R., B.J. McCaffery, and P.L. Flint. 2003. Post-breeding distribution of Long-tailed Ducks *Clangula hyemalis* from the Yukon-Kuskokwim Delta, Alaska. *Wildfowl* 54:103-113.
- Petersen, M.R., and D.C. Douglas. 2004. Winter ecology of Spectacled Eiders: environmental characteristics and population change. *Condor* 106:79-94.
- Phillips, L.M., A.N. Powell, E.J. Taylor, and E.A. Rexstad. 2007. Use of the Beaufort Sea by King Eiders breeding on the north slope of Alaska. *J. Wildl. Manage.* 71:1892-1898.
- Plowman, B.W., L.M. Conner, M.J. Chamberlain, B.D. Leopold, and L.W. Burger, Jr. 2006. Annual dynamics of Bobcat (*Lynx rufus*) home range and core use areas in Mississippi. *American Midland Naturalist* 156:386-393.
- R Development Core Team. 2005. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.
- Scribner, K.T., M.R. Petersen, R.L. Fields, S.L. Talbot, J.M. Pearce, and R.K. Chesser. 2001. Sex-biased gene flow in Spectacled Eiders (Anatidae): inferences from molecular markers with contrasting modes of inheritance. *Evolution* 55:2105-2115.
- Service Argos, Inc. 2001. Argos user's manual, Service Argos, Inc., Largo, MD. Website: <http://www.cls.fr/manuel>.
- Stehn, R.A., C.P. Dau, R. Conant, and W.I. Butler, Jr. 1993. Decline of Spectacled Eiders nesting in western Alaska. *Arctic* 46:264-277.
- The GEBCO\_08 Grid, version 20090202. 2008. <http://www.gebco.net>. Accessed 9 Oct 09.

