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Effects of Gas Flaring on the Behavior of Night-Migrating Birds at an Artificial Oil-Production Island, Arctic Alaska

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ABSTRACT. We studied movement rates and the general flight behavior of bird flocks seen on radar and recorded visually at Northstar Island, Arctic Alaska, from 13 to 27 September 2002. Most of this period (13–19 and 21–27 September) had no gas-flaring events, but a major gas-flaring event occurred on the night of 20 September. Movement rates of targets on radar and of bird flocks recorded visually in the first ~50%–60% of the night were much lower during the non-flaring period than during the night of flaring, whereas rates in the last ~40%–50% of the night were similar in all periods. The general flight behavior of birds also differed significantly, with higher percentages of both radar targets and bird flocks exhibiting straight-line (directional) flight behaviors during the non-flaring periods and higher percentages of radar targets and bird flocks exhibiting non-straight-line (erratic and circling) flight behaviors during the gas-flaring period. During the night of gas flaring, the bright illumination appeared to have an effect only after sunset, when flocks of birds circled the island after being drawn in from what appeared to be a substantial distance from the island. On both radar and visual sampling, the number of bird flocks approaching the island declined over the evening, and the attractiveness of the light from flaring appeared to decline. The visibility of the moon appeared to have little effect on the behavior of birds. Because illumination from extensive gas-flaring is such a strong attractant to migrating birds and because most bird flocks fly at low altitudes over the water, flaring booms on coastal and offshore oil-production platforms in Arctic Alaska should be positioned higher than the mean flight altitudes of migrating birds to reduce the chances of incineration.

Key words: Alaska; behavior; *Clangula*; collision; eider; gas flaring; gull; light attraction; loon; migration; sea duck; shorebird; *Somateria*

RÉSUMÉ. Nous avons étudié les taux de déplacement et le comportement de vol général des troupeaux d’oiseaux captés par radar ou consignés visuellement à l’île Northstar, dans l’Alaska de l’Arctique, du 13 au 27 septembre 2002. Pendant presque toute cette période (du 13 au 19 et du 21 au 27 septembre), il n’y a pas eu de brûlage de gaz à la torche, mais la nuit du 20 septembre, il y a eu un important brûlage de gaz à la torche. Les taux de déplacement des cibles radar et des troupeaux d’oiseaux consignés visuellement pendant la première tranche d’environ 50 % à 60 % de la nuit étaient beaucoup moins élevés pendant la période où il n’y avait pas de brûlage à la torche que pendant la nuit où il y a eu brûlage à la torche, tandis que pendant la deuxième tranche d’environ 40 % à 50 % de la nuit, les taux de déplacement étaient semblables pendant toutes les périodes. Le comportement de vol général des oiseaux a également affiché une différence considérable. De plus grands pourcentages de cibles radar et de troupeaux d’oiseaux adoptaient un comportement de vol rectiligne (direct) pendant les périodes où il n’y avait pas de brûlage à la torche, et de plus grands pourcentages de cibles radar et de troupeaux d’oiseaux affichaient un comportement de vol non rectiligne (erratique et indirect) pendant la période où il y a eu brûlage à la torche. La nuit du brûlage à la torche, la vive illumination n’a semblé avoir un effet qu’après le coucher du soleil, quand les troupeaux d’oiseaux encerclaient l’île après avoir été attirés depuis un endroit qui semblait très lointain. Tant pour l’échantillonnage prélevé par radar que par consignation visuelle, le nombre de troupeaux d’oiseaux s’approchant de l’île diminuait dans le courant de la soirée, et l’attrait de la lumière émanant du brûlage à la torche semblait également diminuer. La visibilité de la lune semblait avoir peu d’effet sur le comportement des oiseaux. Puisque l’illumination provenant du brûlage prolongé à la torche exerce une si grande force d’attraction chez les oiseaux migrateurs, et puisque la plupart des troupeaux d’oiseaux volent en basse altitude au-dessus de l’eau, le torchage effectué sur les plateformes pétrolières côtières et extracôtières dans l’Alaska de l’Arctique devrait être positionné plus haut que les altitudes moyennes de vol des oiseaux migrateurs afin de réduire les risques d’incinération.

Mots clés : Alaska; comportement; *Clangula*; collision; eider; brûlage du gaz à la torche; mouette; attraction à la lumière; huard; migration; canard de mer; oiseau de rivage; *Somateria*

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INTRODUCTION

At high latitudes, marine-oriented birds may face a variety of anthropogenic obstacles during migration to and from breeding grounds or on their wintering grounds. These possible obstacles include structures (buildings, towers, boats) in coastal or offshore regions and the presence of bright lights. Perhaps the most dangerous conditions for birds occur when they encounter bright lights in conjunction with large structures such as buildings or fishing boats, especially during stormy or foggy conditions (e.g., Howell et al., 1954; Dick and Donaldson, 1978; Hope-Jones, 1980; Jones and Francis, 2003; Montevecchi, 2006; Gauthreaux and Belser, 2006) or during certain lunar phases (e.g., Overing, 1936; Crawford, 1981b; Verheijen, 1981b).

In the U.S. and Canadian Arctic, there generally is little coastal development that can cause light attraction in birds. One notable exception is the large development known as the Prudhoe Bay – Kuparuk oilfields of the Arctic Coastal Plain of Alaska. This area has gone from no development in the late 1960s to an extensive network of pads, roads, wellheads, pipelines, and processing facilities. An addition to this network is Northstar Island, an oil-production island lying ~6 mi (~10 km) northwest of Prudhoe Bay that was constructed in the winter of 2000 – 01 to tap the offshore Northstar oilfield (Fig. 1). This artificial island, which lies offshore in the U.S. Beaufort Sea and is in the path of birds that are migrating along the coast, has several features that reduce its attractiveness to migrating birds, including shielded exterior lights that point downward and inward toward the island, buildings painted tan (not white) so they are visible to birds but are not so bright that they reflect light up into the night sky, and the use of strobe lights as a bird-deterrent device (Day et al., 2005). Studies of these anti-collision strobe lights indicate that they are effective in many ways in repelling birds from the island (Day et al., 2005), although Esmoil and Anderson (1995) found that oil pits with flagging, reflectors, and strobes all had fatality rates similar to pits without deterrents. One night in September 2002, however, a large gas-flaring event created a light source that overrode the effects of the island's strobe lights. This paper describes the responses of the birds to that gas-flaring event.

Light Attraction in Seabirds

One of the challenges for ecologists is to help develop new technology or to use existing technology to reduce the impacts of environmental development and, specifically to reduce bird collisions as a result of lights associated with that development. For example, airport ceilometers were useful to aviation in determining the height of cloud cover until it was discovered that their continuous bright lights occasionally attracted and killed large numbers of birds that were migrating past them; as a result, ceilometers now illuminate the sky at intervals, rather than continuously. Similarly, lighthouses have saved many lives by keeping ships away from reefs, but their bright lights also occasionally attracted large numbers of birds; as a result, they now rotate, often have a more focused beam, and generally have different wavelengths of light than they formerly did. Lighting issues may affect a variety of bird species in many locations, so one of our challenges is to find ways to reduce the attractiveness of lights to birds in the Arctic in the face of increasing development, especially as oil and gas development moves onto the continental shelf.

During stormy or foggy conditions in Alaska, eiders (*Somateria* spp.) have been recorded landing on the main street of the city of Nome at night (J.J. Burns, Fairbanks, Alaska, pers. comm. 2001), on fishing boats in the Bering Sea (J. Sease, Rutland, Vermont, pers. comm. 1985), and in the Gulf of Alaska near Kodiak Island (Dick and Donaldson, 1978). Other seabirds sometimes are attracted to bright lights during storms in Alaska, occasionally in the tens of thousands and sometimes plugging the scuppers of ships (Dick and Donaldson, 1978). Other birds reported to land on ships in Alaska waters include Short-tailed Shearwaters (*Puffinus tenuirostris*); Leach's (*Oceanodroma leucorhoa*) and Fork-tailed (*O. furcata*) Storm-Petrels; Thick-billed Murres (*Uria lomvia*); Crested (*Aethia cristatella*), Whiskered (*A. pygmaea*), Parakeet (*A. psittacula*), and Cassin's (*Ptychoramphus aleuticus*) Auklets; Puffins (*Fratercula* spp.); Common Eiders (*Somateria mollissima*); Long-tailed Ducks (*Clangula hyemalis*); several shorebird species; raptors; and passerines (Rojek, 2001; Greer et al., 2010; R.H. Day and D.J. Forsell, unpubl. data; R.H. Day and B.E. Lawhead, unpubl. data; A.E. Gall and R.H. Day, unpubl. data). Most boarded ships in storms, although not all did, including some nocturnal species, which were attracted to the flashlight in a sailor's back pocket and came aboard during non-stormy periods (R.H. Day and D.J. Forsell, unpubl. data). In addition, Maillard (1898) reported that Fork-tailed Storm-Petrels sometimes were attracted to lights of bonfires in southeastern Alaska.

Seabirds also have been found to be attracted to lights elsewhere in the Pacific Ocean (e.g., Imber, 1975; Harrow, 1976; Reed et al., 1985; Telfer et al., 1987; Rojek, 2001; Bertram, 1995; Greer et al., 2010; Rodriguez et al., 2014; R.H. Day, unpubl. data), the Atlantic Ocean (e.g., Wingate, 1964; Swales, 1965; Rodríguez and Rodríguez, 2009; Merkel, 2010; Miles et al., 2010; Fontaine et al., 2011; Rodríguez et al., 2012), the Mediterranean Sea (e.g., Arcos and Oro, 2002; Raine et al., 2007), the Antarctic and Sub-Antarctic (e.g., Swales, 1965; Warham, 1996; Black, 2005), and the Indian Ocean (e.g., Le Corre et al., 2002; Pinet et al., 2009). Tubenoses (Procellariiformes), in particular, seem to be prone to light attraction, although other taxa of seabirds and coastal birds that are primarily nocturnal at terrestrial nesting areas or are migrating at night also may be attracted in numbers (e.g., shorebirds, nocturnal alcids).

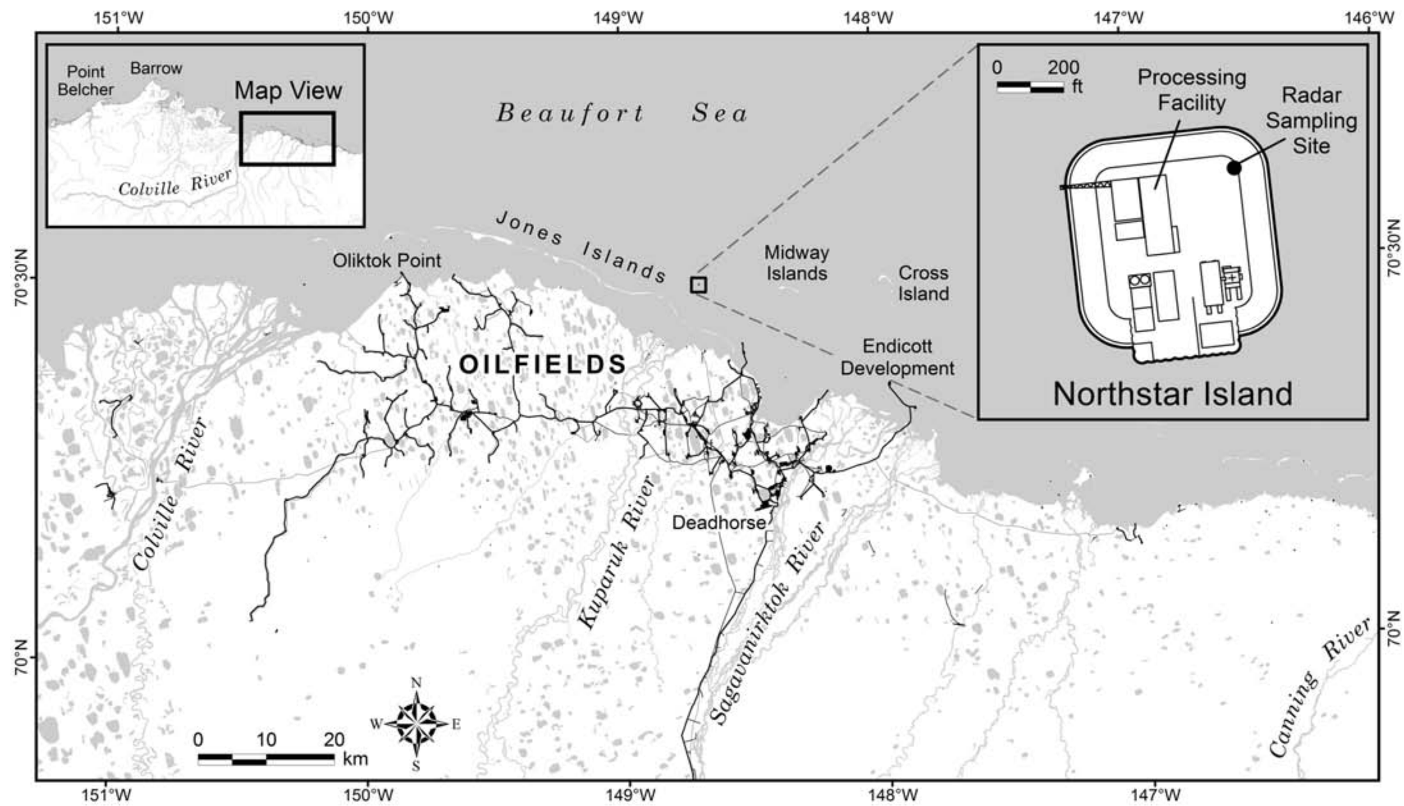

FIG. 1. Location of Northstar Island, Alaska, and radar sampling site.

METHODS

Study Area and Flaring Event

Northstar Island (70˚13.5′ N 146˚20.6′ W) is an artificial oil-production island that lies ~6 mi (~10 km) northwest of Prudhoe Bay, Alaska. It covers ~3.6 ha and is ~8 m high at the seawall (Fig. 1). This island consists of a sheet-pile perimeter wall filled with gravel and surrounded by a beach made of steel-reinforced concrete mats. The highest buildings on the island are ~35 – 40 m above sea level (asl); the top of the flaring boom, which is located on the northwestern corner of the island, is ~66 m (~215 ft) asl. The island has an anti-collision strobe-lighting system for birds consisting of 14 white lights mounted ~15 m above the ocean's surface along the island's perimeter; these lights fire asynchronously at 40 flashes/min with a daytime intensity of 20 000 candela and a nighttime intensity of 2000 candela (Day et al., 2005). Numerous bird species, including eiders, nest on nearby islands and the mainland and migrate through the surrounding area (Thompson and Person, 1963; Schamel, 1977; Richardson and Johnson, 1981; Johnson and Richardson, 1982; Divoky, 1984; Johnson and Herter, 1989; Suydam et al., 1997, 2000a, b; Day et al., 2004; Fischer and Larned, 2004).

The gas-flaring event that we discuss here began at 1835 hours (h) on the night of 20 September 2002, when an electrical panel that controlled gas reinjection failed, creating excessive gas pressure that had to be flared off. With the exception of a 5 min period in which the flaring was brought under control from 2216 h to 2221 h, the flaring continued unabated until being brought under control for good at 0300 h. During the gas-flaring event, the night sky and ocean around the island were illuminated brightly to at least 1000 m away, and we suspect that the flare was visible much farther away. The flaring was so bright that we were able to observe birds at night either unaided or with binoculars instead of a night-vision scope.

Data Collection

We studied the movements, behavior, and flight altitudes of migrating birds during 20 nights/year between late August and mid-October 2001 – 04 (Day et al., 2005). This paper discusses the subset of data collected between 13 and 27 September 2002, emphasizing the night of gas flaring (20 September). We also have included data during non-flaring periods 1 week before (13 – 19 September) and 1 week after (21 – 27 September) the gas-flaring event for comparison of general movement patterns. We sampled ~7 – 11 h/night with radar and visual equipment (binoculars and night-vision equipment).

We collected radar and visual data for 25 min sampling sessions during each 30 min sampling period (e.g., all sessions occurring at 1905 – 1929 h, all occurring at 1935 – 1959 h, etc.) between 1800 h and 0600 h. The other 5 min were used to check weather and to give the observers a short break. Hence, we collected data during ~20 sessions

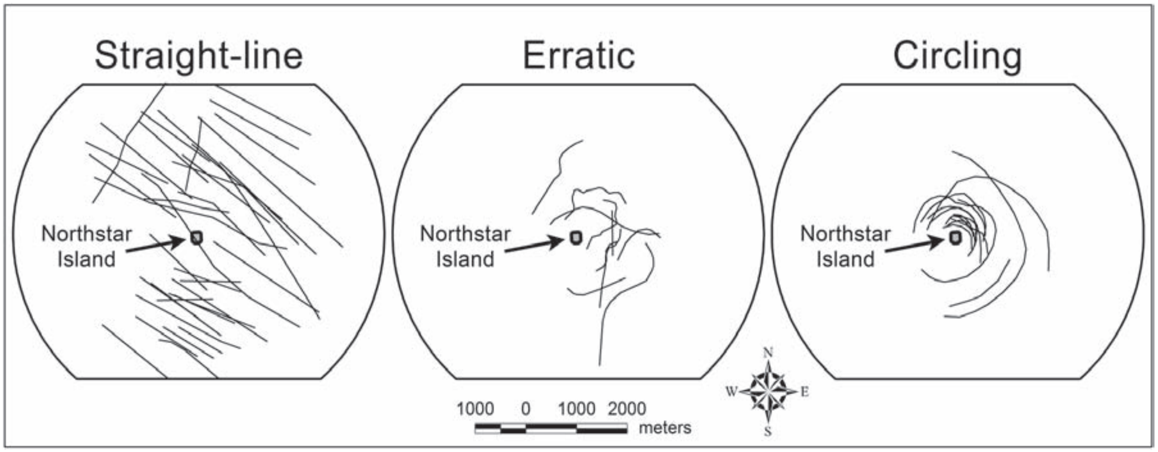

FIG. 2. General flight behaviors: GIS-digitized tracings of straight-line, erratic, and circling tracklines on radar near Northstar Island, Alaska.

each day, depending on weather and other conditions. A sampling day began at 0700 h and ended at 0659 h the following morning, so an entire night's sampling was classified as occurring on the same day. We were able to sample the entire night with both radar and night-vision equipment during the night of the gas-flaring event. We sampled with radar during eight nights and visually during all 14 nights in the non-flaring period. At times, data collection was prevented by heavy precipitation, the presence of polar bears (*Ursus maritimus*), which required us to move indoors for safety, and excessive sea clutter on the radar screen caused by high wind-driven waves.

On 13 September 2002, the sun set at 2044 h and rose the next morning at 0659 h, for a total of 10 h, 15 min of darkness; times of civil sunset, evening twilight, morning twilight, and civil sunrise at Prudhoe Bay, Alaska, were taken from the U.S. Naval Astronomical Observatory (http://aa.usno.navy.mil/index.php). On 27 September 2002, the sun set at 1938 h and rose the next morning at 0755 h, for a total of 12 h, 17 min of darkness. The lunar first quarter occurred on 13 September, providing a waxing gibbous moon for that week; the full moon occurred on 20 September, the night of the gas-flaring event; and the third quarter occurred on 29 September, for a waning gibbous moon during the last week of observations. Civil twilight is defined as the time when the center of the sun is geometrically 6 degrees below the horizon; in the evening after the end of civil twilight and in the morning before the beginning of civil twilight, artificial illumination is normally required to carry on ordinary outdoor activities (http://aa.usno.navy.mil/faq/docs/RST_defs.php).

Radar

We monitored bird movements with a Furuno™ FCR 1411 X-band surveillance radar transmitting at 9.410 GHz with a peak power output of 10 kW (Furuno Electric Co., Nishinomiya, Japan; Cooper et al., 1991). The radar's range was set at 1.5 NM (~2.77 km) in a north–south direction, although the field of view was ~3.67 km to the east because the screen was not circular in shape (Fig. 2). We used the radar to determine movement rates (radar targets/h), ground speeds (velocities), general flight behaviors (three categories: straight-line, erratic, and circling; Fig. 2), and flight paths of birds (i.e., where they occurred in relation to the island). This paper focuses on movement rates and flight behavior. The sampling unit was a radar target (echo), which indicated a flock of birds (regardless of flock size) on the display screen. For each target, we recorded time, flight direction, velocity, and general flight behavior. We also traced target tracklines and digitized them later with GIS software.

Visual

We identified bird species and monitored their movements, flight behavior, and island-passing behavior (i.e., responses to the island) with 10× binoculars during periods of sufficient ambient light and with night-vision equipment after dark (5× Noctron-V night-vision scope; Aspect Technology & Equipment, Inc., Plano, Texas). We estimated flight altitudes and described detailed behavior of birds as they approached the island. The sampling unit was a flock (observation) of birds, regardless of its size.

We categorized general flight behavior into the three categories described above for the radar sampling and categorized island-passing behavior, which described specific behavioral responses as the birds passed the island. These five categories of island-passing behavior were 1) no change in either flight direction or flight altitude, 2) change in flight direction, but no change in flight altitude, 3) no change in flight direction, but change in flight altitude, 4) change in both flight direction and flight altitude, and 5) behavioral flaring (i.e., a last-second collision-avoidance behavior in which birds undergo extreme changes in both flight direction and altitude to avoid imminent collision with a structure).

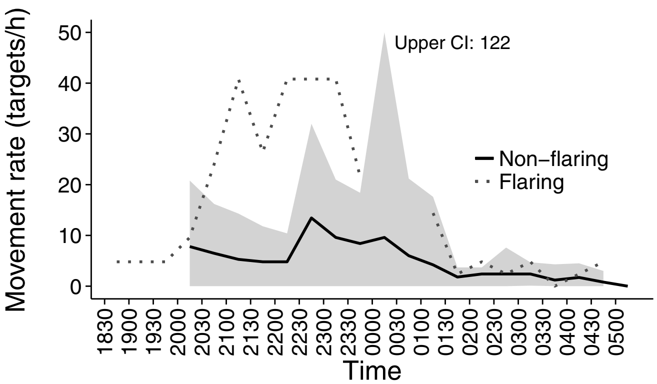

FIG. 3. Movement rates (targets/h) of bird targets seen on radar at Northstar Island, Alaska, during nights without gas flaring (13–19 and 21–27 September 2002, solid line) and a night with gas flaring (20 September 2002, dotted line), by 30 min period. The gap in the flaring line represents a 1 h break in the middle of the night. Shaded areas represent 95% confidence intervals.

Data Analysis

To examine responses of migrating birds to the island, we summarized data recorded during radar and visual sampling by period (non-flaring vs. flaring). We pooled data from 1 week before the night of the flaring event (13–19 September) with those from 1 week after the event (21–27 September) as the non-flaring period for comparisons with data from the night of flaring (20 September). Although most of the data presented here for both the radar and visual sampling are on movement rates and general flight behavior, we also discuss island-passing behavior for the visual data.

We summed the total number of radar targets (visually recorded flocks) during each sampling session, then divided by the number of minutes sampled during that session to calculate the movement rate (targets/h; flocks/h). We then calculated the mean ± 95% confidence interval (CI) movement rate (targets/h; flocks/h) across all sessions within each 30 min sampling period. We plotted mean ± 95% CI movement rates by 30 min sampling period for the non-flaring period and compared them with rates during the night of flaring. Non-overlap of the flaring period's value with the 95% CI for the non-flaring period's value indicated a significant difference in movement rates.

We compared proportions of radar targets (visually recorded flocks) that were seen exhibiting each general flight behavior during non-flaring and flaring periods. Because two of the three general flight behaviors (erratic and circling) were quite different from straight-line, directional flight behavior and because erratic behavior was not common, we pooled them as non-directional behavior (also see Day et al., 2005). We used a 2 × 3 chi-square test for row-by-column independence (Zar, 1984) between the three behavioral categories and two periods (flaring vs. non-flaring) to test whether we could pool data from the erratic and circling categories. For the radar data, the test was significant (χ^2 = 29.408; df = 2; $p < 0.001$), and erratic behavior contributed little to the overall significance (overall χ^2 contribution = 0.457), supporting our decision to pool the data. Similarly, for the visual data, the test was significant (χ^2 = 14.367; df = 2; $p < 0.001$), and erratic behavior contributed little to the overall significance (overall χ^2 contribution = 2.000), supporting our decision to pool the data. We then tested for differences between the two behavioral categories by period with a 2 × 2 chi-square test for row-by-column independence (Zar, 1984).

We also examined the general flight behavior of radar targets (visually recorded flocks) on the night of the gas-flaring event by tabulating by 30 min sampling period the numbers and percentages of targets (flocks) that were flying with non-directional flight behaviors. We then plotted the percentages of targets (flocks) exhibiting non-directional general flight behavior by sampling period. We also plotted digitized tracklines from the week before, the night of, and the week after the flaring event.

RESULTS

We recorded 176 radar targets during the non-flaring period and 123 radar targets on the night of the gas-flaring event. We recorded 86 bird flocks visually during the non-flaring period and 49 flocks on the night of the gas-flaring event.

Movement Rates

Movement rates of bird flocks on radar differed between flaring and non-flaring periods, but only in the first part of the evening. During non-flaring periods, mean movement rates earlier in the evening ranged from ~5 to ~13 targets/h and averaged 7.6 targets/h from sunset to ~0100 h; for the rest of the night, the average rate was much lower (1.9 targets/h) (Fig. 3). In contrast, movement rates during the night of flaring ranged from 5 to 41 targets/h. Average rate was 22.8 targets/h from sunset to ~0130, but much lower (3.1 targets/h) during the rest of the night. The lack of overlap between movement rates on the night of flaring and 95% CIs for the non-flaring period indicate that movement rates were significantly higher between 2030 h and 0000 h. After 0000 h, CIs overlapped the movement rates for flaring, so there was no difference between flaring and non-flaring periods.

Movement rates of bird flocks seen visually followed a pattern similar to that of flocks detected by radar: they differed between periods, but only in the first part of the evening. Mean movement rates during non-flaring periods were steadily low at three or fewer flocks/h during the entire night and averaged 1.1 flocks/h overall (Fig. 4). In contrast, movement rates during the night of flaring averaged five or more flocks/h for all sessions except two from sunset to ~0000 h, with a peak estimate of 60 flocks/h between ~1900 h and 2030 h; thereafter, rates dropped quickly to 0 flocks/h from 0100 h onward. The lack of overlap between movement rates on the night of flaring and 95% CIs for

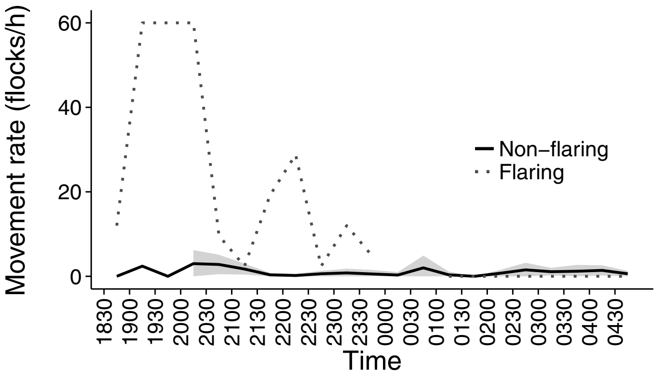

FIG. 4. Movement rates (flocks/h) of bird flocks seen visually at Northstar Island, Alaska, during nights without gas flaring (13–19 and 21–27 September 2002, solid line) and a night with gas flaring (20 September 2002, dotted line), by 30 min period. The gap in the flaring line represents a 1 h break in the middle of the night. Shaded areas represent 95% confidence intervals.

the non-flaring period indicate that movement rates were significantly higher between at least 2000 h (no CIs were calculated for earlier periods because only single samples were available) and 0100 h; after ~0100 h, CIs overlapped the movement rates for flaring, so there was no difference between flaring and non-flaring periods.

Behavior

The general flight behavior of radar targets differed between non-flaring and flaring periods. During the non-flaring period, 86% of the targets exhibited directional behavior and 14% exhibited non-directional behavior, whereas comparable figures for the flaring period were 67% directional and 32% non-directional (Fig. 5a). This difference was significant ($\chi^2 = 14.245$; df = 1; $p < 0.001$), indicating a significant increase in the frequency of non-directional behaviors during the flaring period.

Like the radar targets, the visually observed targets also exhibited non-directional behavior more frequently during the flaring period. During the non-flaring period, 65% of the targets exhibited directional behavior and 35% non-directional behavior, whereas comparable figures for the flaring period were 41% directional and 59% non-directional (Fig. 5b). This difference was significant ($\chi 2 = 6.536$; df = 1; $p = 0.011$), again indicating a significant increase in non-directional behaviors during flaring.

Night of the Gas-flaring Event

The gas-flaring event began at 1835 h, which was during daylight, and occurred continuously except for one 5 min break until 0300 h; hence, we considered flaring to have occurred continuously from 1835 h to 0300 h. Before the sun set, the flare was extremely bright, but the background light in the evening sky presumably overshadowed it. Sunset occurred at 2011 h, so we considered the crepuscular and nocturnal period to occur from the beginning of the 2005 h sampling session onward for the rest of the night. There was a full moon that night, and the moon was visible to an observer on the ground during the periods 2230–2330 h and 0100–0330 h; otherwise, the moon was below the horizon (it rose at 2043 h) or obscured by clouds (the rest of the night).

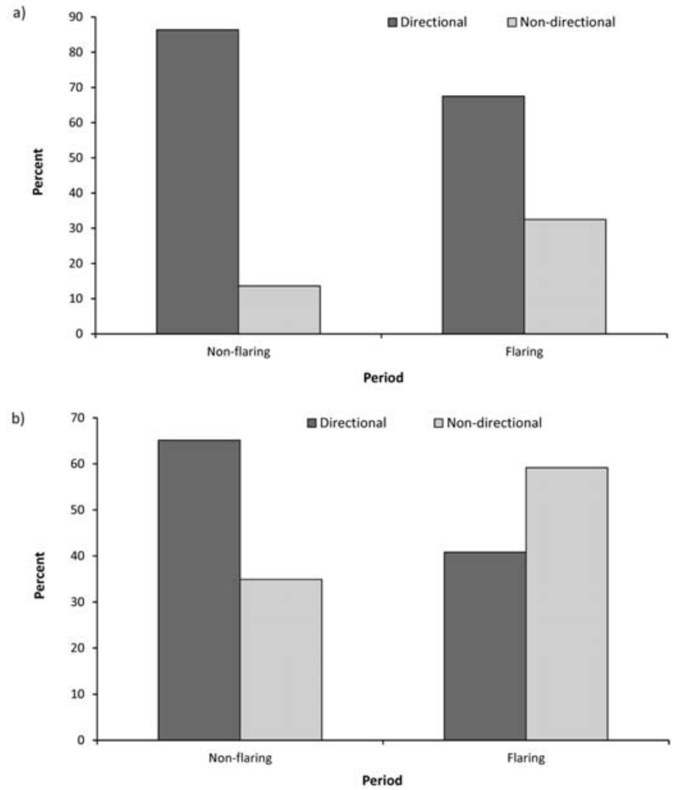

FIG. 5. Percentages of a) bird targets seen on radar, and b) bird flocks seen visually at Northstar Island, Alaska, that were exhibiting directional and non-directional flight behaviors during nights without gas flaring (13–19 and 21–27 September 2002) and a night with gas flaring (20 September 2002). For radar targets, sample sizes (*n*) were 176 during the non-flaring period and 123 during the flaring period. For bird flocks, sample sizes (*n*) were 86 during the non-flaring period and 49 during the flaring period.

The percentage of radar targets exhibiting non-directional general flight behavior varied dramatically during the night of flaring. No targets exhibited non-directional flight behavior before sunset, but the percentage rose to 100% immediately after sunset, declining within 30 min to 30%–50%, where it remained until 0000 h. By 0130 h, it had declined to ~20%, but none of the radar targets exhibited non-directional behavior after 0130 h (Figs. 6 and 7). The gas flaring was brought under control at 0300 h, with no apparent effect on the frequency of non-directional flight behavior, in that the birds had already stopped flying with non-directional behavior. We caution, however, that only 15 radar targets were recorded after 0100 h and only five radar targets were recorded after the flaring ended at 0300 h. Nevertheless, the general pattern appeared to be one of lower movements late at night (Fig. 3).

During the period of darkness, the moon was visible during two periods. During the first period (2230–2330 h), frequencies ranged from 29% to 41% (average 35%), compared

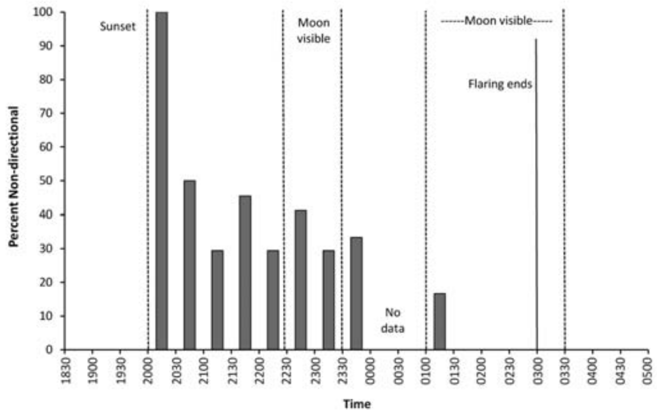

FIG. 6. Non-directional movement of radar targets on the night of gas flaring, showing percentage of targets exhibiting non-directional flight behaviors during each 30 min period. No sampling was conducted at 0000–0100 h. Times of sunset, when the moon was visible, and the end of flaring are marked.

with 29% to 50% (average 37%) in the dark periods before and after. Clearly, moon visibility had no effect on the frequency of non-directional behavior of radar targets during this period. During the second period (0100–0330 h), the frequency of non-directional behavior dropped from 17% on the first sampling session to 0% during the rest of the period. Again, however, few targets were seen late at night.

The percentage of visually observed bird flocks exhibiting non-directional behavior varied dramatically during the night of flaring, in that only 1 of 11 flocks exhibited non-directional flight behavior before sunset, whereas 58% to 100% did so after sunset; the percentage then declined to 30%–50% until 0000 h, after which no flocks exhibited non-directional flight behavior (Fig. 8). As with the radar targets, cessation of flaring at 0300 h had no apparent effect on the frequency of non-directional flight behavior of bird flocks. We caution, however, that only four bird flocks were recorded visually after the flaring ended.

Like the radar targets, bird flocks were not strongly influenced by visibility of the moon. During the first period when the moon was visible, the average frequency of non-directional behavior was 90% (range: 80%–100%), compared with an average of 80% (range: 58%–100%) in the preceding and following periods. During the second period when the moon was visible, no bird flocks were seen.

During the visual surveys, we recorded at least four taxa of birds: one flock of unidentified eiders, 31 flocks of Long-tailed Ducks, one flock of Pacific Loons (*Gavia pacifica*), two flocks of unidentified loons (*Gavia* sp.), and 19 flocks of Glaucous Gulls (*Larus hyperboreus*). The flocks of unidentified eiders, Pacific Loons, and unidentified loons all exhibited no response to the gas-flaring event, in that they continued flying directionally with no change in altitude. In contrast, changes in island-passing behavior occurred in Long-tailed Ducks (22 of 31 flocks seen that night) and Glaucous Gulls (7 of 14 flocks seen that night), both of which intensively circled the island or flew erratically. Although these birds were not individually identifiable, the night sky was so illuminated and the island was so small that one could see many of them circling the island. In addition, four flocks of Long-tailed Ducks (40, 20, 7, and 3 individuals) flying within 5–10 m of the island exhibited behavioral flaring—a behavior in which birds undergo extreme changes in both flight direction and altitude to avoid imminent collision with a structure.

Because the large gas-flaring boom was located on the opposite side of the island from where we were working, we were unable to determine with certainty whether any birds were burned by the gas flare. However, workers on the island whose job was to monitor the area did not report any downed birds. Hence, we suspect that no birds were injured or killed by the gas flare during this event.

DISCUSSION

Effects of Gas-flaring on Behavior

This gas-flaring event attracted birds that were migrating at night past Northstar Island, in spite of the repelling effect of the anti-collision lighting system designed to deter birds (Day et al., 2005). Movement rates of both radar targets and bird flocks recorded within the sampling zone during the gas-flaring event were significantly higher than rates recorded during the non-flaring period, suggesting that the bright light was a significant attractant for migrating birds and brought them closer to the island from far outside the range of the radar. In addition to movement rates, percentages of radar targets and bird flocks exhibiting non-directional general flight behaviors increased significantly during the gas-flaring event compared with the non-flaring period. This increase in non-directional behaviors was due primarily to increased circling behavior. In fact, percentages of radar targets and bird flocks exhibiting erratic flight behaviors (not presented) decreased during the gas-flaring period, suggesting that even some birds that would have exhibited erratic behavior in the absence of gas flaring changed behavior and circled the island when gas flaring occurred.

Although the increase in non-directional behavior during gas flaring was significant overall, not all bird taxa appeared to be attracted by the bright light. Unidentified eiders and Pacific and unidentified loons continued migrating to the northwest past the island, presumably because the weather conditions were not conducive to light attraction. Overcast skies with fog, snow, or fine drizzle can increase the areal extent of illumination and attract and entrap nocturnally migrating birds (Montevecchi, 2006). The main taxa that appeared to be attracted by the gas flaring were Long-tailed Ducks and, to a lesser extent, Glaucous Gulls. In fact, four of the 22 flocks of Long-tailed Ducks seen exhibiting non-directional flight behavior almost hit buildings on the island, which triggered extreme collision-avoidance behavior via behavioral flaring. The attraction of eiders and Long-tailed Ducks to bright lights has been recorded several times in the Gulf of Alaska, the Bering

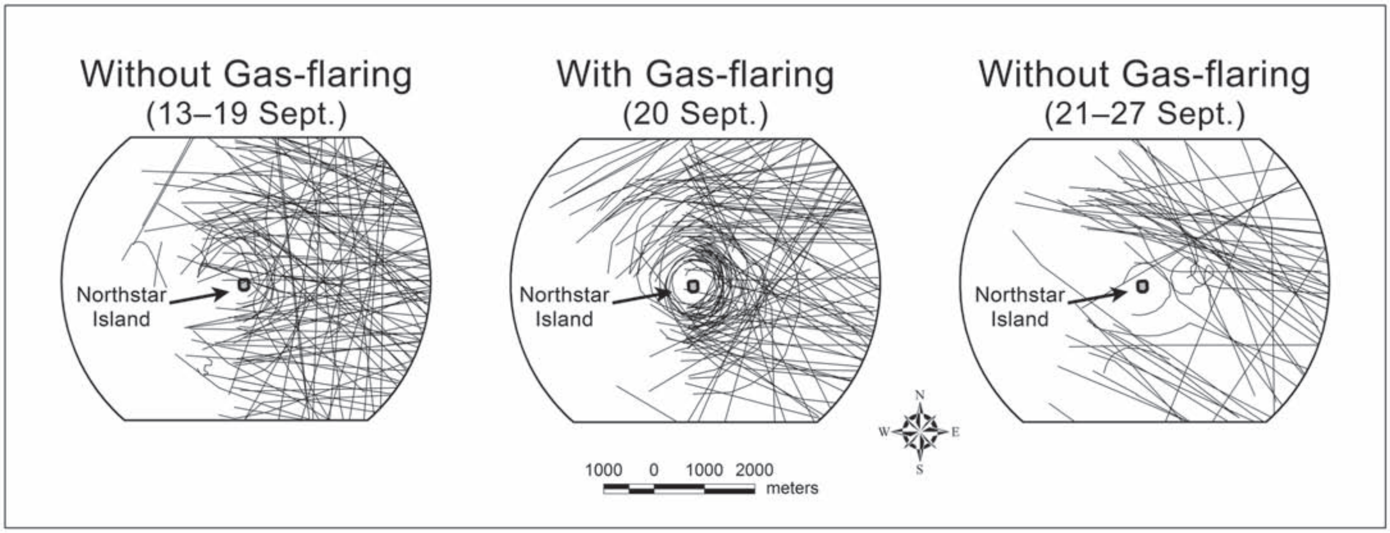

FIG. 7. Radar tracklines of targets of migrating birds at Northstar Island, Alaska, during the week before the gas-flaring event (left), the night of the gas-flaring event (center), and the week after the gas-flaring event (right).

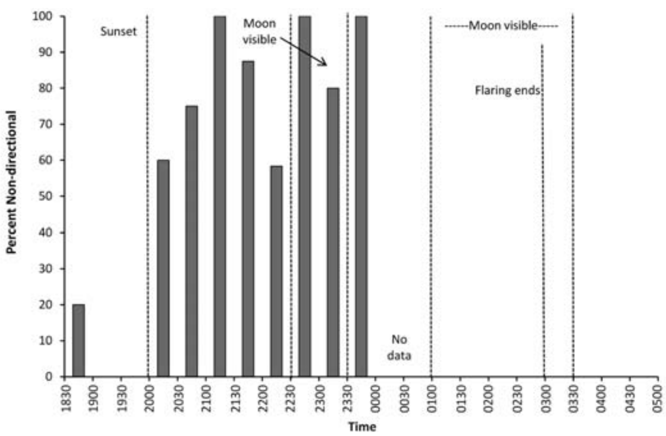

FIG. 8. Non-directional movement of bird flocks visually observed on the night of gas flaring, showing percentage of flocks exhibiting non-directional flight behaviors during each 30 min period. Details as in Figure 6.

Sea, and the Chukchi and Beaufort Seas (Dick and Donaldson, 1978; A.E. Gall and R.H. Day, unpubl. data); however, waterfowl in general are believed not to be strongly attracted to light (Hill, 1992).

It was surprising to us that, as strong as the gas-flare-caused attraction to the island was, its effects appeared to decrease over the course of the night. During both radar and visual sampling, the circling birds had decreased in number or stopped circling the island by ~0130 h, well before the gas flaring itself actually ended. This cessation of non-directional flight behavior occurred several hours before there began to be light in the morning sky, suggesting that the morning light was not what was causing the birds to reorient their flight directions. However, the data from the non-flaring period suggest that the substantial pulse of movement early in the evening, which then declines over time, is followed by a second pulse around 2200 h that then declines over time to low numbers in the latter ~40% of the night. These pulses point to an early-evening movement of birds that are from fairly close to the island, followed by a second movement of birds a few hours' flight away, but very low movement rates of birds from a great distance away. These patterns suggest that birds were attracted to the island from several kilometers away, but their numbers slowly declined throughout the night as the attraction to light declined and no new birds came late at night to replace them. Such a pattern matches the habituation of birds to strobe lights seen by Lustick (1973).

This circling behavior of birds around offshore oil and gas platforms has also been seen elsewhere. In the North Sea, attraction occurs primarily on overcast nights with misty or rainy weather; the average fatality rate may be a few hundred birds per oil platform each year (Bourne, 1979; Hope-Jones, 1980; Wallis, 1981), although it is possible that fatality rates are higher but most carcasses are lost at sea. Many birds are passerines that become disoriented on overcast and misty or rainy nights during fall migration between Scandinavia and Great Britain, although some are seabirds (e.g., Herring Gull *Larus argentatus*, Shag *Phalacrocorax aristotelis*) that become attracted to the illumination of the gas flares. Hope-Jones (1980) posited that the late timing of arrival of passerines at the oil platform suggested that these birds should have hit landfall in Great Britain hours earlier. He speculated that they had become disoriented and eventually were attracted to the light from the flare. Surprisingly, on one night, the passerines did not reorient around dawn (contra Alerstam, 1990) and continued circling the platform until noon, perhaps because the sky was heavily overcast. In the Bering Sea, Alaska, and the Grand Banks, Canada, higher densities of seabirds occur near drillships than away from them (Baird, 1990; Wiese et al., 2001). Densities are also higher near drillships during drilling, when the ship is stationary and presumably because bright deck-lights are on, than they are during non-drilling periods (Baird, 1990). The diverse suite of taxa attracted to drillships includes tubenoses, gulls, and alcids

(Baird, 1990; Wiese et al., 2001). In the Gulf of Mexico, the nearly 4000 oil-and-gas production platforms provide resting sites for exhausted migrating passerines and other bird taxa. Artificial lights and gas flares on these platforms induce circling behavior in birds, especially on overcast nights, resulting in some fatalities as a result of collision with structures (Russell, 2005).

Alerstam (1990:333) presented evidence from Hope-Jones (1980) that at least some bird species lose a significant amount of body mass as a result of extensive circling of gas platforms. This loss of body mass presumably decreases the chances that these birds will survive long-distance migration. Long-tailed Ducks traveled the equivalent of 155 – 280 mi (~250 – 450 km) during the night of flaring, given their flight velocity (mean = 39 mi/h [62 km/h]; range = 30 – 55 mi/h [48 – 88 km/h]; n = 36 flocks; Day et al., 2005) and the assumed 4 – 7 h in which they circled Northstar Island. This extended flight time may have resulted in a substantial loss of body mass. For comparison, King Eiders average only 50 km/day during fall migration across the Beaufort and Chukchi Seas (Oppel et al., 2008), a distance that can be achieved in less than 1 h of flight judging by mean flight speeds of King and Common Eiders at Barrow (Day et al., 2004). Hence, hours of continuous flying will expend much more energy than will short periods of migration in a species that appears to feed daily after short migratory hops.

Lights attract birds for various reasons. Explanations include the loss of visual clues to the horizon and visual disorientation (Herbert, 1970); the loss of night-vision, resulting in a reluctance to enter the zone of darkness (Avery et al., 1976); and the loss of visibility of the moon and stars for help with orientation (Gastman, 1886; Avery et al., 1976; Dick and Donaldson, 1978; Gauthreaux and Belser, 2006). Factors that can influence the degree of light attraction include color of the lights (Wiltschko et al., 1993; Gauthreaux and Belser, 2006; Evans et al., 2007; Poot et al., 2008; Kerlinger et al., 2010), the species or age-classes of birds that are attracted (Gauthreaux and Belser, 2006), the total brightness of the light or the amount of light escaping into the night sky (Verheijen, 1981a; Reed et al., 1985; Ogden, 2002; Jones and Francis, 2003; Gauthreaux and Belser, 2006; Hirata, 2007), and whether the light is flashing or stationary (Spofford, 1949; Howell et al., 1954; Ferren, 1959; Gauthreaux and Belser, 2006; Kerlinger et al., 2010).

Effects of the Moon on Behavior and Fatalities

Although the gas-flaring event caused great attraction to the island during much of the night when the full moon was not visible, the two periods that night when the moon became visible appeared to have little or no effect on the ability of the birds to reorient and continue migrating westward with directional flight behavior. In the first (1 h) period during which the moon was visible, percentages of radar targets and bird flocks exhibiting non-directional flight behavior were not noticeably different from percentages during the moonless periods before and after that hour. In the second (2.5 h) period during which the moon was visible, the percentage of radar targets exhibiting non-directional flight behavior was extremely low, and no bird flocks were recorded visually: all appeared to have reoriented by that time. Hence, the limited evidence from this gas-flaring event suggests that either the visibility of the full moon was not important in changing the birds' behavior as they reoriented their migratory movements, or the attractiveness of the gas flare overrode the effects of the moon.

This result contrasts somewhat with that of Day et al. (2005), who looked at the effects of moon phase and visibility to an observer on the ground on the flight behavior of "eiderlike" radar targets. They found that, if the moon phase was near full, the frequency of non-directional behavior was significantly higher when the moon was not visible than when it was visible, whereas moon visibility had no effect when the moon was not full. Moreover, the percentage of radar targets flying non-directionally was significantly higher when the full moon was not visible than when it was visible, suggesting that the migrating "eiders" were orienting to the full moon or stars and became confused by the lights of Northstar Island if the moon was not visible.

Numerous other studies have shown lunar effects on the fatality of night-flying birds (e.g., Telfer et al., 1987; Rodríguez et al., 2014), although the effects have been claimed to differ between lunar phases. For example, Verheijen (1981b) presented two sets of data that both indicated a strong periodicity, with large numbers of birds killed around a new moon and very few or no large kills around a full moon. In contrast, Crawford (1981b), using data from a long time-series study of bird mortality at a tall TV tower in Florida (Stoddard, 1962; Stoddard and Norris, 1967; Crawford, 1974, 1981a), found that bird fatalities showed a bimodal pattern, with higher fatalities around both the new moon and the full moon. The Crawford (1981b) study was much more powerful than the Verheijen (1981b) one because it consisted of daily checks of the tower area for dead birds over decades of time, whereas the Verheijen study simply relied on literature that cited large numbers of birds killed. In both cases, however, there is evidence of a lunar periodicity in bird fatalities.

Implications for Offshore Oil Development in the Arctic

Many instances of light attraction occur in the North Sea, where tens of millions of passerines migrate from Scandinavia to Great Britain in the fall (e.g., Sage, 1979; Alerstam, 1990). Large-scale passerine migration does not occur in the Beaufort Sea, so the risk to passerines in the Arctic is low; however, the Beaufort Sea is an important migration route for shorebirds (Alerstam et al., 2007, 2008), and some seabird species appeared to be attracted to the light from the flaring event. Therefore, these species are at risk of light attraction and potential fatality.

Although none of the early studies on gas-production platforms reported birds being killed in the flares and no incinerated birds were found (Bourne, 1979; Sage, 1979; Hope-Jones, 1980; Wallis, 1981), recent observations in Canada indicate that substantial numbers may be killed (Bjorge, 1987; CBC, 2013). We point out, however, that these examples of mass fatalities occurred in passerines, rather than seabirds. More important, gas-flaring events in the Arctic may indirectly have detrimental effects on fat stores needed for energy during migration because of extensive periods of circling the flares. Such an effect was shown for Redwings (*Turdus iliacus*) that died after repeatedly circling the oil platforms during gas-flaring events (Alerstam, 1990:333). These birds had lost ~40% of their body weight, suggesting a dramatic expenditure of energy during extended periods of flight.

Ships and platforms are important rest stops for disoriented terrestrial birds and some seabird species. Landings have been recorded in multiple locations, including the Arctic (e.g., Merkel, 2010). Recently, oceanographic research ships out in the Chukchi Sea have recorded at least 22 bird species landing on the ship, including one waterfowl, six seabirds, three shorebirds, two raptors, and 10 passerines (A.E. Gall and R.H. Day, unpubl. data). Some of those birds undoubtedly are attracted to the lights of the ship at night and land on the ship, with a small percentage striking some of the ship's structures, whereas other birds land during the daytime, seemingly for other reasons. The terrestrial birds, in particular, usually landed on the ship when they became exhausted after migrating in high winds; consequently, they boarded the ship any time of the day or night.

No matter how hard a drillship or oil-production island may try to avoid it, gas flaring will occur on occasion. Hence, to reduce the probability of attracting and incinerating birds, one should design flaring booms in coastal or offshore developments with potential impacts to birds in mind. At Northstar Island in 2001–04, we visually estimated the minimal flight altitude of bird flocks migrating past the island (Table 1). Although a few groups of gulls were estimated to be flying as high as 350 m asl, no other species-groups were recorded flying more than 100 m asl. In addition, mean flight altitudes for all groups, including gulls, were below 20 m asl, suggesting that most birds in this region migrate at fairly low flight altitudes—much lower than the 66 m (215 ft) height of the end of the flaring boom at Northstar Island. Consequently, the height of this flaring boom at Northstar Island seems to reduce the probability that birds will be incinerated during the occasional flaring events that do occur.

In addition, paying attention to external aspects of drilling ships and oil-production structures may help to reduce their attractiveness to birds. For example, other attributes that have helped to reduce the attractiveness of Northstar Island to migrating birds in general include painting the buildings light tan, rather than white or very dark colors; reducing the amount of external lighting, although it needs to be bright enough for safe operations in an area in which polar bears occur; shielding external lights; pointing lights inward, toward the building, to reduce the amount of light lost from the island; and using a strobe-based light-repellant system (Day et al., 2005; Greer et al., 2010).

TABLE 1. Flight altitudes (m above sea level) of bird flocks (n = number of flocks) migrating past Northstar Island, Alaska, in fall 2001–04 (from Day et al., 2005).

Species-group	Flight altitude		
	Mean ± SE	Range	n
Eiders	6.0 ± 8.9	1–50	109
Other ducks[1]	6.8 ± 0.8	1–55	184
Unidentified ducks	8.1 ± 0.8	1–60	187
Loons	8.8 ± 1.0	1–100	215
Shorebirds	12.6 ± 1.6	1–65	69
Gulls	19.2 ± 1.6	1–350	261
Alcids	3.1 ± 0.8	1–10	14

[1] American Wigeon (*Anas americana*), Northern Pintail (*Anas acuta*), and Long-tailed Duck.

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