INTRODUCTION

Since the discovery of oil and gas on the Alaskan Arctic Coastal Plain, interest in maintaining healthy wildlife populations has accompanied industrialization of the region. Recent expansion of oil and gas development from on-shore sites into the near-shore waters of the Beaufort Sea raised concerns that wildlife using these waters may be at risk to disturbance and oil spills (US Army Corps of Engineers 1999). Wildlife species of particular concern to managers are more than one hundred thousand sea ducks and other marine birds that use the Beaufort Sea each summer (Johnson and Herter 1989, USFWS 1999). Despite high abundance of sea ducks in the Beaufort Sea, recent declines in some sea duck species have been documented state-wide and along the Arctic Coastal Plain (Goudie et al. 1994, Suydam et al. 2000, US Fish and Wildlife Service 1999). One potential threat to these birds in the Beaufort Sea is disturbance resulting from human presence on barrier islands and increased boat and air traffic in near-shore and offshore waters (Gollop et al. 1974; Johnson 1982, 1984; Schamel 1974). These potential disturbances are expected to increase within the Northstar unit where development of offshore oil and gas reserves is underway.

To address the potential threats to these wildlife resources, the Outer Continental Shelf Lands Act and its amendments include provisions for post-lease monitoring studies to identify environmental changes, establish trends in marine bird populations, and design experiments to identify the causes of any changes (Johnson and Gazey 1992). Accordingly, the Minerals Management Service and the USGS Biological Resources Division signed an Intra-agency Agreement in 1999 to assess impacts of human activities on distribution and density of Long-tailed Ducks in Beaufort Sea lagoons. To accomplish this, the USGS-BRD subcontracted the Waterfowl Branch of the USFWS Migratory Bird Management Division to conduct a Near-shore aerial survey in 1999 and 2000 using existing MMS protocol (OCS- MMS 92-0060). This protocol was designed to measure effects of near-shore industrialization on marine bird abundance and distribution (Johnson and Gazey 1992). Rather than test for industry effects on all species, the protocol identified the Long-tailed Duck (*Clangula hyemalis*) as a focal species to test for industry effects due to its relative abundance within the area of interest. We used this protocol to collect density and distribution data on Long-tailed Ducks in 1999-2000 to compare relative densities between an “industrial” and “contol” area. These areas were delineated in the early 1990s at a time when human activity was concentrated in the “industrial” area (Johnson and Gazey 1992). In addition, we sought to identify the relationship between bird density and human activity.

Although human disturbance may have indirect effects on marine birds, an oil spill could directly expose birds to oil and cause mortality in some individuals of these species (Stehn and Platte 2000). The probability and relative severity of oil spill impacts on population status depends on the temporal and spatial distribution of marine birds in the region. To understand marine bird distribution in the region we expanded aerial surveys throughout the near-shore environment between Oliktok Point and Brownlow Point.

The Near-shore aerial survey protocol provides a means to monitor trends and distribution patterns of bird populations close to shore, but bird use of offshore waters is poorly documented. Previous studies demonstrated that Spectacled Eiders (*Somateria fischeri*), a threatened species, use offshore waters extensively (Petersen et al. 1999). Surveys in the Canadian Beaufort Sea revealed that eiders used waters as far as 115 km from shore (Searing et al. 1975). Thus, we designed an Offshore survey to delineate concentrations of eiders and other marine birds that use waters within and beyond the barrier island lagoons between Cape Halkett and Brownlow Point. In contrast to the Near-shore survey that was designed to detect small-scale distribution patterns within the barrier island lagoons, the Offshore survey covered a much larger area. Consequently, inferences drawn from the Offshore survey are not limited to small-scale localized patterns of distribution.

The specific objectives of this study were to:

1. Monitor Long-tailed Ducks and other species within and among “industrial” and “control” areas using existing protocol (OCS-MMS 92-0060).
2. Use data from 1999-2000 and data collected by Johnson and Gazey (1992) in 1990-1991 to compare Long-tailed Duck population trends between “industrial” and “control” areas, and to describe the relationship between distribution patterns and human activities.
3. Expand the Near-shore survey area to encompass habitats between the original “industrial” and “control” areas, and sample Near-shore Marine habitat from Oliktok Point to Brownlow Point to delineate small-scale distribution patterns of marine birds throughout the expanded study area.
4. Correlate variation in marine bird populations with environmental factors, human activities, and temporal and spatial variables.
5. Implement an Offshore survey that targets Spectacled (*Somateria fischeri*), Common (*S. mollisima*) and King Eiders (*S. spectabilis*).
6. Document distribution patterns of marine birds within the Offshore survey area.

METHODS

U.S. Fish and Wildlife personnel completed a series of 12 Near-shore and 6 Offshore aerial surveys between Cape Halkett and Brownlow Point, Alaska in 1999-2000 (Fig. 1). These efforts replicated historical Long-tailed Duck surveys, expanded the geographical extent of sampling, and widened the breadth of analysis to include all marine birds in Central Beaufort Sea waters. To accomplish these tasks, we conducted separate Near-shore and Offshore surveys.

Near-shore Survey Methods

We completed 12 Near-shore aerial surveys from 1999-2000 using a standard protocol (OCS-MMS 92-0060) developed by Johnson and Gazey (1992) based on nine years of aerial survey data (1977-1984, 1989). They tested this protocol using two additional years of data (1990-1991) and recommended the technique be applied for subsequent comparable data collection and analysis. Thus, we collected comparable data in 1999-2000, combined these data with those collected by Johnson and Gazey in 1990-1991, and used the combined data set to compare trends in Long-tailed Duck density between an "industrial" and "control" site, and to identify a relationship between density and human activities.

We surveyed 24 established transects that passed through three habitats in two areas (Fig. 2). Habitats sampled included Barrier Island (lee side of the barrier islands), Mid-Lagoon (midway between barrier islands and mainland shoreline), and Mainland Shoreline (mainland coast). These habitats were sampled in two separate regions that represented an "Industrial" area between Oliktok Point and Prudhoe Bay, and a "Control" area between Tigvariak Island and Brownlow Point.

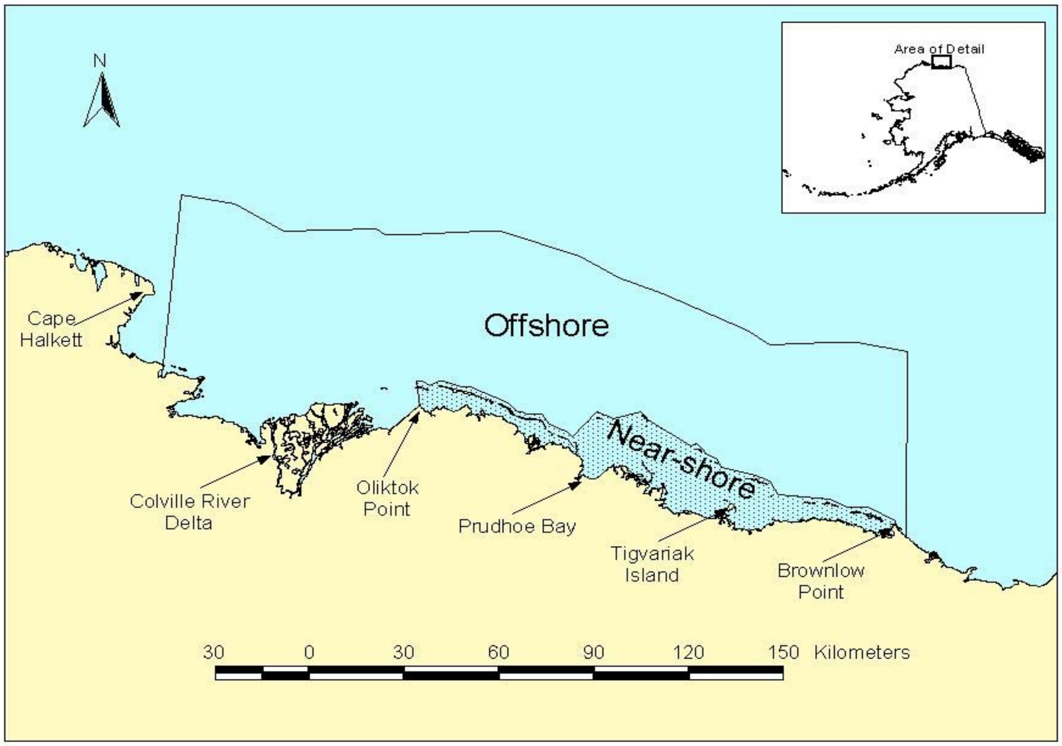

Figure 1. Study area for Near-shore and Offshore marine bird surveys, Beaufort Sea, Alaska, 1999-2000.

In addition to monitoring Long-tailed Ducks in these two regions, we recorded all marine birds in an expanded survey area that included a fourth habitat called Near-shore Marine (1.5 km north of Barrier Islands). We sampled these four habitats in the "Industrial" and "Control" areas, and in the "Central" area between Prudhoe Bay and Tigvariak Island (Fig. 3). The resulting 44 transects spanned 723 km and sampled 289 sq. km of near-shore waters (Table 1).

We completed 6 Near-shore surveys between mid-July and early September in both 1999 and 2000. This period corresponded with the Long-tailed Duck flightless molt when populations are relatively stable (Johnson and Gazey 1992). To sample this period evenly, we attempted to space our replicates approximately 1 week apart, although occasional poor weather precluded strict adherence to the 7-day sampling interval.

We used a single-engine Cessna as the survey sample platform for 10 of the 12 replicates (Table 2). Mechanical difficulties in 1999, however, required us to use a twin-engine Aero Commander to complete 2 replicates. We maintained survey altitude and speed at 30-45 m and 160-180 km/hr, respectively. While on transect, we recorded all birds within 200 m of either side of the aircraft. In addition to recording bird observations, we estimated wind speed, wave height, and ice cover associated with each transect.

Prior to conducting surveys, observers were trained in flock size estimation using computer simulation software. The simulation software, "Counting Wildlife", is a tool for estimating wildlife populations from the air (Hodges 1993). Designed specifically for aerial surveys of waterbirds, the program simulates realistic flocks of birds in clumped, non-normal distributions. At the end of a series of random test trials, results are displayed showing the observer's estimate and the percent error. By providing scores by trial, this program helps

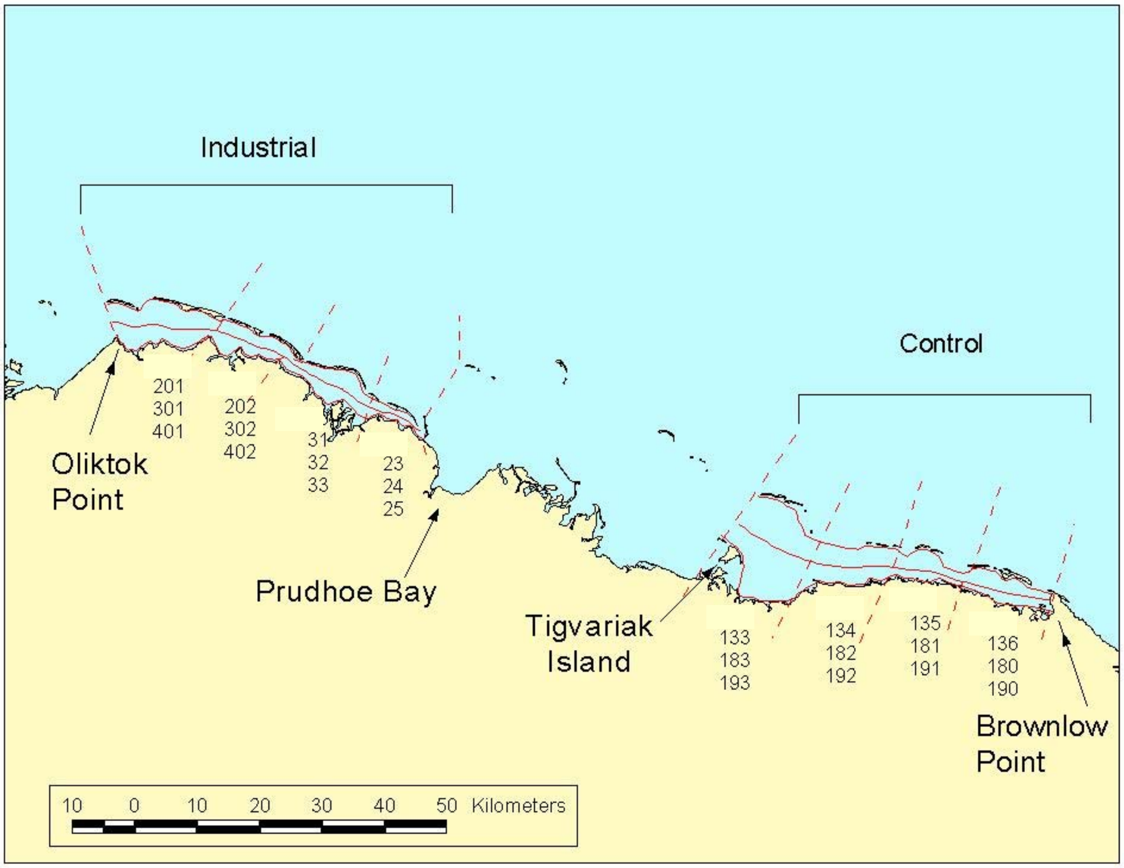

Figure 2. Aerial survey transects in Industrial and Control areas, Beaufort Sea, Alaska.

observers identify inherent bias in counts prior to actual aerial surveys, promotes improvement in accuracy, and helps standardize flock size estimation among observers. To aid in accurate transect width estimation, we used markings on the aircraft wing struts that were calibrated with clinometers. Similarly, prior to conducting surveys observers practiced estimating transect width by flying over markers at varying survey altitudes. All individuals who participated in this study had prior experience in aerial surveys of waterbirds in Alaska.

We improved the data recording protocol described by Johnson and Gazey (1992) by implementing standard aerial survey procedures used by USFWS Division of Migratory Bird Management. This method combines direct voice input data with position data continuously received from the aircraft's Global Positioning System (GPS). This provides position coordinates and time of day for all bird observations. Rather than recording data during 30-second intervals, as described by Johnson and Gazey (1992), we recorded continuously along transects, enabling greater accuracy in mapping of bird distribution. Moreover, we used the system's Moving Map function to display and navigate along fixed "electronic" transects for more precise replication of survey lines.

Following each survey, we transcribed digital voice recordings using customized software. In this process, bird observations were linked to position data, covariates and weather variables. We then checked all entries for accuracy. Next, we subjected the data files to a customized computer check program that identified missing or miscoded data, interpolated positions where latitude and longitude data were missing, calculated distance and area surveyed, and performed a datum shift on position data to adjust GPS data collected in NAD83 to correspond with USGS NAD27 maps. After completing these steps, we generated ArcInfo coverages from bird location files. Finally, these coverages were imported into ArcView to produce distribution maps.

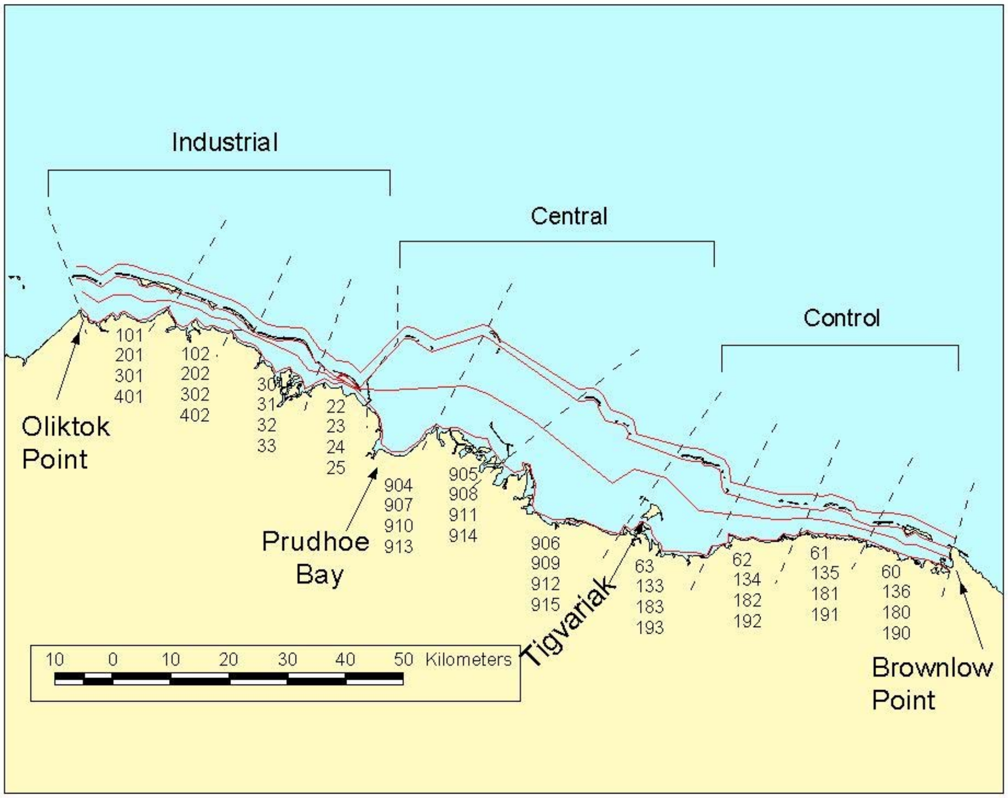

Figure 3. Aerial survey transects in an expanded Near-shore survey. Sampling occurred in four habitats among three areas.

Table 1. Transect length and area surveyed during 12 Near-shore aerial surveys, Beaufort Sea, Alaska, 1999-2000.

Area	Habitat	Transect	Length (km)	Km^2 Surveyed
Industrial	Near-shore Marine	22	17.53	7.01
		30	13.53	5.41
		101	22.08	8.83
		102	16.25	6.50
	Barrier Island	23	10.83	4.33
		31	13.98	5.59
		201	21.80	8.72
		202	15.38	6.15
	Mid-lagoon	24	9.83	3.93
		32	15.33	6.13
		301	18.23	7.29
		302	13.25	5.30
	Mainland-Shoreline	25	11.88	4.75
		33	19.73	7.89
		401	18.93	7.57
		402	14.73	5.89
Central	Near-shore Marine	904	16.55	6.62
		905	21.48	8.59
		906	20.68	8.27
	Barrier Island	907	25.10	10.04
		908	21.35	8.54
		909	20.90	8.36
	Mid-lagoon	910	15.53	6.21
		911	17.03	6.81
		912	24.68	9.87
	Mainland-Shoreline	913	19.28	7.71
		914	14.10	5.64
		915	32.30	12.92
Control	Near-shore Marine	60	13.63*	5.45*
		61	12.43	4.97
		62	12.83	5.13
		63	14.38	5.75
	Barrier Island	133	16.73	6.69
		134	13.85	5.54
		135	14.35	5.74
		136	15.90*	6.36*
	Mid-lagoon	180	14.58	5.83
		181	11.70	4.68
		182	13.55	5.42
		183	14.35	5.74
	Mainland-Shoreline	190	16.45	6.58
		191	13.48	5.39
		192	17.33	6.93
		193	18.90	7.56

* Transects 60 and 136 were truncated on 15 August 2000, due to fog. On that day, transect 60 was 5.75 km (2.3 km^2) and transect 136 was 6.43 km (2.57 km^2).

Table 2. Aerial survey flight specifications.

Survey Type	Year	Date	Aircraft	Altitude (m)	Speed (km/hr)	Survey Crew
Near-shore	1999	July 22	Cessna-185	30-45	160-180	T.J. Tiplady, W.W. Larned
		July 30	Aero Commander			T.J. Tiplady, R.M. Platte
		Aug. 11	Cessna-185			T.J. Tiplady, E. Taylor
		Aug. 26	Cessna-185			T.J. Tiplady, C.P. Dau
		Sept. 2	Aero Commander			T.J. Tiplady, S. Kendall
		Sept. 8	Cessna-185			T.J. Tiplady, E.J. Mallek
	2000	July 21				J.B. Fischer, E.J. Mallek
		Aug. 1				J.B. Fischer, E.J. Mallek
		Aug. 7				J.B. Fischer, E.J. Mallek
		Aug. 15				J.B. Fischer, E.J. Mallek
		Aug. 24				J.B. Fischer, E.J. Mallek
		Aug. 31				J.B. Fischer, E.J. Mallek
Offshore	1999	June 28-30	Aero Commander	90	200	T.J. Tiplady, D.K. Marks
		July 27-31		45	180	T.J. Tiplady, R.M. Platte
		Aug. 31-Sept. 3				W.W. Larned, J. Stich
	2000	June 24-27				J.B. Fischer, A. Brackney
		July 25-28				J.B. Fischer, D.K. Marks
		Aug. 25-30		90	200	J.B. Fischer, D.K. Marks

Near-shore Survey Data Analysis

EFFECTS OF HUMAN ACTIVITIES ON LONG-TAILED DUCKS

We used the general linear models designed by Johnson and Gazey (1992) to identify the effects of human activities on Long-tailed Ducks. We limited data analysis to 24 transects in Barrier Island, Mid-lagoon, and Mainland Shoreline Habitats within "Industrial" and "Control" areas. We combined data collected by LGL Ltd. in 1990-1991 with data collected by USFWS in 1999-2000. We first calculated Long-tailed Duck density for each transect on each survey day. We calculated density as the number of individuals per transect divided by transect area (transect length*400m). We then log transformed these density estimates (Ln [density+1]) to better meet the assumptions of normality required by parametric statistics (Johnson and Gazey 1992). Next, we subjected the dependent variable (log density) to a mixed-effects nested ANOVA and ANCOVA (Table 3) as specified by Johnson and Gazey (1992). These models were considered "mixed" because they incorporated both fixed and random factors. For example, Disturbance, Year, and Area were fixed factors, while Habitats and Transects were considered random factors. Unlike a factorial ANOVA that uses the residual error for calculation of the test statistic, a mixed-effects model uses specific error terms appropriate for particular tests (Table 3).

Table 3. Factors and error terms used to calculate F-statistic in ANOVA and ANCOVA models.

Term	Code	Error Term
Disturbance	D	Residual Error
Area	A	H(A)
Year	Y	YH(A)
Area*Year	AY	YH(A)
Habitat(Area)	H(A)	TH(A)
Year*Habitat(Area)	YH(A)	YT(H(A))
Transect(Habitat(Area))	T(H(A))	Residual Error
Year*Transect(Habitat(Area))	YT(H(A))	Residual Error
Ln (Wave+1)	W	Residual Error

Anova Model: Ln(Density+1) = Constant + D + A + AY + H(A) +YH(A) + T(H(A)) + YT(H(A))

Ancova Model: Ln(Density+1) = Constant + D + A + AY + H(A) +YH(A) + T(H(A)) + YT(H(A)) + W

In addition to having fixed and random factors in these models, some factors were nested. For example, Habitat was nested within Area. That is, a given Habitat was considered within the context of a given Area. Constructing the model in this fashion provided a means for comparing Area-Habitat strata. For example, if Long-tailed Duck densities in Mainland Shoreline habitat were not the same in the Industrial and Control areas, then the nested Habitat(Area) term would be significant. Similarly, Transects were nested within Habitat and Area; thus, transects were considered within the context of a particular Habitat in a specific Area.

To compare Long-tailed Duck population trends among the "Industrial" and "Control" areas, we examined the p-value associated with the Area*Year term. A significant Area*Year term would indicate that trends in density estimates were different between the "Industrial" and "Control" areas.

To determine if Long-tailed Duck densities were significantly related to human activities, we examined the p-value of the Disturbance term in the ANOVA model. The Disturbance term was based on human activities that we recorded on transect (boat traffic, low-level aircraft overflights [< 150 m], and land-based human activities [workers on land adjacent to transect]). We then applied an ordinal Disturbance code to each transect for each survey (1= 0 occurrences, 2= 1-5 occurrences, 3= 5-10 occurrences, 4= >10 occurrences; Johnson and Gazey 1992).

In accordance to MMS protocol (Johnson and Gazey 1992), these tests were re-assessed using ANCOVA. The process was identical to the ANOVA, with the exception that the covariate term Wave height was included in the model (Table 3). Wave height was calculated as Ln(Wave height in inches+1), and was estimated for each transect during all surveys (Johnson and Gazey 1992). Introduction of this covariate provided a control for lower sightability of Long-tailed Ducks due to high waves.

DISTRIBUTION IN THE NEAR-SHORE ENVIRONMENT

To assess distribution patterns of marine birds in 1999 and 2000, we log transformed (Ln[density+1]) densities of all taxa recorded on 44 transects in Near-shore Marine, Barrier Island, Mid-lagoon, and Mainland Shoreline Habitats, within “Industrial”, “Central” and “Control” areas. We then subjected these data to an ANCOVA model to assess how densities varied both among and within 12 Area-Habitat strata (4 Habitats nested in 3 Areas) while controlling for Year, Time of Day (morning, midday, afternoon, evening), and Wave Height (Ln[Wave height in inches+1]). To identify differences among strata we assessed the significance of the Habitat(Area) term. Similarly, to identify differences within strata we assessed the significance of the Transect(Habitat(Area)) term. We then used Sheffe multiple comparison methods to identify where differences occurred when terms were significant (Kleinbaum et al. 1988).

ASSESSING BIAS IN NEAR-SHORE SURVEYS

Mechanical difficulties in the single-engine survey aircraft in 1999 forced USFWS survey crews to use a twin-engine aircraft as an alternate survey platform during two replicates of the Near-shore survey. Because this change may have influenced density estimates of marine birds, we tested the effect of Survey Platform on density of Long-tailed Ducks in two ways. First, we used an independent two-tailed *t*-test to compare Long-tailed Duck log densities estimated from the single-engine platform with those estimated from the twin-engine platform. This test used Long-tailed Duck density as the independent variable and Survey Platform (single engine, twin engine) as the grouping variable. Second, we included a Platform factor (single-engine, twin-engine) in the ANOVA and ANCOVA models developed by Johnson and Gazey (1992) and re-evaluated the inter-area trend comparisons.

Offshore Survey Methods

The Offshore survey was designed specifically to monitor Spectacled Eider use of near-shore and offshore waters. Accordingly, transects were established in 1999 within areas of known Spectacled Eider presence as determined from telemetry studies (Petersen et al. 1999). This area included 36 transects spanning from Cape Halkett to Bullen Point (Fig. 4, transects 1-36). Given the need, however, to obtain distribution and abundance data for marine birds within range of a potential oil spill (Stehn and Platte 2000), we extended coverage east to Brownlow Point in 2000 with the addition of 7 transects (Fig. 4, transects 37-43). Unlike the Near-shore survey, offshore transect lines ran perpendicular to shore for approximately 60 km. Due to persistent fog on transects, we were unable to survey the northern extent of all transects during every flight; thus, the area (km^2) surveyed varied between replicates (Tables 4, 5). While on transect we recorded bird observations within 200m of both sides of the aircraft. Transects were spaced 5.4 km apart providing a 7.4% sample of the study area.

We completed 3 Offshore surveys in both 1999 and 2000. The surveys were conducted at the end of June, July, and August in each year. This timing was planned to coincide with estimated peaks of offshore abundance for local breeding Spectacled Eiders (i.e., exodus of breeding males [late June], failed or non-breeding females [late July], and successful breeding females with broods [late August]). Appropriate dates for surveying King (*Somateria spectabilis*) and Common Eiders (*S. mollisima*) were expected to be similar.

We contracted a twin-engine Aero Commander as a survey platform for the Offshore survey. Most surveys were flown at 45m and 180km/hr. Due to safety concerns, however, surveys in June 1999 and August 2000 were flown at approximately 90m and 200km/hr. Data recording methods were similar to the Near-shore survey. Specifically, we recorded bird observations directly as voice inputs into onboard computer systems interfaced with GPS; used a computerized moving map to navigate along fixed "electronic" transects for precise replication; and recorded wind speed, wave height, and percent ice cover on each transect within a strata.

As in the Near-shore surveys, individuals who participated in the Offshore surveys had prior experience in aerial surveys of waterbirds in Alaska. Similarly, observers were trained in flock size estimation using computer simulation software. Unlike the single-engine aircraft that were used for Near-shore surveys, twin-engine aircraft used in Offshore surveys do not have visible wing struts to provide a surface for outer-transect boundary markers; thus, observers relied on pre-survey training to practice distance estimation whereupon they flew over marked outer-transect boundaries at varying altitudes. Further, all observers that participated in Offshore surveys also completed surveys in the near-shore Beaufort Sea lagoons and in other locations in Alaska from single-engine aircraft. During surveys from single-engine aircraft, observers practiced transect width estimation using clinometer-calibrated wing-strut markings.

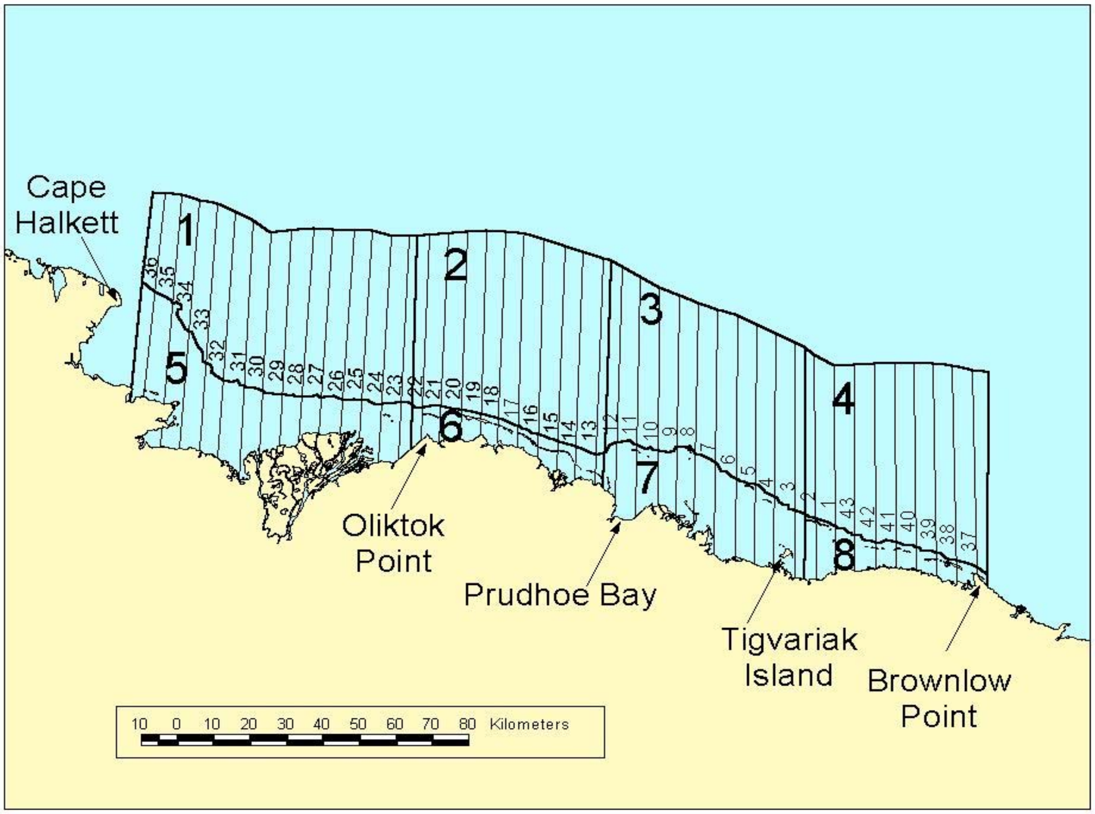

Figure 4. Offshore survey transects and strata, Beaufort Sea, Alaska, 1999-2000. Strata are indicated with bold numbers. Strata: 1- Harrison Bay Deep, 2- Industrial Deep, 3- Central Deep, 4- Control Deep, 5- Harrison Bay Shallow, 6- Industrial Shallow, 7- Central Shallow, 8- Control Shallow.

Offshore Survey Data Analysis

Unlike the Near-shore survey that was designed to assess effects of human activites on marine birds, the Offshore survey was initiated to delineate general distribution patterns of eiders and other marine birds. Prior to analysis, therefore, we divided the study area into 8 strata composed of four areas divided into deep (>10m) and shallow (<10m) zones (Fig. 4). The western area, located in Harrison Bay, extended from the mouth of the Kogru River, near Cape Halkett to Oliktok Point (transects 23-36). The remaining three areas corresponded to the Near-shore survey areas. For example, the Industrial area was bounded by Oliktok Point and Prudhoe Bay (transects 13-22), the Central area spanned from Prudhoe Bay to Tigvariak Island (transects 3-12), and the Control area was defined by Tigvariak Island and Brownlow Point (transects 1-2, 37-43).

To identify the components of variation in density (#birds/transect area) estimates, we used log density (Ln [density+1]) of a given taxa as the dependent variable in an ANCOVA. Using a saturated model of all factors, interaction terms and covariates (Table 6), we sequentially removed non-significant independent variables in a backward stepwise selection process (Kleinbaum et al. 1988) until only significant terms remained in a “final model”. This process provided a means for detecting differences in density of each marine bird taxa among strata, years, and months after controlling for significant interaction effects and confounding covariates.

We included three parameters in the ANOVA and ANCOVA models for Offshore survey analysis that were not included in the Near-shore models. Ice cover, and Wind speed were found to be unimportant in explaining variation of Long-tailed Ducks in the Near-shore area (Johnson and Gazey 1992), but these covariates had not been assessed in the Offshore survey area, thus we included them in our analyses. In addition, we included a Month factor in Offshore survey analysis because unlike the Nearshore survey that is conducted during a period of assumed stable density (Johnson and Gazey 1992), Offshore surveys were conducted over three months when it was assumed that distribution patterns would change.

ASSESSING BIAS IN OFFSHORE SURVEYS

We assessed potential bias introduced from fluctuating altitude during Offshore surveys in two ways. First we conducted a two-tailed *t*-test with Long-tailed Duck log density as the independent variable and Altitude (45 m vs. 90 m) as a grouping variable. Second, we tested the significance of an altitude term (45 m vs. 90 m) while controlling for all variables and covariates in the “final model”. This step provided a means to ask, given variability in density estimates associated with temporal and spatial factors (Year, Month, Strata, etc.), did Survey Altitude explain a significant proportion of variation?

Analysis and Presentation

Presentation of density estimates in figures and tables are reported in log transformed format (Ln [density+1]) to correspond with existing MMS protocol (OCS-MMS 92-0060, Johnson and Gazey 1992). This format allows the reader to distinguish the degree of statistical significance of inter-area comparisons and distribution differences. Because these surveys were aimed at detecting trends rather than abundance estimates, transformed density estimates provide a reliable indicator of statistical differences. Readers can find actual counts and standard densities for each survey in Appendices 1, 2 and 4.

We used SYSTAT 7.0 (SYSTAT 1997) for statistical analysis in this report.

Table 4. Area (sq. km) surveyed by subtransect and stratum during each of six Offshore surveys, Beaufort Sea, Alaska, 1999-2000. Subtransect suffix refer to depth class (d = deep, s = shallow). See Figure 4 for location of strata.

			1999			2000	
STRATUM	SUBTRANSECT	June	July	August	June	July	August
Harrison Bay Deep (1)	23d	18.6	17.7	17.6	18.7	18.8	18.7
	24d	19.7	18.1	17.9	19.7	19.7	19.8
	25d	25.8	20.2	20.6	19.4	19.6	19.6
	26d	24.2	20.3	20.3	24.0	24.1	24.0
	27d	21.5	14.2	19.5	21.6	21.8	21.6
	28d	20.8	14.2	19.5	21.1	21.2	21.1
	29d	19.1	17.5	16.9	18.7	19.1	18.9
	30d	18.3	17.1	16.9	18.5	18.2	18.4
	31d	14.9	12.9	15.7	17.5	16.7	16.4
	32d	16.9	14.8	16.1	16.8	17.1	16.8
	33d	16.7	14.0	14.2	16.2	16.6	16.6
	34d	12.1	10.6	10.7	12.1	12.1	12.0
	35d	13.5	8.8	12.1	10.9	10.9	10.6
	36d	9.7	9.6	10.9	11.2	11.0	11.0
	Stratum Total	**251.8**	**209.9**	**228.8**	**246.5**	**246.9**	**245.5**
Industrial Deep (2)	13d	20.3	8.2	17.5	20.1	8.7	20.2
	14d	18.9	19.0	16.7	19.9	10.7	19.9
	15d	20.1	18.4	16.4	20.7	17.3	20.4
	16d	19.5	13.3	16.2	21.1	20.1	21.0
	17d	20.7	12.6	22.7	21.1	21.2	20.7
	18d	19.9	5.2	21.6	20.5	20.6	18.1
	19d	21.0	18.2	21.3	21.0	21.1	7.0
	20d	20.6	17.8	20.5	20.8	20.7	10.3
	21d	17.1	20.4	20.5	20.5	20.5	20.7
	22d	18.2	21.2	21.4	21.4	21.5	21.8
	Stratum Total	**196.3**	**154.3**	**194.8**	**207.2**	**182.3**	**180.0**
Central Deep (3)	10d	-	17.8	17.7	18.2	18.0	17.7
	11d	12.5	17.1	15.2	16.8	16.9	16.9
	12d	12.7	8.5	15.0	17.6	17.1	18.7
	3d	18.6	20.1	17.3	17.8	6.5	18.0
	4d	15.5	14.4	16.0	17.2	4.8	16.3
	5d	8.4	15.1	14.2	15.1	4.4	15.1
	6d	9.3	10.8	14.0	14.3	3.8	13.9
	7d	5.2	12.5	16.9	13.6	2.4	13.4
	8d	2.3	13.5	16.4	14.6	1.9	14.5
	9d	0.6	12.1	16.7	17.4	17.6	17.3
	Stratum Total	**84.9**	**141.9**	**159.4**	**162.8**	**93.5**	**161.9**
Control Deep (4)	1d	24.2	18.9	18.6	19.9	7.6	19.4
	2d	22.9	18.3	17.8	18.6	7.2	18.6
	37d	-	-	-	23.0	11.2	7.9
	38d	-	-	-	20.5	12.2	20.4
	39d	-	-	-	21.2	11.0	21.3
	40d	-	-	-	20.9	10.2	21.1
	41d	-	-	-	20.9	9.5	21.1
	42d	-	-	-	19.7	10.2	20.1
	43d	-	-	-	19.6	8.9	19.5
	Stratum Total	**47.1**	**37.3**	**36.3**	**184.4**	**88.0**	**169.5**

			1999			2000	
STRATUM	SUBTRANSECT	June	July	August	June	July	August
Harrison Bay Shallow (5)	23s	6.6	6.6	6.6	6.6	6.6	6.6
	24s	6.7	6.7	6.7	6.7	6.7	6.7
	25s	4.5	4.5	4.5	4.5	4.5	4.5
	26s	4.1	4.1	4.1	4.1	4.1	4.1
	27s	4.3	4.3	4.3	4.3	4.3	4.3
	28s	5.4	5.4	5.4	5.4	5.4	5.4
	29s	6.2	6.2	6.2	6.2	6.2	6.2
	30s	7.5	7.5	7.5	7.5	7.5	7.5
	31s	11.2	11.2	11.2	11.2	11.2	11.2
	32s	9.1	9.1	9.1	9.1	9.1	9.1
	33s	10.2	10.2	10.2	10.2	10.2	10.2
	34s	13.7	13.7	13.7	13.7	13.7	13.7
	35s	14.0	14.0	14.0	14.0	14.0	14.0
	36s	12.2	12.2	12.2	12.2	12.2	12.2
	Stratum Total	**115.5**	**115.5**	**115.5**	**115.5**	**115.5**	**115.5**
Industrial Shallow (6)	13s	3.6	3.6	3.6	3.6	3.6	3.6
	14s	3.9	3.9	3.9	3.9	3.9	3.9
	15s	3.4	3.4	3.4	3.4	3.4	3.4
	16s	2.7	2.7	2.7	2.7	2.7	2.7
	17s	2.5	2.5	2.5	2.5	2.5	2.5
	18s	2.9	2.9	2.9	2.9	2.9	2.9
	19s	2.6	2.6	2.6	2.6	2.6	2.6
	20s	3.5	3.5	3.5	3.5	3.5	3.5
	21s	4.4	4.4	4.4	4.4	4.4	4.4
	22s	3.7	3.7	3.7	3.7	3.7	3.7
	Stratum Total	**33.0**	**33.0**	**33.0**	**33.0**	**33.0**	**33.0**
Central Shallow (7)	10s	5.8	6.5	6.5	6.5	6.5	6.5
	11s	8.3	8.3	8.3	8.3	8.3	8.3
	12s	6.6	6.6	6.6	6.6	6.6	6.6
	3s	8.0	8.0	8.0	8.0	8.0	8.0
	4s	8.1	8.1	8.1	8.1	8.1	8.1
	5s	9.3	9.3	9.3	9.3	9.3	9.3
	6s	9.7	9.7	9.7	9.7	9.7	9.7
	7s	10.6	10.6	10.6	10.6	10.6	10.6
	8s	8.6	8.6	8.6	8.6	8.6	8.6
	9s	8.4	8.4	8.4	8.4	8.4	8.4
	Stratum Total	**83.4**	**84.2**	**84.2**	**84.2**	**84.2**	**84.2**
Control Shallow (8)	1s	5.5	5.5	5.5	5.5	5.5	5.5
	2s	7.1	7.1	7.1	7.1	7.1	7.1
	37s	-	-	-	0.9	0.9	0.9
	38s	-	-	-	2.8	2.8	2.8
	39s	-	-	-	2.7	2.7	2.7
	40s	-	-	-	2.7	2.7	2.7
	41s	-	-	-	2.9	2.9	2.9
	42s	-	-	-	3.2	3.2	3.2
	43s	-	-	-	4.1	4.1	4.1
	Stratum Total	**12.6**	**12.6**	**12.6**	**31.8**	**31.8**	**31.8**

Table 5. Area (km^2) surveyed per stratum during each of six replicates, Beaufort Sea, Alaska, 1999-2000.

		Stratum[a]							
Year	Month	1	2	3	4	5	6	7	8
1999	June	251.8	196.3	84.9	47.1	115.5	33.0	83.4	12.6
	July	209.9	154.3	141.9	37.3	115.5	33.0	84.2	12.6
	August	228.8	194.8	159.4	36.3	115.5	33.0	84.2	12.6
2000	June	246.5	207.2	162.8	184.4	115.5	33.0	84.2	31.8
	July	246.9	182.3	93.5	88.0	115.5	33.0	84.2	31.8
	August	245.5	180.0	161.9	169.5	115.5	33.0	84.2	31.8

[a] Strata: 1- Harrison Bay Deep, 2- Industrial Deep, 3- Central Deep, 4- Control Deep, 5- Harrison Bay Shallow, 6- Industrial Shallow, 7- Central Shallow, 8- Control Shallow.

Table 6. Independent variables incorporated into ANOVA and ANCOVA models to explain variability in marine bird log densities (Ln[density+1]) during Offshore surveys, Beaufort Sea, Alaska, 1999-2000.

Independent Variable	Variable Code	Variable Type
Stratum	S	Factor (1-8)
Year	Y	Factor (1999, 2000)
Month	M	Factor (June, July, August)
Altitude	A	Factor (45 m, 90 m)
Stratum*Year	SY	Interaction term
Stratum*Month	SM	Interaction term
Year*Month	YM	Interaction term
Stratum*Year*Month	SYM	Interaction term
Percent ice cover	I	Covariate (Arc-sine transformed)
Wave height (ft.)	Wa	Covariate (Ln transformed)
Wind speed (mph)	Wi	Covariate