

Preassessment Data Report #8:

Aerial surveys of birds near the grounded M/V *Selendang Ayu* on the northwest coast of Unalaska Island, Alaska, January 2005



Aerial photo of wreck, December 13, 2004. USFWS.

Robert A. Stehn, Robert M. Platte, Dennis K. Marks, Jim G. King, and Debbie J. Groves

U.S. Fish and Wildlife Service, Region 7, Migratory Bird Management, Waterfowl Branch,
1011 E. Tudor Rd., Anchorage, AK 99503

INTRODUCTION

On 8 December 2004, the M/V *Selendang Ayu* ran aground and broke in half in rough seas off Unalaska Island, Alaska (53°38'N, 167° 07'W). An estimated 354,218 gallons of oil (339,538 gallons of bunker oil [IFO 380] and 14,680 gallons of marine diesel and miscellaneous oils) were discharged. As part of the “pre-assessment” phase of natural resource damage assessment, an aerial survey was conducted to estimate the population sizes of birds in marine habitat near the grounded freighter on the northwest coast of Unalaska Island. Initial assessment of the wreck suggested substantial oil remained in the two halves of the ship and the likelihood that it would eventually spill was high. Therefore, even though the aerial survey was not initiated until 28 days after the initial wreck, it was designed both to provide data on the number, distribution, and species of marine birds and mammals wintering in the area, and to provide fine scale data on species near the wreck in case of additional spills. Eventually it was estimated that most of the oil spilled from the vessel during or shortly after the grounding, so the aerial survey data provide documentation of species wintering in the area that likely were at risk of contact with the spilled fuel oil, but this data does not precisely estimate the relative abundance of various species near the wreck at the time of the spill. Nevertheless the findings provide a framework for assessment of potential impacts on wildlife.

We report on aerial observations made from 5 January to 2 February, a period during which the distribution of migratory birds wintering in the Aleutians Islands is relatively stable (Gibson and Byrd in press). For example, Emperor Geese (*Chen canagica*) wintering in the Aleutians migrate to the Aleutians from August to November and return from mid-March to May (Petersen et al. 1994). Nevertheless, many species show local shifts in distribution in response to changing tide, wind, and weather. The range of movement is highly variable among species. For example, plankton-feeding auklets may forage over fairly broad regions based on shift in prey and opportunistic foraging. Glaucous-winged Gulls (*Larus glaucescens*) can easily move large distances searching for food resources exposed by certain tide or weather conditions. In contrast, Harlequin Ducks (*Histrionicus histrionicus*) show limited movement both within and between years in winter shoreline habitat (Robertson et al. 2000, Iverson and Esler, unpubl. ms.). Individuals of most species were undoubtedly shifting in and out of our sampled study area, although the distances of such movements and rates of turnover are unknown. Clearly, more pelagic species such as Northern Fulmar (*Fulmarus glacialis*) and Crested Auklet (*Aethia cristatella*) likely are highly variable in the survey area.

Our survey observations and data analyses provide a minimum estimate of the average number of birds and marine mammals present in the study area during the period of observations. It is an underestimate of the actual number. Aerial survey detection rates of birds and marine mammals are never 100% even with optimal conditions. Animals present but not detected, and turnover of individuals as they move through the area, will both contribute negative bias to (underestimate) the number of birds and marine mammals that could have been exposed to oil. In addition, considerable mortality, of at least birds, had occurred due to the oil spill prior to the start of our surveys potentially resulting in reduced populations from pre-spill numbers. We did not use correction factors for turnover or

visibility rates because their magnitudes are unknown. There are no opposing major factors in our survey methods that can cause any overestimate in the number of birds or marine mammals. That is, for example observers do not mistake other objects for birds, and the survey aircraft does not attract animals. Our replicated extensive survey coverage over a large area provided a useful estimate of the average number, species composition, and relative distributions of birds. Data from these aerial survey sampling methods are not intended to provide precise numbers at a local scale and specific time. This report provides a minimum estimate (and likely a substantial underestimate) of birds in the vicinity of the spill area during the observation period.

STUDY AREA

We devoted the majority of survey efforts to the area defined initially by the Incident Command as the spill zone, but we also conducted broader surveys to document relative abundance of species in the region of Unalaska and nearby Umnak island. Specifically we used 3 general types of surveys to geographically subdivide the area and allocate appropriate sampling effort. These included:

- 1) nearshore water habitat 0-400 m off the coast up to about 50 km from the grounded vessel,
- 2) offshore marine areas 0.6 km to 50 km from the coastline between Cape Kovrizhka, Unalaska Island, and Cape Tanak, Umnak Island (Figs. 1 and 2), and
- 3) other nearshore habitat on the coastlines of Unalaska and Umnak Islands (Fig. 3).

All nearshore surveys were further divided into 2 zones, the inshore habitat, 0 to 200 m from the high tide line, and the outshore habitat, 200 to 400 m from the coastline.

A relevant subdivision of the nearshore habitat (both inshore and outshore) was defined by the Shoreline Cleanup Assessment Team (SCAT) segments that extended roughly 30 km each direction from the grounded vessel, from Cape Kovrizhka to Chernofski Point. The U.S. Coast Guard and Alaska Dept. of Environmental Conservation identified these sections to organize field operations and categorize observations. The 25 operational divisions (e.g. a specific bay or linear stretch of shoreline between certain landmarks) and between 1 and 33 subdivided shoreline segments within each division defined a continuous linear framework totaling 300.9 km with 377 SCAT segments for which we were able to collect aerial bird observation data.

Another potentially important data component used in our analysis was the Environmental Sensitivity Index (ESI) shoreline coverage (<http://response.restoration.noaa.gov/esi/pdfs/aleutian.pdf>, <http://response.restoration.noaa.gov/esi/pdfs/metadata/ALEUTIAN.pdf>). All shorelines in the Aleutian Islands have been classified with respect to their physical structure, or mixture of structural types coded in landward to seaward order. ESI type was coded for 9,136 segments along 10,392 km of Aleutian Island coastline. The shoreline structure may relate to the severity of oil spill effects based on exposure, weathering, and oil accumulation properties of the habitat, as well as likely biological resources associated with these shoreline habitats. We used this stratification to examine whether or not ESI classification related to the distribution and density of birds in the nearshore habitat. We

also used the stratification to allow for the correction of sampling bias where disproportionate sampling effort occurred among the shoreline segments and types.

SURVEY METHODS

On each aerial survey we recorded all species of waterbirds and marine mammals observed. Although we include observed marine mammals and estimates in this report, the survey methods were not optimal for marine mammals. Additional surveys flown at higher altitude and slightly further from shorelines were more efficient (Haddix 2005). Henceforth, we simply refer to our data and results as for bird species, our primary concern, although Steller sea lion (*Eumetopias jubatus*), sea otter (*Enhydra lutris*), and harbor seal (*Phoca vitulina*) indices are included in the tabular results following the same analysis as for bird species.

Certain species of birds were not possible to identify from the air due to their subtle differences in identifying characteristics that are not visible at distance or high speed. These species were grouped into broader taxonomic categories (e.g. small alcid species) as observable identifying characteristics (general size, shape, color) allowed (Table 1). The primary observer (DKM) usually sat in the left rear seat and the second observer (JGK, later DJG) sat in the right rear seat. On most days, we flew the nearshore survey in a clockwise direction allowing the left observer to view the inshore zone. On 8 Jan and 2 Feb, we flew flightlines counterclockwise putting the right observer in position to view inshore, 0-200 m from the tide line. We tried the reversed direction to see if this made any change in typical sun angle or amount of glare, but it did not make any noticeable difference.

Surveys were flown at 30-40 m (100-130 ft) altitude and 166-177 km per hr (103-110 mph) airspeed, parallel to the shoreline at an average distance of 200 meters offshore. We used a 690A Turbo Commander, N57095, a high-winged twin-engine aircraft, equipped with long-range fuel tanks and a GPS serial data port (Commander Northwest, Ltd., Wenatchee, Washington). The Turbo Commander has bubble windows for the two observer positions forward of the engines. With the bubble windows, reflection was not a problem and distortion was minimal.

All aerial bird observers were trained and experienced from at least 6 seasons of observing and recording waterfowl on various breeding-ground transect surveys plus other nearshore waterbird surveys flown in Cook Inlet, Prince William Sound, or Southeast Alaska. Observers recorded all birds, marine mammals, and any sign of human presence. Observations were recorded vocally directly into laptop computers linked to the aircraft GPS using GPSVOX software developed by John Hodges, U.S. Fish and Wildlife Service, Juneau, AK, which produced files with species, number seen, geographic coordinates, time, observer, and environmental data for each observation. We recorded covariates of wind direction, wind speed, sea state, glare, and cloud cover at least twice per day, and whenever we noticed conditions to change. A flight-tracking data file of the aircraft's position and time was recorded at about 5 second intervals during all flights.

We flew surveys two to four times per week depending on suitability of weather. We flew NW from the Dutch Harbor airport and upon activating the two computers, began to fly the

nearshore portion of the survey. Starting locations varied but were always along the north coast of Unalaska, northeast of Cape Kovrzhka. After completion of the nearshore survey at Cape Tanak on Umnak Island, the pelagic transects were flown as time and conditions allowed on the way back to Dutch Harbor. On 8 Jan, we flew directly to the pelagic transects and then followed with the nearshore segments.

Aerial survey observers expected lower detection rates of waterbirds under weather conditions with higher winds, larger waves, and more sun glare. Increased wind speed and wave height have been related to a reduction in number of Long-tailed Ducks (*Clangula hyemalis*) counted on North Slope nearshore surveys (Johnson and Gazey 1992). We only surveyed when wind speed remained below 30 knots. Waiting for lower winds or optimal weather conditions to increase visibility rates was not practical.

Surveys within 50 km of the grounded vessel were flown on 8 different dates: Jan 5, 7, 8, 15, 18, 19, and 27 and 1 Feb. Flights that circled the remaining portions of Unalaska and Umnak Island shorelines occurred on 10 Jan and 2 Feb. All observations were recorded between 12:02 pm and 18:01 pm. Data recording duration varied between 3.6 and 5.2 hours per day with a total of 44.62 hours. Including departure and return to Dutch Harbor, total flight duration was somewhat longer. All nearshore and pelagic segments were not completely covered each time by both right and left seat observers. Numerous lapses in data recording were caused by malfunctions of the laptop computers, connections with the microphone, mouse pointer, or GPS output. On 7 Jan all the outshore data was lost and on 15 Jan all the inshore data was lost. On 5 of the 6 other days, small portions of the nearshore observations were lost while computers were locked-up or being rebooted. We totaled 55 skips in recording data for various reasons and when summed, this represented 15.5% of the total nearshore observation time (Table 2). Nevertheless, because there was no geographic pattern in the skipped sections, or any correspondence with bird numbers or specific habitats, using the data from other replicates added no bias to the estimate of average density of birds for the surveyed area at the time of survey. In other words, because the gaps in recorded data did not always occur in one specific habitat, time, or location, we expected the average based on all available data to be representative.

At least some of the pelagic transects were flown on all 8 survey days although the distance flown varied due to conditions of wind, weather, fuel capacity, and computer problems. Figure 2 shows the flight track for each day. Observers recorded birds under all conditions of tide, cloud cover, sea surface, or wind (if below 30 knots) that occurred on the survey days (Table 3). Some reduction in detection rate was suspected when significant glare was recorded for 16% of the observation time, or when whitecaps were recorded for 13% of the total survey duration of 86.4 observer-hours (Table 3). The lack of any noticeable pattern or trend in the observation conditions supported the assumption that wind, sea state, sky, and glare did not bias relative density estimates for any particular area. Certainly less than perfect observation conditions greatly reduced our ability to detect birds nevertheless we considered the average relative density of birds to be a useful index because this average was based on numbers seen in various areas, weather conditions, and days, even with scattered missing data.

The width of the survey strip was held constant at 200 meters. Width was calibrated by inclinometer measuring an angle of 8.7 degrees below horizontal at 100 ft altitude (9.9 degrees at 115 ft, 11.2 degrees at 130 ft altitude). With any departure from absolutely level (not banked), straight (non-crabbed), constant altitude flight (no turbulence), the sighting angle or any accessory guide marks on the window cease to be very useful. For most of the time, simply learning the apparent size of commonly observed species when seen at 200 m is the only guide. The combination of various learned cues and occasional recalibration by sighting angle are used by experienced aerial observers to maintain a fixed transect width of 200 m. All birds observed within 200 m of the aircraft were recorded. We selected 200 m as a balance between a narrower width that would have higher detection rate, but because it covers less area, would result in fewer observations. The observers were most accustomed to a 200 m width.

ANALYSIS PROCEDURES

The basic objective was to estimate the total population size for each species of bird observed in the aerial survey. In the simplest case, the total count of birds observed divided by the sum of area observed estimates the average density, and then density multiplied by the total area would provide an estimate of total population size. The observed areas must be a strictly random or systematic sample of the total area of interest to ensure that the mean density is representative and the total population estimate is unbiased. One approach to avoid bias would be to have identical and complete coverage on each replicate of all transects, and for transects to proportionately sample all parts of the area. In reality, this did not occur exactly. Nevertheless, we calculated such a pooled estimate of density, the sum of the birds observed divided by total transect area observed, as approximations for each of the regions sampled by shoreline transects or offshore pelagic transects. At a large scale, the assumption of proportionate sampling was reasonably accurate. In contrast, at a fine scale, we were concerned that variation in sampling intensity could bias estimates of bird numbers for specific bays or shoreline stretches. Such finer scale estimates and analyses may be necessary for comparisons with oil concentrations or other data. Therefore, because the sampling intensity was in fact not uniform due to a variety of causes, we re-examined the same data in detail to reduce potential bias in average density by carefully measuring variation in sampling effort in every strata defined by either geographic location or shoreline type. The analysis became bulky due to the large number of small size strata, but the basic method of calculating density and expanding to an appropriate area did not differ from the simple case.

Locations of Bird Observations and Sampling Effort

A first step was to produce a series of geographic information system (GIS) coverages that represented the location of the sampling effort and the birds observed by each observer on each day. The aircraft track file and the transcribed observation data file were read with a custom program (sf8a.tru, TrueBASIC) to write GIS ARC/INFO format files. Line coverages for the midline of the strip observed by either the right seat or left seat observer were generated as a path offset 100 m directly right or left of the aircraft's curved flight path based on the GPS locations recorded at 5 seconds intervals. The recorded START and END

points for transect observations, or the last observation before or first after a computer malfunction, determined the endpoints of these arcs. GIS point coverages were written for all bird locations. At the time of each bird observation, the latitude and longitude coordinates of the aircraft's position were offset by 100 m, either right or left depending on the observer, at an angle perpendicular to the direction of travel. Observations with multiple species or groups recorded at one location (with one mouse click) were offset in increments of 33 meters (closer, further, ahead, behind) to preserve a unique geographic location point for each species and group size observed. The direction of travel was determined by the azimuth between the last two locations found in the aircraft's flight track file immediately prior to the time of the bird observation. Flight azimuth and perpendicular angle changed constantly with the curving nearshore transects. The geographic locations were accurate within approximately 100-200 m of the true position of the bird. The location error combines independent effects of several factors including:

- a) the 100 m offset that only approximates the actual distance of each bird away from the aircraft centerline,
- b) up to a 3 second lag (and irregularly, with delays of more than 3 seconds) since the last satellite GPS position calculation and downloaded coordinates while flying at 47 m/sec air speed,
- c) hesitation or anticipation in the recording of birds observed rather than recording only at the moment they are perpendicular to the aircraft's path,
- d) map error, and
- e) GPS error.

All coordinates were recorded in WGS84 by the aircraft and shifted to NAD27 datum (tabulated for the center of each degree block) to match the USGS topographic maps and coastline coverages.

We buffered the mid-flightline arcs by 100 m to produce 200 m wide ribbon-like polygons containing the area sampled by each observer on each day. The mid-flightline arcs and their buffered polygons were converted to GRID coverages with 20 m pixel resolution. Likewise, the point coverage of bird observations was converted to a GRID coverage with 20 m pixels. The integrity of each observation point on a given day was maintained by a minimum offset of 33 m between every point as written to the location coverage. Nevertheless, with up to 8 replicates of the same flightlines, some data locations were lost when converting to a 20 m grid due to overlap in locations between survey days. The final grid coverage indicated 192 fewer points (1.5% of 12,353 locations) due to multiple points located within the same 20 m cells.

Allocation to Strata

Bird observations and the sampled transect strips observed were assigned to specific ESI nearshore segments based on the nearest ESI segment (least distance) that was still within 600 m. We combined the ESI types into 9 slightly broader classes (Table 4). A Euclidean distance allocation grid was constructed from the nearshore ESI arc coverage with all distances greater than 600 m turned to NoData. The reason that simple polygon overlays of the bird point locations and the buffered mid-transect lines could not be used was two-fold. First, it was impossible for the aircraft to exactly follow a complex coastline flying at 47

m/sec. Small promontories were passed closer than 200 m and small concave bays were passed at greater than 200 m. Second, it was apparent that a combination of aircraft GPS error and/or map coverage location error caused occasional sections where the flightpath location data were suspect. At scattered locations, the flight track was essentially over land or too far offshore rather than 200 m from the coastline. We interpreted this to be either map error or positional error because the pilot was very skilled at following a flightpath 200 m offshore for the vast majority of the survey. Simple polygon-polygon or point-polygon overlays would force discarding the sampling effort lines and those bird locations that were apparently (but probably erroneously) located either over land or more than 400 m from the mapped shoreline. The Euclidean allocation grid provided a method to assign data to the most likely nearshore segment with a leniency of up to 600 m. In other words, we knew that the pilot was flying as closely as possible to 200 m offshore, and that the left-side observer was recording birds 0-200 m from the aircraft while looking towards shore. We believed that the sample effort and the observation data correctly represented the nearest nearshore segment even if the mapped result was incorrectly producing locations more than 200 m from shore or less than 0 m from shore. The topographic map or the GPS locations were assumed the problem. The recorded bird locations and the mid-flightline arcs were not moved, yet by using the 600 m Euclidean allocation grid procedure, most of the sampling effort and observational data could still be assigned to the appropriate nearshore segment.

The nearshore habitat was also subdivided into 25 SCAT operational divisions and a total of 376 segments with bird observations. Assignment to SCAT segments was similar except the SCAT coverage already had assigned polygons for each nearshore segment. The SCAT polygon creation scheme was not based on lines drawn perpendicular to the shoreline at the segment endpoints, and was not based on Euclidean allocation to the nearest nearshore segment. Because we did not know the reasons for the various shapes or the potential uses for the SCAT polygons, we did not alter any of the SCAT polygon boundaries (except combining SPR10, 10a, 10b, 10c, and two other minor corrections as detailed in Appendix 2). The allocation to SCAT polygons of the sampling effort and birds observed was based on exact geographic overlay of these polygons.

Calculation of Density

We calculated the density for each species as observed birds per unit area of the strip observed (length in km x 0.200 km width). A ratio estimator was used to combine all the data across replicated days for every transect section within a given strata. The ratio estimator appropriately allowed for unequal size sampling units. The ratio estimate of mean bird density equaled the sum of all birds divided by the sum of all the area observed. If the area observed within a segment on any one survey replicate was only 0.003 km² (1 pixel), or if the sum of area observed with all replicates was less than 0.010 km² (3 pixels), the segment and associated bird observations were excluded. The variance of mean density was estimated by the variance formula for the ratio estimator (Cochran 1963).

We subdivided the survey area into 7 distinct sampling regions. The first division was based on 4 major geographic areas: the nearshore water 0-30 km from the vessel (SCAT defined shoreline, Fig. 5), nearshore water roughly 30-50 km from the vessel (nonSCAT area, Fig.

5), all offshore water roughly 0.6-50 km from coast within 50 km of the vessel (Offshore area, Fig. 4), and other nearshore areas of Unalaska and Umnak Islands (UnAK-Umnak area, Fig. 3). These first 3 areas are loosely referenced as the “50 km risk area”, roughly within a 50 km radius of the grounded vessel. Our use of the term “risk area” does not imply anything about the actual occurrence, size, or location of any oil spill or spill-impacted area. The 3 nearshore areas were further divided into 2 zones referred to as inshore (0-200 m from the coast) versus outshore (200-400 m), with each zone sampled by one observer viewing from one side of the aircraft flown to follow a curving path 200 m from the coast. Each region was sampled by 200 m wide transect strips flown and replicated from 2 to 8 times on different days (Table 3).

The SCAT or ESI defined nearshore segments variously subdivided the nearshore sampling regions. Latitude-longitude blocks or distance zones subdivided the single offshore region. While the main objective was to estimate total population size for each species in the major sampling regions, the subdivision into smaller strata served two purposes. First, it provided a means to avoid bias due to unequal sampling effort in various parts of the survey area caused by computer problems or other reasons (see next paragraph). Second, it may provide important accessory information relevant to damage assessment studies should the pattern in bird density relate to oiled locations or other types of data collected on particular shoreline sections. Stratification into segments or blocks was not done to improve the precision of the estimated population indices, nor to allow for improved allocation of sampling effort, even though these typically are reasons that stratification is used in the design of sampling plans.

Without stratification, a particular difficulty occurred in calculating population size for each ESI shoreline type based on our aerial transects. The linear distance flown through each small segment of nearshore habitat was only approximately proportional to the area of the habitat (Table 6). Thus, the sampling effort (measured by area observed = length flown * 200 m transect width) was not strictly proportional to size of the sample unit, and unless density was homogeneous across any unequally-sampled areas, a self-weighted or unstratified estimate of the total population may be biased. Typically, for nearly any sampling design, it is simplest and most useful to allocate sampling effort in proportion to the size of each unit. The reason that distance flown across a patch of habitat was not always in proportion to the area of that habitat was two-fold. First, the straight flight distance across each segment was not strictly proportional to actual area because the nearshore water habitat patches were not rectangles. Along convex shorelines, such as around points, spires, and islands, the area of nearshore water habitat within 400 m of the coast exceeded the shoreline distance multiplied by a width of 400 m. Along concave shoreline segments, such as bays, coves, and bights, the opposite pattern holds and the shoreline distance multiplied by 400 m overestimated the area of nearshore water habitat within 400 m of the coast. This was greatest for class ESI910 (types 10A, 10A+, 9A, 9B) that included sheltered tidal flat and marsh habitats that tend to occur in small bays with a long shoreline (perimeter) length relative to their often restricted area of associated nearshore water. A second reason that sampling effort was not necessarily proportional to the area of nearshore water habitat was that certain segments, such as at the head of bays especially in fiords with steep sides, were difficult to fly safely. Although the flown transects under-represented the coastline length of sheltered tide flat and marsh habitat

(ESI910) at the end of bays, their coastline length tended to over-represent the associated nearshore water area of this type, and fortuitously, the departures were in opposite directions. The observed sampling effort was reasonably close to the actual proportion of the nearshore water area associated with this shoreline type (Table 6). When ESI type stratification was included, we were able to measure sampling effort at a fine-scale, calculate density, and expand to estimated population size appropriately.

The offshore region was sampled by straight line transects flown on 8 days (Fig. 2). We calculated average density of birds observed with a ratio estimator across all days and areas observed within each stratum. Strata were defined either by 10-minute blocks of longitude and latitude or by zones of distance from the shore and the grounded vessel (Fig. 4). The distance zones were defined as **dz1** 0.6-10 km from shore and 0-30 km from ship, **dz2** >10 km from shore and 0-30 km from ship, **dz3** >10 km from shore and >30 km from ship, and **dz4** 0.4-10 km from shore and >30 km from ship. Right- and left-seat observers both provided equivalent sample estimates of density of birds per km² of pelagic habitat.

Population Estimates

We calculated pooled population estimates for each species in each region. These overall approximate estimates were susceptible to bias because of the unequal sampling effort occurring in various portions of the regions sampled (see above). More rigorous analysis calculated the population for each species as the sum of populations estimated from the areas and mean densities observed in each ESI shoreline type segment. A ratio estimate calculated mean and variance of density to combine birds seen and area observed for each segment during the replicated surveys. We measured the area observed as the sum of 20 m pixels in the mid-flightline coverage allocated to each ESI nearshore segment. The number of pixels multiplied by 20 meters is not the actual distance flown because the pixel representation of the curved flight path includes stair-stepped patterns and diagonal distances (20 m * 1.4142). Linear regression on a plot of actual vector distance of the ESI nearshore segments against the number of pixels in the same segment arcs indicated a slope of 15.71 m per pixel accurately predicted arc length (Fig. 7). Therefore, the sum of the number of pixels * 0.0157 km/pixel * 0.2 km strip width was used to calculate the area observed for each segment. The estimated density for each segment for each observer was then multiplied by half the area of the nearshore water habitat allocated to each ESI nearshore segment. The area of the allocated nearshore water habitat also directly relates to the shoreline actual arc length (Fig. 8), but with more variability because of convex or concave shoreline patterns, close proximity to other arcs, and arcs that have little allocated nearshore water area. We did not need to use the average linear relationship because we already had the nearshore water area for each individual ESI segment. We considered it sufficiently accurate to use half the area of the 400 m allocation area rather than conduct separate calculations using 0-200 m and 200-400 m allocation area grids. The mean density times the 200 m allocation water area (1/2 * 400 m allocation of nearshore water to ESI segments) estimated the average population size for each segment.

For the inshore or offshore observer, average density in each SCAT polygon was calculated using a ratio estimator of the number of birds and areas observed. The density was

multiplied by nearshore water area, 0-200 m or 200-400 m from the shoreline, to calculate population within each SCAT polygon. Populations of the inshore and offshore zones were summed.

RESULTS

Survey flights occurred on 10 days (Fig. 2, Fig. 3). Bird observations were recorded on a total of 11,477 kilometers of 200 m wide survey strips by the two observers (Table 5). The most commonly seen birds were Emperor Geese (23% of the total birds observed), Black Scoters (*Melanitta nigra*) plus unidentified scoters (23%), Cormorant species (*Phalacrocorax* spp.) (14%), Harlequin Duck (8%), Glaucous-winged Gulls (6%), and Steller's Eider (*Polysticta stelleri*) (4%) (Table 1). These 6 species made up 78% of the birds actually observed, however this tabulation of raw data overly represented the nearshore habitats that were sampled at a much higher proportion and frequency. We observed species that favor offshore areas less often because offshore sampling was less frequent and more widely spaced. Although fewer individuals were seen, the estimated total population sizes for some offshore species were large (see below).

Total transect area observed after summing across the replicated surveys, and the total area of marine habitat in each region, indicated that nearshore habitat in the SCAT and the nonSCAT region was, on average, observed 5.60 times. The remaining nearshore water of Unalaska and Umnak Islands were observed 1.29 times. The fraction of the total pelagic offshore habitat observed was 0.28 (Table 7). Adding the regions together, a pooled population index combining all species indicated an estimate of 17,142 birds within the 50 km risk area, and a total of 45,213 birds for the entire Unalaska and Umnak sampled area (Table 7). For each species, we calculated nearshore population estimates for each region (Table 8).

We revised these estimates to account for the potential bias in sampling effort among the various shoreline types. We calculated the population size for each species in all ESI types (Table 9) from the average bird density observed in all ESI segments of that type multiplied by the sum of the area for each type. The ESI population totals therefore included birds from unsampled nearshore segments based on the observed density of birds in sampled segments of that same ESI type. The size of the expansion was reflected by the total 200 m allocation area of the water habitat divided by the sum of the 200 m allocation area for the segments observed (column 7 divided by column 10 in Table 6), therefore correcting for the small discrepancies caused by unsampled segments. The result was the total area and total population index for each ESI class in each region (Table 9). We then calculated the average density for each ESI class from the sum of the stratified population estimates divided by the sum of the nearshore water areas (Table 10). These estimates of population size and density are free from any bias caused by the combination of disproportionate sampling effort and heterogeneity in density within each region.

The pattern of average density shown for each ESI nearshore class indicated that most species were not restricted to specific shoreline types (Fig. 9) but rather were observed at quite similar densities over several ESI types. Nevertheless, for all species combined, the

highest densities were observed in sheltered tidal flat and marsh habitat of class ESI910. Many of the duck species (harlequin, common eider (*Somateria mollissima*), mallard (*Anas platyrhynchos*), goldeneye (*Bucephala albeola*), shorebirds, emperor geese, and glaucous-winged gulls made high use of this ESI type (Fig. 9). Highest use of the most exposed rocky shoreline, ESI types 1, 1+, and 2, occurred for cormorants, Steller's sea lions, and bald eagles (*Haliaeetus leucocephalus*) (Fig. 9). Black scoters, Steller's eider, long-tailed ducks, and black oystercatchers (*Haematopus bachmani*) were observed to have roughly equal nearshore densities across all ESI types (Fig. 9). The tabulation of the more detailed data (Table 10) documented the high degree of sampling error in these estimates. The relative distribution of nearshore types, measured as the proportion of total length within each region, shows that the SCAT and nonSCAT regions we observed had particularly high coverage of ESI6, gravel beach types, relative to its frequency of occurrence throughout the Aleutians (Fig. 6). The distribution of density across ESI classes (Fig. 9) did not show any species with a clear preference for gravel beach nearshore type ESI6.

We used the area of nearshore water and the amount of area observed in each SCAT unit (Table 16) along with the number of birds observed to estimate a population index for every SCAT segment (Table 17). The population indices were then summed for each SCAT operational division (Table 18). The average density was calculated from the population totals and the nearshore areas (Table 19).

Three different estimates of total population sizes within the SCAT region (inshore and offshore zones combined) agreed remarkably well (Table 20). The SCAT polygon area observed and the defined nearshore water habitat area was slightly smaller (2%) compared to the ESI segment divisions. The total estimated population index summing all species was 12.7% smaller using the SCAT polygons (Table 20). We attribute this difference to the strict point-in-polygon overlay process that eliminated 2379 observations (6.6% of the total) that were beyond the 400 m shoreline buffer and outside of the SCAT polygons. With the ESI segments, we used a 600 m limit for allocation to the nearest segment and then independently determined the flightline area observed and the nearshore water area. This compensated for various location errors (map, GPS, recording) and therefore we are more comfortable with the ESI segment derived estimates.

For either the 10-minute blocks or the 4 distance zones stratification of the offshore region, the densities (Tables 11 and 12) and population estimates (Tables 13 and 14) were essentially equivalent. The 2% (35.8 km²) smaller total area of the 10-minute block strata is due to loss of small tips of blocks (Fig. 4) excluded because they were not sampled by transects. Combining all species, we estimated a slightly higher population and smaller standard error with the 10-minute block stratification, but this pattern did not hold for all species.

In the offshore region, small alcids (auklet and murrelet species) had the largest population index of 3,032 (SE = 893), followed by murres (*Uria* spp.) (2020 ± 364), Northern Fulmar (895 ± 266), Glaucous-winged Gull (776 ± 110), Steller's Eider (492 ± 344), Black Scoter (383 ± 257), cormorants (196 ± 55), Laysan Albatross (*Phoebastria immutabilis*) (94 ± 27), and King Eider (89 ± 63) (Table 14). Two of these 9 pelagic species also had similar, but

slightly smaller, size populations nearshore (Steller's eider and Glaucous-winged gulls) and two had larger populations in the adjacent nearshore region (Black scoter and cormorants).

The combined population indices for both nearshore and offshore regions (Table 15) indicated that small alcids were the most common species group with a population index of 3,098 (SE = 893), followed by Emperor geese ($2,420 \pm 335$), murre (2,197 \pm 365), Black Scoter ($2,149 \pm 273$), and cormorants ($1,862 \pm 146$). Combined population indices for each species are tabulated as ranked by total abundance, by relative preference for offshore versus nearshore habitats, and by preference for inshore versus outshore zones (Table 15).

All detailed tabular results are available as separate Microsoft Excel spreadsheets so they can be readily transferred to other investigators and available for further analyses in digital format.

DISCUSSION

Summing the nearshore and pelagic regions within 50 km of the grounded vessel (Table 15), the largest estimated population index recorded was 3,098 small alcids and the 3rd largest was 2,197 murre. These two species groups occurred essentially only in offshore waters at the time of our surveys. Definite species identification was not possible from the aircraft and several possible species of small alcids occur in this area (Table 1). Small alcids showed highest densities near Umnak Pass and in offshore water just east of Umnak Island, with <2% seen in areas near Spray Cape or further east (Table 11). In contrast, murre were widespread. The second most abundant species was Emperor Geese with an estimated 2,420 birds. This nearshore species favored sheltered tidal flats and sheltered rocky shores (Fig. 9) especially in Kismaliuk Bay, Naginak Cove West, Pumicestone Bay North, Pumicestone Bay South, and Alimuda Bay. Although smaller in size, Spray Cape, Ram Point, and Skan Bay South had fairly high densities of Emperors as well (Table 19). The 4th most common species was Black Scoter with an index of 2,150 plus many of the 353 unidentified scoters. Scoters showed no particular preference for any shoreline type (Fig. 9) but were found predominantly in Portage Bay North, Portage Bay South, Makushin Bay, Pumicestone Bay North, Naginak Cove West, Alimuda Bay, Udinak Cove East, and Udinak Cove West (Table 18). Other species including Cormorants (1,862), Glaucous-winged Gulls (1,313), Steller's Eiders (915), Northern Fulmar (895), Harlequin Ducks (731), and Long-tailed Ducks (391) completed the list of the 10 most common species and 90% of all estimated birds (Table 15). Northern Fulmar is restricted to offshore habitat whereas Glaucous-winged Gulls and Steller's Eiders are found in both offshore and nearshore regions. These 5 nearshore species were widespread occurring in nearly every SCAT operational division and shoreline type. Glaucous-winged Gulls had their highest observed density at Spray Cape.

Some species showed a tendency to be somewhat more common on shorelines relatively close to the grounded vessel. The percentage of total SCAT nearshore water area in the Spray Cape, Skan Bay East, and Skan Bay West operational divisions was 10.5%. The only common species for which proportions exceeded 10.5% of their total SCAT nearshore populations were Emperor Geese (169 of 1,193), Glaucous-winged Gulls (92 of 297), unidentified ducks (45 of 141), and Black Oystercatchers (6 of 27) (Table 19).

We also looked for species with a tendency to occupy shorelines relatively near the vessel by summing bird population indices estimated for the SCAT area, roughly within 30 km of Spray Cape. The SCAT segments totaled 118 km² of nearshore water habitat, 19% of the sampled nearshore waters around Unalaska and Umnak Islands. Average densities estimates stratified by ESI type (from Table 10) for the SCAT area compared to the remainder of the survey area (sum of non-SCAT and UnAK-Umnak areas) showed total birds were at slightly lower density in the SCAT area (Table 21). Emperor Geese, cormorants, Harlequin Ducks, and Steller's Eiders all averaged slightly lower in density; and Glaucous-winged Gulls, Common Eiders, and Black Oystercatchers had significantly lower density in the SCAT area (Table 21). Unidentified ducks, Bald Eagles, loons, Red-necked grebes, Pigeon Guillemots, and Red-breasted Mergansers had significantly higher densities in the SCAT area (Table 21).

We observed relatively weak tendencies for species to associate with preferred ESI types (Fig. 9). Association may be difficult to document because the ESI segments were often small and interspersed, and because some species showed some degree of movement in response to the aircraft (e.g. Emperor Geese). Additionally, some characteristics of nearshore marine habitat that influence availability of fish or benthic invertebrates to foraging birds could be strongly influenced by currents, depth, or substrate conditions that may not always closely correlate with ESI shoreline structure.

Although indexing populations of marine mammals was not the primary objective of aerial surveys, our analysis and results included observed Steller Sea Lions, Sea Otters, and Harbor Seals. As with birds, the observed populations of marine mammals were an underestimate of actual numbers. Observers noted that many sea lions abandoned their haul-out sites in response to aircraft flying at 30-40 m altitude, and therefore, on 20 and 26 January, separate surveys were flown at greater altitude to obtain counts of marine mammals that were more accurate (Haddix 2005).

When we were able to fly aerial surveys, typically the recorded weather conditions ranged from NE to SE winds at 10-25 knots (Table 3). Waves with whitecaps were seldom encountered in the nearshore areas but were more frequent on pelagic transects (Table 3). We attribute the differences observed to be just as likely associated with chance (sampling error) than any bias caused by correlated differences in density and sampling effort. The proportion of the actual nearshore area in each ESI class, the proportion of area observed in our sample, and the sum of the allocated areas in the observed segments, although they all differed, they remained relatively close (Table 6). This reduced the potential for bias in the estimated total population index even if the bird density had strongly differed among the ESI classes. For most species, the differences in density among the ESI classes were not very large, again reducing the magnitude of bias that might have resulted with disproportionate sampling. Nevertheless, without completion of the detailed stratified analysis procedures, the pooled estimate of density result would have been open to criticism. Also in hindsight, we found only minor differences between the overall pooled estimates and those made using the detailed stratifications controlling for differences in sampling intensity. The unequal coverage caused by inadvertent lapses in data recording or the difficulty in sampling

complex locations such as sheltered tidal flats or exposed headlands proved was a minor influence.

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