Breeding ecology of Spectacled Eiders Somateria fischeri in Northern Alaska

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Spectacled Eiders *Somateria fischeri* were studied on the Colville River delta during 1994–1999, prior to oil field development, to document aspects of breeding biology that are poorly known, especially for northern-nesting populations. Both sexes arrived June 6–12; many males remained for only about 10 days. Density on the 178-km^2 study area was 0.48 birds/km^2, comparable to densities reported from extensive surveys in western Alaska and Russia. Wetlands with numerous islands and peninsulas were utilised prior to incubation, a little-studied period. Females spent considerably more time feeding than males (56% vs. 18%). Males travelled, rested and were alert more than females, and actively defended females from intruding males. Whole nest survival was 31% and varied substantially between years, as has been demonstrated in other studies. Brood size showed no detectable decline from hatch about July 10 to mid-August, suggesting low mortality during this period, a sharp contrast with results from a study in a lead-contaminated area of western Alaska in which duckling survival to 30 days post-hatch was 34%. The likelihood of adverse impacts on this threatened species, from oil-related or other activities, can be reduced by industry avoiding areas, throughout the summer, with numerous islands, peninsulas and deep water.

Key Words: Spectacled Eiders, Somateria fischeri, habitat, behaviour, survival, populations, oil

Spectacled Eiders *Somateria fischeri* breed in five disjunct populations in western Alaska, northern Alaska and arctic Russia (Petersen *et al.* 2000) and are listed as threatened under the Endangered Species Act (Federal Registry 1993), due in part to population declines in western Alaska (Petersen & Douglas 2004; Stehn *et al*. 1993). Several studies have documented Spectacled Eider survival, incubation behaviour, productivity and brood survival in western Alaska (Dau 1974, 1976; Flint & Grand 1997, 1999; Grand & Flint 1997), but less is known of their breeding biology in northern Alaska where half or more of the U.S. population resides and where oil exploration and drilling are rapidly proceeding as the National Petroleum Reserve – Alaska is developed. One published study has described Spectacled Eider nesting habitat in northern Alaska (Anderson *et al*. 1999). This study supplements that work by describing (a) density and population size in a 178-km^2 study area, (b) habitat use during pre-incubation and for nesting, (c) foraging and social behaviour during pre-incubation, and (d) clutch size, hatching success and brood survival. The study also suggests how the risk of adverse impacts on eiders from oil exploration and other activities can be reduced.

Methods

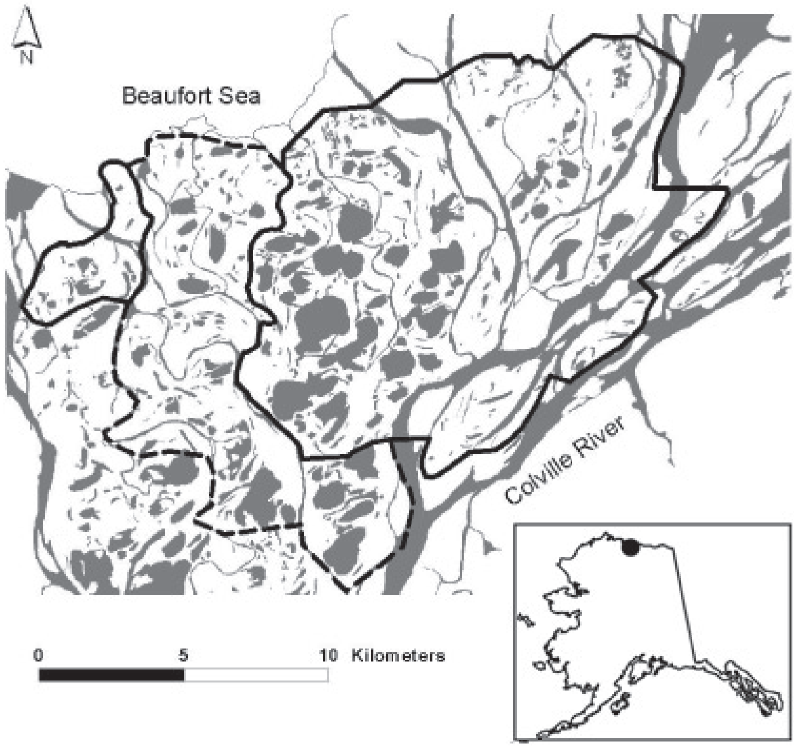
Field work was conducted throughout the period that Spectacled Eiders were present on the delta (June through August). Extensive surveys were conducted for males and females prior to nesting and for females on nests or with broods later in the season. Searching frequency and intensity varied considerably between years. During 1994, approximately 500 person-hours were spent between 9 June and 7 August searching for individuals, nests and broods, and making behavioural observations on pairs. During 1995, about half as much effort was expended as in 1994, and in other years, eider observations were made primarily in the course of other activities. Phenology was studied most intensively in 1994.

Study area and habitat types

The study area was on the Colville River delta in northern Alaska, 90 km west of Prudhoe Bay (**Figure 1**). The 500-km^2 delta is bisected by multiple river channels and characterised by numerous lakes and diverse wetland types (described below). Emergent vegetation growing along wetland edges was primarily *Carex aquatilis* and *Arctophila fulva*, and the drier soils of upland (i.e. non-wetland) areas were characterised by *Carex aquatilis*, *Eriophorum* spp. and dwarf willows *Salix* spp. Some areas bordering the Beaufort Sea were dominated by halophytic vegetation including *Dupontia fischeri*, *Carex subspathacea* and *Puccinellia phryganodes*. The delta was primarily pristine during the years of study, but construction of a housing facility, oil pipeline and oil drilling pads began in 1998.

Eleven wetland types were distinguished, based on a habitat map prepared by C. Markon (Rothe *et al*. 1983), aerial photographs and the authors' own field work. Polygon Ponds were dominated by discrete

Figure 1. Location of the study area on the Colville River delta, northern Alaska. During early June, 1994, 77% of the wetland area within the solid black lines was thoroughly searched for Spectacled Eiders and results were used in population size estimates. Search effort for nests varied among years and locations and included areas within dashed and solid lines. Major lakes and river channels are shown in black.



(i.e. not joined) ponds mainly of < 1.0 ha and separated by rims whose width was generally 1–10 m. Polygon Series were formed when the rims of several Polygon Ponds breached, producing a thin, linear waterbody with many peninsulas and often with islands. Polygon Series often bordered, and were partly continuous with, small to large lakes. Polygon Series Complexes consisted of several adjacent Polygon Series joined together, typically with many peninsulas and islands. Polygon Ponds, Polygon Series and Polygon Series Complexes were further divided into those bordered by halophytic versus non-halophytic vegetation (see study area description). Old Channels were former active river channels that were closed at both ends and were classified as small (< 1.5 ha), medium and large (>6.4 ha). Flooded Meadows were sparsely vegetated and covered by < 0.5 m of water during early spring but were moist or dry by late June. Drained Lake Basins were former lakes partially drained as a result of erosion by streams, and contained a mosaic of deep and shallow water, islands, saturated tundra and uplands, and had few if any polygonal formations.

Population size and habitat use

Sampling intensity varied among the 11 wetland types so the types were viewed as (non-continuous) strata, and equations for stratified sampling (Cochran 1977) were used to estimate population size. Upland areas between wetland strata were not sampled because eiders are restricted to aquatic areas (Petersen *et al*. 2000) and were not observed in the uplands during pre-incubation. The strata were divided into 190 compartments. Compartments to be surveyed were selected randomly within wetland strata, and each was surveyed once while male eiders were present in the study area in 1994. The study area is largely flat, and male eiders were nearly always visible from >100 m in most or all directions. Each compartment selected for survey was searched thoroughly. It is considered, therefore, that detection rates for males were essentially 100%. In total, 146 compartments (77%) were surveyed covering 17 km^2 (77% of the 22 km^2 wetland area). Survey results were used to estimate eider density by wetland type and to estimate population size in the study area during the pre-incubation period.

Nest searches were conducted throughout incubation. During 1994–1997, wetlands were searched specifically for Spectacled Eiders, and during all years, eider nests were found while searching the 11 wetland types for nests of Red-throated Loons *Gavia stellata*, Pacific Loons *Gavia pacifica* and Yellow-billed Loons *Gavia adamsii*. Some patches of each wetland type were searched intensively and some moderately in each year. During an intensive search of a wetland patch (for either eiders or loons), all associated banks, peninsulas and islands were walked; a moderate search encompassed < 100% of the potential nest sites. Nest sites were categorised by nearest wetland type and by landform, defined as island, peninsula, bank (land within 5 m of water, excluding islands and peninsulas) and upland.

Behaviour

In 1994 and 1995, instantaneous focal animal sampling (Altmann 1974) was used to produce time-activity budgets of pairs during the pre-incubation period. At 1-min intervals, the instantaneous behaviour of the male and female and the distance (in eider body-lengths) between the male and female were recorded; microhabitat (water–vegetation or water–shore interface, open water and bank) was also recorded at each 1-min interval in 1995. Pairs were treated as different primary units if data were collected in different locations or in different years. All known pairs within 1.5 km of the camp were observed. Observation periods were initiated without regard to the pair's behaviour, and were conducted between the hours of 0900 and 1800 during 9–14 June. Observations were made with a spotting scope at > 200 m from eiders. Some observations were made from permanent, enclosed, elevated blinds. Analyses are based on 13 pairs observed for a total of 24.5 bird-hours, with individual pairs observed for a total of 1.0–2.0 h (n = 8), 3.0–4.0 h (n = 2) or 0.5 h (n = 3).

Behaviours were recorded as travelling (walking, swimming, flying), resting (sitting, standing, sleeping – i.e. head resting on back or tucked under wing), alert and/or interacting with same-sex conspecific (alert posture defined as neck at 90° angle to water surface, head held high), foraging, and out-of-sight. Foraging was further distinguished as neck-under (all or most of neck submerged), head-under (head only submerged), and tip-up (neck and upper body submerged, tail near 90° to water surface).

Productivity

Nests were re-visited after hatch to document the presence of egg membranes separated from shells; a nest with one or more separated membranes was considered successful (Petersen *et al.* 2000). Counts of separated membranes were not considered reliable enough to estimate partial nest failure.

Nest success was estimated using the Mayfield (1975) method. It was not possible to re-visit nests until after hatch (to avoid disturbance), so a single exposure interval was obtained for each nest. The interval began on the day the nest was discovered and ended on the day the nest hatched, if it survived. The hatch date was estimated using the average initiation date, based on nests found during laying and at hatch. Most eider nests were initiated within a few days of each other so little error (and no bias) was caused by not knowing hatch dates exactly.

Females with broods were not marked and moved widely around the study area and thus could not be followed individually. To estimate survivorship during the brood-rearing period, the number of ducklings in broods encountered throughout the summer was recorded. Brood size was regressed on date, and the slope of the regression equation was used as an estimate of the rate at which ducklings were lost from surviving broods (i.e. partial brood loss). The regression equation was also used to predict brood size at the average hatch date, so that predicted size at hatch could be compared to average clutch size near the start of incubation to estimate partial nest loss.

Results

Phenology

In 1994, Spectacled Eiders were first sighted on the study area on 9 June. Most birds were seen in pairs until about 17 June. Lone males were frequently seen during 17–20 June, presumably reflecting the onset of incubation, and few sightings of either sex (except females on nests) were made after 20 June. For the two nests found during hatch, hatch dates were 11 and 14 July, indicating onset of incubation on 17 and 20 June, respectively (assuming a 24-day incubation period, Petersen *et al*. 2000). Thus, observations during 1994 suggest that Spectacled Eiders arrived on the study area during 9–12 June, incubation began on about 18–20 June, males departed 20–25 June, and hatching occurred during 11–15 July. Events in 1995 were a few days earlier (eiders arrived about 6 June) but were otherwise similar. Arrival was several days later in 1997 and 1999 than in other years, associated with low temperatures and late snow melt.

Population size and habitat use

In 1994, 28 pairs and 11 single males were found within the surveyed area. To facilitate comparison to other studies, the number of birds within the surveyed area was estimated as number of birds in pairs plus twice the number of single males (e.g. Hodges & Eldridge 2001). The estimated population size, adjusting numbers recorded for the fraction of each stratum surveyed, was 86.20 birds (s.e. = 4.10, coefficient of variation = 0.05); the estimated density for the wetland portion (21.9 km^2) of the study area was 3.94 birds/km^2 (s.e. = 0.19) and for the entire 178 km^2 study area was 0.48 birds/km^2 (s.e. = 0.023).

Males occurred at highest densities on Small Old Channels, Polygon Series, Polygon Series Complexes and Drained Lake Basins (**Table 1**). Densities in other habitats were markedly lower. Many standard errors are zero because all of the habitat type was searched (i.e. the finite population correction (Cochran 1977) was 0.0).

Fifty nests were found during 1994–1999, many of them while conducting other studies. Although search effort was not standardised among wetland types, many wetlands of each type were searched intensively each year (except for Drained Lakes, see below), and several conclusions are evident (**Table 2**). Most nests (84%) were placed near Polygon Ponds, Polygon Series and Polygon Series Complexes, and this corresponds to the high relative use of these habitats by pre-nesting pairs (**Table 1**). On the other hand, pairs were often seen on Small Old Channels during the pre-nesting and nesting periods, but only 4% of nests were found near Old Channels despite extensive search effort in this habitat. Pairs using Old Channels for foraging appeared to place nests in nearby Polygon Pond, Polygon Series and Polygon Series Complex habitat, perhaps because the banks of Old Channels were often saturated or covered by flood or melt-water during the period of nest-site selection. Lakes also appeared to be avoided by nesting eiders. Each year while searching for loon nests, observers walked the perimeter of dozens of lakes, but only two Spectacled Eider nests were found on lake edges. The low proportion of nests found in Drained Lake Basins may reflect the limited search effort in that habitat (five basins searched) and its relative rarity on the delta (eight basins in the stratified area and 15 in the entire delta). In 1994, the only year in which Drained Lake Basins were searched, 25% (4/16) of nests were found in this habitat.

The landforms used for nest sites also reveal several patterns (**Table 2**). Nearly all nests were within 1 m of the edge of the waterbody (47/50 = 94%), one was at 2 m, and two were > 50 m. Islands (all < 3 m^2) were the most commonly used nest site (54% of nests) but were rare in the study area. Peninsulas (20% of nests) were probably also used more commonly than expected, based on availability. Islands and peninsulas

Table 1. Number and density of Spectacled Eiders in 10 wetland habitats on the Colville River delta, northern Alaska, during 1994.

Habitat	Total area (km²)	Area searched (km²)	Indicated birds[1]	Density (birds/km²)	s.e.	Estimated number	s.e.
Polygon Ponds	13.80	9.85	2	0.20	0.12	2.80	1.64
Polygon Series	0.63	0.50	10	20.00	2.18	12.50	1.36
Polygon Series Complex	0.50	0.50	14	28.00	0.00	14.00	0.00
Small Old Channel	0.18	0.13	8	64.00	17.34	11.20	3.04
Medium Old Channel	0.60	0.33	2	6.16	2.92	3.70	1.74
Large Old Channel	0.28	0.28	0	0.00	0.00	0.00	0.00
Halophytic Polygon Ponds	2.68	2.50	0	0.00	0.00	0.00	0.00
Halophytic Polygon Series/ Series Complex	1.08	1.08	6	5.58	0.00	6.00	0.00
Flooded Meadows	0.83	0.83	6	7.28	0.00	6.00	0.00
Drained Lake Basin	1.38	1.38	30	21.82	0.00	30.00	0.00
All wetland strata	21.90	17.35	78	3.56	0.18	86.20	4.10

[1]Number of birds in pairs plus twice the number of single males.

were particularly common in Polygon Series, Polygon Series Complexes and Drained Lakes, and nearly all nests in these waterbody types (25/26 = 96%) were found on peninsulas and islands. Banks were by far the most abundant landform close to water but contained only 22% of nests.

Nests were loosely aggregated in some high-quality wetlands. For example, within six well-searched wetlands, 44% (12/27) of within-year,

Table 2. Number of Spectacled Eider nests on the Colville River delta, northern Alaska, 1994–1999, classified by nearest waterbody and landform type. Most nests (40/50) were within 1 m of the edge of the waterbody.

	Landform					
Waterbody	Upland	Bank	Peninsula	Island	Total	Proportion of total
Old Channel	2	0	0	0	2	0.04
Drained Lake	0	0	1	3	4	0.08
Lake	0	1	0	1	2	0.04
Polygon Ponds	0	9	2	9	20	0.40
Polygon Series	0	0	5	5	10	0.20
Polygon Series Complex	0	1	2	9	12	0.24
Total	2	11	10	27	50	1.00
Proportion of total	0.04	0.22	0.20	0.54	1.00	1.00

nearest-neighbour distances between nests were < 200 m and 81% were < 400 m. Wetlands that consistently supported multiple eider nests also supported many nests of other waterbird species known to prefer nesting on peninsulas, including Red-throated Loon, Pacific Loon, Black Brant *Branta bernicla*, Long-tailed Duck *Clangula hyemalis*, Sabine's Gull *Xema sabina*, Glaucous Gull *Larus hyperboreaus* and Arctic Tern *Sterna paradisaea*.

Behaviour

During the pre-incubation period, females spent considerably more time feeding than males (56% vs. 18%, paired *t*-test, t_{12} = 6.28, P < 0.0001, **Table 3**). Males actively guarded their mates when other males were in the vicinity, and males travelled, rested and were alert more than females. Pair members spent 32% of their time within one body-length of one another, 84% within 10 body-lengths, and 93% within 20 body-lengths.

Pairs primarily used the neck-under foraging mode rather than head-under or tip-up (70% and 64% of female and male foraging behaviours, respectively), and foraged primarily near shore or near emergent vegetation rather than in open water (76% of foraging time). Birds appeared to be foraging in the sediment or root mass of emergent vegetation when near the shore. The tip-up foraging mode, which was rarely used (13% of foraging behaviours; **Table 3**), was used primarily in open water (88% of tip-ups were in open water), presumably corresponding to deeper water there than along the shore. Diving was not observed. Males and females did not differ in the proportion of foraging time spent in different foraging modes (paired *t*-tests, all P > 0.05, **Table 3**) nor in microhabitat use while foraging.

Sufficient data were collected to compare time spent foraging in two habitat types – Polygon Series/Polygon

Table 3. Time-budgets of female and male Spectacled Eiders during pre-incubation on the Colville River delta, northern Alaska, 1994–1995.

A. Proportion of time spent in five general behaviours (n = 13 pairs).

	Females	Males	Paired difference (± s.e.)	t-value	*P*-value
Feed	0.559	0.175	0.383 (0.061)	6.28	<0.0001
Travel	0.093	0.198	-0.105 (0.043)	2.44	0.031
Rest	0.237	0.541	-0.304 (0.068)	4.47	0.001
Alert/Interact	0.021	0.047	-0.027 (0.011)	2.46	0.03
Out of sight	0.091	0.038	0.053 (0.019)	2.79	0.016

B. Proportion of foraging time spent in three foraging modes (n = 12 pairs).

	Females	Males	Paired difference (± s.e.)	t-value	*P*-value
Neck-under	0.720	0.645	0.057 (0.082)	0.7	0.5
Head-under	0.207	0.180	0.026 (0.054)	0.48	0.64
Tip-up	0.091	0.175	-0.083 (0.065)	1.28	0.23

Ponds combined and Old Channels (n = 5 and 8 pairs, respectively). Neither females nor males spent significantly more time foraging in one habitat than another (**Table 3**). Females foraged during 49% and 60%, and males during 14% and 20%, of time spent on Polygon Series/Polygon Ponds and Old Channels, respectively (independent *t*-tests, females, t_{11} = 1.05, P = 0.31, and males, t_{11} = 0.59, P = 0.57). The high variation among primary units, resulting in high standard errors and low power, limited the authors' ability to detect differences between habitats.

Time-budgets and incidental observations indicate that paired males sometimes left their mates to search for and visit additional females. In two cases, observations were begun on lone females who were then joined by their mate during the observation period. Also during two time-budgets, intrusions by second males were observed; both intrusions were estimated to be during or just prior to laying, based on known hatch dates for that year. Because few such interactions have been described in the literature (Petersen *et al*. 2000), a narrative by our assistant, J. Stephens, is repeated here, with minor editing. Names of displays follow Johnsgard (1964).

"12 June 1995. The intruding male entered the Old Channel about 200 m east of the focal pair and advanced towards them. The focal male became alert when the intruding male was within 30 m, then moved toward the intruder, meeting him about 15 m away from the female. The female did not follow but gave Inciting movements, including Chin-Lifting Displays. The focal male gave a Head-Forward-Rearing Display towards the intruder, and the intruder responded with the same display. A fight ensued 5–6 s later and lasted for 4 s. The fight involved bodily contact and much water displacement. Immediately after the fight, the intruding male retreated 15 m to the east. The focal male returned to the female and the pair engaged in mutual Wing-Flapping and Upward-Stretch Displays towards each other. The intruding male then flew about 300 m to the southeast and landed among eight Northern Pintails *Anus acuta*. The focal pair and intruding male preened on the bank for 15 and 40 minutes, respectively, before returning to foraging near the end of the scheduled time-budget. The intruder moved back towards the pair, but remained >30 body-lengths away."

Incidental observations also indicated that paired males visited additional females. In 1995, three females were observed, each of which appeared faithful to a given wetland across multiple days; birds arriving at each site could be seen by a human observer stationed at any one wetland. A single male was observed visiting each of the three females in succession. Because multiple observers were in the field, it was possible to confirm that there were no additional males at two of these three sites; the presence of an additional male at the third site was unknown. Active nests were eventually found in each of the three sites. It is likely that the male in question was actively seeking extra-pair copulations with multiple females, and it is possible that he was socially paired to more than one female.

Productivity

The proportion of nests that produced at least one nestling varied between years from 11% to 100%; the estimated overall success rate was 31% (**Table 4**). The within-year standard errors, calculated as in Johnson (1979), were small, suggesting that most of the apparent variation in rates between years is real (i.e. not just due to sampling error).

Loss of individual eggs in nests that produced at least one hatchling appeared to be small. The average clutch size for nests found during June 19–24 was 4.32 (s.e. = 0.18, n = 22). The estimated brood size at hatch was only slightly lower, 4.19, based on 17 sightings and the linear regression of brood size against hatch (**Figure 2**). The observed decline in brood size was 0.0042/day (**Figure 2**), indistinguishable from 0.0 (P = 0.85). Thus, individual survival of eggs and chicks in surviving nests and broods appeared to be high during the present study. No evidence of permanent creching was seen (i.e. one female leaving her brood with another female; see also Flint & Grand 1997; Petersen *et al.* 2000).

Discussion

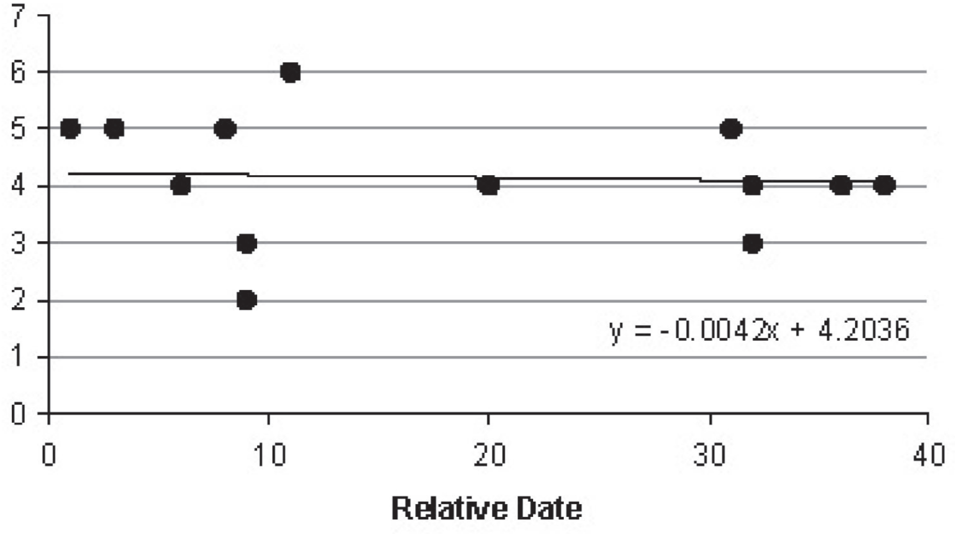
Phenology

In this study, Spectacled Eiders began arriving during June 6–12. Arrival was later in years when snow melt was later, but snow had often disappeared well before eiders arrived. Our dates for arrival and onset of incubation are similar to reports from Prudhoe Bay (Petersen *et al.* 2000) and from Russia (Pearce *et al.* 1998). Little has been reported on length of time males remain on the breeding grounds, but

Table 4. Estimated nest success of Spectacled Eiders on the Colville River delta, northern Alaska, 1994–1999.

Year	Number of nests	Number failed	Exposure days	Daily survival rate	Proportion of nests successful	Standard error
1994	15	12	146.5	0.918	0.13	0.02
1995	9	3	146.0	0.979	0.61	0.01
1996	3	0	34.0	1.000	1.00	0.00
1997	5	3	47.5	0.937	0.21	0.04
1998	4	4	46.0	0.913	0.11	0.04
1999	5	0	39.0	1.000	1.00	0.00
All	41	22	459.0	0.952	0.31	0.01

Figure 2. Spectacled Eider brood size in relation to sighting date (day 0 = July 10) on the Colville River delta, northern Alaska, 1994.



this information is important for aerial surveys, which rely on sightings of males. The period between arrival and egg laying was reported as 7.2 days in western Alaska (Dau 1974). The interval within which 90% of nests were initiated was 12, 17 and 21 days in different areas and years in Russia (Pearce *et al.* 1998). These results might suggest that males remain on the breeding grounds for 3–4 weeks. In this study, however, a few males remained for 2–3 weeks, but most were present for only about 11 days (~10–20 June). Consistent with our results, Troy (cited in Petersen *et al*. 2000) reported peak departure by male eiders from the Prudhoe Bay area on 20 June, and the average date of departure by radio-marked males was June 22 (Petersen *et al.* 1999). It thus appears that the window within which aerial and other breeding pair surveys should be made is only about 10 days, and that it may shift by a week between years. When surveys occur after this brief period, numerous male eiders may still be recorded, but population size may be under-estimated, both because a substantial number of males may have left the breeding grounds and because lone females are presumably less easily detected than those accompanied by boldly marked males.

Population size and habitat use

Historically, in western Alaska, eider density (assuming that all birds nest) was 8.8 birds/km^2 in central coastal areas, 2.0 birds/km^2 in central regions and 0.40 birds/km^2 in inland regions (Stehn *et al*. 1993). Following a major decline, densities were 1.32 birds/km^2 in central coastal areas and 0.12 birds/km^2 elsewhere. Hodges & Eldridge (2001) surveyed most of the range of Spectacled Eiders in Russia and reported an overall density of 0.93 birds/km^2. Some areas, however, had much higher densities. They distinguished 15 geographic strata. The four highest densities were 8.8, 7.3, 3.8 and 3.6 birds/km^2. The results of the present study, 3.94 birds/km^2 in wetlands and 0.48 birds/km^2 overall, are thus within the range of results from western Alaska prior to the decline and from Russia.

In this study, density prior to incubation was highest in the Drained Lakes, Polygon Series, Polygon Series Complexes and Small Old Channels. These areas all had both water >1 m deep and peninsulas and/or islands. Other areas with deep water (Polygon Ponds, larger old channels) usually did not have islands or peninsulas. Some halophytic areas did have islands, and three eiders were seen in these areas, but most did not. The important feature thus seems to have been islands and peninsulas surrounded by deep water, rather than other habitat features. The authors are not aware of any other reports of habitat-specific eider densities during the pre-incubation period, a period of particular importance to females that are spending considerable time foraging (see **Behaviour**) and presumably acquiring reserves for use during laying and incubation (e.g. Afton & Paulus 1992; Flint & Grand 1999).

Habitat use during nesting has been described for northern Alaska, western Alaska and Russia. Anderson *et al.* (1999) searched for nests in the Kuparak oil field just east of the Colville River delta, in habitats where eiders were located during pre-incubation surveys, and in two randomly-selected 10-ha plots on the Colville River delta. As in the present study, Anderson *et al.* (1999) found nests on small islands, peninsulas and polygon rims. Similar patterns of nest site placement were reported in western Alaska (Dau 1974) and northern Russia (Pearce *et al*. 1998). Results of this pre-incubation survey indicate that habitat use during pre-incubation is similar to that during nesting, except that eiders also used Small Old Channels during pre-incubation, even though most Small Old Channels did not have islands or peninsulas.

Behaviour

Although Spectacled Eiders are described as socially monogamous (Petersen *et al*. 2000), the behaviour of males and females prior to incubation has not been well described. The present study describes the active defence of females by their mates, intrusions by lone males, and visits of single males to more than one pre-laying female. In Spectacled Eiders, as in other ducks, one function of mate-guarding presumably is to facilitate male assurance of paternity (e.g. McKinney *et al.* 1983). The lone males that interacted with pre-laying pairs were probably seeking extra-pair copulations, and were either unpaired males or paired males whose mates had begun incubation. Likewise, in Common Eiders *Somateria mollissima*, the increase in encounter rates between paired and single males increased from 9.2 to 17.5 interactions per hour as more females initiated incubation, and was interpreted as paired males seeking extra-pair copulations when their mate started to incubate (Christensen 2000).

Mate-guarding has also been shown to facilitate female foraging in pre-laying ducks (e.g. Ashcroft 1976). In this study, Spectacled Eider females spent 56% of their time foraging, compared to only 17% by males, and males spent nearly twice as much time as females in agonistic behaviours directed towards other males. Similarly, in pre-laying Common Eiders, females devoted 51–62% of available daylight to foraging, compared to 17% by males (Christensen 2000). Acquisition of resources during pre-laying is particularly important to those arctic-nesting waterfowl in which females rely on and deplete endogenous reserves throughout laying and incubation. Because mass loss during incubation is positively correlated with incubation constancy among waterfowl species (Afton & Paulus 1992), the condition of females prior to incubation has been implicated in lower rates of abandonment, higher egg hatchability and lower predation. In eiders, female body mass loss during incubation is among the highest reported in waterfowl (reviewed in Afton & Paulus 1992), with female Common Eiders losing 33%, King Eiders *Somateria spectabilis* 30%, and Spectacled Eiders 26% of pre-incubation mass (Flint & Grand 1999; Kellet & Alisauskas 2000; Korschgen 1977). Common Eiders and Spectacled Eiders have correspondingly high incubation constancy (96% and 90%, respectively, Flint & Grand 1999; Korschgen 1977). Although it might be expected that female body condition is related to incubation constancy and thus nest success within eider species, the evidence is equivocal (Flint & Grand 1999; Kellet & Alisauskas 2000; Korschgen 1977). Further study is needed to clarify the link between the high rates of female foraging and male mate-guarding reported here during pre-incubation, and female body condition, incubation constancy and nest success.

Males and females primarily used head-under and tip-up foraging modes and primarily foraged in shallow to medium depths (< 2 m) along shorelines and the edges of emergent vegetation rather than in deeper, open water. Although foraging behaviour is rarely quantified, the results of this study are consistent with descriptions of Spectacled Eiders and other eider species foraging on the breeding grounds (e.g. Christensen 2000; Dau 1974; Petersen *et al.* 2000), and are consistent with foraging on the following items reported in the Spectacled Eider diet (reviewed in Petersen *et al*. 2000) and known to be present on the study area: insect larva (especially midges (Chronomidae) and mosquitoes (Culicidae)), crustaceans (especially fairy shrimp (Brachinecta), tadpole shrimp *Lepidurus* spp. and gammarid amphipods (Gammaridae)) and snails.

Productivity

The average clutch size found in the present study, 4.32, was similar to that from a large river delta (4.3) and a coastal area in Russia (4.6), and was intermediate between estimates from oil fields near Prudhoe Bay (3.5) in northern Alaska and those from western Alaska (5.0, 5.1), an area thought to be more productive because it is further south (studies summarised in Petersen *et al.* 2000). The estimate of 31% hatching success (i.e. nests with at least one egg hatching) is similar to that reported for the Prudhoe Bay region but lower than the 41–43% reported for western Alaska (reviewed in Petersen *et al*. 2000). The comparison of clutch sizes in early incubation to brood sizes predicted near hatch suggest that partial egg loss in successful nests is low, as has been documented in other studies (Grand & Flint 1997; Pearce *et al.* 1998).

The authors suspect, but cannot prove, that whole brood survival was high because there was no apparent decline in brood size. Entire broods could have died, but the authors believe it likely that ducklings would be lost singly during a period of at least a few weeks, which would cause a detectable decline in average brood size. Thus, they suspect that duckling survival was quite high. In contrast, in western Alaska duckling survival to 30 days post-hatch was only 34% (Flint & Grand 1997). Lead poisoning from spent lead shot was a significant mortality factor in western Alaska, whereas in this study area hunting pressure was light (a few party-hours per year) and confined almost entirely to navigable river channels rather than habitats frequented by Spectacled Eiders. Investigations into lead poisoning and the availability of lead in eider habitats at various sites in northern Alaska would be worthwhile, especially given the threatened status of this species.

Avoiding adverse impacts

The results of this study, in combination with others cited above, provide a basis for recommendations on how the oil industry and others working in regions with Spectacled Eiders might avoid adverse impacts (e.g. 'take' under the Endangered Species Act). Polygon Ponds, Polygon Series and Polygon Series Complexes were used during the pre-incubation, incubation and brooding periods. In contrast, medium and large old channels, upland areas, and lakes were seldom used at any time of year. Thus, industry avoiding areas with numerous islands and peninsulas, and with deep water, will reduce the likelihood of adverse impacts. In most parts of northern Alaska, these habitats occupy a small fraction of the landscape and can be identified using a recently prepared habitat map of the National Petroleum Reserve – Alaska (U.S. Department of Interior 1995).

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