COLLISION POTENTIAL OF EIDERS AND OTHER BIRDS NEAR A PROPOSED WINDFARM AT ST. LAWRENCE ISLAND, OCTOBER–NOVEMBER 2002

Prepared for

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EXECUTIVE SUMMARY

- During spring and fall, many eiders pass St. Lawrence Island during their passage between breeding and wintering grounds. At those times, they may collide with human-made structures at the village of Gambell, on northwestern St. Lawrence island. Because the Alaska Industrial Development Authority (AIDEA)/Alaska Energy Authority is planning on installing a windfarm at Gambell, we were hired to study bird movements in the vicinity of Gambell and to evaluate the probability of collision with the proposed windfarm, especially the collision of endangered Spectacled (*Somateria fischeri*) and Steller's (*Polysticta stelleri*) eiders.
- The objectives of this study were to: (1) use visual sampling and ornithological radar to observe the migration and movements of eiders and other bird species near Gambell during late fall; (2) measure movement rates, locations of movement, behavior, and flight altitudes of eiders and other bird species near Gambell during late fall; (3) collect information on bird movements that could be used to help site the proposed windfarm in such a manner as to minimize the risk of bird collisions; and (4) to evaluate the collision potential for eiders at Gambell during late fall. To complete these objectives, we conducted surveys for eiders and other species at Gambell in October–November 2002.
- We recorded 876 groups of birds visually (representing 26,172 birds) and 687 radar targets of birds during this survey.
- Frequent precipitation (rain) and high winds (causing high swells at sea and extensive sea clutter on the radar display) made radar sampling impossible or difficult much of the time. Consequently, we emphasized the visual sampling but conducted radar sampling when conditions allowed.
- During visual sampling, movement rates were dominated numerically (in decreasing order) by alcids (almost entirely murres), eiders, unidentified waterbirds, gulls (especially Glaucous Gulls and Black-legged Kittiwakes), other ducks (especially Long-tailed Ducks), and cormorants. Eider movements consisted of Spectacled, King, and Common eiders; Steller's Eider were not recorded.
- Mean movement rates of total eiders observed visually varied geographically, with all recorded flying only over the ocean and none flying over the mountain, the windfarm, or the town. Almost all non-eider taxa were recorded moving over the ocean, with raptors recorded moving only over the windfarm and the town and with only gulls recorded moving over all four zones.
- Mean flock sizes varied dramatically among species and species-groups. The mean flock size of eiders was 28.0 birds.
- Mean flight altitudes also varied dramatically among species and species-groups. The highest mean flight altitude occurred in total gulls, followed (in decreasing order) by cormorants, raptors, unidentified waterbirds, loons, other ducks, eiders, and alcids. Eiders had a mean flight altitude of 1.8 m and a maximal flight altitude of 15 m. Because essentially all birds flew only over the ocean, we were unable to examine whether mean flight altitudes varied geographically.
- Flight behavior of birds observed visually was dominated overall by contouring flight (i.e., following the shoreline; ~64% of all flocks), followed (in decreasing frequency) by straight-line directional flight (~30% of all flocks), erratic, flying/landing, and circling. Because essentially all birds flew over the ocean, we were unable to examine whether flight behavior varied geographically.
- The high seas recorded during this study and the low flight altitudes of eiders resulted in an underestimation of movement rates of that group over the ocean with ornithological radar. Although the number of eiders recorded by the radar over the ocean was underestimated, the radar did an excellent job of detecting targets over land, which was an important aspect of this study. The view over land was excellent and was not affected by sea clutter. Therefore, we considered the radar to provide an underestimate of numbers of eiders moving over the ocean but to provide an accurate

estimate of numbers of eiders moving over land.

- "Eiders" exhibited low mean movement rates on radar during most dates and under most weather conditions, with most means averaging 1–3 targets/h. "Non-eiders" exhibited mean movement rates that were ~20 times larger than those for "eiders," with most means averaging ~25 targets/h.
- Mean movement rates of "eiders" were ~175% higher at night than during the day, whereas mean movement rates of "non-eiders" were ~160% higher during the day than at night (primarily because of all of the daytime gull movements).
- Mean movement rates of "eiders" on radar varied geographically, with essentially all birds flying only over the ocean and none flying over the mountain and town, similar to what was recorded visually. We believe that the one "eider" target recorded flying over the proposed windfarm was not that of not eiders. Mean movement rates of "non-eiders" also varied geographically, with none recorded over the mountain, moderate numbers moving over the proposed windfarm and town, and much higher numbers moving over the ocean.
- "Eiders" were recorded on radar exhibiting three of the five standardized behaviors, although ~90% of all "eider" targets flew with straight-line directional characteristics. "Non-eiders" exhibited all five of the standardized behaviors, with ~60% of all "non-eider" targets flying with straight-line characteristics and another 34% flying by contouring (i.e., following the shoreline).
- We recorded no bird mortality at either the FAA towers or the meteorological tower.
- Both the radar and visual data indicate that the number of birds moving and wintering in this area is large: we saw a total of >26,000 birds during our visual sampling, with an overall mean daily movement rate of 700 birds/h.
- The visual data indicate that eiders form a significant proportion of the birds seen near Gambell at this time of the year, representing 24.5–42.9% of all birds.
- Both the daytime visual and daytime and nighttime radar-movement data indicate that most birds passing Gambell in the fall do so over the ocean, with very little movement over land, including the proposed windfarm (primarily gulls and raptors). Although we saw no eiders or waterfowl of any species flying over land, local villagers informed us that eiders and Long-tailed Ducks fly over the spit on which Gambell occurs after the sea freezes and snow obscures the boundary between sea and land. At those times, these birds "cut the corner" over the spit while moving back and forth as polynyas open and close on the northern and southern sides of the island. Local villagers told us that, when these birds do cross the spit, they occasionally hit the FAA towers.
- The flight-altitude data indicate that flight altitudes of most species over the ocean are so low that, unless they change altitude as they cross land, they would pass under the rotor blades of the turbines as they are envisioned at this time.
- The behavioral data indicate that, because most of the birds seen in this study fly by contouring (i.e., following the shoreline), those birds flying over the ocean will have little chance of hitting wind turbines. On the other hand, if a flock of eiders does deviate to cross over the spit, the other members of the flock will follow, resulting in a low probability of collision but a high probability of substantial mortality if a collision does occur.
- Although summer bird movements were not studied, we suggest that the location of the auklet colony should be a consideration in site selection at this windfarm.

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INTRODUCTION

During spring and fall migration, many Common (*Somateria mollissima*) and King (*S. spectabilis*) eiders pass St. Lawrence Island during their passage between breeding and wintering grounds (Fay and Cade 1959). In addition, smaller numbers of Spectacled (*S. fischeri*) and Steller's (*Polysticta stelleri*) eiders, both of which have undergone population declines and currently are protected by the Endangered Species Act, move through the same area (USFWS 1996, 2002). Counts of birds passing Barrow indicate that Common and King eider populations also are declining (Suydam et al. 2000), and there is concern that populations of these species will decline so much that they also will need protection under the Endangered Species Act.

Eiders are thought to be susceptible to collision with human-made structures because they fly at low altitudes (Thompson and Person 1963, Johnson and Richardson 1982; Day et al. 2001, 2002) and fly rapidly (Day et al. 1998, 2001, 2002), making collision avoidance difficult. Indeed, they frequently have been recorded colliding with human-made structures, including boats (Dick and Donaldson 1978; John L. Sease, National Marine Mammal Laboratory, Seattle, WA, pers. comm.), streetlights and other bright lights (John J. Burns, Alaska Department of Fish and Game [retired], Fairbanks, AK, pers. comm.; Patricia Kaminsky, University of Alaska/Seward Marine Station, Seward, AK, pers. comm; Lori T. Quakenbush, Alaska Department of Fish and Game, Fairbanks, AK, pers. comm.), buildings (James Short, ARCO, Anchorage, AK, pers. comm.), and powerlines (Dean Kulowiyi, Savoonga, AK; *fide* G. Balogh, USFWS, Anchorage, AK). Waterfowl commonly collide with man-made structures (e.g., Anderson 1978, Dick and Donaldson 1978) and have been recorded colliding with wind turbines (Erickson et al. 2001), indicating that they are susceptible to this sort of mortality.

The Alaska Energy Authority (AEA) is planning to construct a series of windpower energy-generation fields (windfields) throughout northwestern Alaska to provide lower-cost energy than presently is available to inhabitants of small rural villages (D. Meiners, AEA, Anchorage, AK, pers. comm.). So far, they have constructed windfields in Kotzebue and Wales and plan to construct windfields at Gambell, Hooper Bay, and possibly other locations in western Alaska. Some of these proposed windfields occur in locations where migrating birds may collide with the wind turbines. Gambell village, which is located on western St. Lawrence Island, is a site where endangered Spectacled Eiders pass during migration and winter (Fay and Cade 1959, Petersen et al. 1995, 1999) and, hence, is one of those sites where collisions between endangered Spectacled Eiders (and other eiders) and wind turbines may occur. At this time, however, knowledge of the migration and movements of eiders and other birds and of the variability in migration and movements of these birds in the immediate vicinity of St. Lawrence Island is limited.

This study was conducted in October–November 2002 to learn more about the migration and movements of eiders and other species near Gambell, Alaska, and to evaluate potential locations for a proposed windfarm near that village. The objectives of this study were to:

- use visual sampling and ornithological radar to observe the migration and movements of eiders and other bird species near Gambell during late fall;
- measure movement rates, locations of movement, behavior, and flight altitudes of eiders and other bird species near Gambell during late fall;
- collect information on bird movements that could be used to help site the proposed windfarm in such a manner as to minimize the risk of bird collisions; and
- to evaluate the collision potential for eiders at Gambell during late fall.

STUDY AREA

St. Lawrence Island is the largest island in the Bering Sea, lying ~320 km (~200 mi) south of Bering Strait (Fig. 1). It has an area of ~4,500 km^2 (~2,000 mi^2) and consists of highly varied topography, from mountains to saltwater lagoons. The island's primary habitat is tundra, with scattered unvegetated, rocky areas. Mys (Cape)

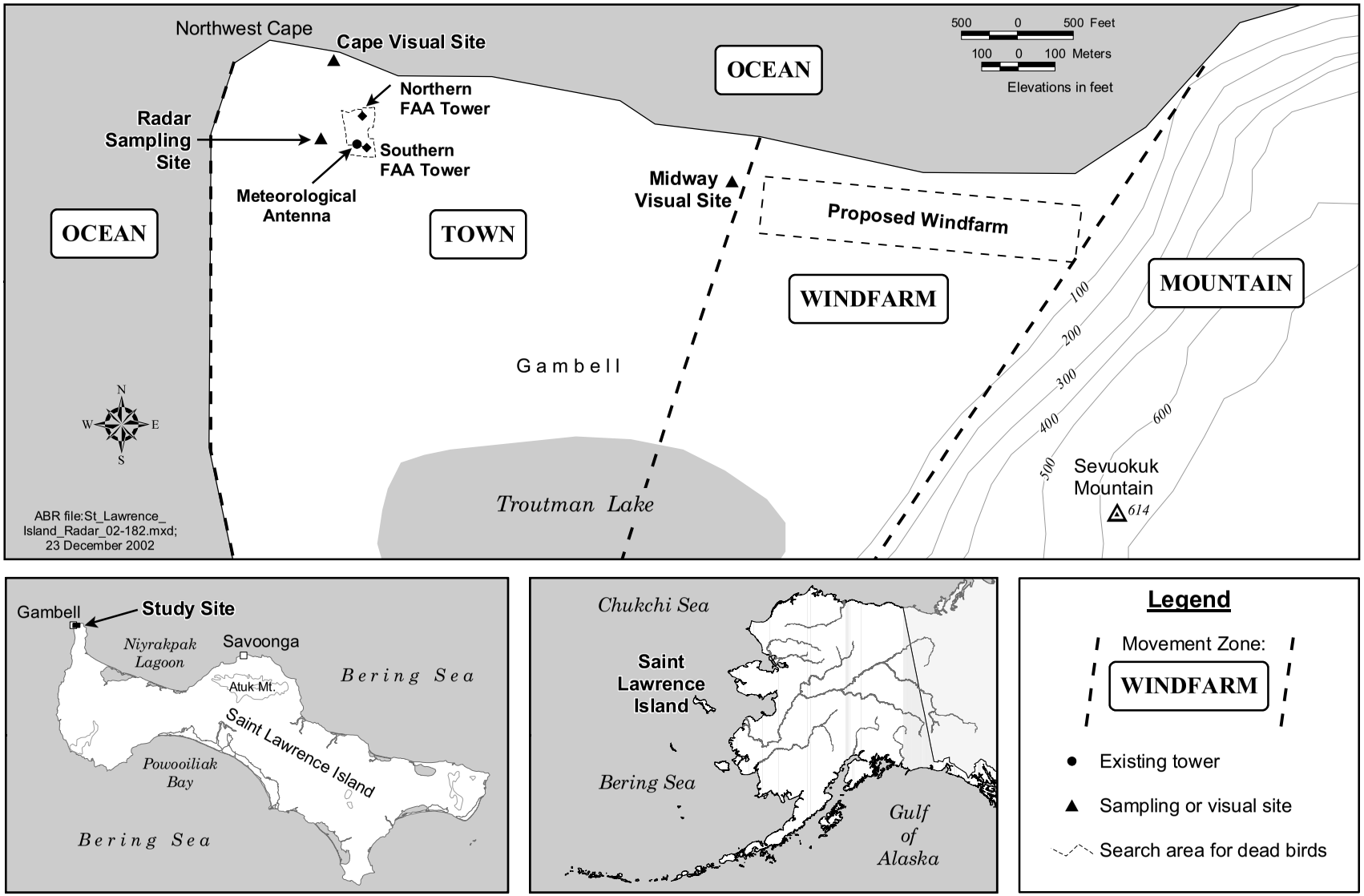

Figure 1. Study area at Gambell, St. Lawrence Island, showing locations of radar and visual sampling sites, movement zones, towers and tower search area, and the proposed windfarm in fall 2002.

Chaplina, a point on the southeastern Chukchi Peninsula of Russia, lies ~65 km (~40 mi) from the northwestern end of St. Lawrence Island. Sea ice usually forms around the island in late November (Fay and Cade 1959). Wind and fog are common, and precipitation occurs ~300 days/year (Alaska Community Database, available at www.dced.state.ak.us/cbd/commdb/CF_BLOCK.cfm).

The village of Gambell is a small, predominantly Native community (Siberian Yup'ik) of ~650 individuals located on a gravel spit at the northwestern corner of the island (Fig. 1; Alaska Community Database). The town abuts the western side of Sevuokuk Mountain, which contains an enormous auklet nesting colony during the summer (Bédard 1969b). South of town lies Troutman Lake, where gulls often congregated. The proposed windfarm is located northeast of town, inland from the ocean and just west of Sevuokuk Mountain (Fig. 1). The proposed windfarm will consist of 5–10 turbines with hub heights of 24, 30, or 40 m above ground level (agl) and rotor diameters 15 m or 20 m; at this time, the exact specifications of the windfarm have not been finalized (D. Meiners, AIDEA/Alaska Energy Authority, in litt.).

The study area consisted of two visual sampling sites, the radar sampling site, the proposed windfarm, and the existing antenna field that was searched for dead birds. The Cape visual site was the primary visual site, whereas the Midway site was secondary and was sampled only two days. The antenna field consisted of two FAA towers each ~23 m (~75 ft) high with a horizontal wire strung between them; the towers were guyed with 2 layers of 3 wires each. In addition, a nearby meteorological antenna ~6 m (~20 ft) high was guyed with 1 layer of 3 wires. We situated the radar sampling site ~50–70 m west of the FAA towers and ~100–120 m southwest of the landfill. The site was in a trough between 3–4-m-high gravel dunes.

Information on the avifauna of St. Lawrence Island may be found in Friedmann (1932), Fay and Cade (1959), Fay (1961), Sauer and Urban (1964), Sealy et al. (1971), Johnson (1975), and Thompson (1967). Information on seabirds at St. Lawrence Island may be found in Bédard (1969a, 1969b), Sealy and Bédard (1973), Sealy (1975, 1981), Piatt et al. 1990a, 1990b). Information on waterfowl at St. Lawrence Island may be found at Fay (1961) and Petersen et al. (1995, 1999).

METHODS

We collected data on the movements, behavior, flight altitudes, and mortality of migrating eiders and other birds between 23 October and 3 November 2002 (Table 1). A severe storm delayed our arrival on the island, eliminating one day of sampling. In addition, sampling time during the first two days was limited because of time spent on coordinating with local organizations about the study, on selection of sampling locations, and on setup of the radar unit. Hence, the data were collected over essentially a 9-day period. We sampled for ~8 h/day with both visual equipment (both 10X binoculars and night-vision equipment with a 5X eyepiece) and ornithological radar (when possible). We also checked the vicinity of the FAA and meteorological towers for dead birds on a daily basis, and often several times a day.

DATA COLLECTION

When possible, we collected visual and radar data concurrently, so that we could use the radar to help the visual observer locate birds for identification and data collection. In return, the visual observer provided information to the radar operator on the identity of individual targets. Although we attempted to sample concurrently at all times, rain often prevented us from collecting radar data (Table 1).

We attempted to collect data during 25-min sessions for both sampling methods; we then used 5-min breaks between sessions to collect weather data and to give observers a short break. Actual lengths of sampling sessions were 25 min for visual data and 6–25 min for radar data, with nearly all sessions of both types being 25 minutes long. We conducted a total of 47.00 h of visual data collection on 92 sampling sessions and a total of 29.25 h of radar data collection on 60 sampling sessions. We lost another 54.50 h of radar sampling time and another 18.00 h of after-dark visual sampling time because of precipitation.

We recorded the following weather and environmental data at the beginning of each sampling session:

Table 1. Hours sampled by radar and/or visual observers, Gambell, Alaska, 23 October–2 November 2002, by date.

	Sampling method							
	Radar				Visual			
Date	Begin	End	Sampled	Rained out	Begin	End	Sampled	Rained out
23 OC	–	–	0	0	1900	2030	1.50	0
24 OC	1900	2200	0	3.00	1900[a]	2200[a]	1.00[a]	2.00
25 OC	1050	1240	1.50	0	1050	1240	1.50	0
	1330	1615	2.75	0	1330[b]	1630[b]	3.00[b]	0
	2030	2330	0	3.00	2030	2330	0	3.00
26 OC	1130	1140	0.17	0	1130	1430	3.00	0
	1140	1430	0	3.00	–	–	–	–
	1830	2030	0	2.00	1830	2030	2.00	0
	2030	2330	0	3.00	2030	2330	0	3.00
27 OC	0800	1315	0	5.25	1015	1315	3.00	0
	1530	1800	0	2.50	1530	1800	2.50	0
28 OC	0730	0800	0	0.50	–	–	0	0
	1015	1245	0	1.50	1015	1245	2.50	0
	1600	1830	0	2.50	1600	1830	2.50	0
	2030	2330	0	3.00	2030	2330	0	3.00
29 OC	1000	1245	0	2.75	1015	1245	2.50	0
	1500	1745	0	2.75	1515	1745	2.50	0
	1900	2230	0	3.50	1900	2230	0	3.50
30 OC	1000	1330	0	3.50	1030	1330	3.00	0
	1530	1745	0	2.25	1545	1745	2.00	0
	1900	2230	0	3.50	1900	2230	0	3.50
31 OC	0800	1000	2.00	0	–	–	–	–
	1200	1545	3.75	0	1200	1545	3.75	0
	1800	1900	1.00	0	1800	1900	1.00	0
	1900	2100	2.00	0	–	–	–	–
1 NO	0600	0900	0	3.00	1000	1315	3.25	0
	1300	1600	0	3.00	–	–	–	–
	1000	1300	3.00	0	–	–	–	–
	1600	1800	2.00	0	1600	1800	2.00	0
	1800	2100	3.00	0	–	–	–	–
2 NO	0745	1300	5.25	0	1015	1315	3.00	0
	1700	1800	0	1.00	1700	1830	1.50	0
	1800	2100	3.00	0	–	–	–	–
Total			29.25	54.50			47.00	18.00

[a] Included 1 h of concurrent sampling at the Midway visual site (1900–2000).
[b] Included 1 h of concurrent sampling at the Midway visual site (1500–1600).

- wind speed (10 categories)—calm, 1–5 mi/h (1–8 km/h), 6–10 mi/h (9–16 km/h), 11–15 mi/ h (17–24 km/h), 16–20 mi/h (25–32 km/h), 21–25 mi/h (33–40 km/h), 26–30 mi/h (41–48 km/h), 31–35 mi/h (49–56 km/h), 36–40 mi/h (57–64 km/h), >40 mi/h (>64 km/h);
- ordinal wind direction (10 categories)—calm, north, northeast, east, southeast, south, southwest, west, northwest, variable/erratic;
- cloud cover (to the nearest 5%);
- ceiling height (10 categories)—0 m above ground level (agl), 1–50 m, 51–100 m, 101–150 m, 151–500 m, 501–1,000 m, 1,001–2,500 m, 2,501–5,000 m, >5,000 m, clear sky;
- minimal distance able to see in a cardinal direction (7 categories)—0–50 m, 51–100 m, 101–500 m, 501–1,000 m, 1,001–2,500 m, 2,501–5,000 m, >5,000 m;
- light condition (6 categories)—daylight with or without precipitation, crepuscular (twilight) with or without precipitation, darkness with or without precipitation;
- precipitation (11 categories)—none, fog, drizzle, light rain, heavy rain, scattered showers, sleet, snow, hail, mixed rain/sleet/ snow, snow flurries;
- minimal visibility (2 categories)—poor (<500 m), good (≥500 m);
- air temperature (to the nearest 1°C); and
- moon visible to an observer on the ground (2 categories)—no, yes.

VISUAL

During the 12 days of sampling, we were able to collect visual data during a total of 92 sampling sessions (Table 1). The emphasis of the visual sampling was on identifying birds, quantifying flight altitudes, and determining the flight location. The sampling unit was a flock of birds, regardless of size.

We collected the following data on each bird or flock of birds seen:

- time;
- identification, to lowest practical taxon;
- flock size;
- ordinal flight direction (9 categories)—north, northeast, east, southeast, south, southwest, west, northwest, variable/erratic;
- general flight behavior (4 categories)—straight-line, erratic, circling, landing on/taking off from the water;
- lowest flight altitude (estimated to the nearest 1 m agl/asl [above ground level/above sea level] when flying ≤25 m agl/asl, in 5-m increments from 26 to 50 m agl/asl, in 10-m increments from 51 to 100 m agl/asl, and in 25-m increments above 100 m agl/asl), with the emphasis on altitude as the birds crossed an East–West line running through Northwest Cape;
- island-passing flight behavior (6 categories)—change in flight altitude, change in flight direction, change in both, change in neither, flaring, contouring (following the shoreline) as the birds passed the island and/or crossed the East–West line; and
- movement zone (4 categories; see Fig. 1)—mountain (over Sevuokuk Mountain), windfarm (over the proposed windfarm), town (over the town or elsewhere over the spit), ocean (only over the ocean north and/or west of the spit).

Migrating eiders sometimes travel in long, undulating strings that exhibit both lateral and vertical motion (Day et al. 2001, 2002). Although there is lateral motion, the flocks clearly exhibit a strongly directional component of flight. As described below for radar sampling, that strongly directional movement of eider flocks is what we are referring to with the term "straight-line flight." The vertical undulations are fairly irregular but generally do not vary by more than 10 m. Hence, we considered a "significant" change in flight direction or flight altitude as one that is more extreme than these regular undulations.

RADAR

We monitored movements of birds with an ornithological radar, described in Cooper et al.

(1991). This Furuno FCR-1411 surveillance radar is a standard X-band radar transmitting at 9,410 MHz with a peak power output of 10 kW. The range of this radar was set at 1.5 nm (~2.8 km), the pulse setting was 0.60 µsec, and targets were plotted every 15 sec. The radar laboratory (i.e., where the radar display was located and where we collected the data) was a small portable tent. We mounted the radar's antenna on a portable tripod near the northwestern corner of the island (Fig. 1). We located this antenna in a depression between 10–12-ft-high gravel dunes, providing an excellent radar fence (see Eastwood 1967) that eliminated much, but not all, of the sea clutter and most ground clutter (energy that is reflected from the ground, surrounding vegetation, waves on the sea, and other objects that surround the radar unit).

The radar scanned a 360° arc and was used to obtain information on flight paths, movement rates, and behavior of birds. This radar has a digital color display with several scientifically useful features, including color-coded echoes (to differentiate the strength of return signals) and on-screen plotting of a sequence of echoes (to depict flight paths). (An echo is a picture of a target on the radar display screen; a target is one or more birds displayed as a single echo on the radar display screen. Flocks of birds typically appear as a single echo, because the individual birds are flying too closely to one another for the radar to be able to differentiate them.)

During sampling, we were able to collect radar data during a total of 60 sampling sessions, with ~36 sessions completely lost because of heavy precipitation (rain or snow) and/or heavy sea clutter, both of which obscured bird-caused echoes. The emphasis of the radar sampling was on quantifying the number of flocks of birds flying within specified zones and on describing aspects of the behavior of those flocks of birds. The sampling unit was a radar echo on the display screen (i.e., a flock of birds, regardless of its size).

We collected the following data on each target echo seen on the radar display screen:

- time;
- target type (2 categories)—"eiderlike," "non-eiderlike" (see below);
- general flight behavior (5 categories)—straight-line (highly directional, with long stretches of straight-line movements), erratic (may or may not be directional; often moved so erratically, especially toward the end of the line examined, that we could not predict with confidence where the target was going), circling (rarely directional and showing evidence of circling the island), landing on/taking off from the water, contouring (following the coastline); and
- movement zone (4 categories; see Fig. 1)—mountain (over Sevuokuk Mountain), windfarm (over the proposed windfarm), town (over the town or elsewhere over the spit), ocean (only over the ocean north and/or west of the spit).
- We also collected other data with the radar (e.g., velocity, flight direction), but they are not presented in this report.

An "eiderlike" target on radar was flying with fairly specific characteristics. Eiders tend to fly in tight flocks that, depending on the scale, may exhibit lateral and vertical motion. On the radar display screen, their echoes generally are large and rapidly flying. At Barrow, 95% of all targets visually confirmed as eiders were flying 40–60 mi/h (64–96 km/h), only 1.4% were flying as slowly as 35 mi/h (56 km/h), and the targets had mostly directional flight behavior (Day et al., unpubl. data). "Non-eiderlike" targets were represented by all other flight characteristics and ranged between small and large sizes, slow and fast speeds, and variable directions (also see Day et al. 1998, 2001, 2002). When possible, however, we determined visually the species and number of birds represented by the radar echo.

The term "straight-line, directional flight" also needs further explanation in the context of eider behavior. As indicated above, eiders may fly in long, undulating strings of birds that exhibit lateral motion. Although these flocks exhibit somewhat variable (i.e., possibly erratic) flight behavior at a small scale, they almost always are strongly directional at a larger scale (e.g., see Richardson and Johnson 1981; Day et al. 1998, 2001, 2002). The scale at which we were sampling was

intermediate between these two scales, so we sometimes could see small undulations in radar flightlines, but the flightlines almost always were strongly directional overall. It is for this sense of overall directional movement that we use the term "straight-line."

MORTALITY

We searched the vicinity of the FAA towers and the meteorological tower for the presence and species-composition of dead birds 1–3 times/day, for a total of 21 surveys (Table 2). The search area was an irregularly shaped polygon that roughly transcribed the area encompassed by the towers (Fig. 1); it was ~9,500 m^2, or ~1 ha (~2.4 ac), in area. Because the searches were conducted in an area entirely covered with gravel, we assume that all dead birds that were present were located by the searchers. The first search of the day almost always occurred during the morning, although 2 of 12 searches first occurred in the afternoon or evening.

DATA ANALYSIS

We pooled both visual and radar data into species-groups and other groupings to increase sample sizes for analyses. For visual analyses, we used individual species and the species-groups (1) loons (= Pacific Loon [*Gavia pacifica*] + unidentified loon); (2) cormorants (unidentified cormorants; all almost certainly were Pelagic Cormorants [*Phalacrocorax pelagicus*]); (3) eiders (= Spectacled Eider + King Eider + Common Eider + unidentified eider); (4) other ducks (= White-winged Scoter [*Melanitta fusca*] + unidentified scoter + Long-tailed Duck [*Clangula hyemalis*] + unidentified duck); (5) raptors (= Gyrfalcon [*Falco rusticolus*] + Common Raven [*Corvus corax*]); (6) shorebirds (= unidentified phalarope); (7) gulls (= Glaucous Gull [*Larus hyperboreus*] + Black-legged Kittiwake [*Rissa tridactyla*] + Sabine's Gull [*Xema sabini*] + unidentified gull); (8) alcids (= Common Murre [*Uria aalge*] + unidentified murre + Pigeon Guillemot [*Cepphus columba*] + unidentified guillemot); and (9) waterbirds (unidentified waterbirds, being birds seen at a great distance and being murres and/or ducks). For radar analyses, we used (1) "eiders" (= targets that were identified visually as eiders + targets that were identified visually as unidentified waterbirds + unidentified eiderlike targets); and (2) "non-eiders" (= targets that were identified visually as non-eiders + unidentified non-eiderlike targets). In the radar section of the report, we first present data on all taxa to see whether they potentially could be misidentified as eiders, then concentrate on two species-groups: "eiders" and "non-eiders." Although flight characteristics of geese (especially Brant) on radar are similar to those of eiders (Day et al. 1999, 2001), we recorded no geese during this study.

In data summaries and analyses, we examined the data in terms of two visibility types, both of which have been shown to affect movements and/or collision rates of migrating birds. We examined the effects of **time of day** after pooling all light-condition samples from daytime and crepuscular periods into "daytime" and retaining all samples from nighttime periods as "nighttime." We examined the effects of **precipitation level** after pooling the light-condition categories into "no precipitation" and "precipitation." We also examined the effects of **wind type** on movements of birds on the radar screen, since it also has been recorded affecting bird migration and/or collision rates. We assumed that all eiders and most other birds would be heading to the southwest, past St. Lawrence Island. Hence, we assumed that winds blowing from the south, southwest, or northwest would represent a headwind, those blowing from the north, northeast, or east would represent a tailwind, those from the northwest and southeast would represent a crosswind, and no winds would represent calm conditions. During this study, we recorded only tailwinds and crosswinds.

We used the software SPSS and Microsoft Excel for all analyses and data summaries. Because the data showed such extreme differences (see Results), we concluded that statistical tests were irrelevant. Hence, we simply summarized the data and discussed them without conducting statistical tests.

VISUAL

We calculated mean, SE, and range in movement rates (birds/h) of birds by date and movement zone. To calculate these estimates, we first divided the total number of birds in each species and species-group by the number of

Table 2. Results of ground-based searches for dead birds in the vicinity of the FAA and meteorological towers near Gambell, Alaska, 23 October–3 November 2002.

Date	Time	Comments
23 October	1845	no birds found
24 October	1015	no birds found
25 October	1230	no birds found
26 October	1115	no birds found
	1815	no birds found
	2045	no birds found
27 October	0730	no birds found
28 October	0715	no birds found
	2030	no birds found
29 October	0730	no birds found
	1000	no birds found
30 October	0700	no birds found
	1800	no birds found
31 October	0730	no birds found
	1800	no birds found
1 November	0700	no birds found
	1300	no birds found; dense fog
	2030	no birds found; dense fog
2 November	1300	no birds found
	1900	no birds found
3 November	1030	no birds found

minutes sampled to derive an estimate of birds/h for each sampling session. Because of the large number of bird species involved, we present the data only for individual eider species and for species-groups for this parameter.

We calculated mean, SE, and ranges in flock sizes of species and species-groups across all data. We also calculated mean, SE, and range in minimal flight altitudes of flocks of species and species-groups overall and by movement zone.

We summarized the data on general flight behavior of species and species-groups into the four behavioral categories (straight-line, erratic, circling, flying/landing), plus the contouring behavior in the island-passing behavior category, both altogether and by movement zone. We counted the number of flocks exhibiting each behavior, then converted those numbers to percentages.

RADAR

We first tabulated counts of numbers of targets of each species-group recorded during each sample. These counts then were converted to estimates of movement rates (targets/h), based on the number of minutes sampled. Because heavy precipitation sometimes obscured significant portions of the screen (Table 1), we subtracted that time from the 25-min sampling period and used the resulting actual number of minutes sampled in the calculation of movement rates. We calculated mean ± SE movement rates by date, time of day, precipitation level, wind type, and movement zone for each species-group.

For flight behavior, we first summarized the flight-behavior data for each species-group into the five behavioral categories (straight-line, erratic, circling, flying/landing, contouring) by visibility

category, wind type, and movement zone. We counted the number of instances of each behavior, then converted the counts into percentages.

MORTALITY

We simply summarized the results of each check for bird mortality in a table. We did not conduct any statistical analyses on the data.

RESULTS

We recorded 878 groups of birds visually but excluded 2 flocks of passerines (McKay's Buntings, *Plectrophenax hyperboreus*) from analyses. The remaining 876 flocks represented a total of 26,172 birds. One taxon that was particularly difficult to identify well was what we called "unidentified waterbirds," which were birds flying so far offshore that we could not see them well enough for identification. They consisted of eiders, Long-tailed Ducks, and/or murres.

We also recorded 687 radar targets of birds during this survey. Of the radar targets, we recorded 42 that we considered to be those of eiders, either being identified visually as eiders or being unidentified visually but having eiderlike flight characteristics. We also recorded 645 non-eider targets that either were identified visually as non-eiders or were unidentified visually but having non-eiderlike flight characteristics.

Weather overall was fair to poor; such conditions were to be expected during this time of the year. Our arrival on the island was delayed by a day because of near-hurricane-force winds (~70 mi/h [~110 km/h]), and winds were >30 mi/h (>50 km/h) much of the time, decreasing to ≤20 mi/h (≤32 km/h) toward the end of our stay on the island before increasing again; the average wind speed was 19.8 mi/h (31.9 km/h; $n = 92$ visual sampling sessions). In addition, frequent precipitation (68 [73.9%] of 92 visual sessions) resulted in difficult sampling conditions much of the time.

VISUAL

Because the weather was so poor that use of the radar was limited much of the time, we emphasized visual sampling. All of the visual data were collected during daylight hours, with additional time spent every night attempting to identify targets for the radar operators.

MOVEMENT RATES

Movements were dominated numerically (in decreasing order) by alcids (almost entirely murres), eiders, unidentified waterbirds, gulls (especially Glaucous Gulls and Black-legged Kittiwakes), other ducks (especially Long-tailed Ducks), and cormorants; other groups, such as loons, raptors, and shorebirds, occurred in essentially trace amounts (Table 3). Surprisingly, we recorded five flocks of Sabine's Gulls, which are very rare this far north at this time of the year (Day et al. 2001); similarly, the records of phalaropes are late for this latitude. For all taxa, there was great among-day variation in mean movement rates and in maximal movement rates for one sampling session. For example, maximal movement rates of total other ducks on single sampling sessions ranged between 0 and 427.2 birds/h.

Eider movements consisted of all three of the larger species (i.e., Spectacled, King, and Common eiders); Steller's Eider were not recorded (Table 3). There was a suggestion that Common Eiders were the most abundant of the three species and that Spectacled Eiders were next in abundance; however, most eiders flew so far offshore that the number of eiders identifiable to species was low. Maximal movement rates of total eiders on single sampling sessions ranged between 14.4 birds/h and 1,814.4 birds/h.

Mean movement rates of total eiders varied geographically, with all birds recorded flying only over the ocean and none flying over the mountain, the windfarm, or the town (Table 4). This absence of overland movements by eiders flying also suggests to us that the single eiderlike radar target that was recorded flying over the windfarm was not one of eiders (see "Radar—movement rates," below).

Almost all non-eider taxa were recorded moving over the ocean, with raptors recorded moving only over the windfarm and the town and with only gulls recorded moving over all four zones (Table 4). Gulls occurred predominantly over the ocean, however.

Table 3. Movement rates (birds/h) of birds recorded visually near Gambell, Alaska, 23 October–2 November 2002, by species/species-group and date; because so many taxa were seen, data are presented only for all eider species and for all species-groups. Data are presented as mean ± SE, range, and *n* flocks (except for the Total across all dates, for which *n* is the number of days).

Species/ species-group	Date							
	23 OC (*n* = 3)		24 OC (*n* = 2)		25 OC (*n* = 10)		26 OC (*n* = 10)	
	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
Total loons	0 ± 0	0–0	0 ± 0	0–0	0.7 ± 0.5	0–4.8	0 ± 0	0–0
Total cormorants	4.8 ± 2.4	0–7.2	70.8 ± 6.0	64.8–76.8	15.6 ± 6.5	0–55.2	19.2 ± 8.6	0–84.0
Spectacled Eider	0 ± 0	0–0	0 ± 0	0–0	0 ± 0	0–0	0.7 ± 0.5	0–4.8
King Eider	0 ± 0	0–0	0 ± 0	0–0	1.2 ± 1.2	0–12.0	0 ± 0	0–0
Common Eider	0 ± 0	0–0	0 ± 0	0–0	19.2 ± 10.5	0–105.6	0.5 ± 0.5	0–4.8
Unidentified eider	870.4 ± 230.8	420.0–1183.2	97.2 ± 39.6	57.6–136.8	228.0 ± 158.8	4.8–1639.2	122.4 ± 103.2	0–1046.4
Total eiders	870.4 ± 230.8	420.0–1183.2	97.2 ± 39.6	57.6–136.8	284.8 ± 168.1	4.8–1744.8	123.6 ± 103.6	0–1051.2
Total other ducks	0 ± 0	0–0	0 ± 0	0–0	20.4 ± 10.4	0–84.0	19.9 ± 11.4	0–100.8
Total raptors	0 ± 0	0–0	0 ± 0	0–0	0 ± 0	0–0	0.5 ± 0.3	0–2.4
Total shorebirds	0 ± 0	0–0	0 ± 0	0–0	0 ± 0	0–0	7.4 ± 5.2	0–48.0
Total gulls	0.8 ± 0.8	0–2.4	42.0 ± 10.8	31.2–52.8	53.5 ± 17.4	0–122.4	33.4 ± 13.2	0–115.2
Total alcids	0 ± 0	0–0	0 ± 0	0–0	181.7 ± 103.7	0–1084.8	156.5 ± 87.1	0–825.6
Total waterbirds	0 ± 0	0–0	42.0 ± 10.8	0–124.8	53.5 ± 17.4	0–3360.0	37.4 ± 20.0	0–177.6
Total birds	876.0 ± 229.4	427.2–1183.2	272.4 ± 39.6	232.8–312.0	1299.4 ± 462.1	64.8–3708.0	397.9 ± 141.2	0–1185.6

Table 3. Continued.

Species/ species-group	Date							
	27 OC (n = 10)		28 OC (n = 10)		29 OC (n 10)		30 OC (n = 10)	
	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
Total loons	0.2 ± 0.2	0–2.4	0 ± 0	0–0	1.4 ± 0.7	0–7.2	0.5 ± 0.3	0–2.4
Total cormorants	53.0 ± 25.3	0–256.8	3.6 ± 2.4	0–24.0	0.7 ± 0.7	0–7.2	10.3 ± 4.5	0–40.8
Spectacled Eider	3.4 ± 2.6	0–26.4	1.2 ± 1.2	0–12.0	0.5 ± 0.5	0–4.8	0.5 ± 0.5	0–4.8
King Eider	0 ± 0	0–0	0 ± 0	0–0	0 ± 0	0–0	1.2 ± 1.2	0–12.0
Common Eider	0 ± 0	0–0	0 ± 0	0–0	0.7 ± 0.7	0–7.2	1.9 ± 1.7	0–16.8
Unidentified eider	31.4 ± 11.4	0–112.8	133.4 ± 118.8	0–1200.0	26.2 ± 10.7	0–105.6	21.8 ± 12.6	0–132.0
Total eiders	34.8 ± 11.6	0–112.8	134.6 ± 118.7	0–1200.0	27.4 ± 10.9	0–105.6	25.4 ± 12.3	0–132.0
Total other ducks	33.4 ± 10.4	0–81.6	13.7 ± 3.6	0–36.0	34.6 ± 9.4	0–98.4	23.5 ± 7.0	0–55.2
Total raptors	0.7 ± 0.4	0–2.4	1.2 ± 1.0	0–9.6	1.4 ± 1.0	0–9.6	3.1 ± 1.8	0–16.8
Total shorebirds	0 ± 0	0–0	0 ± 0	0–0	0 ± 0	0–0	0 ± 0	0–0
Total gulls	8.6 ± 4.3	0–43.2	13.4 ± 8.3	0–84.0	2.4 ± 1.5	0–14.4	30.2 ± 22.6	0–232.8
Total alcids	6.0 ± 5.0	0–50.4	17.0 ± 6.9	0–64.8	1008.7 ± 611.2	0–6156.0	5.0 ± 1.7	0–14.4
Total waterbirds	75.8 ± 53.6	0–549.6	146.9 ± 118.9	0–1207.2	0 ± 0	0–0	0 ± 0	0–0
Total birds	212.6 ± 79.4	36.0–828.0	330.5 ± 156.9	9.6–1267.2	1,076.6 ± 611.2	0–6208.8	99.1 ± 43.3	0–477.6

Table 3. Continued.

Species/ species-group	Date							
	31 OC (n = 9)		1 NO (n = 10)		2 NO (n = 8)		Total (n = 11)	
	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
Total loons	0.3 ± 0.3	0–2.4	0.7 ± 0.7	0–7.2	0.3 ± 0.3	0–2.4	0.4 ± 0.1	0–7.2
Total cormorants	14.1 ± 3.7	0–36.0	14.9 ± 5.5	0–48.0	73.5 ± 27.2	0–196.8	25.5 ± 8.1	0–256.8
Spectacled Eider	0 ± 0	0–0	0 ± 0	0–0	0 ± 0	0–0	0.6 ± 0.3	0–26.4
King Eider	0 ± 0	0–0	1.4 ± 1.0	0–7.2	0 ± 0	0–0	0.3 ± 0.2	0–12.0
Common Eider	0.8 ± 0.8	0–7.2	0 ± 0	0–0	0.6 ± 0.6	0–4.8	2.2 ± 1.7	0–105.6
Unidentified eider	10.7 ± 5.4	0–45.6	1.4 ± 1.4	0–14.4	342.9 ± 218.0	0–1814.4	171.4 ± 76.8	0–1814.4
Total eiders	11.5 ± 5.2	0–45.6	2.9 ± 1.6	0–14.4	343.5 ± 217.9	0–1814.4	174.5 ± 76.7	0–1814.4
Total other ducks	0 ± 0	0–0	1.0 ± 1.0	0–9.6	144.6 ± 55.5	0–427.2	26.5. ± 12.5	0–427.2
Total raptors	5.1 ± 3.7	0–33.6	0 ± 0	0–0	0 ± 0	0–0	1.1 ± 0.5	0–33.6
Total shorebirds	0 ± 0	0–0	0 ± 0	0–0	0 ± 0	0–0	0.7 ± 0.7	0–48.0
Total gulls	145.3 ± 35.8	0–604.8	35.8 ± 32.4	0–326.4	619.8 ± 402.2	0–3360.0	89.6 ± 54.4	0–3360.0
Total alcids	0 ± 0	0–0	0 ± 0	0–0	1135.2 ± 369.2	0–2059.2	228.2 ± 127.6	0–6156.0
Total waterbirds	0.5 ± 0.5	0–4.8	60.0 ± 60.0	0–600.0	526.2 ± 331.4	0–2412.0	153.5 ± 77.5	0–3360.0
Total birds	181.6 ± 61.5	16.8–645.6	115.2 ± 69.9	0–645.6	2483.1 ± 1,038.4	117.6–8714.4	700.4 ± 247.6	0–8714.4

Table 4. Movement rates (birds/h) of birds recorded visually near Gambell, Alaska, 23 October–2 November 2002, by species/species-group and movement zone; because so many taxa were seen, data are presented only for all eider species and for all species-groups. Data are presented as mean ± SE; n = 92 sampling sessions for all samples.

	Movement zone			
Species/species-group	Mountain	Windfarm	Town	Ocean
Total loons	0 ± 0	0 ± 0	0 ± 0	0.4 ± 0.1
Total cormorants	0 ± 0	0 ± 0	0 ± 0	22.2 ± 4.4
Spectacled Eider	0 ± 0	0 ± 0	0 ± 0	0.7 ± 0.3
King Eider	0 ± 0	0 ± 0	0 ± 0	0.4 ± 0.2
Common Eider	0 ± 0	0 ± 0	0 ± 0	2.6 ± 1.3
Unidentified eider	0 ± 0	0 ± 0	0 ± 0	122.7 ± 35.0
Total eiders	0 ± 0	0 ± 0	0 ± 0	126.4 ± 35.5
Total other ducks	0 ± 0	0 ± 0	0 ± 0	28.5 ± 6.5
Total raptors	0 ± 0	0.2 ± 0.1	1.1 ± 0.4	0 ± 0
Total shorebirds	0 ± 0	0 ± 0	0 ± 0	0.8 ± 0.6
Total gulls	0.7 ± 0.7	5.6 ± 1.9	2.9 ± 1.2	79.2 ± 38.1
Total alcids	0 ± 0	0 ± 0	0 ± 0	248.2 ± 83.5
Total waterbirds	0 ± 0	0 ± 0	0 ± 0	166.6 ± 55.3
Total birds	0.7 ± 0.7	5.7 ± 2.0	4.0 ± 1.2	672.4 ± 144.9

FLOCK SIZE

Mean flock sizes varied dramatically among species and species-groups (Table 5). The largest mean flock sizes occurred in unidentified waterbirds, followed (in decreasing order) by total alcids, total eiders, total gulls, total shorebirds, total other ducks, total cormorants, total raptors, and total loons. Flocks of up to 1,000 gulls, 900 unidentified waterbirds, 720 alcids, and 550 eiders were recorded.

FLIGHT ALTITUDE

Mean flight altitudes also varied dramatically among species and species-groups (Table 5). The highest mean flight altitude occurred in total gulls, followed (in decreasing order) by total cormorants, total raptors, unidentified waterbirds, total loons, total other ducks, total eiders, and total alcids. Eiders had a mean flight altitude of 1.8 m and a maximal flight altitude of 15 m.

Because essentially all birds flew only over the ocean, we were unable to examine whether mean flight altitudes varied geographically (Table 6). One species, however, the Glaucous Gull, occurred in all four zones, with a tendency for decreasing mean flight altitudes from the mountains to the ocean.

FLIGHT BEHAVIOR

Flight behavior was dominated overall by contouring (i.e., following the shoreline; ~64% of all flocks), followed by straight-line, directional flight (~30% of all flocks); erratic behavior was third in frequency, flying/landing was fourth in frequency, and there was one case of circling flight (Table 7). Loons, cormorants, eiders, other ducks, phalaropes, alcids, and unidentified waterbirds all exhibited high frequencies of contouring behavior, whereas raptors and gulls exhibited substantial frequencies of erratic flight.

Again, because essentially all birds flew over the ocean, we were unable to examine whether flight behavior varied geographically (Table 8). In general, however, birds flying over the land tended to exhibit lower frequencies of straight-line behavior and higher frequencies of erratic behavior than did birds flying over the ocean. To some extent, this difference was driven by taxonomic differences in behavior (i.e., loons, cormorants, eiders, other ducks, alcids, and unidentified waterbirds all exhibited high frequencies of contouring flight, whereas gulls and raptors exhibited more erratic flight), but some of the difference also was driven by the fact that both the gulls and the raptors were foraging over the land. The gulls, in particular, foraged around the landfill and over the shoreline, which resulted in substantial erratic behavior.

RADAR

RADAR EFFICACY AND TARGET IDENTIFICATION

During this study, the radar sampling was more limited in coverage than the visual sampling was. As indicated above, frequent heavy rain made radar sampling impossible much of the time because the electronic adjustments needed to remove the rain-caused echoes from the display screen also removed the bird-caused echoes from the screen (Table 1). In addition, the proximity of this sampling site to the ocean, in conjunction with sea clutter caused by windy conditions and associated high seas (up to 5 m high), affected the accuracy of target detection and recognition.

Because the eiders were flying just off the water's surface, they were very difficult for the radar to detect during periods of high winds and high seas (i.e., the eiders were flying in the wave troughs and, hence, often were missed by the radar; Table 9). As a result, the radar detected only ~17% of the flocks of eiders that were seen moving by the sampling site, and eider targets were not recorded on 11 (42.3%) of 26 sampling sessions when eiders were recorded visually. In addition, a large movement of cormorants during a period of tailwinds on 31 October–2 November resulted in the misidentification of another 12 eiderlike targets, plus the misidentification of a kittiwake as an eider. (The 13 misidentified cormorant targets were birds flying 40–50 mi/h (64–80 km/h) with tailwinds or crosswinds of 10–25 mi/h (16–40 km/h). The one unidentified kittiwake target consisted of birds flying 50 mi/h (80 km/h) with a 25-mi/h (40 km/h) tailwind.) Hence, the misidentification rate may have been on the order of 52% for targets that we otherwise would have called "eiders." We suspect that part of the inflated misidentification rate was caused by species-specific differences in flight altitudes

Table 5. Flock sizes and flight altitudes (m agl/asl) of birds recorded visually near Gambell, Alaska, 23 October–2 November 2002, by species/species-group. Data are presented as mean ± SE, range, and *n* flocks.

	Flock size			Flight altitude (m)		
Species/species-group	Mean ± SE	Range	n	Mean ± SE	Range	n
Pacific Loon	1.0 ± –	1–1	1	10.0 ± –	10–10	1
Unidentified loon	1.5 ± 0.2	1–3	11	3.5 ± 1.7	1–20	11
Total loons	1.4 ± 0.2	1–3	12	4.0 ± 1.6	1–20	12
Unidentified cormorant	6.0 ± 0.8	1–65		22.1 ± 2.1	1–100	141
Total cormorants	6.0 ± 0.8	1–65	142	22.1 ± 2.1	1–100	141
Spectacled Eider	2.9 ± 1.1	1–11	9	2.1 ± 0.6	1–5	9
King Eider	4.0 ± 0.3	3–5	4	1.3 ± 0.3	1–2	4
Common Eider	5.8 ± 1.6	1–28	17	1.4 ± 0.1	1–3	17
Unidentified eider	32.9 ± 7.9	1–550	143	1.9 ± 0.1	1–15	143
Total eiders	28.0 ± 6.5	1–550	173	1.8 ± 0.1	1–15	173
White-winged Scoter	10.8 ± 5.1	2–30	5	2.4 ± 0.7	1–5	5
Unidentified scoter	36.0 ± –	36–36	1	2.0 ± –	2–2	1
Long-tailed Duck	9.0 ± 11.4	1–85	108	1.9 ± 0.1	1–10	108
Unidentified duck	30.0 ± –	30–30	1	1.0 ± –	1–1	1
Total other ducks	9.5 ± 1.1	1–85	115	1.9 ± 0.1	1–10	115
Gyrfalcon	1.0 ± 0	1–1	3	12.0 ± 4.2	6–20	3
Common Raven	2.8 ± 0.6	1–7	16	20.2 ± 12.1	2–200	16
Total raptors	2.5 ± 0.5	1–7	19	18.9 ± 10.1	2–200	19
Unidentified phalarope	15.5 ± 4.5	11–20	2	1.0 ± 0	1–1	2
Total shorebirds	15.5 ± 4.5	11–20	2	1.0 ± 0	1–1	2
Glaucous Gull	13.0 ± 2.6	1–200	107	52.1 ± 4.9	1–200	99
Black-legged Kittiwake	26.8 ± 7.3	1–200	36	6.4 ± 1.3	1–30	36
Sabine's Gull	3.4 ± 0.2	1–12	5	10.6 ± 4.2	3–25	5
Unidentified gull	202.8 ± 199.3	3–1,000	5	28.0 ± 2.0	20–30	5
Total gulls	22.1 ± 6.9	1–1,000	153	38.5 ± 3.8	1–200	145
Common Murre	3.0 ± 0.9	1–5	4	1.3 ± 0.3	1–2	4
Unidentified murre	56.5 ± 7.0	1–720	168	1.3 ± 0.1	1–5	168
Pigeon Guillemot	1.0 ± 0	1–1	3	1.3 ± 0.3	1–2	3
Unidentified guillemot	1.0 ± –	1–1	1	1.0 ± –	1–1	1
Total alcids	54.1 ± 6.8	1–720	176	1.3 ± 0	1–5	176
Unidentified waterbird	76.0 ± 13.8	1–900	84	5.2 ± 1.6	1–100	84
Total waterbirds	76.0 ± 13.8	1–900	84	5.2 ± 1.6	1–100	84
Total	29.8 ± 2.7	1–1000	876	11.9 ± 0.9	1–200	867

Table 6. Flight altitudes (m agl/asl) of birds recorded visually near Gambell, Alaska, 23 October–2 November 2002, by species/species-group and movement zone. Data are presented as mean ± SE and *n* flocks.

	Movement zone							
	Mountain		Windfarm		Town		Ocean	
Species/species-group	Mean ± SE	*n*	Mean ± SE	*n*	Mean ± SE	*n*	Mean ± SE	*n*
Pacific Loon	– ± –	0	– ± –	0	– ± –	0	10.0 ± –	1
Unidentified loon	– ± –	0	– ± –	0	– ± –	0	3.5 ± 1.7	11
Total loons	– ± –	0	– ± –	0	– ± –	0	4.0 ± 1.6	12
Unidentified cormorant	– ± –	0	– ± –	0	– ± –	0	22.1 ± 2.1	141
Total cormorants	– ± –	0	– ± –	0	– ± –	0	22.1 ± 2.1	141
Spectacled Eider	– ± –	0	– ± –	0	– ± –	0	2.1 ± 0.6	9
King Eider	– ± –	0	– ± –	0	– ± –	0	1.3 ± 0.3	4
Common Eider	– ± –	0	– ± –	0	– ± –	0	1.4 ± 0.1	17
Unidentified eider	– ± –	0	– ± –	0	– ± –	0	1.9 ± 0.2	143
Total eiders	– ± –	0	– ± –	0	– ± –	0	1.8 ± 0.1	173
White-winged Scoter	– ± –	0	– ± –	0	– ± –	0	2.4 ± 0.7	5
Unidentified scoter	– ± –	0	– ± –	0	– ± –	0	2.0 ± –	1
Long-tailed Duck	– ± –	0	– ± –	0	– ± –	0	1.9 ± 0.1	108
Unidentified duck	– ± –	0	– ± –	0	– ± –	0	1.0 ± –	1
Total other ducks	– ± –	0	– ± –	0	– ± –	0	1.9 ± 0.1	115
Gyrfalcon	– ± –	0	– ± –	0	12.0 ± 4.2	3	– ± –	0
Common Raven	– ± –	0	107.5 ± 92.5	2	7.7 ± 1.3	14	– ± –	0
Total raptors	– ± –	0	107.5 ± 92.5	2	8.5 ± 1.3	17	– ± –	0
Unidentified phalarope	– ± –	0	– ± –	0	– ± –	0	1.0 ± 0	2
Total shorebirds	– ± –	0	– ± –	0	– ± –	0	–1.0 ± 0	02

Table 6. Continued.

	Movement zone							
	Mountain		Windfarm		Town		Ocean	
Species/species-group	Mean ± SE	*n*	Mean ± SE	*n*	Mean ± SE	*n*	Mean ± SE	*n*
Glaucous Gull	70.0 ± –	1	67.1 ± 10.6	28	47.0 ± 10.1	16	45.4 ± 6.4	54
Black-legged Kittiwake	– ± –	0	– ± –	0	– ± –	0	6.4 ± 1.3	36
Sabine's Gull	– ± –	0	– ± –	0	– ± –	0	10.6 ± 4.2	5
Unidentified gull	– ± –	0	– ± –	0	– ± –	0	28.0 ± 2..0	5
Total gulls	70.0 ± –	1	67.1 ± 10.6	28	47.0 ± 10.1	16	28.7 ± 4.0	100
Common Murre	– ± –	0	– ± –	0	– ± –	0	1.3 ± 0.3	4
Unidentified murre	– ± –	0	– ± –	0	– ± –	0	1.3 ± 0.1	168
Pigeon Guillemot	– ± –	0	– ± –	0	– ± –	0	1.6 ± 0.2	3
Unidentified guillemot	– ± –	0	– ± –	0	– ± –	0	1.0 ± –	1
Total alcids	– ± –	0	– ± –	0	– ± –	0	1.3 ± 0.1	176
Unidentified waterbird	– ± –	0	– ± –	0	– ± –	0	5.2 ± 1.6	84
Total waterbirds	– ± –	0	– ± –	0	– ± –	0	5.2 ± 1.6	84

Table 7. Flight behavior of birds recorded visually near Gambell, Alaska, 23 October–2 November 2002, by species/species-group. Data are presented as number (percentage) in each category and *n* flocks.

	Behavior					
Species/species-group	Straight-line	Erratic	Circling	Flying/landing	Contouring	*n*
Pacific Loon	0 (00)	0 (0)	0 (0)	0 (0)	1 (100.0)	1
Unidentified loon	2 (18.2)	0 (0)	0 (0)	0 (0)	9 (81.8)	11
Total loons	2 (16.7)	0 (0)	0 (0)	0 (0)	10 (83.3)	12
Unidentified cormorant	26 (18.3)	0 (0)	0 (0)	2 (1.4)	114 (80.3)	142
Total cormorants	26 (18.3)	0 (0)	0 (0)	2 (1.4)	114 (80.3)	142
Spectacled Eider	1 (11.1)	0 (0)	0 (0)	1 (11.1)	7 (77.8)	9
King Eider	0 (0)	0 (0)	0 (0)	0 (0)	4 (100.0)	4
Common Eider	3 (17.6)	0 (0)	0 (0)	1 (5.9)	13 (76.5)	17
Unidentified eider	42 (29.4)	1 (0.7)	0 (0)	7 (4.9)	93 (65.0)	143
Total eiders	46 (26.6)	1 (0.6)	0 (0)	9 (5.2)	117 (67.6)	173
White-winged Scoter	1 (20.0)	0 (0)	0 (0)	0 (0)	4 (80.0)	5
Unidentified scoter	0 (0)	0 (0)	0 (0)	1 (100.0)	0 (0)	1
Long-tailed Duck	15 (13.9)	0 (0)	0 (0)	2 (1.9)	91 (84.3)	108
Unidentified duck	1 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	1
Total other ducks	17 (14.8)	0 (0)	0 (0)	3 (2.6)	95 (82.6)	115
Gyrfalcon	0 (0)	3 (100.0)	0 (0)	0 (0)	0 (0)	3
Common Raven	6 (37.5)	10 (62.5)	0 (0)	0 (0)	0 (0)	16
Total raptors	6 (31.6)	13 (68.4)	0 (0)	0 (0)	0 (0)	19
Unidentified phalarope	0 (0)	0 (0)	0 (0)	1 (50.0)	1 (50.0)	2
Total shorebirds	0 (0)	0 (0)	0 (0)	1 (50.0)	1 (50.0)	2
Glaucous Gull	81 (75.7)	15 (14.0)	1 (0.9)	0 (0)	10 (9.3)	107
Black-legged Kittiwake	12 (33.3)	3 (8.3)	0 (0)	1 (2.8)	20 (55.5)	36
Sabine's Gull	2 (40.0)	1 (20.0)	0 (0)	0 (0)	2 (40.0)	5
Unidentified gull	5 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	5
Total gulls	100 (65.4)	19 (12.4)	1 (0.7)	1 (0.7)	32 (20.9)	153
Common Murre	2 (50.0)	0 (0)	0 (0)	0 (0)	2 (50.0)	4
Unidentified murre	20 (11.9)	0 (0)	0 (0)	3 (1.8)	145 (86.3)	168
Pigeon Guillemot	0 (0)	0 (0)	0 (0)	1 (33.3)	2 (66.7)	3
Unidentified guillemot	1 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	1
Total alcids	23 (13.1)	0 (0)	0 (0)	4 (2.3)	149 (84.7)	176
Unidentified waterbird	45 (53.6)	1 (1.2)	0 (0)	0 (0)	38 (45.2)	84
Total waterbirds	45 (53.6)	1 (1.2)	0 (0)	0 (0)	38 (45.2)	84
Total	265 (30.3)	34 (3.9)	1 (0.1)	20 (2.3)	556 (63.5)	876

Table 8. Flight behavior of birds recorded visually near Gambell, Alaska, 23 October–2 November 2002, by species/species-group and movement zone. Data are presented as number (percentage) in each category and *n* flocks.

	Mountain					
Species/species-group	Straight-line	Erratic	Circling	Flying/landing	Contouring	*n*
Pacific Loon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified loon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total loons	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified cormorant	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total cormorants	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Spectacled Eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
King Eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Common Eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total eiders	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
White-winged Scoter	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified scoter	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Long-tailed Duck	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified duck	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total other ducks	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Gyrfalcon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Common Raven	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total raptors	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified phalarope	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total shorebirds	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Glaucous Gull	0 (0)	0 (0)	1 (100.0)	0 (0)	0 (0)	1
Black-legged Kittiwake	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Sabine's Gull	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified gull	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total gulls	0 (0)	0 (0)	1 (100.0)	0 (0)	0 (0)	1
Common Murre	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified murre	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Pigeon Guillemot	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified guillemot	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total alcids	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified waterbird	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total waterbirds	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total	0 (0)	0 (0)	1 (100.0)	0 (0)	0 (0)	1

Table 8. Flight behavior of birds recorded visually near Gambell, Alaska, 23 October–2 November 2002, by species/species-group and movement zone (continued).

	Windfarm					
Species/species-group	Straight-line	Erratic	Circling	Flying/landing	Contouring	*n*
Pacific Loon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified loon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total loons	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified cormorant	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total cormorants	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Spectacled Eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
King Eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Common Eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total eiders	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
White-winged Scoter	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified scoter	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Long-tailed Duck	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified duck	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total other ducks	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Gyrfalcon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Common Raven	1 (50.0)	1 (50.0)	0 (0)	0 (0)	0 (0)	2
Total raptors	1 (50.0)	1 (50.0)	0 (0)	0 (0)	0 (0)	2
Unidentified phalarope	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total shorebirds	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Glaucous Gull	26 (86.7)	4 (13.3)	0 (0)	0 (0)	0 (0)	30
Black-legged Kittiwake	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Sabine's Gull	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified gull	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total gulls	26 (86.7)	4 (13.3)	0 (0)	0 (0)	0 (0)	30
Common Murre	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified murre	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Pigeon Guillemot	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified guillemot	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total alcids	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified waterbird	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total waterbirds	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total	27 (84.4)	5 (15.6)	0 (0)	0 (0)	0 (0)	32

Table 8. Flight behavior of birds recorded visually near Gambell, Alaska, 23 October–2 November 2002, by species/species-group and movement zone (continued).

	Town					
Species/species-group	Straight-line	Erratic	Circling	Flying/landing	Contouring	*n*
Pacific Loon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified loon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total loons	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified cormorant	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total cormorants	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Spectacled Eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
King Eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Common Eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified eider	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total eiders	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
White-winged Scoter	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified scoter	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Long-tailed Duck	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified duck	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total other ducks	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Gyrfalcon	0 (0)	3 (100.0)	0 (0)	0 (0)	0 (0)	3
Common Raven	5 (35.7)	9 (64.3)	0 (0)	0 (0)	0 (0)	14
Total raptors	5 (29.4)	12 (70.6)	0 (0)	0 (0)	0 (0)	17
Unidentified phalarope	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total shorebirds	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Glaucous Gull	14 (77.8)	4 (22.2)	0 (0)	0 (0)	0 (0)	18
Black-legged Kittiwake	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Sabine's Gull	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified gull	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total gulls	14 (77.8)	4 (22.2)	0 (0)	0 (0)	0 (0)	18
Common Murre	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified murre	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Pigeon Guillemot	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified guillemot	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total alcids	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified waterbird	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total waterbirds	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total	19 (54.3)	16 (45.7)	0 (0)	0 (0)	0 (0)	35

Table 8. Flight behavior of birds recorded visually near Gambell, Alaska, 23 October–2 November 2002, by species/species-group and movement zone (continued).

	Ocean					
Species/species-group	Straight-line	Erratic	Circling	Flying/ landing	Contouring	*n*
Pacific Loon	0 (0)	0 (0)	0 (0)	0 (0)	1 (100.0)	1
Unidentified loon	2 (18.2)	0 (0)	0 (0)	0 (0)	9 (81.8)	11
Total loons	2 (16.7)	0 (0)	0 (0)	0 (0)	10 (83.3)	12
Unidentified cormorant	26 (18.3)	0 (0)	0 (0)	2 (1.4)	114 (80.3)	142
Total cormorants	26 (18.3)	0 (0)	0 (0)	2 (1.4)	114 (80.3)	142
Spectacled Eider	1 (11.1)	0 (0)	0 (0)	1 (11.1)	7 (77.8)	9
King Eider	0 (00)	0 (0)	0 (0)	0 (0)	4 (100.0)	4
Common Eider	3 (17.6)	0 (0)	0 (0)	1 (5.9)	13 (76.5)	17
Unidentified eider	42 (29.4)	1 (0.7)	0 (0)	7 (4.9)	93 (65.0)	143
Total eiders	46 (26.6)	1 (0.6)	0 (0)	9 (5.2)	117 (67.6)	173
White-winged Scoter	1 (20.0)	0 (0)	0 (0)	0 (0)	4 (80.0)	5
Unidentified scoter	0 (0)	0 (0)	0 (0)	1 (100.0)	0 (0)	1
Long-tailed Duck	15 (13.9)	0 (0)	0 (0)	2 (1.9)	91 (84.3)	108
Unidentified duck	1 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	1
Total other ducks	17 (14.8)	0 (0)	0 (0)	3 (2.6)	95 (82.6)	115
Gyrfalcon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Common Raven	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Total raptors	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Unidentified phalarope	0 (0)	0 (0)	0 (0)	1 (50.0)	1 (50.0)	2
Total shorebirds	0 (0)	0 (0)	0 (0)	1 (50.0)	1 (50.0)	2
Glaucous Gull	41 (70.7)	7 (12.1)	0 (0)	0 (0)	10 (17.2)	58
Black-legged Kittiwake	12 (33.3)	3 (8.3)	0 (0)	1 (2.8)	20 (55.5)	36
Sabine's Gull	2 (40.0)	1 (20.0)	0 (0)	0 (0)	2 (40.0)	5
Unidentified gull	5 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	5
Total gulls	60 (57.7)	11 (10.6)	0 (0)	1 (1.0)	32 (30.8)	104
Common Murre	2 (50.0)	0 (0)	0 (0)	0 (0)	2 (50.0)	4
Unidentified murre	20 (11.9)	0 (0)	0 (0)	3 (1.8)	145 (86.3)	168
Pigeon Guillemot	0 (0)	0 (0)	0 (0)	1 (33.3)	2 (66.7)	3
Unidentified guillemot	1 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	1
Total alcids	23 (13.1)	0 (0)	0 (0)	4 (2.3)	149 (84.7)	176
Unidentified waterbird	45 (53.6)	1 (1.2)	0 (0)	0 (0)	38 (45.2)	84
Total waterbirds	45 (53.6)	1 (1.2)	0 (0)	0 (0)	38 (45.2)	84
Total	219 (27.1)	13 (1.7)	0 (0)	20 (2.5)	556 (68.8)	808

Table 9. Efficiency of detection of eider radar targets near Gambell, Alaska, 23 October–3 November 2002, by sampling session. Data are presented as *n* eiderlike targets, *n* visual flocks of eiders recorded visually, and *n* eiders recorded visually during concurrent sampling.

Sampling session	Number of eiderlike radar targets	Number of flocks of eiders seen visually	Number of eiders seen visually
298.01	1	2[a]	72
298.02	2	3[a]	98
298.03	1	8[a]	727
298.04	0	3	13
298.05	0	5[a]	26
298.07	0	2	9
298.08	0	5[a]	61
298.09	1	4	10
298.10	0	1	2
304.05	0	1	19
304.06	0	1	3
304.08	0	1	3
304.09	0	2	11
304.10	3 (but 3 are cormorants)	2	7
304.11	3 (but 2 are cormorants)	0	0
304.12	3 (but 2 are cormorants)	0	0
305.01	5 (but 3 are cormorants)	0	0
305.02	2 (but 1 is cormorant)	2	6
305.03	2	1	3
305.05	1	1	3
305.10	1	0	0
306.06	1 (but kittiwake)	3	205
306.07	0	8	82
306.08	1 (but cormorant)	5	41
306.09	0	4	756
306.10	0	7	61
Total	12 (plus 13 misidentified)	69	2,224

[a] Because so many eiders were moving by in long strings, multiple flocks sometimes were counted as one on this first day of sampling because the emphasis was on an accurate count of birds, rather than on flocks; hence, the number of flocks probably is underestimated.

(Table 5), in that targets of cormorants flying with a tailwind looked much like those of eiders on the radar screen, but the eiders were flying so low and the cormorants were flying so high that the number of misidentified eiders was inflated because of a higher probability of detecting cormorants.

Although it is clear that the number of eider flocks and eiders recorded by the radar over the ocean was underestimated, the radar did an excellent job of detecting targets over land, which was an important aspect of this study. The view over land was excellent and was not affected by sea clutter. Hence, we believe that we missed no targets flying over land, especially targets of eiders. Therefore, we considered the radar to provide an underestimate of numbers of eiders moving over the ocean but to provide an accurate estimate of numbers of eiders moving over land.

MOVEMENT RATES

"Eiders" exhibited low mean movement rates during most dates and under most weather conditions, with most means averaging 1–3 targets/h (Table 10). The maximal movement rate for one sampling session was 9.6 targets/h, recorded on 31 October. Mean movement rates were ~175% higher at night than during the day, 200% higher during periods of no precipitation than during precipitation, and 50% higher during crosswinds than during tailwinds.

"Non-eiders" exhibited mean movement rates that were ~20 times those for "eiders," with most means averaging ~25 targets/h (Table 10); there was substantial among-day variation in movement rates. The maximal movement rate for one sampling session was 196.8 targets/h, recorded on 2 November. Mean movement rates were ~160% higher during the day than at night (primarily because of all of the daytime gull movements), ~72% higher during periods of no precipitation than during precipitation, and ~20% higher during tailwinds than during crosswinds.

Mean movement rates of "eiders" varied geographically, with essentially all birds flying only over the ocean and none flying over the mountain and town (Table 11). We did, however, record one unidentified target over the proposed windfarm that we classified as an "eider" on 25 October. This target occurred during the day, during a period of no precipitation, and during tailwinds (Table 11). We suspect that this target was not one of eiders and instead suspect that it was gulls flying with a tailwind; however, we were unable to locate it visually as it passed over the windfarm to confirm this suspicion. Mean rates were <0.1 targets/h over the windfarm, 0 targets/h over the mountain and town, and ~1.5 targets/h over the ocean.

Mean movement rates of "non-eiders" also varied geographically, with none recorded over the mountain, moderate numbers moving over the proposed windfarm and town, and much higher numbers moving over the ocean (Table 11). Mean rates were ~2 targets/h over the windfarm, ~4 targets/h over town, and ~20 targets/h over the ocean.

FLIGHT BEHAVIOR

"Eiders" were recorded exhibiting three of the five standardized behaviors (Table 12). Overall, ~90% of all "eider" targets flew with straight-line, directional characteristics. Another ~7% of all "eider" targets flew by contouring (i.e., following the coastline); low percentages of "eider" targets flew erratically. Frequencies of erratic flight behavior, which could be associated with a higher probability of hitting structures, were so low overall that no pattern by factor could be discerned.

"Non-eiders" were recorded exhibiting all five of the standardized behaviors (Table 12). Overall, ~60% of all "non-eider" targets flew with straight-line characteristics. Another ~34% flew by contouring; this behavior was seen most frequently in foraging gulls, which frequently followed the shoreline. The remaining three behaviors occurred infrequently, with erratic behavior being the most common of the three.

The one "eider" target recorded over the proposed windfarm flew with straight-line characteristics (Table 13). Otherwise, all other targets were recorded over the ocean, flying primarily with straight-line behavior.

Most of the "non-eider" targets passing over the proposed windfarm flew with straight-line characteristics, with the remaining targets flying erratically, by circling, or flying/landing (Table 13). Over town, most "non-eider" targets flew with straight-line characteristics, with the remaining birds flying erratically or contouring along the shoreline north of town. Over the ocean, most

Table 10. Movement rates (targets/h) of birds recorded migrating on radar near Gambell, Alaska, 23 October–2 November 2002, by species-group and factor. Data are presented as mean ± SE radar targets/h, range, and *n* sampling sessions (except for the Total across all dates, for which *n* is the number of days).

Species-group	Factor	Attribute	Mean ± SE	Range	*n*
"Eiders"	Date	25 OC	1.0 ± 0.5	0–4.8	10
		26 OC	0 ± –	0–0	1
		31 OC	3.4 ± 0.9	0–9.6	17
		1 NO	1.1 ± 0.4	0–4.8	16
		2 NO	0.9 ± 0.4	0–4.8	16
		Total	1.3 ± 0.4	0–9.6	5
	Time of day	Day	1.2 ± 0.3	0–7.2	47
		Night	3.3 ± 1.1	0–9.6	13
		Total	1.6 ± 0.3	0–9.6	60
	Precipitation level	No precipitation	2.4 ± 0.6	0–9.6	31
		Precipitation	0.8 ± 0.3	0–6.0	29
		Total	1.6 ± 0.3	0–9.6	60
	Wind type	Crosswind	2.4 ± 1.0	0–9.6	11
		Tailwind	1.6 ± 0.4	0–9.6	49
		Total	1.6 ± 0.3	0–9.6	60
"Non-eiders"	Date	25 OC	40.1 ± 8.0	9.6–88.8	10
		26 OC	24.0 ± –	24.0	1
		31 OC	19.2 ± 2.5	4.8–38.4	17
		1 NO	16.1 ± 4.6	2.4–69.6	16
		2 NO	36.2 ± 12.8	0–196.8	16
		Total	27.1 ± 4.7	0–196.8	5
	Time of day	Day	30.5 ± 5.0	0–196.8	47
		Night	11.8 ± 2.5	0–26.4	13
		Total	26.4 ± 4.1	0–196.8	60
	Precipitation level	No precipitation	33.1 ± 6.6	4.8–196.8	31
		Precipitation	19.3 ± 4.3	0–112.8	29
		Total	26.4 ± 4.1	0–196.8	60
	Wind type	Crosswind	22.7 ± 2.9	7.2–38.4	11
		Tailwind	27.3 ± 4.9	0–196.8	49
		Total	26.4 ± 4.1	0–196.8	60

Table 11. Movement rates (targets/h) of birds recorded on radar near Gambell, Alaska, 23 October–2 November 2002, by species-group, factor, and movement zone. Data are presented as mean ± SE (range) radar targets/h by movement zone; for all samples, *n* for all is 60 sampling sessions.

	Movement zone			
Species-group	Mountain	Windfarm	Town	Ocean
"Eiders"	0 ± 0 (0–0)	<0.1 ± <0.1 (0–2.4)	0 ± 0 (0–0)	1.6 ± 0.3 (0–9.6)
Non-eiders"	0 ± 0 (0–0)	2.2 ± 0.6 (0–24.0)	4.0 ± 0.8 (0–33.6)	20.2 ± 3.9 (0–196.8)

Table 12. Flight behavior of birds recorded on radar near Gambell, Alaska, 23 October–2 November 2002, by species-group. Data are presented as number (percentage) in each category and n flocks.

			Flight behavior					
Species-group	Factor	Attribute	Straight-line	Erratic	Circling	Flying/ landing	Contouring	*n*
"Eiders"	Time of day	Day	20 (83.3)	1 (4.2)	0 (0)	0 (0)	2 (8.3)	23
		Night	17 (94.4)	0 (0)	0 (0)	0 (0)	1 (5.6)	18
	Precipitation level	No precipitation	30 (96.8)	1 (3.2)	0 (0)	0 (0)	0 (0)	31
		Precipitation	7 (63.6)	0 (0)	0 (0)	0 (0)	3 (27.3)	10
	Wind type	Crosswind	11 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	11
		Tailwind	26 (83.9)	1 (3.2)	0 (0)	0 (0)	3 (9.7)	30
	Total	Total	37 (90.2)	1 (2.4)	0 (0)	0 (0)	3 (7.3)	41
"Non-eiders"	Time of day	Day	342 (58.8)	29 (5.0)	2 (0.3)	3 (0.5)	206 (35.4)	582
		Night	42 (65.5)	7 (10.9)	1 (1.6)	0 (0)	14 (21.9)	64
	Precipitation level	No precipitation	276 (65.9)	28 (6.7)	2 (0.5)	0 (0)	113 (27.0)	419
		Precipitation	108 (47.1)	8 (3.5)	1 (0.4)	3 (1.3)	107 (47.1)	227
	Wind type	Crosswind	91 (87.5)	13 (12.5)	0 (0)	0 (0)	0 (0)	104
		Tailwind	293 (54.1)	23 (4.3)	3 (0.6)	3 (0.6)	220 (40.6)	542
	Total	Total	384 (59.4)	36 (5.6)	3 (0.5)	3 (0.5)	220 (34.1)	646

Table 13. Flight behavior of birds recorded on radar near Gambell, Alaska, 23 October–2 November 2002, by species-group and movement zone. Data are presented as number (percentage) in each category and *n* flocks.

	Movement zone											
	Mountain						Windfarm					
Species-group	Straight-line	Erratic	Circling	Flying/ landing	Contouring	*n*	Straight-line	Erratic	Circling	Flying/ landing	Contouring	*n*
"Eiders"	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0	1 (50.0)	0 (0)	0 (0)	0 (0)	0 (0)	1
"Non-eiders"	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0	46 (93.9)	1 (2.0)	1 (2.0)	1 (2.0)	0 (0)	49

	Movement zone											
	Town						Ocean					
Species-group	Straight-line	Erratic	Circling	Flying/ landing	Contouring	n	Straight-line	Erratic	Circling	Flying/ landing	Contouring	n
"Eiders"	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0	36 (90.0)	1 (2.5)	0 (0)	0 (0)	3 (7.5)	40
"Non-eiders"	75 (75.8)	14 (14.1)	0 (0)	0 (0)	10 (10.1)	99	263 (52.8)	21 (4.2)	2 (0.4)	2 (0.4)	210 (42.2)	498

"non-eider" targets flew with straight-line characteristics or by contouring, with the other three behaviors occurring sparingly.

AVIAN MORTALITY

We recorded no birds of any species dead at the FAA towers and the meteorological tower (Table 2). No dead birds were found in spite of the presence of dense fog on some days.

DISCUSSION

These data suggest several important insights about the movements of birds in the vicinity of the proposed windfarm at Gambell. First, the number of birds moving and wintering in this area is large, with birds constantly in motion: we saw a total of >26,000 birds during our sampling, for an overall mean daily movement rate of 700 birds/h. Although Fay (1961) suggested that waterfowl were scarce at St Lawrence in the fall (September–late November), we saw large numbers of ducks (4,845 eiders and 1,092 other ducks). We also saw 9,513 alcids, essentially all of which were murres, and another 6,388 waterbirds (ducks or murres), indicating that a diversity of bird species occurs in number near Gambell in the fall.

Eiders form a significant proportion of the birds seen near Gambell at this time of the year, representing 4,845 (24.5%) of the 19,784 identified birds; if all of the unidentified waterbirds actually were eiders, up to 42.9% of the birds seen would have been eiders. Hence, eiders represented 24–43% of the birds occurring at Gambell during this period. Although sample sizes were small, Common Eiders appeared to be the most abundant eider species, with Spectacled Eiders second in abundance and King Eiders third in abundance. Spectacled Eiders winter in the polynyas off of the southern side of St. Lawrence Island and in the zone of labile ice southwest of St. Lawrence Island, passing Gambell in substantial numbers (Petersen et al. 1995, 1999, 2000).

The movement-rate data indicate that most birds pass by Gambell over the ocean, with very little movement of any species over the proposed windfarm (primarily gulls and raptors). This pattern also was true at night, as indicated by the radar data, and was especially true at all times for eiders on radar: we recorded only one eiderlike target on radar flying over the proposed windfarm, and we suspect that it was not of an eider. We also saw no eiders (and few birds of only a few species) flying over land during extensive visual surveys.

Although we saw no eiders or waterfowl of any species flying over land, local villagers informed us that eiders and Long-tailed Ducks fly over the spit on which Gambell occurs after the sea freezes and snow obscures the boundary between sea and land. At those times, these birds "cut the corner" over the spit while moving back and forth as polynyas open and close on the northern and southern sides of the island. Local villagers told us that, when these birds do cross the spit, they occasionally hit the wires at the FAA towers. Hence, the absence of dead birds that we recorded at the FAA towers probably reflects the fact that birds were not yet flying over land because the sea had not yet frozen.

The flight-altitude data indicate that flight altitudes of most species over the ocean (with the exception of cormorants and gulls) were so low that, unless they changed altitude as they crossed land, they would pass under the rotor blades of the turbines, given the dimensions that are envisioned at this time. The towers will be 24, 30, or 40 m high, and the rotors will be either 15 or 20 m in diameter (i.e., having 7.5–10 m blade lengths), resulting in sweep areas for the three tower designs of 14–34 m high, 20–40 m high, and 30–50 m high, respectively. On the other hand, it is likely that many gulls, cormorants, and raptors will fly at altitudes that put them at risk of collisions. It is unclear whether eiders will increase in height as they cross the spit later in the winter; at Pt. Barrow, birds do increase in altitude as they cross the base of Barrow Spit, but that increase appears to be related much more to the presence of numerous hunters than it does to an aversion to flying over land (Day and Rose, pers. obs.). At Northstar Island, the mean flight altitude of eiders flying over the ocean was 7.9 m (Day et al. 2002), or slightly higher than what we recorded here.

The behavioral data indicate that most of the birds seen in this study flew by contouring (i.e., following the shoreline); by flying over the ocean or the shoreline, those birds will have little chance of hitting the turbines. On the other hand, if a flock does deviate to cross over the spit, the other

members of the flock will follow, resulting in a low probability of collision but a high probability of substantial mortality if a collision does occur. Erratic behavior is one that we believe results in a higher risk of collision, because the birds are moving around the northern part of the spit in numerous directions. Foraging gulls and ravens both seem to exhibit frequent erratic behavior, suggesting that they have a higher probability of collision with turbines than the eiders do. On the other hand, their slow flight speeds, which gives them a fair degree of maneuverability, may help to some extent to counteract the higher probability of collision caused by straight-line flight behavior. Of nine windpower sites for which mortality data were summarized (Erickson et al. 2001), gulls were recorded being killed at three of them and ravens were recorded being killed at four of them (and several of the other sites occurred in locations outside of the range of ravens). The mortality of gulls and ravens represented up to 4.8% and 5.4%, respectively, of all birds killed at windpower sites, suggesting that their slow flight speeds do not prevent their mortality.

Finally, the visual and radar data indicate that, at this site, the utility of radar was limited because of two factors: heavy precipitation and high seas. Rain limited the use of this X-band radar a substantial percentage of the time; given the fact that Gambell receives precipitation (Alaska Community Database; see website in "Study Area," above) ~83% of the days/year, this limitation should not be unexpected. High seas caused problems in detection because the eiders flew between wave troughs during periods of high seas, so that the radar often could not detect them below the wave-tops. The problems noted here are important, in that they indicate that radar will be limited as a sampling tool in some circumstances (e.g., some locations, some seasons) in coastal communities of western Alaska, particularly if wind turbines are constructed on the coast itself. On the other hand, the ability of the radar to sample a much larger area than the visual observers can sample, the fact that over -land observations near proposed turbines are important and that the radar sampled those areas well, and the fact that the radar can sample during periods of limited visibility (the radar indicated that nocturnal movement rates of all birds were substantial) compensate for its limitations in most cases.

CONCLUSIONS AND RECOMMENDATIONS

Although it is difficult to evaluate with certainty the probability of mortality of eiders, especially Spectacled Eiders, and other seabirds at the proposed windfarm at Gambell, we believe that the probability of fall mortality of eiders while the sea is unfrozen is extremely low. On the other hand, local residents indicated that, once the ocean freezes and the exact boundary of the shoreline is obscured, eiders and other ducks moving back and forth past the island occasionally cross over the spit, sometimes hitting the FFA towers or their guy wires. It is unclear what the frequency of this overland flight is during those conditions and, hence, what the actual collision probability will be. We believe, however, that locating the windfarm toward the base of Sevuokuk Mountain (i.e., in the vicinity of the proposed location) will decrease the probability of collision for ducks crossing the spit considerably from that if the windfarm is located toward the tip of the spit. Finally, although summer bird movements were not studied, there are large auklet colonies on nearby Sevuokuk Mountain . We suggest that the location of the auklet colony be a consideration in site selection at this windfarm.

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