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Oilfield Development and Glaucous Gull (*Larus hyperboreus*) Distribution and Abundance in Central Alaskan Beaufort Sea Lagoons, 1970–2001

LYNN E. NOEL,[1] STEPHEN R. JOHNSON[2] and WILLIAM J. GAZEY[3]

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ABSTRACT. We evaluated aerial survey data for glaucous gulls (*Larus hyperboreus*) in central Alaskan Beaufort Sea lagoons near the Prudhoe Bay oilfields during June to September 1978–2001 for trends in numbers of glaucous gulls, associations with human activity, and confounding relationships with environmental variables. Most glaucous gulls were in barrier island and mainland shoreline habitats, and the total number of gulls per survey ranged from 50 to 1600. Seasonal variation in abundance was apparent, with the largest numbers of gulls consistently recorded during September surveys. Ice cover and wave height had a significant negative correlation with the linear density of glaucous gulls (gulls/km). There was no clear trend in abundance of gulls in the lagoons at Prudhoe Bay or obvious interaction with human activity (such as air traffic, boat traffic, or humans on land or water) in the survey area during the period of oilfield development (1978–2001). We compiled glaucous gull nest counts from 1970 to 2001 across barrier islands to evaluate trends in the number of nests and associations with other colonial nesting species. The mean number of active glaucous gull nests increased from 1970–74 (77.6 nests per year) to 1975–85 (154.4 nests per year), but there was no evidence of a difference from 1970–74 to 1987–2001 (153.0 nests per year). However, the change in 1976 from aerial to ground-based nest surveys confounds comparison of the survey periods before this date (1970–74) with those after it (1975–85 and 1987–2001). A strong positive relationship between the number of glaucous gull nests and both common eider and snow goose nests suggests that common environmental variables may be regulating nesting for these species.

Key words: ANCOVA, aerial monitoring surveys, multiple linear regression, nest surveys, predator-prey relationship, time trend

RÉSUMÉ. On a évalué les données de relevés aériens pour les goélands bourgmestres (*Larus hyperboreus*) des lagunes de la mer de Beaufort dans le centre de l'Alaska, près des champs pétrolifères de la baie Prudhoe des mois de juin à septembre des années 1978 à 2001 afin de déterminer les tendances caractérisant le nombre de goélands bourgmestres, leurs associations avec l'activité humaine et les relations confondues avec les variables environnementales. La plupart des goélands bourgmestres évoluaient dans des habitats faisant partie de cordons d'îles et de rivages continentaux. Le nombre total de goélands faisant l'objet de chaque relevé variait de 50 à 1600. Du point de vue de l'abondance, les variations saisonnières étaient évidentes, le nombre le plus élevé de goélands étant constamment enregistré en septembre. La couverture de glace et la hauteur des vagues avaient une importante corrélation négative sur la densité linéaire des goélands bourgmestres (goélands/km). Il n'y avait pas de tendance claire en ce qui a trait à l'abondance des goélands sur les lagunes de la baie Prudhoe ou d'interaction évidente avec l'activité humaine (comme la circulation aérienne, la circulation maritime ou les êtres humains évoluant sur la terre ou sur l'eau) dans la zone visée par les relevés pendant la période de mise en valeur des champs pétrolifères (soit de 1978 à 2001). On a compilé le nombre de nids de goélands bourgmestres de 1970 à 2001 à l'échelle du cordon d'îles pour évaluer les tendances caractérisant le nombre de nids et d'associations avec d'autres espèces à nidification qui vivent en colonies. Le nombre moyen de nids de goélands bourgmestres actifs a augmenté de 1970–74 (77.6 nids par année) à 1975–85 (154,4 nids par année). Cependant, il ne semblait pas y avoir de différence entre 1975–85 et 1987–2001 (153,0 nids par année). Cela dit, l'écart enregistré en 1976 entre les relevés aériens et les relevés terrestres à l'égard des nids confond la comparaison des périodes de relevés avant cette date (1970–74) avec celles qui suivent (1975–85 et 1987–2001). Une forte relation positive entre le nombre de nids de goélands bourgmestres et le nombre de nids d'eiders à duvet et d'oies blanches suggère que des variables environnementales communes peuvent régulariser la nidification de ces espèces.

Mots clés : ANCOVA, relevés de surveillance aérienne, régression linéaire multiple, relevés de nids, relation prédateur-proie, tendance temporelle

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[1] Corresponding author: LGL Alaska Research Associates, Inc., 1101 East 76th Avenue, Suite B, Anchorage, Alaska 99518, U.S.A.; present address: ENTRIX, Inc., 1600 A Street, Suite 304, Anchorage, Alaska 99501, U.S.A.; lnoel@entrix.com
[2] LGL Limited, environmental research associates, 9768 Second Street, Sidney, British Columbia V8L 3Y8, Canada; srj@lgl.com
[3] W.J. Gazey Research, 1214 Camas Court, Victoria, British Columbia V8X 4R1, Canada; bgazey@telus.net

INTRODUCTION

Glaucous gulls (*Larus hyperboreus*) have a circumpolar distribution and commonly prey on nesting birds in the Arctic, particularly on waterfowl eggs and chicks (Campbell, 1975; Åhlund and Götmark, 1989; Johnson et al., 1992; Gilchrist and Gaston, 1997; Day, 1998; Gilchrist et al., 1998; Samelius and Alisauskas, 1999; Noel et al., 2001). These large gulls occur within the breeding ranges of two threatened species, spectacled eider (*Somateria spectabilis*) and Steller's eider (*Polysticta stelleri*) (58 U.S. Federal Register 27474; 62 U.S. Federal Register 31748), and 10 other species of sea ducks thought to be declining in number (Bowman et al., 1997; Elliot, 1997; USFWS, 1999).

Although glaucous gulls are predators, they are also generalists that use a broad range of food resources (Strang, 1976, 1982; Barry and Barry, 1990; Schmutz and Hobson, 1998; Gilchrist, 2001). In the oilfield area of Arctic Alaska, glaucous gulls feed at the Prudhoe Bay landfill and at open garbage dumpsters, and they have been implicated as predators of nesting birds there and at other Arctic locations. Waste management techniques, such as continual covering of the active surface and nighttime dumping, have eliminated access to refuse by gulls at most modern landfills (Davis and Mangino, 2001). However, these techniques are not commonly used in Arctic Alaska. Although the nutritional value of access to the Prudhoe Bay landfill for nesting glaucous gulls is not known (Murphy et al., 1987; Belant et al., 1993), Murphy et al. (1987) noted that the numbers of glaucous gull nests on the barrier islands decreased with increasing distance from Prudhoe Bay and speculated that this trend indicated a possible benefit to gulls from the garbage produced by the oilfield. It has been suggested that the availability of these food sources has caused increases in glaucous gull numbers on the North Slope (Murphy et al., 1987; Day, 1998). In some cases, the potential for increasing gull populations is perceived as a threat:

> Domestic and industrial development activities on the North Slope are generating large volumes of solid waste in unnatural settings, precisely the sort of environment that facilitates explosive increases in juvenile gull survival. Artificially high glaucous gull populations will pose problems in northern and western Alaska similar to the problems abnormally high glaucous-winged gull populations present in south coastal areas. (Patten, 1994)

In this paper we (1) review distribution and population trends of glaucous gulls on Alaska's Arctic Coastal Plain (ACP) and (2) analyze two historical datasets from the Prudhoe Bay region to evaluate the influence of this industrial development on glaucous gulls.

REVIEW OF ALASKA'S ACP GLAUCOUS GULLS

Glaucous gull numbers have apparently increased at some sites in western Alaska. For example, Springer (1987) reported a threefold increase in the numbers of glaucous gulls at the Nome landfill over a 10-year period, while Bowman et al. (1997) reported that the nesting glaucous gull population more than doubled during a 12-year period between 1985 and 1996 in the Yukon-Kuskokwim Delta (Y-K Delta). However, a circumpolar review of glaucous gulls concluded that both the total population size and population trend are poorly known (Gilchrist, 2001).

Current Numbers

In Alaska, the glaucous gull population has been estimated at more than 100 000 individuals (S. Stephensen and T. Bowman, pers. comm. in Gilchrist, 2001). About 18 000 individuals inhabited the ACP and ACP coastline during June–July 2001 (Dau and Anderson, 2001 [5499 individuals]; Mallek et al., 2002 [12 225 ± 1273 individuals]). For comparison, the nesting population in western Alaska's Y-K Delta was approximately 30 000 individuals (Bowman et al., 2001 [13 043 ± 5711 nests]).

Current Distributions

Glaucous gull numbers recorded during late June–early July along the coastline of Alaska's ACP in 2001–02 (Dau and Anderson, 2001, 2002) generally increased from east to west (from the Alaska–Canada border to Cape Beaufort, Alaska), with concentrations documented near coastal villages and at Prudhoe Bay (Fig. 1). Transects adjacent to villages had the largest proportions of total glaucous gulls: mean percentages of the total number of glaucous gulls during 2001–02 were 12.2% near Point Lay (transects 3 and 4), 23.7% near Wainwright (transects 8 and 9), 20.2% near Barrow (transects 11 and 12), and 6.5% near Kaktovik (transects 25 and 26; Fig. 1). One transect between the Colville River delta and the western edge of the Sagavanirktok River delta (transect 19, roughly equivalent to the industrial area in Fig. 2) adjacent to the Prudhoe Bay oilfields had, on average, 2.0% of the glaucous gulls observed (Fig. 1). A transect covering the coastal area adjacent to the Badami oilfield (transect 20, roughly equivalent to the reference area in Fig. 2) had, on average, 3.2% of glaucous gulls during 2001–02 (Fig. 1).

Trend in Numbers Since 1992

Glaucous gull numbers have been recorded during the U.S. Fish and Wildlife Service's (USFWS) aerial waterfowl breeding pair surveys on the ACP of Alaska since 1992 (Mallek et al., 2002). Trend analysis indicates that this glaucous gull population is increasing at a rate of 4.3% ± 6.0% per year (90% confidence interval [CI]; $p = 0.216$; Mallek et al., 2002). Glaucous gull numbers collected

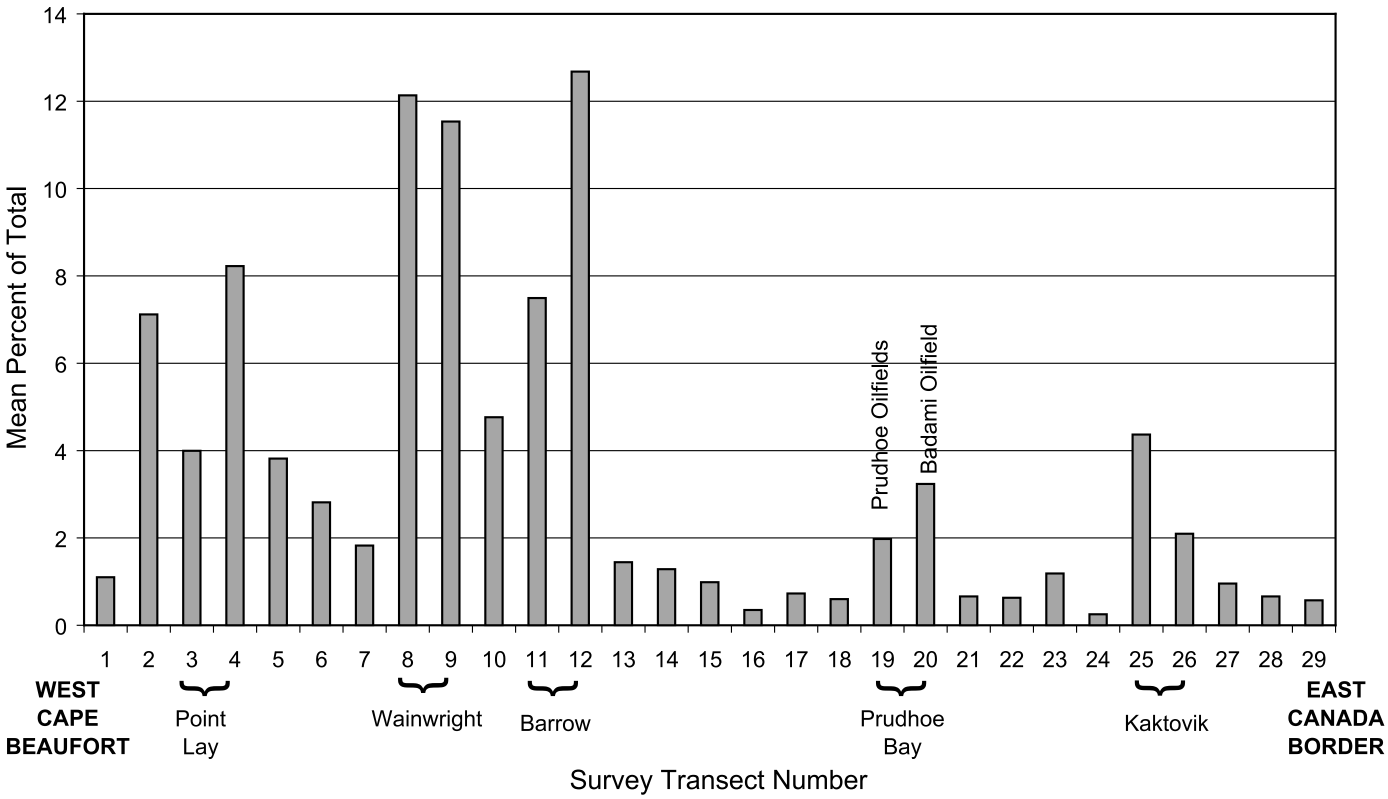

FIG. 1. Distribution of mean percent of total glaucous gulls on coastal aerial survey transects in late June to early July, Arctic Coastal Plain of Alaska, 2001–02. Mean proportions were calculated by averaging the proportion of total glaucous gulls for each transect in 2001 (Dau and Anderson, 2001: Table 2), and 2002 (Dau and Anderson, 2002: Table 2).

during eider surveys across the northern half of the ACP survey area show a growth rate of 2.0% ± 3.1% per year (90% CI) from 1992 to 2001 ($p = 0.545$; Larned et al., 2001). Although both surveys show increasing trends, neither trend is significant.

Nesting Trends

Ground-based nest searches also indicate the status of a nesting population within an area both in terms of changes in the total number of nests and with additional information on the proportion of active nests and clutch sizes. Clutch size may reflect population growth and health in gulls (Pierotti and Bellrose, 1986). Most Larid gulls lay two or three eggs per nest, and resource abundance may be indicated by clutch size, egg size, and in particular the size of the third egg in the clutch (Kadlec and Drury, 1968; Murphy et al., 1984; Pierotti and Bellrose, 1986; Hiom et al., 1991; Pons and Migot, 1995; Kilpi et al., 1996; Oro et al., 1996).

Nest surveys within a portion of the Y-K Delta in western Alaska have been conducted since 1985, and population estimates for glaucous gulls have been calculated since 1992 (Bowman et al., 2001). The mean annual rate of increase in glaucous gull nests from these ground-based nest searches during 1992–2001 was 4.5% (Bowman et al., 2001).

The proportion of active nests and mean clutch sizes recorded for glaucous gulls since 1983 in the Y-K Delta indicate (1) that since 1993, over 90% of nests have been active, and (2) that since 1990, except during 2001 when predation rates were high, mean clutch size has consistently been greater than 2.5 eggs/nest (Bowman et al., 2001). By contrast, on the central Beaufort Sea barrier islands during 1999–2001, both the proportion of active nests (< 60%: 28% in 1999, 58% in 2000, and 57% in 2001) and mean clutch size of 2.1 eggs/nest (1.8 ± 0.65 95% CI in 1999, 2.2 ± 0.43 95% CI in 2000, and 2.4 ± 0.39 95% CI in 2001) were lower than in the Y-K Delta (Noel and Johnson, 2000; Bowman et al., 2001; Noel et al., 2001, 2002a). This lower clutch size on the barrier islands may indicate either that resources were limited during egg laying, which leads to smaller clutch sizes, or that depredation and second clutches (usually only two eggs) may be more common on the Beaufort Sea barrier islands than in the Y-K Delta. In either case, the Beaufort Sea coastal area appears to be less productive than the Y-K Delta for nesting glaucous gulls.

ANALYSIS OF HISTORICAL DATA SETS – METHODS

Beaufort Sea Aerial Survey Data

We compiled glaucous gull numbers recorded on systematic aerial survey transects in the Beaufort Sea lagoons during June to September 1978–2001 (Fig. 2) collected in

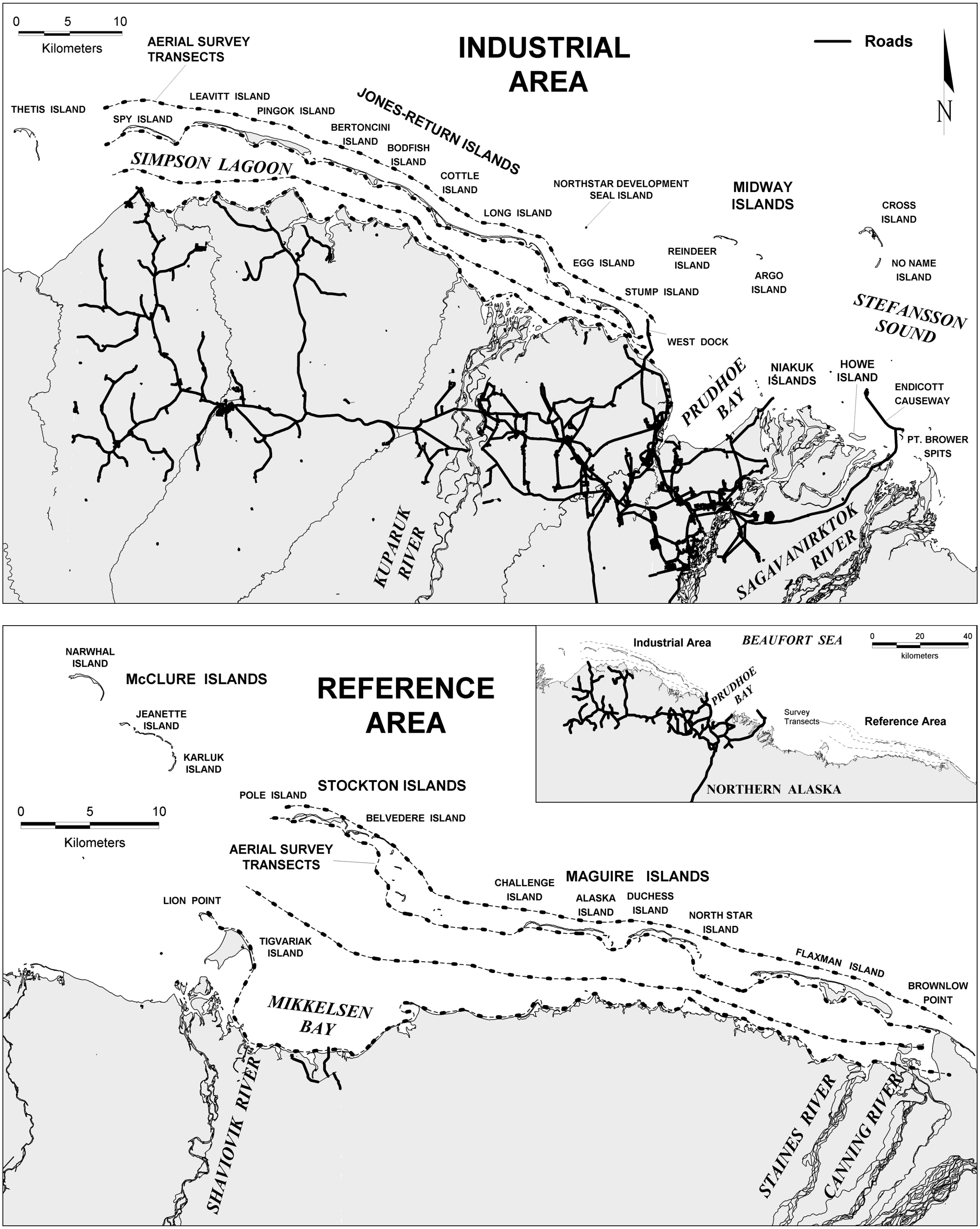

FIG. 2. Aerial survey transects monitored during 1978–2001 and barrier islands censused for nests during 1970–2001 in the barrier island-lagoon systems, Beaufort Sea, Alaska.

TABLE 1. Variable names and descriptions for aerial survey data collected in central Alaskan Beaufort Sea lagoons, June to September 1978–2001 (Fig. 2).

Description	Cases	
Dependent Variables:		
Number of glaucous gulls on-transect	Gulls sighted within 200 m each side of plane by 2 observers	
Linear density of glaucous gulls	On-transect density (gulls/km) - 400 m wide transects	
Grouping variables:		
Survey day	June to September (73 dates in 14 years)	
Transect number	7 transects in Area 1, 16 transects in Area 2, 16 transects in Area 3	
Survey year (Y)	1978 to 2001 (14 years)	
Habitat (H)	Island – 200 m south of barrier island shoreline Mid-lagoon Mainland shore – 200 m north of mainland shoreline Nearshore marine – 1 km north of barrier islands	
Survey area (A) (Fig. 2)	1. Stefansson Sound (transects not shown on Fig. 2) - Prudhoe Bay to Stockton Island 2. Industrial Area – Simpson Lagoon to West Dock 3. Reference Area – Mikkelson Bay/Flaxman Island area	
Covariates:		
Wind speed (km/h)		
Wind direction (degrees)		
North component of wind	wind speed × cos wind direction	
Northeast component of wind	wind speed × cos wind direction + 45˚	
Percent ice on transect	visual estimate (0% to 100%)	
Wave height in inches (WAVEHT)		
Wave height in inches (WAVE)	log transformation of mean wave height + 1	
Upwelling potential	Low, Medium, High	
Season	Day in season – 1 June = 1 (range 22 to 115)	
Human activity (DISTURB)	Nil:	No human activity or disturbance
	Low:	5 or fewer cases of low-level (< 500 ft) aircraft overflights, boat traffic, or human activity on land or water during survey
	Moderate:	5 to 9 cases of low-level aircraft overflights, boat traffic, or human activity
	High:	10 or more cases of low-level aircraft overflights, boat traffic, or human activity, or spillage of low levels or toxic materials and associated clean-up activities on land or water during survey, or semi-permanent structures established in area with frequent human activity, or a combination
	Extreme:	Major spill of toxic materials and associated clean-up activities on land or water during survey, or permanent structures established with near-continuous human activity, or both
Sum of human activity (D)	Sum of human activity for one habitat (4 transects) within a survey area	
Indicator of human activity (IDIST)	Minimal:	All 10 transects for regression and ANCOVA coded as no human activity
	Some:	Some disturbance recorded on any of the 10 transects used for regression and ANCOVA

conjunction with a monitoring program designed for molting male long-tailed ducks (*Clangula hyemalis*) (Johnson and Gazey, 1992; Johnson et al., 2005). Aerial surveys were conducted within a geographically structured hierarchy of area (industrial and reference), habitat within an area (nearshore marine, south of the south barrier island shoreline, mid-lagoon, and north of the mainland shoreline), and transect within habitat (four transects per habitat per area). All variables used in our analyses are described in Table 1 and were recorded for each transect established in 1978, depicted in Figure 2, and described in detail in Johnson and Gazey (1992) and Johnson et al. (2005).

We evaluated trends in numbers of glaucous gulls over time, associations with recorded human disturbances, and confounding relationships with environmental variables, using three analytic approaches: (1) simple correlation analysis, (2) multiple linear regression and analysis of covariance (ANCOVA), and (3) structured ANCOVA similar to that used by Johnson and Gazey (1992) and Johnson et al. (2005).

Correlation Analysis: To identify interactions between predictor variables and linear density of glaucous gulls (gulls/km; Table 1) that could be used to increase the power of the regression and ANCOVA analyses, we calculated pair-wise correlations for all covariates. We used the non-parametric rank order Kendall’s Tau correlation because of the frequent observations with zero glaucous gulls on transect. All transect observations (n = 1524, 73 days during 1978–2001) were used to calculate correlation coefficients.

Regression and ANCOVA: We evaluated the longest-term, consistently collected survey data for trends in abundance over time and for interactions with human activity and covariates using multiple linear regression and ANCOVA.

Ten transects in the industrial area, four along the south side of the barrier islands, four through the middle of the lagoon, and two along the mainland shoreline (Fig. 2), were consistently sampled on 50 days during 1978–2001. The numbers of glaucous gulls observed on transect for each survey date were summed for these 10 transects. Sums were log-transformed to normalize their distributions, and a multiple linear regression of the log-transformed sums with survey day and season was then completed.

An ANCOVA of the time trend data was completed by casting an indicator of human activity as either none (all 10 transects coded as no human activity) or some (some human activity recorded on any of the 10 transects). Multiple covariates, transformed to normalize their distribution, were also introduced (Table 1). Any statistically non-significant covariates or interactions with survey day or indicator of human activity were then eliminated following a stepwise procedure (Johnson, 1990; Milliken and Johnson, 2002). The distributions of the ANCOVA residuals were examined with probability plots (Milliken and Johnson, 2002) to ensure normality and lack of kurtosis.

Structured ANCOVA: We used a structured ANCOVA of survey data balanced for habitats within the industrial and reference areas to increase the power of our time trend and human activity analyses. This structured ANCOVA, similar to that used by Johnson and Gazey (1992) and Johnson et al. (2005), was conducted on the 1990–2001 glaucous gull data to test for time trend and disturbance interactions. This model was balanced for habitats along the south side of barrier island shorelines, through the middle of the lagoon, and along the mainland shoreline in the industrial and reference areas (Fig. 2). To reduce the frequency of zero glaucous gull observations, we simplified the model by summing all on-transect observations that occurred on the same survey day, within the same area, and within the same habitat. This reduced the frequency of observations with zero glaucous gulls to 7.7%. The model used to investigate distribution related to human activity was as follows:

$$\ln(\Sigma N + 1) = \text{constant} + D + \{\text{covariates}\} \\ + A + Y + AY + H(A) + YH(A)$$

where N is the number of glaucous gulls on-transect, D is the indicator of human activity, {covariates} represents the set of all covariates, A is area (reference and industrial), Y is year, and H is habitat. Parentheses designate the factors that are nested, e.g., H(A) means that habitat is nested within area.

The indicator of human activity (D) was treated as a simple blocking (stratification) variable instead of a covariance adjustment (Johnson and Gazey, 1992; Johnson et al., 2005). If the covariance relationship is non-linear, then stratification provides reduction in the experimental error, a more powerful test, and a function-free regression scheme (Winer, 1971). Dropping transect as a factor by summing the number of gulls for transects within the same area and within the same habitat for each survey day did not introduce bias, but some power may have been lost by the reduction in degrees of freedom.

Factors chosen on a systematic, non-random basis (indicator of human activity, year, and area) were considered fixed factors, and inferences were applied only to the levels tested. Factors chosen at random from a very large population of potential levels were considered random factors, and inferences were extended to the entire population. Because habitat classifications could have been defined from many alternatives, habitat was considered "random" during analyses (i.e., fewer degrees of freedom for test statistics) but inferences were restricted to the levels tested (Milliken and Johnson, 1984).

Unique effects associated with one factor that were confined to levels of another factor were considered nested (e.g., habitat can only be considered in the context of an area). We assumed that interactions between area and habitat were confined to each of the areas. The sum of squares for nested factors was calculated as the sum of the factors obtained from a fully crossed model, i.e.,

$$H(A) = H + HA$$
$$YH(A) = YH + YHA$$

For the year-habitat interaction, the pooled components (YH and YHA) were separate measures of the variation of the year-habitat interaction. Results showed that the sum of squares for YH and YHA were almost equal (6.09 versus 7.76), providing some empirical justification for nesting. A biological justification for nesting habitat within area was that habitat was not identical in the two study areas. The mainland shoreline in the reference area contains many small bays and lagoons with protective spits and islands; such habitats are mostly absent from the industrial area (Fig. 2).

Covariates considered for the model were wind speed, wind direction, northern component of wind, northeastern component of wind, percent ice cover, and wave height. Percent ice cover was recast through an arc sine square root transformation in order to normalize the residuals. Non-significant covariates or interactions with year and area were eliminated following the step procedure recommended by Milliken and Johnson (2002).

The model presented above was considered a two-factor experiment for year and area with repeated measurements (survey dates) for area. Under the condition that all measurements were complete in each area for each survey date, and that the entire experiment is replicated for each survey date, the univariate tests for year and year-area interaction were not confounded with the differences between groups (Winer, 1971). The practical implication of this study design was that as long as the analysis was restricted to survey days when all transects were sampled, the tests for year and year-area effects were valid regardless of any correlation between or among habitats. The tests for year and year-area effects were also valid in the

TABLE 2. Numbers of glaucous gulls summarized by month for 14 years of aerial surveys in central Alaskan Beaufort Sea lagoon habitats, June to September 1978–2001 (Fig. 2).

			Industrial Area					Reference Area				
		Habitat[1]	I	M-L	MS	N	IT	I	M-L	MS	N	RT
Month	Year	No. of Surveys					(I + M-L + MS)					(I + M-L)
June	1978	1	41	0	1	1	42					
July	1978	3	127.3	8.3	31.0	1.0	167	18.5	4.0			23
August	1978	4	44.7	1.0	3.0	0.0	49	18.5	3.5			22
September	1978	4	212.7	3.8	9.3	0.3	226	133.0	44.0			177
June	1979	1	42	5	1	0	48					
July	1979	1	40	0	5	0	45	15	1			16
August	1979	1	304	0	21	1	325					
September	1979	2	705.5	19.0	6.0	0.0	731					
August	1980	1	132	0	14	0	146	116	18			134
July	1981	2	48.5	2.5	14.0	1.5	65					
August	1981	3	134.7	0.7	9.0	1.0	144	45	1			46
September	1981	1	1155	15	29	7	1199					
July	1982	2	40.5	5.5	28.5	1.0	75					
August	1982	2	90.5	39.5	48.5	2.5	179					
September	1982	1	145	20	46	17	211					
July	1983	1	0	0								
August	1984	1	31	0	28	1	59	5	8			13
August	1989	3	101.0	1.0		0.3		36.3	14.3		1.3	51
July	1990	3	20.0	1.7	5.7	1.3	27	11.7	17.7	27.0	15.0	29
August	1990	5	122.2	0.2	15.6	0.0	138	27.3	2.8	10.3	1	30
September	1990	3	262.3	0.7	5.3	0.0	268	612.3	447.7	60.7	0	1060
July	1991	4	66.0	0.5	43.3		110	16.3	41.7	29.3		58
August	1991	5	50.8	1.0	12.6	0.0	64	4.0	7.0	5.0	1.0	11
August	1998	4						23.5	10.0	16.8		34
September	1998	1						4	6	25		10
July	1999	1	69	5	52	23	126	8	47	23	2	55
August	1999	5	102.0	2.3	22.8	3.3	127	32.7	3.3	42.7	3.7	36
August	2000	5	138.6	1.6	38.6	8.4	179	11.3	12.0	41.3	0.8	23
July	2001	1	226	17	104	0	347	28	4	163	3	32
August	2001	2	46.5	1.5	16.0	0.0	64	8.5	3.0	12.0	0.0	12

[1] I = Island; M-L = Mid-Lagoon; MS = Mainland Shore; N = Nearshore; IT = Industrial Total; RT = Reference Total.

presence of additive carryover or lingering effects (e.g., events during a survey that may affect the distribution and abundance of gulls in a subsequent survey). In contrast, the test for relating glaucous gull distribution to human activity requires independent observations within a cell (surveys taken within a habitat/area over a year).

Barrier Island Nest Data

Glaucous gull nests were counted by agency- and industry-sponsored groups on the barrier islands from Thetis Island to Flaxman Island during the period 1970–2001 (Fig. 2). Data for common eider (*Somateria mollissima v-nigrum*) nests on the same barrier islands and for lesser snow goose (*Chen caerulescens caerulescens*) nests on Howe Island were also compiled so that glaucous gull trends could be associated with those of other colonial nesting species. Common eiders, snow geese, and black brant (*Branta bernicla nigricans*) represent the majority of colonial nesting waterfowl potentially affected by predatory glaucous gulls in the Prudhoe Bay area. Nest searches were conducted either from aircraft during overflights (1970–75, 1986) or during ground-based searches (1976–2001) on dates ranging from early June to late July.

To evaluate trends in the number of glaucous gull nests and associations with other colonial nesting prey species, we first selected those barrier islands with the most nearly complete long-term data. We selected 19 of 30 islands for which 14 years of census numbers existed for the period 1970–2001. We evaluated changes in the total number of active glaucous gull nests by grouping these data into three blocks of years, and calculating the mean number of glaucous gull nests on these 19 islands for each time block (1970–74, 5 years; 1975–85, 5 years; and 1987–2001, 4 years). These time period ranges were selected to equalize sample sizes across periods and relate time periods to changes in human activity, changes in garbage management at North Slope oilfields, and changes in field survey methods. Construction of the Trans-Alaska Pipeline began in 1974, landfill of garbage at Prudhoe Bay began in 1986, and animal-proof dumpsters were installed throughout the oilfields in 1999. A one-way ANOVA was used to compare the number of nests among the three time periods.

We used simple linear regression to evaluate associations between the number of glaucous gull nests and the number of common eider nests on the 19 barrier islands and between the number of gull nests on the 19 islands and the number of snow goose nests on Howe Island.

TABLE 3. Kendall's Tau correlation coefficients for on-transect density of glaucous gulls (gulls/km) and environmental variables[1] recorded for aerial survey transects in central Alaskan Beaufort Sea lagoons on 73 survey dates from 1978 to 2001 (n = 1524).

	Density	NE Wind	% Ice Cover	Wave Height (inches)	Upwelling	Disturbance
NE Wind	0.029					
Ice Cover	**-0.144**[2]	0.022				
Wave Height	**-0.096**	**0.170**	**-0.109**			
Upwelling	-0.032	0.009	**0.120**	0.016		
Disturbance	0.048	-0.001	**-0.088**	-0.002	0.022	
Season	0.019	-0.064	**-0.241**	**0.098**	0.035	-0.006

[1] Variable definitions: Density = linear density of birds sampled within 200 m on either side of the plane (gulls/km); NE Wind = northeast component of the wind velocity; Upwelling = upwelling index (low, medium, or high); Disturbance = human activity index (scale 1 to 5); Season = day in season (1 June = 1).

[2] Numbers in bold are significant at $p < 0.05$.

ANALYSIS OF HISTORICAL DATA SETS – RESULTS

Beaufort Sea Aerial Survey Data

Data for 73 survey days in 14 years over a 23-year period (Table 2) were analyzed for trends in glaucous gull numbers over time, interactions with human disturbances, and interactions with environmental variables. A fundamental characteristic of the data was the lack of glaucous gull observations on many transects (43% of surveyed transects had no glaucous gulls). Most glaucous gulls were recorded in barrier island and mainland shoreline habitats, with the total number of gulls in the survey area ranging from about 50 to 1600 (Table 2). Seasonal variation in abundance was apparent, with the largest numbers of gulls consistently recorded during September surveys (Fig. 3).

Correlation Analysis: The complete aerial survey dataset consisting of 1524 transects on 73 days during 1978–2001 was used for the correlation analysis, shown in Table 3. Percent ice cover and wave height were significantly negatively correlated with the linear density of glaucous gulls, i.e., more gulls were recorded during periods with less ice and smaller waves. Day in season (Day 1 = 1 June) was not correlated with glaucous gull density, but was negatively correlated with ice cover (ice cover decreased later in the season) and positively correlated with wave height (wave height increased later in the season). Human activity for individual transects was not significantly correlated with glaucous gull density.

Regression and ANCOVA: A total of 50 survey days during 1978–2001 were consistently sampled over 10 transects in the industrial area. Probability plots show that the log-transformed numbers of gulls observed on these 10 transects were distributed normally. Although our multiple linear regression analysis indicated no significant trend in the number of glaucous gulls over time (Fig. 4), day in season was a significant predictor of the number of glaucous gulls observed (Table 4). The power of this analysis was sufficient to detect a 47% change in the number of glaucous gulls at the 95% confidence level for the 23 years of survey coverage, or a 2.0% annual rate of change.

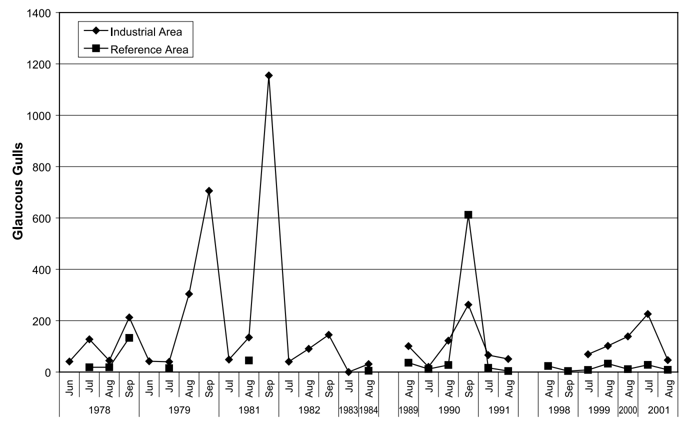

FIG. 3. Number of glaucous gulls recorded in central Alaskan Beaufort Sea barrier island habitats with industrial and reference areas, by month, for surveys during June to September 1978–2001.

Neither time trend nor human activity showed significant relationships to the number of glaucous gulls (Fig. 5, Table 4). Season and wave height were significant covariates (Table 4).

Structured ANCOVA: A total of 26 survey days during 1990–2001 met the criteria for inclusion in the structured ANCOVA (Table 5). As with the larger data set, neither time trend nor human activity showed a significant relationship to the number of glaucous gulls, although year reached the 90% confidence level, both with and without the inclusion of covariates.

Barrier Island Nest Data

Nesting data have been collected on a number of islands since 1970 (Fig. 2, Table 6). Unfortunately, the islands with the largest glaucous gull nesting aggregations, i.e., the Niakuk Islands and Point Brower Spits, were not consistently surveyed (Fig. 2, Table 6). We found remnants of human garbage near glaucous gull nests on the Niakuk Islands, presumably carried to the islands by the gulls.

The number of active glaucous gull nests on 19 barrier islands in the central Alaskan Beaufort Sea was not consistent among time periods (F = 5.74, p = 0.02). The

TABLE 4. Results of the a) multiple linear regression and b) ANCOVA of the number of glaucous gulls with survey day (n = 50) using wave height, season, and disturbance as covariates[1] for 10 transects (1978 to 2001).

a) Multiple Linear Regression, Adjusted $R^2 < 0.147$, $p = 0.009$

Effect	Coefficient	Standard Error	t -value	p-value
Day	-7.9×10^{-6}	4.6×10^{-5}	-0.173	0.863
Season	0.021	0.007	3.229	0.002

b) ANCOVA with wave height, season, and disturbance as covariates, $R^2 = 0.256$

Source	Sum of squares	Degrees of freedom	Mean square	F-ratio	p-value
Day	0.088	1	0.088	0.104	0.749
Wave[2]	**3.743**	**1**	**3.743**	**4.431**	**0.041**
Season	**8.086**	**1**	**8.086**	**0.003**	**0.003**
IDisturbance	0.090	1	0.090	0.106	0.746
Error	38.018	45	0.845		

[1] Variable definitions: Day = day of observation (day 1 = 23 June 1978); Wave = log transform of mean wave height + 1; Season = day in season (day 1 = 1 June); IDisturbance = indicator of human activity (minimal, or some).

[2] Variables in bold are significant at $p < 0.05$.

number of nests increased between 1970–74 (mean nests per year = 77.6 ± 18.04 standard error [SE]) and 1975–85 (mean nests per year = 154.4 ± 18.04 SE; Fig. 6). This increase was not significant between 1970–74 and 1987–2001 (mean nests per year = 153.0 ± 20.16 SE; Fig. 6).

There was a strong positive relationship between the number of glaucous gull nests and both common eider (R^2 = 60%) and snow goose (R^2 = 64%) nests (Fig. 7).

DISCUSSION

Results of our long-term aerial surveys did not show a significant change in glaucous gull abundance in coastal marine habitats. Trends from two different aerial survey sources indicated glaucous gull numbers on the Arctic Coastal Plain may have increased from 1992 to 2001, but trends were not significant: 2% ± 3% (Larned et al., 2001) and 4% ± 6% (Mallek et al., 2002). Although it is not clear that glaucous gulls on the ACP are becoming more abundant, there are indications that human populations may influence their pattern of coastal distribution (Fig. 1). Glaucous gull numbers during 2001 and 2002 generally increased from the eastern to the western border of Alaska's Arctic Coastal Plain coastline, with concentrations near coastal villages and at Prudhoe Bay (Fig. 1; Dau and Anderson, 2001, 2002). The aggregation of birds across the ACP shoreline appears more prominent near the villages of Point Lay, Wainwright, Barrow, and Kaktovik than near the Prudhoe Bay oilfields (Fig. 1).

Aerial surveys of 10 transects in Beaufort Sea lagoons near the Prudhoe Bay oilfields indicated there was no significant trend in glaucous gull numbers from 1978 to 2001 (Figs. 4 and 5). But individual survey data were variable, and the numbers of glaucous gulls would have to increase or decrease by 47% over the 23-year period (or a rate of 2.0% or more per year) before a significant change could be detected. Human activity was also not significantly correlated with glaucous gull density for transects near Prudhoe Bay from 1978 to 2001. The structured ANCOVA for 1990–2001 Beaufort Sea lagoon data similarly indicated that neither time trend, nor human activity, nor covariates were significantly related to the numbers of glaucous gulls.

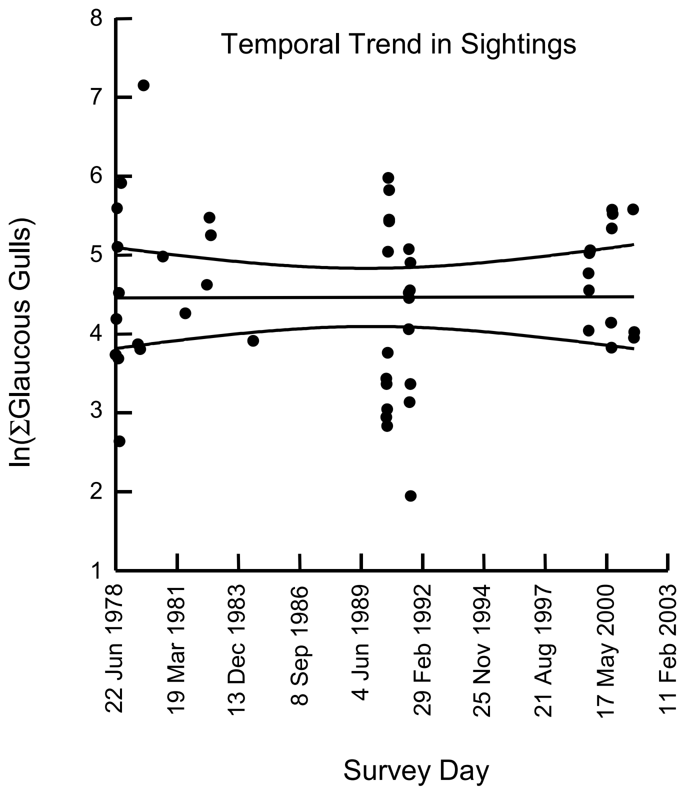

FIG. 4. Simple linear regression without covariates for ln(Σglaucous gulls) sighted on-transect (10 transects in central Alaskan Beaufort Sea lagoons) on 50 survey dates during 1978–2001, showing mean trend and 95% confidence bounds.

TABLE 5. Results of the structured ANCOVA for aerial survey date and human activity with the sum of the number of on-transect glaucous gulls for two areas with three habitats on 26 survey dates (n = 156) from 1990–2001.[1]

Source	Sum of squares	Sum of squares (test)	Degrees of freedom	Degrees of freedom (test)	Mean square	Mean square (test)	F-ratio	p-value
Case A: Covariates = WAVE and ICE, R^2 = 0.612								
WAVE	0.047	116.062	1	116	0.047	1.001	0.047	0.828
ICE	0.794	116.062	1	116	0.794	1.001	0.793	0.375
D	5.755	116.062	8	116	0.719	1.001	0.719	0.674
A	0.730	113.058	1	4	0.730	28.265	0.026	0.880
Y	7.927	13.845	4	16	1.982	0.865	2.290	0.105
AY	3.801	13.845	4	16	0.950	0.865	1.098	0.391
H(A)[2]	**113.058**	**116.062**	**4**	**116**	**28.265**	**1.001**	**28.250**	**0.000**
YH(A)	13.845	116.062	16	116	0.865	1.001	0.865	0.610
Case B: No Covariates, R^2 = 0.609								
D	5.697	116.963	8	118	0.712	0.991	0.718	0.675
A	0.509	112.669	1	4	0.509	28.167	0.018	0.900
Y	7.587	12.863	4	16	1.897	0.804	2.359	0.097
AY	3.605	12.863	4	16	0.901	0.804	1.121	0.381
H(A)[2]	**112.669**	**116.963**	**4**	**118**	**28.167**	**0.991**	**28.417**	**0.000**
YH(A)	12.863	116.963	16	118	0.804	0.991	0.811	0.671

[1] Variable definitions: WAVE = log transform of mean wave height + 1; ICE = percent ice cover; D = human activity index; A = area (industrial and reference); Y = year; H = habitat.

[2] Variables in bold are significant at $p < 0.05$.

Nest abundance data for the Prudhoe Bay region suggests the annual number of glaucous gull nests in this area likely increased after 1976 (Fig. 6). Unfortunately the change from aerial to ground-based nest survey methods after 1975 confounds this comparison. Because researchers used different nest census methods during 1970–75, it is also possible that the post-1976 increase is an artifact of survey methodology or timing (Fig. 6, Table 6). Recent nesting data from the Alaskan Beaufort Sea barrier islands indicated that the mean annual number of glaucous gull nests had not increased from 1970–74 to 1987–2001. The low proportion of active nests and small mean clutch sizes on the barrier islands during 1998–2001 (i.e., compared to the Y-K Delta) were also not typical of a growing gull population (Murphy et al., 1984; Hiom et al., 1991; Pons and Migot, 1995; Pierotti and Bellrose, 1986; Kilpi et al., 1996; Oro et al., 1996). In contrast, nest productivity data for the Y-K Delta indicated that the nesting glaucous gull population there may be increasing (Bowman et al., 2001).

It is tempting to evaluate population changes of large gulls in the context of a single variable, such as increased anthropogenic food. The population (breeding, non-breeding, or post-breeding) using the anthropogenic resource and the quantity of available nutrition are important factors. In the Prudhoe Bay region, there is potential for anthropogenic food to cause increases in breeding, non-breeding, and post-breeding populations, which would likely be reflected in the numbers of gulls recorded in the lagoon systems within and adjacent to the Prudhoe Bay oilfields. We have included analyses of breeding and post-breeding glaucous gulls, although it is certain that many of the individuals recorded during our surveys were also non-breeding birds. Many

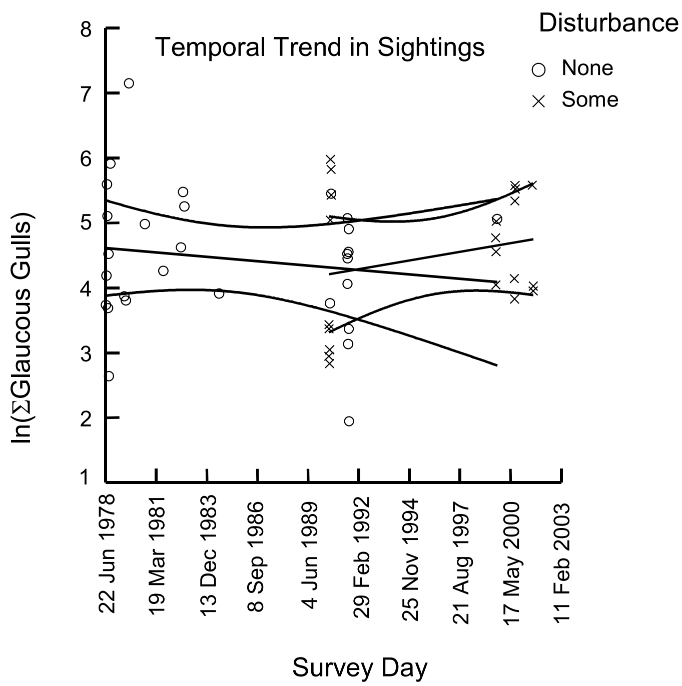

FIG. 5. Simple linear regressions without covariates for ln(Σglaucous gulls) sighted on-transect (10 transects in central Alaskan Beaufort Sea lagoons on 50 survey dates during 1978–2001) on two human activity levels, showing mean trend and 95% confidence bounds.

authors have documented both human- and prey resource-induced changes in gull productivity and population size. Herring gulls wintering in Gothenberg, Sweden, decreased when food availability was reduced at a nearby refuse site (Kihlman and Larsson, 1974). This wintering population could easily relocate to a more productive habitat. In contrast,

TABLE 6. Glaucous gull nests counted on barrier islands along the central Alaskan Beaufort Sea coast, 1970–2001.

	Year of Census[1]																										
Location	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1982	1983	1984	1985	1986	1987	1988	1989	1990	1995	1996	1997	1998	1999	2000	2001
Source[2]	A	A	A	A	A	A	B	C	C[3],D	D	E	D	D	D	D,F[4]	G[5]	D	D	H	H	H	H	H	H,I	H,J	H,K,L	H,M,N
Date of Search							early July	1–7 July	22–30 July	13 July - 9 Aug	21 July	18–27 July	23 July - 4 Aug	17–24 July	17–26 July	15 June -18 Aug	18–25 July	18–22 July							13 June - 5 July	18–27 June	5 June - 5 July
Method[6]	A	A	A	A	A	A	G	G	G	G	G	G	G	G	G	A	G	G	G	G	G	G	G	G	G	G	G
Thetis I.	2	2	4	6	5	6	4		5	6	5	0	5	2	13	0	12	8							4	2	4
Spy I.	2	1	2	2	1	3	3	0	4			3	6	21	11	0	5	5							6	2	5
Leavitt I.	2	2	1	1	1	2	0		1				0	0	0	0	0								0	0	0
Pingok I.	0	0	0	0	0	0	0		0			0	0			0									0	0	0
Bertoncini I.	0	0	0	0	0	0	0	0				0	0	0	0	0									0	0	0
Bodfish I.	0	0	0	0	0	0	0	0	0			0	0		2	0									0	0	0
Cottle I.	2	1	2	3	2	3	0	0	1			0	0	0	4	0	6	1							0	0	0
Duck I.	51	40	54	47	41	48	22							47	41	52	42		44	32	34	39	32	35	26	34	19
Long I.	1	3	3	4	3	4	24		27	27		0	34	10	18		15	30							1	0	2
Egg I.	2	16	3	3	3	5	21			16			35	32	22	24	22	24							15	2	21
Stump I.	2	2	2	2	1	3	5		10	12			12	40	39	0	34	44									63
Gull I.	1	0	1	1	0	0			0				0	0													
Reindeer I.	1	0	1	1	0	0	1						4	2	2		2	1							8	4	5
Argo I.	1	0	1	0	0	0	2					2	1	3	2		3	2								0	0
Niakuk I.	53	57	55	55	66	67	151		37						30	80											
Cross I.	0	3	0	3	4	3	2					2	12	7	3		10	5									4
NoName I.	1	1	0	1	0	1	1					1	1	2	0		2	1									
Narwhal I.	1	1	2	2	2	3	1						4	4	1		2	4							2	1	0
Pt. Brower Spits							81									40											
Jeanette I.	2	1	1	1	0	1	0					1	4	2	2		2	1							1	1	1
Karluk I.	1	1	1	1	0	1	0					0	1	3	1		2	0							1	2	
Lion Point							5								4	0	9	9								2	1
Pole I.	1	2	1	2	2	3	1			2		0	35	12	5		10	9								10	0
Cold I.	1	1	2	1	2	1																					
Belvedere I.	1	1	2	1	0	2	1					0	5	11	1		1	0								3	0
Challenge I.	1	1	1	2	1	1	4					2	6	1	4		3	4						2		3	3
Alaska I.	1	1	2	1	0	1	1			0			9	7	2		1	2						1		7	2
Duchess I.	1	1	1	1	1	2	0			0			17	6	0		4	3						2		4	4
Northstar I.	1	1	2	2	1	1	0						2	2	1		0	3						0		4	3
Flaxman I.	2	1	1	1	0	1	0			0			0	0	2									1		0	0
All Locations	134	140	145	144	136	162	330	0	85	63	5	11	193	214	210	196	187	156	44	32	34	39	32	41	64	81	137

[1] Censuses were conducted on various dates from 25 June to 31 July. Timing may influence census results because it was possible to miss nests that were initiated late or failed early or to fail to recognize some empty nests as active nests if census began after the peak of hatch.

[2] Sources: A = Gavin, 1976; B = Divoky, 1978; C = Johnson and Richardson, 1981; D = U.S. Fish and Wildlife Service, Office of Ecological Services, Fairbanks, Alaska, unpubl. data; E = Johnson et al., 1987; F = Johnson, 1985; G = Murphy et al., 1987; H = LGL Alaska Research Associates, Inc., Anchorage, Alaska, unpubl. data, I = Noel et al., 1999; J = Noel and Johnson, 2000; K = Noel et al., 2001; L = Flint et al., 2001; M = Noel et al., 2002a, b; N = Lanctot et al., 2001.

[3] Thetis and Spy Island data for 1978 from Johnson and Richardson, 1981.

[4] Johnson reports at least 41 glaucous gull nests for Duck Island in 1985; count is known to be low, as survey was terminated early.

[5] Duck Island census on 18 August 1986, Murphy et al., 1987; total of 35 nests for Egg Island includes nests on Long Island.

[6] Method: A = aerial, G = ground.

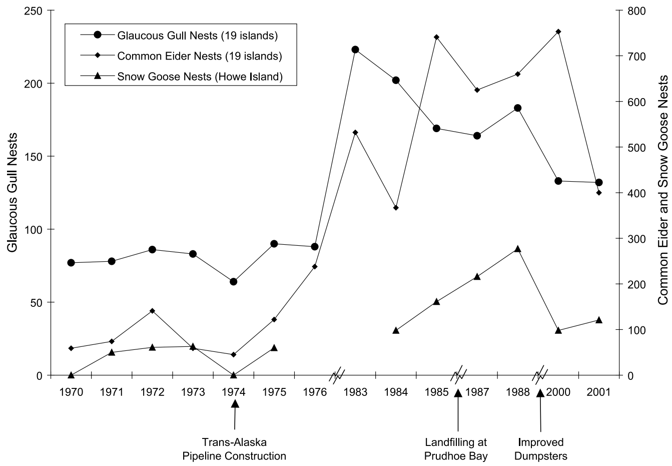

FIG. 6. Total active glaucous gull and common eider nests on 19 islands and snow goose nests on Howe Island in central Alaskan Beaufort Sea lagoons, for 14 years during 1970–2001.

the total number of adult herring gulls in a nesting colony in France remained stable after closure of a nearby refuse site (Pons and Migot, 1995). This nesting population would likely respond to the reduction in nutrition over a longer time period; in fact, mean adult body weight, mean clutch size, and mean young per pair all declined after closure of this refuse site (Pons and Migot, 1995).

The strong positive relationships between annual numbers of glaucous gull nests and both common eider and snow goose nests on Alaskan Beaufort Sea barrier islands (Fig. 7) suggests some common environmental variables may be regulating nesting for these species. Numbers of active gull nests may be more strongly related to these environmental variables than to variables that affect only gulls, such as the availability of refuse. Gilchrist (2001) concluded that the factors regulating glaucous gull populations are not well known, but that the population is likely limited by the availability of predator-free nesting areas with an abundant food source during breeding.

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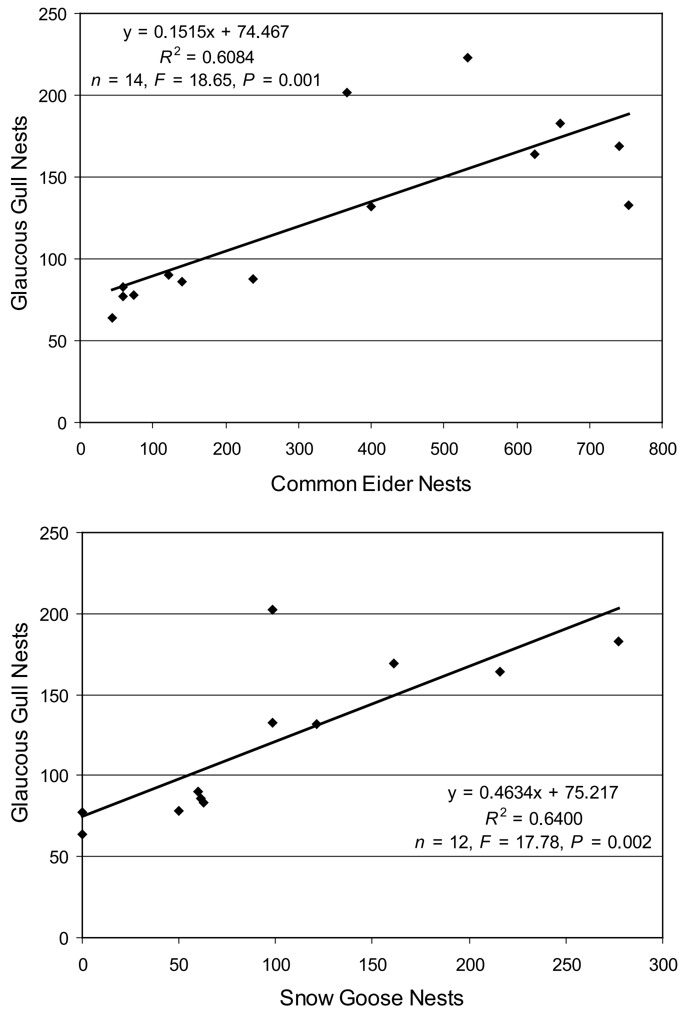

FIG. 7. Relationships between glaucous gull nests and common eider nests on 19 islands in central Alaskan Beaufort Sea lagoons, and between glaucous gull nests on these 19 islands and snow goose nests on Howe Island, during 1970–2001 (Noel et al., 2002a, b).

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