Exposure of birds to assumed oil spills at the Liberty Project

Robert Stehn and Robert Platte
U.S. Fish & Wildlife Service, Migratory Bird Management, 1011 E. Tudor Rd, Anchorage, AK 99503

Unpublished report prepared for Minerals Management Service 19 September 2000

EXECUTIVE SUMMARY

Environmental impact statements require prediction of possible harm to wildlife populations that may result from a development project. Before this report, predicting the potential impact of an offshore oil spill to migratory birds in the Beaufort Sea was limited by insufficient information on the likely movement patterns of oil, and by the lack of data on the distribution of avian resources. For this report, the Minerals Management Service and the U.S. Fish and Wildlife Service Migratory Bird Management Division cooperated to develop quantitative methods to more accurately estimate potential effects of an assumed offshore oil spill from the proposed Liberty Project in the nearshore Beaufort Sea. The goals of this assessment were to estimate the number of sea ducks, loons, and gulls exposed to oil, the proportion of the total populations affected, the expected variability among spills, and the daily rate of bird exposure.

We determined bird distribution and abundance in a 15,174 km^2 study area based on observations during 6 systematic aerial surveys flown in late June, July, and August, 1999 and 2000. Simulated oil spill trajectories for July and August were obtained from Minerals Management Service. We used a geographic information system (GIS) to construct a spatial model to overlay the bird density estimates with the predicted trajectories for spill volumes of approximately 5,912 barrels (bbl) and 1,580 bbl. Numbers of birds exposed to oil each day of each spill were determined for long-tailed ducks (*Clangula hyemalis),* glaucous gulls (*Larus hyperboreus*), king eider (*Somateria spectabilis*), common eider (*Somateria mollisima nigra*), spectacled eider (*Somateria fischeri*), Pacific loons (*Gavia pacifica*), red-throated loons (*Gavia stellata*), yellow-billed loons (*Gavia adamsii*) and scoters (*Melanitta* spp.).

Long-tailed ducks (oldsquaw) were the most numerous species averaging 21,000 total birds in July and 37,800 birds in August. King eider averaged 4,600 and 6,700 birds during these months, while scoter species averaged 4,800 and 3,500 birds. Common eider and glaucous gulls were next most abundant. The spectacled eider population estimate averaged 540 birds in July and 30 birds in August.

The July spills differed from August spills in average duration and amount of new area oiled per day. The median July spill lasted 8 days compared to 4 days for the median August spill. August spills moved faster, covered more area, but did not last as long as July spills in part because some oil moved beyond the bird study area.

The average number of birds exposed to oil was greatest for long-tailed ducks with 1,443 and 2,062 birds affected by 5,912 bbl spills modeled for July and August conditions, respectively. Similarly, the average of all 1,580 bbl spills exposed 1,130 long-tailed ducks to oil in July and 1,710 in August. Bird numbers and oil spill trajectories were both highly variable and the combination caused extreme variability in avian exposure estimates. For example, between 4 and 7,744 long-tailed ducks were estimated to have been exposed to oil from a 5,912 bbl spill in July based on the lower and upper 90% confidence limits of bird numbers at the 10^{th} and 90^{th} quantiles among the 500 oil trajectories.

Based on the average of 500 spills of each size during July and August, the average proportions of the total populations exposed to oil were between 3% and 9% for long-tailed ducks, glaucous gulls, and common eider. The upper 10% of the 5,912 bbl spills caused greater than 17%, 18%, and 13% exposure to long-tailed ducks, glaucous gulls, and common eider populations respectively during July, and 19%, 13%, and 38% exposure to these species during August. King eider, spectacled eider, and scoters were least likely to have a high proportion of their populations exposed to oil because of their widespread distribution or tendency to occur farther from the spill source. Exposure to oil averaging the 5,912 bbl spill trajectories resulted in 2,234 individuals of nine species exposed to oil during July and 2,300 individuals in August. The average numbers exposed averaging all 1,580 bbl spills were 1,732 and 1,908 birds during July and August, respectively. Therefore, a 73% decrease in oil volume resulted in a decline of 23% or less in the number of birds exposed to oil.

INTRODUCTION

Birds that swim, roost, or feed in water contaminated by oil often die from hypothermia unable to maintain needed insulation and buoyancy normally provided by their water-repellent plumage. The toxicity of oil ingested with their food may kill other birds. Nevertheless, due to positive population growth rates and natural compensatory mechanisms, many populations can recover following a one-time mortality event (e.g., a localized oil spill) if the fraction of the total population killed remains small. As the fraction killed becomes higher, the severity of population impact can increase above that expected by a simple proportional change. Disruption of social behavior, loss of mates, competition with other species, or increased predation, may prevent or extend the time before population recovery. Declining populations or populations with a limited capacity for growth would be at greater risk. Many of the species that could be exposed to oil spilled in the Beaufort Sea are of this type. All loons, eiders, and other seaducks have a relatively low capacity for population growth. Long-tailed ducks, scoters, and all species of eider and loons are declining in at least some portions of their ranges in Alaska or Canada (USFWS 1999, Conant et al. 2000). Some species of birds from North Slope nesting populations and from populations nesting further east in Canada use the coastal waters of the central Beaufort Sea for feeding, resting, and molting.

Aerial surveys monitoring nesting populations on the North Slope of Alaska showed that most waterfowl populations have been relatively stable since 1986 or 1992 when these surveys began (Larned et al. 1999, Mallek and King 2000). However, red-throated loons have declined in the early June survey and long-tailed ducks have declined in the later June survey. The magnitude of these trends differ somewhat between the surveys apparently due to differences in timing, geographic extent, or sampling error. The U.S. Fish and Wildlife Service remains concerned and continues to carefully monitor these populations.

The U.S. Fish and Wildlife Service (FWS), Migratory Bird Management Division collaborated with the Minerals Management Service (MMS) to assess the impact on waterfowl and other birds of a assumed oil spill from the Liberty project in nearshore waters of the central Beaufort Sea. Using Geographic Information System (GIS) analysis programs, FWS integrated avian aerial survey data with oil spill trajectory data (MMS 2000) to estimate potential avian exposure to oil.

METHODS

Oil model

We received the oil spill trajectory data from MMS in Arcview shapefile format. We used simulated spills from July and August because we had sufficient bird data only for those months. Although many birds migrate through the central Beaufort Sea in June and September, no standardized survey data were available for these times. The model data included 500 trajectories for July and 500 for August. Each trajectory was composed of 500 spilletes. We converted the trajectories to ARC/INFO arc coverages with the SHAPEARC command. Because of the extreme degree of overlap of many of the arcs especially near the point of origin, some arcs were lost due to limits of “fuzzy” tolerance even with double precision options. For example, the July-2-ic shapefile of 100 oil spill trajectories had 8,279,463 arc shape records that converted to 8,229,464 arc segments with 49,999 missing, 0.6% of the arcs. These lost arcs had no effect on the outcome of the model as they only represented redundant exposure to oil. Nevertheless, had we selected a more complex quantitative or probability-based interpretation of the trajectory model in which multiple or continued exposures to oil at the same location could be assessed, the loss of some spillete arcs could be of significant concern. Each coverage was then projected from longitude and latitude decimal degrees to UTM Zone 6. All arcs from each trajectory were reselected to 1000 separate ARC coverages.

We chose to analyze the potential impacts of two different spill volumes. Each arc in a trajectory represented the simulated movement in a 1-hour period of one spillete of oil defined approximately as either a 12 bbl (1/500th x 5,912 bbl) or 3 bbl (1/500th x 1,580 bbl) spill. Each spillete arc was influenced by a wind force vector common to the entire spill for that day, by a location-specific current vector, and by a random dispersal force vector each hour to simulate turbulence and spreading of the oil. Seventeen years of daily wind speed and direction data were available. The sequence of wind conditions for each spill trajectory was selected to start on a different day from the 527 possible days (17 years x 31 days) for each month. The year and Julian day items in the INFO table indicated the conditions selected, however, we did not tabulate the frequency of these data. We interpreted the resulting set of 500 trajectories as a representative sample drawn systematically from all the equally possible sequences of wind that could occur for any given spill. We calculated the number of days since spill initiation based on the last four digits of the arc ID item, hours 1 through 721 (24 hours x 31 days) since the start of the spill. The combined network of all 500 spillete paths defined the spatial pattern of each modeled trajectory.

The total size and duration of trajectories differed greatly. For example, trajectory 3106 had 3,499 arcs with a maximum duration of 7 hours, while trajectory 3183 had 358,989 arcs lasting all 30 days. The theoretically largest possible spill contained 360,000 arcs from 500 spilletes x 24 hours x 30 days. Movement ended when a spillete ran into mainland shoreline, but the spillete path did not end upon encountering barrier islands. For our tabulation of number of birds and area exposed to oil, a trajectory was also considered to end when it moved entirely beyond the area for which we had bird density information. Many trajectories moved partially out of the bird survey area.

We chose to convert the oil trajectory data to a raster or grid cell format for more efficient analysis in the GIS spatial overlay model. Each spill trajectory ARC coverage was converted from vector to raster format using the GRID module LINEGRID command (Fig. 1). Thus, a spill previously represented by a set of 500 lines was now represented as a grid of square cells with a surface area that represented the geographic "footprint" of the spill. An alternative would have been to buffer the arcs by a distance equal to the radius of a spillete to produce an oiled polygon, however due to the large number and complexity of arcs, it was not possible. We used a grid cell size of 50x50 meters to represent the larger spill volume of 5,912 bbl and a grid cell size of a 25x25 meters to represent a 1,580-barrel spill. The grid cell size that would most closely match the actual estimated area of oil after conversion to a grid coverage would have been 42.2m (= $(2(2)^{0.5})/pi$ or 0.9003 times 46.85m) and 24.3m (0.9003 times 27.04m) using calculated radial spill diameters (Table 8, MMS 2000). The 50x50m and 25x25m cell sizes were considered reasonable approximations.

We assigned each grid cell a data value equal to the number of days (1 to 31) after initiation of the trajectory when a spillete first entered that cell. If a cell contained spilletes from more than one day, a weight table was used to give priority for the value of that cell to the earliest day. Trajectories (≈70 of 500) too complex to be converted by the LINEGRID command were converted to individual day coverages, then to grids for each day, and finally merged into a complete trajectory grid. The trajectories, originally modeled as a connected series of arcs representing movement during 720 hours, were now modeled as oiled grid cells each coded by day on which it was first oiled. All other cells were considered unoiled and coded as "No Data" to be excluded from the analysis. Several trajectories had one or more spilletes with data extending to day 31. The day 31 spilletes of these trajectories were not included in the analysis.

Aerial surveys for waterbirds

Several different aerial survey data sets have been collected in the central Alaskan Beaufort Sea, however, data were not equally useful for spatial overlay analysis. LGL Limited (Steve Johnson, Lynn Noel) provided avian data from repeated aerial survey transects for 2 areas (termed "industrial" and "control") located on either side of the Liberty project during 1977-1984, 1989-1991 (Johnson and Gazey 1992), and 1998-1999 (Noel 1999) (Fig. 2). The objective for the LGL survey was to detect change in bird numbers over time between the two areas. The data from these surveys were not readily useable in a GIS. Locational accuracy of observations was at best within 1,260 m because data were recorded by 30-second intervals (30 sec x 42 m/sec average flight speed). Transects were not placed randomly or systematically across gradients of bird density or habitat. Any interpretation of spatial pattern of bird density from these data was almost entirely dependent on assumptions concerning delineation of the area that each transect "sample" represented. This held whether the bird density was interpolated by any of several methods between the sampled transects, or whether the observed transects were taken as a representative sample of the density in some larger delineated area. The LGL survey was not intended as a valid sample of the entire area; it was an indexing procedure. Therefore, we did not use these data for this analysis.

FWS flew six nearshore surveys intended to replicate the LGL design in July and August of 1999 and 2000 (Fig. 3). In 1999, FWS also conducted 3 offshore surveys consisting of 36 north-south transects evenly spaced at 5.4 kilometers and extending from the Kogru River to Mikkelsen Bay (Fig. 4). The objective of these offshore surveys was to verify the presence of spectacled eider near locations received from satellite transmitters implanted in eiders. In 2000, the same 36 transects plus seven additional transects were flown extending coverage east to Brownlow Point. The systematic offshore transects started at the coast and extended north across nearshore, mid-lagoon, and barrier island habitats. Fog conditions determined the northern extent of some of the late June and July survey transects. June and July offshore transects averaged 56 km long (range 14 - 76 km). The August offshore survey transects were less affected by fog conditions and averaged 60 km in length (range 22 - 70 km).

The available aerial survey data included:

1. nearshore index transect data, LGL, 1977-1984, 1989-1991 (Johnson and Gazey 1992),
2. nearshore index transect data, LGL, 1998-1999 (Noel 1999),
3. nearshore index transect data, FWS, 1999-2000,
4. offshore systematic survey transect data, FWS, 1999-2000.

Because the data from systematic designs provided unbiased population estimates and useful bird distribution data for spatial analysis, we used only the data from the June, July, and August 1999 and the June, July, and August 2000 offshore surveys for our analyses. Surveys flown between 24 June and 31 July were assumed to represent average July bird density, and those flown 1 August to 6 September represented August bird density. We estimated variance among the surveys by jackknife or standard methods to provide an appropriate estimate of variation in average bird density.

Details of aerial survey procedures, navigation to transect waypoints, flight speed, altitude, and data recording methods have been reported elsewhere (Butler et al. 1995a, 1995b). Instead of using the method of continuous tape recording and interpolation of positions based on time, observers used custom data-recording and transcription programs (J.I. Hodges, FWS, Juneau) on laptop computers to record observations with locations downloaded directly from the aircraft GPS. Dates and observers for the 6 aerial surveys used in this analysis were: 1) 28, 29, 30 June 1999 by observers TT and DM; 2) 27, 28, 30, 31 July 1999 – TT and RP; 3) 31 August, 2, 3 September 1999 – WL and JS; 4) 24, 25, 26, 27 June 2000 – JF and AB; 5) 25, 26, 28 July 2000 – JF and DM; and 6) 25, 26, 27, 30 August 2000 – JF and DM.

Aerial survey data consisted of the location, avian species, and group size for each observation. The observed sample transect area was a 400 meter-wide strip centered along the aerial transect flight path flown and recorded by GPS coordinates which were downloaded every 5 seconds to a data file.

Stratification of the survey area

We expanded the bird densities observed along narrow strip transects to the area within each stratum. If no other information were available, or if both the habitat and bird density were relatively homogeneous, various mathematical methods could interpolate a smoothed density surface from a series of sample points. However, the bird densities determined along the curved nearshore survey transects were not random or systematic within the entire area. For example, descriptions and maps available from previous observers characterized high concentrations of molting long-tailed ducks in specific habitats (e.g., along the leeward side of barrier islands). We chose to divide the study area into strata based on a combination of habitat-based features following those defined by Johnson and Gazey (1992). Delineation of stratum boundaries was somewhat arbitrary and not without error; but it was more accurate than simple numerical smoothing methods that would ignore previous biological observations and descriptions. We then calculated bird density using standardized methods assuming that the flightlines were a representative sample within each stratum. Although bird population estimates could be derived from the offshore aerial surveys without stratification, or with fewer strata, a single stratified design was selected to allow comparisons among all surveys when additional data are incorporated into the analysis.

We divided the study area into strata based on the location of the aerial survey nearshore index transects and geographical features such as proximity to the coast, major river deltas, barrier islands, and water depth. The coastline was buffered to create a 400-meter-wide strip from Brownlow Point to the Kogru River. The width of this strip was then expanded where necessary to include the shoreline aerial survey transects which sometimes crossed bays at greater than 200 meters from the coast. The shoreline strip was subdivided into geographic sections from the Kogru River to the west side of the Colville Delta, around the Colville River Delta, from the Colville Delta to near Oliktok Point, from Oliktok Point to the east side of Prudhoe Bay (Sagavanirktok Delta), from Prudhoe Bay to east of Foggy Island Bay, the finally from there to Brownlow Point.

Barrier islands were also buffered to create a 400-meter-wide strip along their inshore (lagoon) sides. We then expanded this strip in some areas to include the locations of the nearshore aerial survey transects designed to sample this habitat. We used actual flight paths flown by FWS during 1999 nearshore surveys to help modify the strata boundaries. The open water gaps between barrier islands defined a "pass" habitat stratum of variable width, depending again on the aerial survey transects locations. We subdivided the barrier islands and the pass habitat into four similarly defined geographic regions: eastern, central, industrial, and western.

We defined the remaining water area between the shoreline strips and the barrier islands or pass habitat as a mid-lagoon stratum. It was subdivided into geographic regions as follows: Brownlow Pt. to Tigvariak Island, Tigvariak I. to the west side of Prudhoe Bay, west of Prudhoe Bay to Oliktok Point, and Oliktok Point to the western edge of the survey area. With only two small areas of barrier islands in the western area, the mid-lagoon, pass, and inshore marine strata were combined in this region and called the western shallow marine stratum.

North of the barrier islands, we used the 8-meter bathymetric contour line to roughly define inshore marine strata that were divided into 3 geographic areas matching the subdivisions for the mid-lagoon strata. The deeper water to the north of the 8-meter bathymetric line to the northern extent of the survey flightlines was partitioned into 3 offshore marine strata: east of the west side of Prudhoe Bay, central from west Prudhoe Bay to about mid-Colville River Delta, and west to the western boundary.

Delineations resulted in 50 polygons classified into 22 strata (Fig. 5) within the 15,174-km^2 study area. Barrier islands were included either within the 400-meter-wide buffer south of the barrier islands or within the nearshore marine water to the north. Some of the spill trajectories moved to the north or east beyond the stratification area for which we estimated bird density (Fig. 7). We estimated only the number of birds exposed to oil within the stratified bird density area. Consequently, the number of birds exposed to oil should be considered a minimum value as those spills leaving the surveyed area affect additional birds.

Bird density estimates

The intersection of the survey transects arc coverage with the stratification polygon coverage determined those sections of each transect within each stratum. The proportions of the total distance along each flight line (i.e., where the transect crossed in and out of a stratum polygon) were written to a stratification file. The bird observations and transect sections located between these two proportions of total distance were considered in that stratum. The number of birds of each species summed for all transects within a stratum, divided by the sum of observed area within that stratum, provided a ratio estimate for the mean bird density. For July, we combined four offshore surveys, flown beginning on 28 June 1999, 27 July 1999, 24 June 2000, and 25 July 2000, to estimate the mean bird density for each stratum. The length and number of transects differed among surveys due to fog conditions. The data were combined as weighted by the transect area observed. The variance of the mean was calculated with a jackknife estimate using the four survey means as weighted by area observed within each survey. However, with only two surveys flown in August, beginning 31 August 1999 and 25 August 2000, the variance was calculated simply from the difference between the two surveys. These variance estimates were compared to the ratio estimate variance formula using all the transect sections within each stratum. For each species and each stratum, we converted the estimated density of observed total birds per km^2 to number of birds in a 50x50 m grid cell by multiplying by 0.0025, and to birds in a 25x25m grid cell by multiplying by 0.000625. For example, spatial distribution of the average number of long-tailed ducks per 50-meter cell for 22 strata is depicted in Fig. 6.

Confidence intervals were derived using the between survey variance estimates rather than the ratio-estimate variance. We calculated the upper and lower 90% confidence interval values for the bird density as the mean plus or minus 1.6448 times the square root of the variance of mean density. If the lower 90% confidence interval was smaller than the actual number of birds seen, the actual number of birds observed on transects divided by the total stratum area was used as the lower 90% limit.

The nine species analyzed for this report were long-tailed duck (*Clangula hyemalis*), glaucous gull (*Larus hyperboreus*), king eider (*Somateria spectabilis*), common eider (*Somateria mollissima nigra*), spectacled eider (*Somateria fischeri*), Pacific loon (*Gavia pacifica*), red-throated loon (*Gavia stellata*), yellow-billed loon (*Gavia adamsii*), and combined scoter species (*Melanitta* spp.). Other species observed (Table 1) included shorebirds, northern pintail, white-fronted geese, scaup, black brant, jaegers, arctic tern, Canada geese, snow geese, and seals.

Identification of scoters and eiders can be difficult at the far edge of transects, under poor visibility conditions, or with large flocks of mixed species. Combining all surveys, we recorded 1032 surf scoters (80% of those identified), 204 (16%) white-winged scoters, 46 black scoters (4%), and 542 unidentified scoters (Table 1). The total number of scoters exposed to oil was estimated without regard to species, and the result could be split by species using these fractions. Similarly, we recorded 5493 king eider (84% of those identified), 935 common eider (14%), 148 spectacled eider (2%), and 333 unidentified eider. Because of the threatened status of spectacled eider, we analyzed the three eider species separately and any unidentified eiders were not included in the estimated numbers exposed to oil. Therefore, if the assumptions hold that unidentified eider occur in the same proportions and with the same spatial distribution as those identified, the unidentified birds represented 279 king, 47 common, and 7 spectacled eider. The total number exposed to oil should therefore be adjusted up by a factor of 1.051 for each species, e.g. 1.051= (5493+279) / 5493 for king eider.

GIS overlay of oil spill trajectories with bird density

We converted the average bird densities from the July and August surveys to average bird numbers per grid cell in each of the 22 strata. We joined the mean, lower 90%, and upper 90% confidence interval of number per cell for nine species into an INFO file template. These INFO files were joined by the common item STRATA to the stratification grid attribute table using the ARC relate command. We used this one grid coverage to model the numbers for each bird species for spatial analysis rather than creating individual grids for each species.

To calculate the potential number of birds exposed to oil, we overlaid the bird density grid with each trajectory grid. For each of the 500 spill grids each month, the number of birds per oiled cell for all cells on each day of the spill was summed using the ZONALSUM grid function and rounded to the nearest integer after adding 0.5. This sum represented the number of birds exposed to oil for each day of each trajectory. We then used the COMBINE grid function to tally the frequency of cells with unique occurrences of day number and bird zonalsum number for each trajectory. For each trajectory, the process output an ASCII file with day, number of cells oiled, and sum of birds exposed to oil each day.

We repeated the overlay process for each of the 27 bird numbers per cell (9 species x 3 density levels representing the mean, lower 90% confidence interval and upper 90% confidence interval) for each of 500 oil spill trajectories in July and in August for both the 50 m and 25 m grid cell sizes. We performed 54,000 grid overlays (27 species measures x 500 trajectories x 2 months x 2 spill volumes) with each result written to a separate output file. From these files, the number of cells with oil and the number of birds exposed to oil each day were assembled into 500 trajectory x 31 day arrays for each species, month, and grid size. We copied these arrays into Excel spreadsheets for descriptive and graphical summarization. Output files from the overlays were used to summarize both the surface area extent and duration of the July and August spills within the 15,174 km^2 of the bird survey area (Figs. 8a-8d).

RESULTS

Oil spills

Many July spills (n = 213, 43% of the total) lasted $\leq$ 3 days, but another 43% (n = 216) remained at least partially within the bird grid for $\geq$ 26 days (Fig. 8). The average extent of all 5,912 bbl spill trajectories during July equaled 376.7 km^2. Most July trajectories remained within the bird grid with only 9% (n = 43) having $\geq$ 10% of their oiled area outside of the bird survey area. In July 370.4 km^2 (98%) of the oiled area remained within the bird density grid. A slightly greater number of August trajectories (n = 250, 50%) lasted $\leq$ 3 days, although only 18 trajectories (4%) remained within the bird grid for 26 or more days. Approximately 25% of the trajectories ended because they moved out beyond the extent of the bird grid. The average extent of all 5,912 bbl spills during August was 558.7 km^2 with only 265.3 km^2 (48%) of the total oiled area remaining in the bird grid. In August, 136 (27%) trajectories had $\geq$ 10% of their oiled area outside of the bird survey area. Consequently, we underestimated the number of birds exposed to oil particularly during August. The degree of bias is not likely proportional to the oiled area beyond the bird-surveyed area because bird density probably differs and the distribution of oil movement north and east of the survey area is unknown.

Bird density

The most abundant species observed during July was long-tailed ducks with a total estimated population of 21,000 birds (Table 2). Highest densities of long-tailed ducks occurred in the shoreline-east, barrier-island-east, and nearshore-marine-east strata that indicated 39% of the average July population in < 2% of the total area. An additional 44% of the July long-tailed duck population occurred in other barrier-island, mid-lagoon, and shoreline strata. Coefficients of variation (CV) ranged from 0.55 to 1.05 indicating that population estimates for individual strata were imprecise. The CV for the total population estimate equaled 0.283. The coefficient of variation is a relative measure of the variability of the mean density estimates for individual strata for comparison purposes. It can also be used for comparing densities between different times. During August, the estimated average long-tailed duck population equaled 37,800 with a CV of 0.344 (Table 3). Similar to July, a high proportion (52%) of the population occurred in the shoreline, barrier island and mid-lagoon strata at the east end of the area.

King eider was the second most abundant species (Table 2) averaging 19,800 birds. Most (91%) were seen in the three offshore strata in water >8m deep north of the barrier islands, with the highest average density of 3.6 birds per km^2 in western offshore-marine strata. By the end of August, king eider had declined to an average of 6,700 birds.

Scoters (species combined) were the third most abundant species with estimated July and August populations of 4,800 and 3,500 individuals, respectively (Tables 2, 3). The shallow-marine-west stratum north of the Colville River Delta and the three similar mid-lagoon strata contained 80% of the scoters in July and 92% in August. Common eider averaged 3,300 and 1,500 total birds, and glaucous gulls averaged 2,700 and 1,700 birds for July and August, respectively (Tables 2, 3). Common eider and glaucous gulls were observed in all habitats and geographic areas. In contrast, spectacled eider were seen only in the western or central offshore marine stratum, the same areas where king eider were abundant. The estimated population size for spectacled eider in the study area was 540 in July and 30 in August (Tables 2, 3).

Pacific loons were the most abundant of the three loon species totaling 764 birds in July. The red-throated loon population was estimated at 164 birds and yellow-billed loons at only 95 birds (Table 2). The three loon species were observed predominantly in mid-lagoon, shallow marine west, and nearshore marine habitats. We obtained very similar results in August with 666, 169, and 17 loons of these species (Table 3).

Variance in bird population numbers based on between survey differences was somewhat higher than variance calculated as a ratio estimate among all transects flown within each stratum. The ratio estimate measured the geographic variability within each stratum assuming all survey transects were independent random samples. The average CV across all nine species for July was 0.346 among surveys (Table 3) compared to 0.285 from ratio estimates among transects. For August, the average CV across all nine species was 0.533 among surveys (Table 3) compared to 0.488 from ratio estimates among transects. The approximate agreement of the two variance estimates adds some degree of reliability to the among survey variance estimates that were based on only 2 - 4 replicates. We used the larger among survey variance to calculate confidence intervals of bird density.

Birds Exposed to Oil

The estimated numbers of birds for each of nine species exposed to oil in July are presented in Figs. 9 - 17 based on an assumed 5,912 bbl spills and in Figs. 18 – 26 for 1,580 bbl spills. Avian exposure estimates during August are presented for 5,912 bbl spills in Figs. 27 - 35 and for a 1,580 bbl spills in Figs. 36 - 44. The top graph on each page indicates the number (frequency) of trajectories relative to the total number of birds exposed to oil summed for the entire 30-day period. All distributions were skewed to the left indicating many spills exposed relatively few birds while a few spills exposed many birds to oil. The center graph shows the mean number of birds exposed to oil each day averaged over all 500 spills. The bottom graph depicts the daily mean number of birds exposed to oil with the average calculated only for the subset of spills that remained active each day. We considered oil spilletes moving southward onto the mainland coast, or trajectories moving north or east beyond the bird survey area, no longer active because they did not continue to expose more birds (in the area with density data) to oil. For example, 250 of the 500 July spills remained active on day 8, therefore we summed all birds exposed to oil on day 8 and divided by 250, rather than 500, to calculate the average. The bottom graphs also showed the mean number of birds exposed to oil per day calculated for the lower and upper 90% confidence intervals of bird density.

Birds were exposed to oil relatively early within the 30-day spill due to generally higher densities of birds closer to the spill origin at the Liberty project. The average exposure rate of birds per day declined from day 2 to day 10 or 11 for all species except king and spectacled eider. There was a slight increase in exposure per day from days 12 to 19 and a small tertiary peak from days 22 to 25. The reasons for the secondary peaks in number of birds exposed per day are unknown. King eider and spectacled eider, occurring at greatest density in the northwestern part of the surveyed area farthest from the Liberty site, showed a different pattern in July. Increasing numbers of birds were exposed to oil up to day 14 for king eider (Figs. 11, 20) and to day 21 for spectacled eider (Figs. 13, 22).

For each species, month, and spill size, the number of birds exposed to oil was estimated at the upper 90% confidence limit, mean, and lower 90% confidence limit of bird density (Table 4). We also tabulated the results by five levels of bird-exposure severity across trajectories; the highest (maximum exposure) trajectory, the 90th percentile, the average across all trajectories, the 10th percentile, and the lowest trajectory (Table 4). Variation was due to differences among the oil trajectories and imprecision in avian population estimates. For example, the average trajectory for a 5,912 bbl oil spill during July resulted in 2,968, 1,443, and 86 long-tailed ducks being oiled based on the upper 90%, mean, and lower 90% estimates of bird density. Similarly, the average long tailed duck density showed 3,667, 1,443, and 84 birds being exposed to oil at the 90th percentile, average, and 10th percentile among oil trajectories (Table 4). For nearly all species, months, and spill sizes, the range of variation at 90th and 10th percentile levels among spill trajectories exceeded the magnitude of variation at 90% and 10% confidence limits due to imprecision in estimated bird density (Table 4).

In July, when the amount of oil spilled per trajectory was reduced by 73% from 5,912 bbl down to 1,580 bbl, the number of long-tailed ducks exposed to oil was reduced only by 22% to an average of 1,130 birds down from 1,443 (Table 4). Similarly, with a 73% reduction in oil spilled, the number of birds exposed to oil in the other species declined only by 22-26%. In August, with 73% reduction in volume of oil spilled, the number of long-tailed ducks exposed to oil declined by 17%. Similarly, for other species in August, the number exposed to oil declined between 26% and 15%. The smaller amount of oil per spillete did not result in a proportional decrease in the number of birds exposed to oil. This non-linear response was likely due to high degree of spatial overlap among spilletes for both spill sizes and because redundant exposure of grid cells to oil did not increase the number of birds exposed to oil.

To assess potential impacts to local populations of each species, we tabulated the mean number of birds exposed to oil as a fraction of the estimated total population size in the entire surveyed area. Based on the average of all 5,912 bbl spills during July, the proportion of the total population exposed to oil was highest for glaucous gulls (7.9%) followed by long-tailed ducks (6.9%), red-throated loons (5.0%), and common eider (4.8%) (Table 5). For each of these species, the most severe trajectory, measured by oil exposure to the greatest number of birds, affected 34%, 31%, 20%, and 19% of these populations, respectively (Table 5). Spectacled eider and king eider populations were least impacted (Table 5) because of their widespread or further offshore distributions. For the other 7 species, at least 10% of the modeled trajectories (90th percentile) caused between 7% and 18% of the estimated total population of the following species to be oiled: glaucous gulls (18%), long-tailed ducks (18%), red-throated loons (13%), common eider (13%), yellow-billed loons (9%), Pacific loons (8%), and scoter species (7%) (Table 5). At the 90th percentile, a 1,580-bbl spill exposed between 6% and 13% of these species to oil.

DISCUSSION

Assessment of oil spill impacts to migratory birds is based on a combination of risk factors such as probability of a spill, spill size, spill duration, weather conditions, and effectiveness of oil spill response. While this analysis assumed that a spill of a specific size had occurred, spatial variation in spill trajectories, combined with spatial and temporal variability in bird numbers, still resulted in a wide range of possible numbers of birds exposed to oil. A single average or median estimate of the number of birds oiled does not indicate this range, nor does it facilitate assessment of risk. We tabulated the number of birds exposed to oil for each species based on time and size of spill across 11 levels of trajectory severity (0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.80, 0.9, 0.99 quantiles) for the lower 90%, mean, and upper 90% confidence levels of avian population sizes within the study area (Tables 6 - 9). This should help convey the chance that a certain number of birds might be exposed to oil. Given oil exposure, then yet another assessment would be needed to determine what number of birds would actually be killed from the exposure, and whether that number would cause a serious reduction in the population for a period of years.

The estimated numbers of birds exposed to oil by simulated oil spill trajectories, apply to a framework defined and constrained by the simulation model. Numerous assumptions and simplifications separate the model from the real world. Nevertheless, even with possible inaccuracy in the predicted numbers of birds exposed to oil, the relative magnitudes and patterns of exposure of birds to oil may have some application for management and protection of migratory bird resources. One general pattern indicated by the model results was that, on average, most spills exposed relatively few birds to oil, and relatively few spills exposed a large number of birds. Because of prevailing wind direction, many spills moved towards and stopped at the mainland coast within a short time. Half the spills in both July and August covered less than 150 km^2. Most exposure occurred soon after a spill due in part to the location of the Liberty project in a lagoon-nearshore-barrier island system where most migratory birds occurred in higher densities. Longer duration spills spread oil farther offshore, an area of relatively lower bird densities for all species except for king and spectacled eiders.

Less variable estimates of average density may be obtained with more replicates of aerial surveys, more rigorous delineation of stratum boundaries, or improved methods to summarize spatial pattern. The variation we observed in six offshore aerial surveys was due to the combination of differences in bird numbers among months, years, habitats, observers, survey conditions, weather conditions, and sampling error. However, even without more accurate aerial survey data, differences among spill trajectories will continue to dominate the variability in number of birds exposed to oil. Management and regulatory agencies must refine the impact assessment questions to be answered before extensive developments or modifications of aerial survey methods or analyses are worthwhile. For example, dividing the various wind direction conditions associated with spill trajectories would allow greater precision in estimating average number of birds exposed to oil.

Factors affecting numbers of birds

Definition of stratum boundaries was somewhat subjective. We tried to be conservative by tightly delineating stratum boundaries around where the nearshore and barrier island flightlines were flown and where the suspected concentrations of long-tailed ducks occurred. This likely prevented overestimation of population size caused by inadvertent expansion of a local concentration of birds into a larger area than would be appropriate. Because we only used the systematic offshore survey data, the magnitude of this potential source of bias was not a problem, although we probably increased sampling error due to the short distance of transects sections that crossed these small strata. Changing the number, size, and location of the strata would result in different estimates of bird density that would in turn affect the number of birds exposed to oil. We did not test the relative sensitivity of model output to different stratifications.

The use of the aircraft Global Positioning System connected to a laptop computer allowed relatively accurate locations ($\pm$ 200 m) for all observations. However, because some of the strata are small (lagoon-side of the barrier islands), any error in locations may cause observations to fall into an adjacent stratum during the overlay process. This would result in some error in estimating the bird density for a particular stratum but, with a counteracting error in the adjacent stratum, it would cause only a small change in the overall population estimate. Bird density estimates in some strata are based on only a small number of transects crossing the stratum, making estimates of the mean and variance imprecise.

The Beaufort Sea coastline boundary used by MMS to define the southern extent of spillete movements was different from the coastline boundary that we used to fly the surveys and analyze the data. In some sections along the coast, the oil spillete paths incorrectly stopped prior to reaching or crossing the nearshore stratum. Consequently, birds in these locations were unable to be exposed to oil likely underestimating avian exposure in this stratum. The potential magnitude of this effect was not determined

Some oil spill trajectories moved beyond the area surveyed for birds. Trajectories extending north beyond the bird survey area would likely impact king eider however, because this species occurred in relatively low densities, any added exposure would expectedly be small. In contrast, historic bird surveys of nearshore and lagoon habitats east of Brownlow Point and into Arctic National Wildlife Refuge found significant numbers of long-tailed ducks, glaucous gulls, and common eider (Garner and Reynolds 1986). Because this area was not assessed by the 1999 and 2000 offshore waterbird surveys, impacts of oil were not determined. Thus, this report underestimated the potential impact to migratory birds. This coastal area further east should be included in future aerial surveys and analyses.

Detection rate of birds on water, especially where they occur in large flocks, is usually high. However, poor visibility due to fog, glare, or rough water can lower the detection rate, therefore surveys were not flown under very poor conditions. Certainly, birds were present but not observed, some moved beyond the strip width before they were noticed, and some birds were missed if they dove underwater before identification. Consistently overestimating the size of large flocks, double counting the same birds by both observers, or including birds observed beyond the 400-meter-wide strip width, were possible errors that could have overestimated bird numbers, but these problems were probably infrequent in comparison to underestimation errors. We did not include any adjustment for visibility bias because none has been determined. Therefore, the bird numbers reported likely represent minimum estimates of the true population sizes.

We estimated bird density averaging only 2 - 4 aerial surveys. The number of birds observed on any one aerial survey was variable due to many factors that affected visibility of birds as well as the response of birds to the survey aircraft. The actual number of birds exposed to oil would be highly variable as well. The variance among surveys was calculated for July and for August but this was based on only four or two replicates. Consistent, unbiased, systematic surveys flown for several more years to document bird distribution and abundance for the entire area potentially exposed to oil would increase our confidence in the reported range and average numbers of birds exposed to oil from analysis of the trajectory models.

Limitations of the bird - oil trajectory overlay analysis

1) We did not include any effects of onshore oil. Oil reaching the mainland shore stopped moving and therefore was no longer a threat to offshore birds. Once reaching the shoreline, the trajectory model did not allow oil to re-enter the water.
2) Barrier island shoreline-specific effects were not estimated. Oil spill paths were apparently modeled without a complete physical boundary imposed by barrier islands, although the water current force vectors did change around the barrier islands. Direct interception, accumulation, or deflection of oil by islands did not appear to occur. Particularly for molting long-tailed ducks that repeatedly used these barrier islands for roosting and protection from wind, any concentration or pooling of oil on the lee side of the barrier islands could greatly increase the number of long-tailed ducks exposed to oil.
3) The influence of ice on the oil trajectories was not included in the model for July and August. Particularly early in July, ice may still concentrate both the birds and oil.
4) Long-term, secondary, or indirect effects were not estimated. For example, changes in food distribution or availability, disturbance associated with oil spill response, or sub-lethal effects on survival and productivity were not included. We measured exposure to oil as an all-or-none response. Oil exposure was considered equivalent to an immediate lethal effect.
5) We estimated and expressed the number of birds exposed to oil considering the spatial and temporal pattern imposed by the spill simulation model, however we considered that the effect of oil exposure on birds was constant. The model did not include any quantitative change due to declining toxicity over time or changing properties of the oil under different time, temperature, or wind conditions.
6) We assumed no residual effect of oil once it passed a location. The path the oil followed did not remain harmful to birds for any period longer than when the first spillete of oil was present at that location.
7) The model did not account for any movement by birds. Because long-tailed ducks are molting and flightless from early-July to mid-September, there probably was little long-range movement by these birds. However, molting birds disperse to feeding locations away from the barrier islands during the morning and return to roosting/preening locations near the barrier islands in the evening. Other species may actively fly and swim considerable distances during a day. Molt

migrating, failed-nesting, or post-breeding birds may pass through or stage for brief periods within the study area. However, the effects of immigration and emigration relative to potential avian injury and exposure from an oil spill were not assessed. The population was interpreted as a uniform series of stationary points at 50m or 25m spacing with a numeric value equivalent to the average fractional density indicated by the aerial survey data within each stratum. As oil spilletes moved along their stair-stepped grid cell routes, they accumulated all fractional birds from each oiled cell. We did not account for any bird movement, either within the hour time step of the oil model or during the time it takes oil to move between grid cells.

8) Birds are in reality integer-sized units, and for many species, occur in larger flocks or in spatially correlated clumps. The conversion of whole birds into fractional birds per grid cell assumed a uniformly distributed population across all grid cells in each stratum. The clumped pattern of birds and flocks was ignored. The mean number of birds exposed to oil after accumulation by a large number of spillete paths probably was not biased because of fractional bird densities, although the variance of the number of birds exposed was likely underestimated.
9) The model did not include any interaction component between birds and oil, i.e., the bird and oil distributions were assumed completely independent. Certain climatic conditions could cause similar (or opposite) patterns in the distribution or movements of both birds and oil. Similarly, the model did not include potential detection and avoidance of oil by birds.

Recommendations for further work

1) Incorporate additional aerial survey data sets into the estimates of bird density and compare results between survey types/years.
2) Modify the existing aerial survey design to ensure systematic and unbiased estimates for both bird distribution and abundance. Improve sampling intensity by flying systematic lines at closer spacing in specific strata (e.g., within 10 km of the coast) as opposed to sampling further offshore where bird density is lower and contributes less variance.
3) Examine alternative stratifications or smoothing techniques for bird density and compare any effects on model output.
4) Explore other overlay model structures with additional variables, interaction terms, or refinements. A stochastic model could be constructed to include distribution, abundance, flock size, and movement patterns of birds as well as oil spill locations.
5) Examine other ways of expressing the large variation among trajectories in the number of birds exposed to oil.
6) Define the actual management uses for models to better construct a model to answer specific management questions. For example, a model that predicted the number of birds exposed to oil given the direction and speed of the wind on the day the spill occurred might be useful for management decisions regarding the allocation of resources or the timing of clean-up efforts.
7) Design or improve data collection methods to document indirect and long-term effects of oil spills and associated disturbance on waterfowl and their habitats in the Beaufort Sea.
8) Conduct aerial surveys or devise alternate methods for data collection that would document the spatial and temporal use of Beaufort Sea nearshore and offshore habitats by eider, long-tailed ducks, and gulls during migration in June and September as well as July and August.
9) Conduct aerial surveys or devise alternate methods for data collection that would document the spatial and temporal use of Beaufort Sea nearshore and shoreline habitats by shorebirds and phalaropes.

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