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Patterns of use and distribution of king eiders and black scoters during the annual cycle in northeastern Bristol Bay, Alaska

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Abstract Northeastern Bristol Bay, Alaska, which includes three large estuaries, is used by multiple sea duck species during the annual cycle. Limited aerial surveys indicate that this area supports tens of thousands of king eiders and black scoters during spring migration and the autumn molt. Existing satellite telemetry data were used to assess the temporal patterns of habitat use and spatial distribution of king eiders and black scoters in northeastern Bristol Bay throughout the annual cycle. King eiders used northeastern Bristol Bay during all months of the annual cycle and black scoters used the area during spring through fall. Both species exhibited a similar seasonal pattern of use that corresponded with the timing of life-cycle stages. Abundance of both species was highest during spring migration and the autumn molting period and lowest during summer. Use by king eiders did not occur during all winter months in every year of the study. King eiders were more broadly distributed than black scoters and were located farther from shore in deeper water. Core use areas had minimal overlap, suggesting a degree of spatial segregation between species and a preference for different habitats in northeastern Bristol Bay. Further study of potential variation in invertebrate community structure that may correlate with the observed interspecific spatial segregation in habitat use is needed to determine preferred forage and describe habitat requirements for each species. Such information is necessary to assess the potential impact that future anthropogenic or environmental changes may have on habitat quality of northeastern Bristol Bay and demography of Pacific sea duck populations that use this area.

Introduction

Habitats important to sea ducks throughout the annual cycle are poorly known, particularly during the non-breeding period when most sea duck species use marine habitats that often are inaccessible to observers and seldom surveyed (Petersen et al. 1999; Phillips et al. 2006). However, the recent use of satellite telemetry has allowed researchers to examine large-scale movements of many sea duck species throughout their annual cycle and begin to identify important staging, molting and wintering habitats (Petersen et al. 1995, 2006; Phillips et al. 2006; Oppel et al. 2008). A growing concern is that many of these habitats have been or have potential to be altered by human development (Guillemette and Larsen 2002; McKinney et al. 2006) or climate-related environmental change (Dickson and Gilchrist 2002; Lovvorn et al. 2003; Grebmeier et al. 2006). Habitat changes may elicit strong demographic responses from sea duck populations either directly (e.g., reduced survival) or indirectly through carryover effects from seasonal interactions between life-history stages, which have the potential to influence individual fitness, and consequently, population dynamics (Norris and Marra 2007; Anteau and Afton 2009). Many sea duck populations have declined substantially in recent decades for unknown reasons, and there is little biological information available to manage these

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population declines (SDJV 2008). However, broad scale declines occurring simultaneously across multiple species suggest that causes may be related to conditions at sea where species are sympatric. Thus, there is emerging interest in improving the understanding of sea duck marine ecology to better manage and conserve their populations in changing environments.

In Alaska, the northeastern Bristol Bay region of the Bering Sea has been identified as an important area for king eiders (*Somateria spectabilis*) and black scoters (*Melanitta nigra*) (Phillips et al. 2006; Oppel et al. 2008; Larned 2008; J. Schamber unpubl data); other sea duck species (e.g., long-tailed ducks [*Clangula hyemalis*], and white-winged scoters [*Melanitta fusca*]) also use the region (Larned 2008). Recent satellite telemetry studies suggest that northeastern Bristol Bay is a principal molting and wintering site for king eiders (Phillips et al. 2006; Oppel et al. 2008) and that significant proportions of the Pacific population of black scoters migrate through the area during spring and fall (J. Schamber unpubl data). Large aggregations of both species were observed at northeastern Bristol Bay in spring during annual coastal surveys of Steller's eiders (*Polystica stelleri*) and in past surveys of molting king eiders; estimates ranged in the tens of thousands (Larned and Tiplady 1997, 1998; Larned 2008). These surveys were constrained to near-shore areas, but yielded estimates of up to 125,000 king eiders in spring; with expanded estimates (survey estimate × [sample area/transect area]) of up to 500,000 king eiders (Larned 2008). Also, spring surveys yielded estimates of up to 45,000 black scoters; however, these surveys (conducted in early to late April) likely were poorly timed to estimate peak abundance of migrating scoters. Autumn surveys (conducted in late September and early October) resulted in estimates of ~20,000 king eiders and ~20,000 black scoters using the area (Larned and Tiplady 1997, 1998). Both the spring and fall estimates should be considered minimums of the total number of birds that use the area during these periods, because northeastern Bristol Bay was surveyed over a one to two-day period with incomplete coverage; as such, these surveys may not have captured the peak abundance and do not account for individual turnover. Nonetheless, the surveys lend support to the satellite telemetry data and indicate that this area is used by large numbers of king eiders and black scoters, particularly during the spring and fall seasons when physiologic condition may have strong fitness-related consequences (Hepp et al. 1986; Anteau and Afton 2009). We suspect that large numbers of sea ducks are attracted to northeastern Bristol Bay because of an abundant and reliable benthic invertebrate food resource, which comprises the primary diet of many sea ducks while in marine habitats (Stott and Olson 1973; Goudie and Ankney 1986; Bustnes and Erikstad 1988). However, despite the apparent importance of northeastern Bristol Bay to both species, little information is available about how they use the area temporally and spatially throughout the annual cycle. Such information is valuable for recognizing population-limiting factors and understanding the potential impacts that future changes, such as suspected climate-related ecosystem shifts in the Bering Sea (Grebmeier et al. 2006) or anthropogenic influences on habitat quality, might have on Pacific sea duck populations that use northeastern Bristol Bay.

Our objectives were to use existing satellite telemetry data to estimate the proportion of king eiders and black scoters that use northeastern Bristol Bay and their mean residence time in each calendar month. We also compared their overall home range distribution and core use of the Bristol Bay area. We interpret our results in the context of species-specific habitat selection.

Materials and methods

Study area

We defined the northeastern Bristol Bay region as the 3 prominent marine tidal embayments that included Nushagak, Kvichak, and Egegik bays, located in the southeastern portion of the Bering Sea, Alaska (Fig. 1). The study area extended from the tip of Cape Constantine on the Nushagak Peninsula to the southern end of the mouth of Egegik Bay. Nushagak Bay and neighboring Kvichak Bay are fed by large river drainages and form the largest portion of the region, comprising ~2850 km^2 of total area. Egegik Bay, also river fed, is located ~20 km south of Kvichak Bay and is much smaller in size at approximately 65 km^2. Northeastern Bristol Bay is relatively shallow and characterized by extensive (~530 km^2) mud flats and sand shoals that are exposed at low tide. However, deep water channels and offshore water depths at low tide may exceed 27 m.

Field methods

We used available satellite transmitter data from previous studies of large-scale movements of king eiders ($n = 157$) and black scoters ($n = 77$) (Oppel and Powell 2009; Read et al. 2010; J. Schamber unpubl data). In those studies, king eiders were captured on their breeding grounds at three locations on the North Slope of Alaska in 2002–2008, and black scoters were captured at four wintering locations and a single breeding location in Alaska in 2003–2007. Birds from both species were instrumented with intra-abdominal satellite transmitters (38 g; Microwave Telemetry Inc., Columbia, Maryland) following methods described by Korschgen et al. (1996). We included the locations of adult (≥2 years old) and sub-adult (<2 years old) males and females

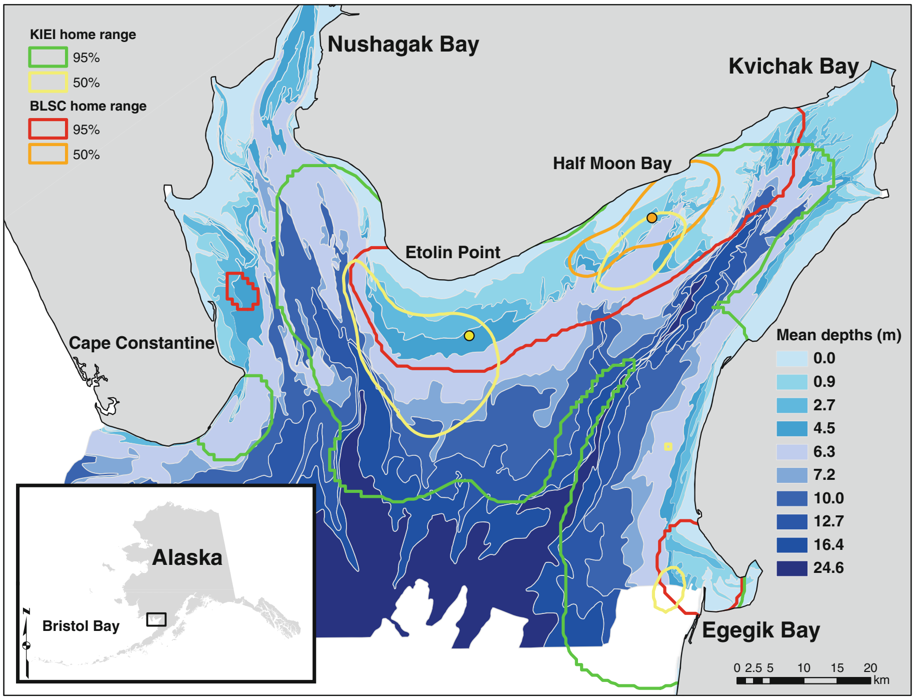

Fig. 1 Map of northeastern Bristol Bay, Alaska depicting the 95 and 50% probability contours for king eiders and black scoters based on a kernel home range analyses using data from previous satellite telemetry studies. The *yellow* (king eider) and *orange* (black scoter) dots denote the centroids of the 50% contours

in analyses if they were documented using our study area (30 king eiders and 58 black scoters). Specifically, our data set included 12 adult female, 3 sub-adult female, 14 adult male, 1 sub-adult male king eiders, 19 adult female, 12 sub-adult female, 26 adult male, and 1 sub-adult male black scoters. Transmitter duty cycles were set to meet the objectives of the original studies; in general, transmitters provided location data every 2–7 days for 10–20 months for king eiders and every 3 days for 12–24 months for black scoters. Location data were filtered using the PC-SAS Argos-Filter Algorithm v.7.02 (D. Douglas, US Geological Survey, Alaska Science Center, Anchorage, Alaska) to remove implausible locations, for accuracy (i.e., quality of location class; classes ranged from 3 to 0 with 3 being of highest quality; Harris et al. 1990) and to retain the best location class per transmission. We plotted bird locations on Electronic Navigational Charts: NOAA ENCs® (NOAA Office of Coast Survey online 2009) of northeastern Bristol Bay using ESRI ArcMap™ 9.2 (Environmental Systems Research Institute, Redlands, CA, USA). In addition, we assigned each bird location a bathymetric value according to polygons drawn along depth contour lines found on the navigational charts. We drew a separate polygon for each depth contour and assigned the mean depth value to each bird location falling within the respective polygon. Mean depth values at lower mean low tide in meters were 0.0, 0.9, 2.7, 4.5, 6.3, 7.2, 10.0, 12.7, 16.4, and 24.6 (Fig. 1). We also calculated distance from shore for each bird location, using ArcMap, as the shortest distance of each point to a polyline shapefile based on the northeastern Bristol Bay coastline in the navigational charts. We used all locations for each individual bird in our analyses; therefore, we note that our data may contain bias because individual bird locations are likely autocorrelated. However, individual bird movements within northeastern Bristol Bay may have included multiple location states (i.e., depth classes and shoreline distances); thus, for this study we included all possible individual states.

Analytical methods

We described use of the bays by each species throughout the annual cycle as the proportion of satellite-tagged birds that occupied northeastern Bristol Bay and their mean residence time for each month. We calculated the proportion of birds as the ratio of the number of individuals in each month to the total number of individuals that ever occurred within northeastern Bristol Bay. In addition, we calculated mean residence time for each month as the total number of days that birds occupied the study area divided by the total number of birds present. We did not account for annual variation in these data; and therefore, in some months we may have overestimated use of northeastern Bristol Bay because birds were not present in all months of every year; we discuss these instances later. Also, small sample size precluded us from examining differences between sexes in each month or between age groups.

We examined the distribution of king eiders and black scoters in northeastern Bristol Bay using a fixed kernel home range analysis (Kernohan et al. 2001) to produce 95% (home range) and 50% (core use) probability contours using the Animal Movement extension (Hooge and

Eichenlaub 2000) in ArcView GIS 3.3 (Environmental Systems Research Institute, Redlands, CA, USA). We compared the overall distribution between species by using a multi-response permutation procedure in BLOSSOM (Cade and Richards 2001) to test locations within respective 95% contours. Also, we measured total area of the 95% and 50% contours and calculated the percent overlap of the contours between species. We used a randomization procedure using Poptools Macro (v.2.7.5; Hood 2006) in Microsoft Excel 2003 to assess the probability that species distribution differed across depth values. First, we calculated the difference in overall mean depth values between king eiders and black scoters. We then randomly reassigned location depths to a species, without replacement, to retain the original sample size of locations for each species and re-calculated the difference in overall mean depth between species. We repeated this process over 1000 iterations, and we report the P-value as the proportion of random trials with greater differences between species than observed in the actual data +1 divided by the number of trials +1 (Davidson and Hinkley 1997). Conditional on the sample of bird location depths, this proportion represents the probability that the variation observed among sample areas occurred by random chance. We also used a randomization procedure to assess the probability that species differed in their proximity to shore. We acknowledge that the tests for water depth and distance from shore are not independent (i.e., distance from shore and water depth tend to be correlated), but we present both analyses as descriptors of habitat use.

Results

King eiders were present in northeastern Bristol Bay during all months of the year. Overall, only 20% of birds satellite-tagged on the North Slope occurred in northeastern Bristol Bay. Given the subset of birds that used the area, the proportion of marked birds was highest in March (0.50) and April (0.63), but was also relatively high in October (0.43; Fig. 2a). The lowest proportion of birds occurred during the months of May (0.10), June (0.03), and July (0.03; Fig. 2a). The monthly mean residence times generally followed the same seasonal pattern of occurrence. Mean residence times were highest in October (20.6 days) and September (19.4 days) and were lowest during May–July (4.0 days, 6.0 days, and 2.0 days, respectively; Fig. 2b).

Black scoters were present in northeastern Bristol Bay in April through November; marked birds were absent December through March. Overall, 75% of the marked population occurred in northeastern Bristol Bay. Given the subset of birds using the area, the highest proportion of marked individuals was present in May (1.00) and October (0.62) with notable changes in proportions occurring before and after these months (Fig. 2a). In all other months, with the exception of November (0.06), the range in proportion of marked birds was 0.36–0.51. Black scoters resided longer, on average, in August (21.8 days) and September (18.4 days) but, with the exception of November (1.0 days), residence times were shortest in April (6.8 days) and May (9.1 days; Fig. 2b).

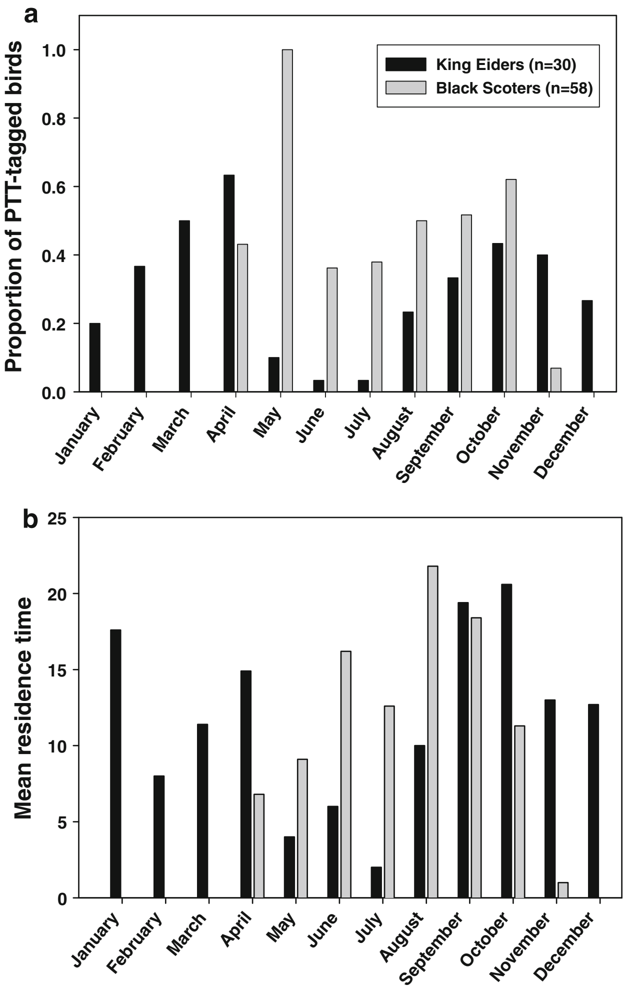

Fig. 2 **a** The proportion of satellite-tagged king eiders (2002–2008) and black scoters (2003–2007) that used northeastern Bristol Bay, Alaska in each calendar month pooled across years **b** Average residence time spent at northeastern Bristol Bay, Alaska by king eiders (2002–2008) and black scoters (2003–2007) in each calendar month pooled across years. Mean residence time was calculated as the total number of days satellite-tagged birds occupied the area divided by the total number of satellite-tagged birds present

Although locations for both species occurred throughout the study area, the overall distribution of king eiders was significantly different from black scoters ($\delta_{1371} = 1.42$, $P < 0.01$). Black scoters were distributed along areas with shallower depths ($P < 0.01$; 2.4 ± 6.8 m, $N = 901$) and located closer to shore ($P < 0.01$; 5.1 ± 3.2 km, $N = 901$) than were king eiders (6.3 ± 15.5 m, $N = 461$ and

10.6 ± 6.3 km, $N = 461$). Overall, king eiders appeared to be more broadly distributed throughout northeastern Bristol Bay than black scoters. Our kernel home range analysis resulted in a 95% contour for king eiders with a total area of ~3669.6 km^2 and encompassed most of the study area, extending from the Nushagak Peninsula to Egegik Bay and including much of Nushagak and Kvichak bays (Fig. 1). In contrast, the 95% contour for black scoters was much smaller with a total area of ~1297.8 km^2; the area extended from Half Moon Bay to Etolin Point and included smaller areas in Nushagak and Egegik bays (Fig. 1). Core use areas were largely unique in terms of location and water depth between species. A single 50% contour was estimated for black scoters with a total area of 159.5 km^2; the centroid was located near Half Moon Bay approximately 5.3 km from shore in the 0.9 m depth contour. In contrast, four contours were estimated for king eiders with a total area of 447.5 km^2 with an averaged centroid located in the 4.5 m depth contour approximately 8.7 km from shore at Etolin Point (Fig. 1). The distance between the centroids of the 50% contours for each species was 32.5 km. The percent overlap in area between the 50% contours of each species was minimal at 6.9%.

Discussion

Patterns of use

In general, use of northeastern Bristol Bay by both species followed a similar seasonal pattern, with increases in the proportion of tagged birds during spring and fall that appeared to correspond with the timing of migration (Bordage and Savard 1995; Oppel et al. 2008); signifying the influx and outmigration of birds using the area. However, we found evidence that black scoters and king eiders were segregated during the winter months; king eiders were present during winter, while black scoters were absent. The pattern of residence times was also similar for both species and agreed with the timing of their life-cycle stages (Bordage and Savard 1995; Oppel et al. 2008). For instance, mean residence times were relatively short (≤2 weeks) during spring, consistent with stopover migration, and longer during fall (>3 weeks), suggesting the autumn wing molt.

King eiders

King eiders appeared to use northeastern Bristol Bay during all months of the year. A minimum of 20–25% of tagged eiders in our study used northeastern Bristol Bay during winter; although, this proportion only included the months of December and January. King eiders exhibit nomadic behavior during winter, and males may arrive at winter locations as early as late July (Oppel et al. 2008). Further, king eiders were not present in all winter months of every year. For example, king eiders used northeastern Bristol Bay in only 4 of 7 years during December and 3 of 7 years in January. Individual movements during winter by king eiders are highly variable and may be primarily exploratory in nature (Oppel et al. 2009); thus, king eiders may frequently move out of northeastern Bristol Bay to find other suitable winter locations. Spring migrants likely began moving into northeastern Bristol Bay as early as February (Oppel et al. 2008) and reached a peak number in April. The month of April had the highest proportion of tagged birds, suggesting that northeastern Bristol Bay was used by a greater number of king eiders during spring migration than during other periods. However, the average spring migrant resided for a short period (≤2 weeks), likely using the bays as a spring stopover site to acquire reserves for continued migration. Most tagged birds departed the bays in April, but in 2 study years, a small number ($n = 3$) of presumed late migrants were present for a short time in May. Accordingly, relatively few eiders seem to use northeastern Bristol Bay during the summer months, and these are likely to be sub-adult birds; a sub-adult bird spent 6 days in late June 2008 and another sub-adult spent 8 days in late July/early August 2007. Near the end of August, fall migrants began to arrive and steadily increased in number to a peak in October. Many of these birds resided for ~3 weeks, consistent with the timing of molt (Phillips et al. 2006; Oppel et al. 2008). However, residence times were highly variable during fall, ranging from 4 to 51 days, suggesting that birds likely also used the bays as a stopover site or a terminal wintering location; the onset of fall migration of eiders can begin as early as September and extend into late November with some individuals reaching wintering areas as early as late July (Oppel et al. 2008).

Black scoters

Black scoters used northeastern Bristol Bay from spring through fall; satellite-tagged scoters were absent during the winter months of December through March. Black scoters tend to inhabit ice-free waters during winter (Bellrose 1980); thus, we suspect that black scoters may move out of northeastern Bristol Bay during winter because it frequently has significant ice cover. Moreover, black scoters may be displaced because their preferred habitat of shallow, near-shore areas (see below) where current flow is reduced likely has semi-permanent shore-fast ice cover during the winter months. Spring migrants began arriving to northeastern Bristol Bay in April, followed by a peak number in May when 100% of tagged birds in the study were present. Similar to king eiders, black scoters resided for only a short period (<10 days) during spring, but the high proportion of tagged birds implies that the bays were of particular importance to spring migrants. Many black scoters departed the bays by June, but ~35% of tagged birds in the study were present in June and July. However, mean residence times were ≤16 days, suggesting that many of these birds spent only a portion of those months in northeastern Bristol Bay. Most of these birds were adult males and sub-adults, and therefore, were likely a mix of late spring migrants (black scoters breed later than most waterfowl species: nests are initiated in late June or early July; Bordage and Savard 1995; Schamber et al. 2010), non-breeding individuals (unpaired males or sub-adults), and molt migrants (males depart the breeding grounds for molting areas when incubation begins; J. Schamber unpubl data). However, nine adult females also were present during summer; these birds likely either didn't breed or were failed breeders. The proportion of tagged birds began to increase in August and reached a peak in October. Mean residence times were ~3 weeks in August and September, consistent with the timing of molt (Bordage and Savard 1995). However, at peak occupancy in October, mean residency was <12 days, suggesting that many of these birds were fall migrants and were likely using the bays as a stopover site. Most birds departed northeastern Bristol Bay by late October or in 2 study years by early November.

Distribution

Overall spatial distribution of satellite-tagged king eiders and black scoters differed between species in northeastern Bristol Bay, although some overlap in satellite locations was apparent. Locations for both species were scattered throughout the study area, but home range estimates were much larger for king eiders than black scoters. Notably, the 95% contour estimate for king eiders was approximately triple the size for black scoters and encompassed most of northeastern Bristol Bay and the estimated home range of black scoters with nearly 100% overlap between 95% contours. However, inspection of king eider core use areas indicated minimal overlap between species; their 50% contour estimates shared ~7% of total area, and the centroids of those contours were separated by >30 km. In particular, the largest (~85% of total area) of four contours estimated for king eiders was situated off the coast of Etolin Point, and the single contour for black scoters was located near Half Moon Bay (Fig. 1). On average, king eiders tended to be located farther from shore and preferred deeper water than black scoters; a finding that is consistent with the distributional relationship of king eiders to other sea duck species elsewhere (Bustnes and Lonne 1997; Fischer and Larned 2004; Merkel et al. 2002). Thus, there appeared to be a level of spatial segregation with regard to core habitat use between king eiders and black scoters, despite significant overlap in their overall distributions. Although we can only speculate about this observed dichotomy in spatial distributions, we hypothesize that it is related to available food resources. Other studies have found that sea duck distribution is influenced by variation in prey distribution and abundance (Larsen and Guillemette 2000; Vaitkus and Bubinas 2001; Kaiser et al. 2006), and differences in spatial distribution between sea duck species may be associated with food habits (Stott and Olson 1973; Goudie and Ankney 1988). Most sea ducks forage on benthic invertebrates (Stott and Olson 1973; Goudie and Ankney 1986; Bustnes and Erikstad 1988), which may exhibit considerable spatial heterogeneity among habitat types (Morrisey et al. 2002; Yeung and McConnaughey 2006), including substrate and depth (Barry and Dayton 1991). Accordingly, sea duck species with broad diets may be more widely distributed across habitat types than those with relatively specialized diets (Stott and Olson 1973).

In northeastern Bristol Bay, the food habits of king eiders and black scoters relative to invertebrate community structure are unknown; however, we envision three hypotheses based on possible prey distributions that may explain the spatial segregation between the two species. First, king eiders and black scoters may forage for different prey species that are spatially variable resulting in the observed differences in core distributions (Bustnes and Systad 2001; Merkel et al. 2007). Second, both species may forage on the same prey that are spatially variable in abundance but differences in body size between king eiders and black scoters result in differences in optimal foraging depth (Mori 1998). King eiders tend to dive deeper for food than black scoters (Bustnes and Lonne 1997; Kaiser et al. 2006); thus, they may be able to exploit a wider array of habitat, and therefore, consume benthic prey unavailable to black scoters. Third, the allopatric core use areas may represent resource partitioning to minimize competition as sea ducks can deplete foraging habitats of invertebrate prey, particularly when they forage in large, dense flocks (Guillemette et al. 1996; Bustnes and Lonne 1997; Hamilton 2000). These hypotheses are not necessarily mutually exclusive, and therefore, we recognize that the mechanisms driving spatial distribution are likely dynamic and complex because numerous other factors (e.g., predator distribution, disturbance) also may influence the distribution of sea ducks (Kaiser et al. 2006). Thus, we encourage further study of potential factors influencing spatial distribution of all sea duck species in northeastern Bristol Bay (i.e., including species other than king eiders and black scoters), with regard to variation in food habits to determine preferred forage and describe specific habitat requirements for each species.

Importance of northeastern Bristol Bay and potential threats to sea ducks

Satellite telemetry data indicated that ~75% of black scoters that were marked throughout their range used northeastern Bristol Bay, which likely represents a significant proportion of the Pacific black scoter population. Further, nearly 20% of king eiders tagged on the North Slope used the area during the annual cycle; as well, king eiders breeding in the western Canadian Arctic and Russia also used the area (Oppel et al. 2008; Dickson et al. 1998; Suydam 2000), suggesting international importance of northeastern Bristol Bay. Consequently, given the proportional use estimated by satellite telemetry and past aerial survey estimates of abundance (see Section "Introduction"), we suspect that northeastern Bristol Bay is an important area for a large segment of the Pacific populations of king eiders and black scoters during the annual cycle. Thus, future impacts from resource development or environmental change could have significant population level effects for both species. Mineral extraction is proposed for adjacent areas in the form of offshore oil and natural gas leases in the North Aleutian Basin (Minerals Management Service 2010) and a large open-pit mine at the headwaters of northeastern Bristol Bay (The Pebble Partnership 2010). Despite the use of technologies designed to minimize the probability of such occurrences, these types of resource development have potential for accidental discharge of pollutants (e.g., oil spills) that can adversely impact nearshore water quality and sea bird foraging habitats (Piatt et al. 1990; Eisler and Wiemeyer 2004). Foraging habitat in northeastern Bristol Bay also may be altered by climate-related change. Possible shifts in benthic infaunal community structure and reductions in benthic biomass are linked to a warming trend in sea surface temperature in the Bering Sea (Grebmeier et al. 2006; Coyle et al. 2007). Such shifts may include alterations to benthic species composition resulting in changes in food availability that may affect the energy balance of sea ducks; such changes have been documented for wintering spectacled eiders (Lovvorn et al. 2003). Potential climate-related changes to sea duck food sources in northeastern Bristol Bay may reduce prey availability, alter interspecific relationships, and potentially influence sea duck population demography. We might predict these changes to reflect strongly in species such as black scoters that appear to have specialized habitat requirements relative to king eiders that exhibit relatively greater flexibility in habitat use. However, sea duck habitat requirements in relation to the benthic community in northeastern Bristol Bay have not been addressed; this information is needed to identify and assess the impact of human development and future environmental changes in sea duck food resources.

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