Response of Fall-Staging Brant and Canada Geese to Aircraft Overflights in Southwestern Alaska

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GEIS, M. B. 1956. Productivity of Canada geese in the Flathead Valley, Montana. Journal of Wildlife Management 20:409–419.

JOHNSON, D. H. 1979. Estimating nest success: the Mayfield method and an alternative. Auk 96:651–661.

———, J. D. NICHOLS, AND M. D. SCHWARTZ. 1992. Population dynamics of breeding waterfowl. Pages 446–485 *in* B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, editors. Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis, Minnesota, USA.

———, AND T. L. SHAFFER. 1990. Estimating nest success: when Mayfield wins. Auk 107:595–600.

KLETT, A. T., AND D. H. JOHNSON. 1982. Variability in nest survival rates and implications to nesting studies. Auk 99:77–87.

KLOPMAN, R. B. 1958. The nesting of the Canada goose at Dog Lake, Manitoba. Wilson Bulletin 70:168–183.

MAYFIELD, H. F. 1961. Nesting success calculated from exposure. Wilson Bulletin 73:255–261.

———. 1975. Suggestions for calculating nest success. Wilson Bulletin 87:456–466.

VERMEER, K. 1970. A study of Canada geese, *Branta canadensis,* nesting on islands in southeastern Alberta. Canadian Journal of Zoology 48:235–240.

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RESPONSE OF FALL-STAGING BRANT AND CANADA GEESE TO AIRCRAFT OVERFLIGHTS IN SOUTHWESTERN ALASKA

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Abstract: Because much of the information concerning disturbance of waterfowl by aircraft is anecdotal, we examined behavioral responses of Pacific brant (*Branta bernicla nigricans*) and Canada geese (*B. canadensis taverneri*) to experimental overflights during fall staging at Izembek Lagoon, Alaska. These data were used to develop predictive models of brant and Canada goose response to aircraft altitude, type, noise, and lateral distance from flocks. Overall, 75% of brant flocks and 9% of Canada goose flocks flew in response to overflights. Mean flight and alert responses of both species were greater for rotary-wing than for fixed-wing aircraft and for high-noise than for low-noise aircraft. Increased lateral distance between an aircraft and a flock was the most consistent predictive parameter associated with lower probability of a response by geese. Altitude was a less reliable predictor because of interaction effects with aircraft type and noise. Although mean response of brant and Canada geese generally was inversely proportional to aircraft altitude, greatest response occurred at intermediate (305–760 m) altitudes. At Izembek Lagoon and other areas where there are large concentrations of waterfowl, managers should consider lateral distance from the birds as the primary criterion for establishing local flight restrictions, especially for helicopters.

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Human-caused disturbance can change behavior and spatial distribution of waterfowl (Manci et al. 1988, Dahlgren and Korschgen 1992). Effects include interruption of feeding (Madsen 1985, Ward et al. 1994), displacement from feeding areas (Kramer et al. 1979, Bélanger and Bédard 1989, Conomy et al. 1998), and increased energy expenditure resulting from escape behaviors (i.e., running, flying; Korschgen et al. 1985, Jensen 1990). If disturbances are sufficiently frequent, disturbance may result in the reduction of energy reserves (White-Robinson 1982, Bélanger and Bédard 1990, Miller

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et al. 1994) important for migration (Owen and Black 1989), molt (Taylor 1993, 1995), and survival (Haramis et al. 1986). Thus, it is important to understand factors influencing disturbance, so that managers can develop strategies to minimize adverse effects.

Geese respond to a variety of human activities but are particularly sensitive to aircraft overflights. Aircraft caused >45% of disturbances to greater snow geese (*Chen caerulescens atlantica*) at an important staging area in Quebec during fall and spring (Bélanger and Bédard 1989). Similarly, aircraft were the most important human-caused disturbance to brant wintering in southwestern England (Owens 1977) and fall-staging in southwestern Alaska (Ward et al. 1994). Geese react to aircraft at most stages of their annual cycle, including breeding (Gollop et al. 1974*a*, Laing 1991), molting (Derksen et al. 1979, Mosbech and Glahder 1991), migration (Jones and Jones 1966, Bélanger and Bédard 1989), and wintering (Owens 1977, Kramer et al. 1979, Henry 1980). Magnitude of the behavioral response is believed to vary with aircraft type (Davis and Wiseley 1974), noise (Mosbech and Glahder 1991, Temple 1993), altitude, and lateral distance (Derksen et al. 1979, Bélanger and Bédard 1989, Ward et al. 1994); however, no study has quantitatively examined the relation between these parameters and the response of geese. Jensen (1990) investigated response of molting brant to experimental overflights by 2 types of helicopters on the North Slope of Alaska; however, these birds were flightless and may have reacted differently from birds capable of flight.

We conducted planned aircraft overflights with control of aircraft type, noise, altitude, and lateral distance to flocks (hereafter, lateral distance) to measure behavioral response of staging brant and Canada geese to fixed- and rotary-wing aircraft. We used these data to develop predictive models of the relation between aircraft type, noise, altitude, lateral distance, and the response of geese, and to determine if response declines with sequential cumulative days of exposure to aircraft overflights.

STUDY AREA

Izembek Lagoon is located on the Bering Sea near the end of the Alaska Peninsula (55°15′N, 163°00′W). Approximately 84% of the lagoon is intertidal, 55% of which is vegetated by eelgrass (*Zostera marina*; Ward et al. 1997). Nearly the entire population of Pacific brant and the majority of Taverner's Canada geese stop at Izembek Lagoon and adjacent estuaries in fall (Bellrose 1980). Brant primarily used intertidal areas throughout the tidal cycle and fed on eelgrass (D. H. Ward and R. A. Stehn, unpublished data). Canada geese usually were found in nearshore intertidal areas during low tides and in adjacent grass–sedge and upland mesic-heath meadows during high tides (D. H. Ward, unpublished data). A more detailed description of habitats is provided in Ward et al. (1997).

METHODS

Aircraft Overflights

We conducted overflights with fixed- and rotary-wing aircraft on 57 days in September and October 1985–88. Aircraft were selected based on availability and frequency of use in Alaska. Fixed-wing aircraft included single- (Arctic Tern, Piper 150, Cessna 206, Cessna 185) and twin-engine (Piper Navajo, Grumman Goose, Twin Otter) airplanes. Rotary-wing aircraft were single- (Bell 206-B Jet Ranger, Hughes 500-D, Bell 205) and twin-engine (Sikorsky HH-3F) helicopters.

Overflights followed prescribed flight lines and altitudes and simulated representative aircraft routes used in the vicinity of Izembek Lagoon. Each overflight began and ended at prominent landmarks adjacent to the lagoon. The pilot followed a flight line plotted on a 1:63,360- or 1:250,000-scale topographic map by referring to landmarks (e.g., tide channels, shoreline features) and using LORAN-C to help locate start and end points. Aircraft were flown at normal cruising speed (150–240 km/hr) and during visual flight rules (VFR) conditions (i.e., below clouds). Aircraft altitude was controlled during each series of overflights, typically between 152 and 610 m, and aircraft direction of travel and lateral distance varied with flight line and flock location.

We observed behavioral responses of flocks of brant and Canada geese from 8 permanent blinds (see Ward et al. 1994) and 3 temporary vantage points along the shore of Izembek Lagoon. A flock was defined as a spatially distinct group of birds (median flock size = 700 birds, range = 10–30,000 birds). In some cases, flock members were dispersed over a 1-km^2 area, and an arbitrary portion of the flock was selected for observation. We typically exposed geese to multiple overflights by the same aircraft each day, with a mean interval of 64 min (range = 5–430 min) between repeated disturbances of the same flock.

Before each overflight, we arbitrarily chose ≥1 flock and plotted their locations on maps of the lagoon, using landmarks (e.g., points of land, tidal channels) and buoys placed at known locations. An observer or the pilot in the aircraft reported, by radio, to ground observers the flight line, aircraft altitude (m above sea level), and the time when the start and end point of each flight line was passed. Observers in blinds recorded radio transmissions on audio cassette recorders and added observations of behavioral responses for >1 flock of geese. Responses were recorded as the percentage of the flock exhibiting an alert or flight response for each overflight. Lateral distance between the aircraft flight line and flock was measured from maps to the nearest 0.16 km.

Data Analysis

We used best subsets logistic regression (Hosmer and Lemeshow 1989:118–126) to model the probability that a flock of geese became alert or flew in response to an overflight. Because individuals in a flock typically react in unison to a disturbance (Bélanger and Bédard 1989, Ward et al. 1994), we treated response as a binary dependent variable: response = 1 if >10% of birds in a flock showed a response, and response = 0 otherwise. Independent variables included lateral distance (L), L^2, altitude (A), and A^2, which were found to be significant predictors during exploratory analyses of responses to individual types of aircraft. We also included aircraft noise (high vs. low), aircraft type (rotary-wing vs. fixed-wing), and the 2-factor interactions of these variables with altitude and lateral distance. Aircraft noise was determined from acoustic measurements made at Izembek Lagoon (D. H. Ward, unpublished data) or during standard tests by the Federal Aviation Adminstration (J. Skalecky, U.S. Department of Transportation, unpublished data). We classified aircraft noise as high if the maximum sound energy exceeded 76 dbA for fixed-wing and 80 dbA for rotary-wing aircraft during level flight at 152 m altitude, and as low if sound energy was below these levels.

We also tested whether behavioral responses decreased with cumulative exposure to disturbance by including the number of consecutive days (3–6) of aircraft overflights in models for disturbance by rotary-wing aircraft. The Bell 206-B helicopter was flown 30 September and 1 and 2 October in 1985, and 18, 20, 22, and 23 October 1986. The Bell 205 helicopter was flown on 1, 2, 3, 5, and 6 October 1987, and the Hughes 500-D helicopter on 14, 15, and 16 October 1988. We assumed a 1- or 2-day skip in overflights of the Bell 206-B and Bell 205 helicopters did not affect results. Exposure models could not be developed for fixed-wing aircraft because of insufficient data.

We used Akaike's Information Criterion (AIC; Akaike 1973) and log-likelihood ratio tests (Hosmer and Lemeshow 1989) to determine the best model. We used each overflight with a batch of observations recorded on flocks as a sampling unit because observations were made on ≥1 flock during an overflight, and observations on flocks were not strictly independent. Final estimates of regression coefficients and standard errors were determined via bootstrap techniques (Manly 1991), where overflights (true experimental units) were sampled with replacement and, for each bootstrap sample, we obtained a maximum likelihood estimate of the logistic regression coefficients. Final bootstrap estimates and standard errors were calculated from 200 bootstrap samples.

RESULTS

Over the 4-year study, we obtained behavioral observations for 1,545 flocks of brant during 356 overflights and for 535 flocks of Canada geese during 209 overflights (Table 1). Twenty-two percent of the overflights were made by low noise, fixed-wing aircraft, 14% by high noise, fixed-wing aircraft, 40% by low noise, rotary-wing aircraft, and 24% by high noise, rotary-wing aircraft (Table 1). Flocks of geese were exposed to overflights over altitudes of 30–1,219 m and lateral distances of 0.0–8.0 km.

Response of Geese

A majority (75%) of brant flocks flew in response to aircraft overflights. More flocks of brant flew in response to rotary-wing (51%) than fixed-wing (33%) aircraft, and to high-noise (49%) than low-noise (40%) aircraft. Responses to overflights occurred up to 1,219 m altitude and 4.8 km lateral distance. Mean flight response of brant decreased with increasing lateral distances, regardless of aircraft type or

Table 1. Number of flocks of Pacific brant and Canada geese exposed to aircraft overflights at Izembek Lagoon, Alaska, 1985–88.

Aircraft			Pacific brant				Canada geese			
				Overflights[a]				Overflights		
Model	Type[c]	Noise	Flocks[b] *n*	*n*[d]	ALT range (m)	LD range (m)	Flocks[b] *n*	*n*[d]	ALT range (m)	LD range (m)
Arctic Tern	Fw	Low	112	38	46–610	0.0–3.5	62	23	61–610	0.0–6.0
Piper 150	Fw	Low	111	32	30–610	0.0–4.8	28	15	76–610	0.0–2.4
Cessna 180	Fw	Low	39	10	152–457	0.0–2.4	5	3	152–305	0.0–2.4
Cessna 206	Fw	High	112	26	46–762	0.0–8.0	10	6	46–762	0.0–0.8
Piper Navajo	Fw	High	169	15	76–914	0.0–2.7	72	17	76–914	0.0–3.5
Grumman Goose	Fw	High	25	4	152–914	0.1–2.9	29	5	152–914	0.0–6.2
Twin Otter	Fw	High	21	5	91–305	0.0–6.4	1	1	91–91	1.8–1.8
Hughes 500-D	Rw	Low	70	50	76–610	0.0–1.6	55	21	76–610	0.0–1.8
Bell 206-B	Rw	Low	422	91	91–1,158	0.0–7.2	125	55	91–914	0.0–4.8
Bell 205	Rw	High	419	68	91–1,219	0.0–7.4	133	60	91–1,219	0.0–3.7
Sikorsky HH-3F	Rw	High	45	17	457–457	0.8–3.0	15	3	457–457	0.4–4.8

[a] ALT = aircraft altitude above sea level; LD = lateral (horizontal) distance between the flight path of the aircraft and flock of geese.
[b] Number of flocks observed.
[c] Fw = fixed-wing aircraft; Rw = rotary-wing aircraft; Low noise = maximum sound energy at 152 m altitude and ≤0.2 km lateral distance to the microphone was ≤76 dbA for fixed-wing aircraft and ≤80 dbA for rotary-wing aircraft; High noise = maximum sound energy >76 dbA for fixed-wing and >80 dbA for rotary-wing aircraft (D. H. Ward, unpublished data).
[d] Number of overflights.

noise (Figs. 1A,C). Brant flight response to aircraft at different altitudes was inconsistent: response generally decreased with increased altitude of fixed-wing and low noise aircraft but tended to remain the same or increase with rotary-wing and high noise aircraft (Figs. 1B,D).

Canada goose flocks rarely flew in response to fixed-wing (5% of flocks responded) or rotary-wing (11% of flocks responded) aircraft; therefore, we combined alert and flight responses for further analysis. The mean percentage of Canada goose flocks that responded was greater for rotary-wing (41%) than fixed-wing (20%) aircraft, and for high noise (43%) than

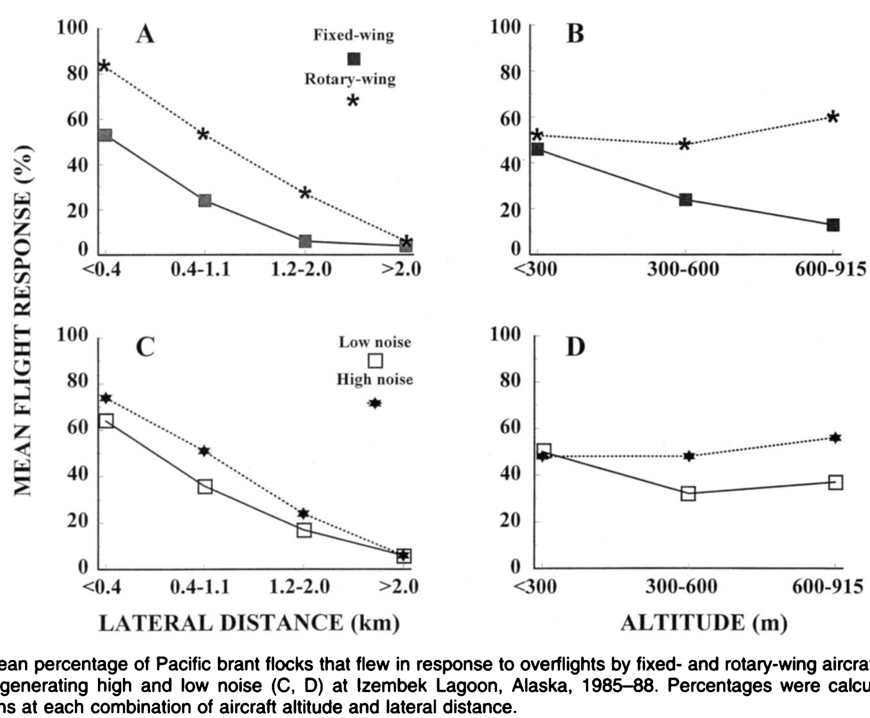

Fig. 1. Mean percentage of Pacific brant flocks that flew in response to overflights by fixed- and rotary-wing aircraft (A, B) and to aircraft generating high and low noise (C, D) at Izembek Lagoon, Alaska, 1985–88. Percentages were calculated for all observations at each combination of aircraft altitude and lateral distance.

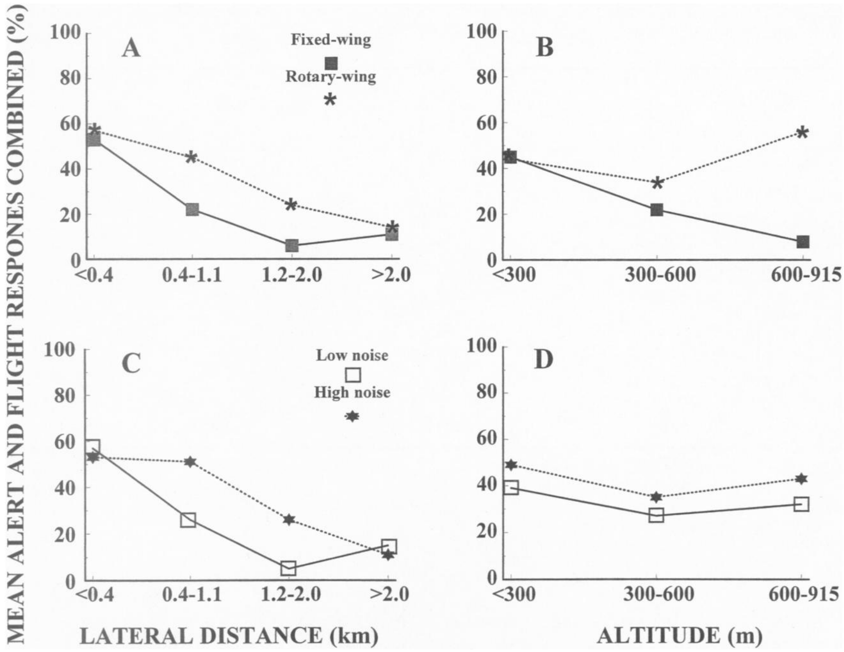

Fig. 2. Mean percentage of Canada goose flocks responding (alert and flight responses combined) to overflights by fixed- and rotary-wing aircraft (A, B) and to aircraft generating high and low noise (C, D) at Izembek Lagoon, Alaska, 1985–88. Percentages were calculated for all observations at each combination of aircraft altitude and lateral distance.

low noise (31%) aircraft. Similar to brant, mean response of Canada geese decreased at increasing lateral distance irrespective of aircraft type and noise (Figs. 2A,C). Mean response of Canada geese decreased or remained the same as altitude increased for fixed-wing aircraft (Figs. 2A,B) and high-noise and low-noise aircraft (Fig. 2D), but mean response increased for rotary-wing aircraft (Fig. 2B).

Predictive Models

Based on AIC values and likelihood-ratio tests, Model 3 was the best logistic regression model for probability of a flight response by brant to overflights (Table 2). This model included altitude (A), A^2, lateral distance (L), L^2, noise, and aircraft type, plus the 2-way interactions aircraft type × latitude and aircraft noise × altitude. Model 3 fit the data as well as more general models that contained additional interaction effects (i.e., Models 1, 2; Table 2).

The best logistic regression model for a response by Canada geese was Model 7, which included altitude (A), A^2, lateral distance (L), L^2, noise, and aircraft type, plus the 2-way interactions aircraft type × altitude, and aircraft noise × lateral distance (Table 2).

The probability (p) that a flock of brant or Canada geese responded to aircraft overflights was estimated from the formula

$$p = e(\beta_o + \beta_1 X_1 + \ldots + \beta_n X_n) \div [1 + e(\beta_o + \beta_1 X_1 + \ldots + \beta_n X_n)],$$

where e = base of the natural logarithm. The estimated flight response by brant was

$$p = 2.101 - 0.247(L) - 0.907(A) + 0.002(L^2) + 0.033(A^2) - 0.213(N) + 0.073(T) + 0.345(N*A) + 0.556(T*A),$$

and the estimated alert and flight responses combined by Canada geese was

$$p = 1.219 - 0.218(L) - 0.495(A) + 0.002(L^2) + 0.028(A^2) + 0.150(N) - 0.368(T) + 0.069(N*L) + 0.371(T*A),$$

where L = lateral distance between the aircraft and flock (1 unit = 100 m), A = aircraft altitude (1 unit = 100 m), N = noise of aircraft (0 = low, 1 = high), and T = type of aircraft (0 = fixed-wing, 1 = rotary-wing).

Predicted probability of response by both species of geese was inversely proportional to lateral distance and altitude, as indicated by

Table 2. Logistic regression models for the probability of a flight response by Pacific brant and alert and flight response by Canada geese to aircraft overflights at Izembek Lagoon, Alaska, 1985–88.

Species and model[b]	R^2[c]	AIC[d]	Likelihood-ratio test[a]: Models compared	χ^2	P
Pacific brant					
1. Main effects plus $N*L$, $N*A$, $T*L$, $T*A$	0.43	1,526.6			
2. Main effects plus $N*L$, $N*A$, $T*A$	0.44	1,525.6	2 vs. 1	0.06	0.81
3. Main effects plus $N*A$, $T*A$	0.43	1,525.3	3 vs. 2	1.69	0.19
4. Main effects plus $T*A$	0.43	1,548.4	4 vs. 3	25.03	<0.01
Canada geese					
5. Main effects plus $N*L$, $N*A$, $T*L$, $T*A$	0.26	603.1			
6. Main effects plus $N*L$, $N*A$, $T*A$	0.26	601.6	6 vs. 5	0.44	0.51
7. Main effects plus $N*L$, $T*A$	0.26	601.0	7 vs. 6	1.38	0.24
8. Main effects plus $N*A$, $T*A$	0.24	608.1	8 vs. 6	8.51	<0.01
9. Main effects plus $T*A$	0.25	602.9	9 vs. 7	3.88	0.05

[a] Likelihood-ratio test compares a general model with a reduced form of the same model.
[b] Main effects = lateral distance between the flight path of the aircraft and flock (L), L^2, altitude (A), A^2, noise (N), and aircraft type (T).
[c] Coefficient of determination in a logistic regression is a transformation of the likelihood-ratio statistic; successful models typically yield values between 0.20 and 0.40 (Henscher and Johnson 1981).
[d] Small Akaike Information Criterion (AIC) values indicate better fit.

negative coefficients of the regression parameters (Table 3). Lateral distance was a more consistent predictor of response than altitude because there were more 2-way interactions involving altitude (Table 3). Predicted response was greater for rotary-wing than fixed-wing aircraft, and for high noise than low noise aircraft at altitudes between 305 and 760 m and lateral distances ≤1.6 km to the flock.

Days of Overflight Exposure

There was weak evidence for a reduction in mean flight response of brant to rotary-wing aircraft over the 3–6-day exposure period. For all rotary-wing aircraft combined, evidence included the low AIC value of the model that included the exposure parameter, the low probability ($P = 0.10$) of the likelihood-ratio test between models with and without the exposure parameter, and the negative coefficient of the exposure parameter. Furthermore, an examination of best models within helicopter types revealed that models including the exposure parameter fit the data in 2 (Bell 205, Hughes 500-D) of 3 cases.

DISCUSSION

Lateral distance between aircraft and flock was the most important parameter in predicting response of brant and Canada geese to over-

Table 3. Logistic regression coefficients and bootstrap standard errors for the probability of a response by Pacific brant and Canada geese to aircraft overflights at Izembek Lagoon, Alaska, 1985–88.

Parameter	Pacific brant[a] Flight response: Coefficient	SE	Canada geese[b] Alert and flight response: Coefficient	SE
Intercept	2.101	0.01	1.219	0.01
Lateral distance	−0.247	0.06	−0.218	0.04
Altitude	−0.907	0.07	−0.495	0.06
Lateral distance^2	0.002	0.03	0.002	<0.01
Altitude^2	0.033	0.01	0.028	0.01
Noise	−0.213	0.03	0.150	0.01
Type	0.073	0.01	−0.368	0.05
Noise*lateral distance			0.069	0.01
Noise*altitude	0.345	0.06		
Type*lateral distance				
Type*altitude	0.556	0.07	0.371	0.06

[a] From Model 3 in Table 2.
[b] From Model 7 in Table 2.

flights. Response of geese decreased consistently at increasing lateral distances, independent of aircraft type or noise. The interaction detected between lateral distance and noise (Model 7 for Canada geese; Table 2) was likely an artifact of the overlap in mean response to low-noise and high-noise aircraft at extreme lateral distances (<0.4 or >2.0 km; Fig. 2) and was not considered biologically meaningful.

Effects of altitude were dependent on aircraft type and noise. Although there generally was an inverse relation between altitude and response, greatest response occurred at aircraft altitudes between 305 and 760 m. This pattern of response was most apparent for overflights of rotary-wing and high-noise aircraft. Previously, Jensen (1990) had investigated the response of geese to aircraft (primarily a Bell 206-L helicopter) flown at varying altitudes and lateral distances. His results for molting (i.e., flightless) brant also showed that escape responses were greatest when helicopters flew at intermediate altitudes (305–760 m). Currently, these are the altitudes used most frequently by aircraft flying under VFR at Izembek Lagoon (Ward et al. 1994; D. H. Ward, unpublished data) and other areas that brant frequent in Alaska (North Slope of Alaska: Jensen 1990; Yukon-Kuskokwim Delta, Alaska: J. S. Sedinger, University of Alaska Fairbanks, personal communication).

We were unable to determine an altitude above which geese did not respond to aircraft because we did not collect sufficient data on goose response to aircraft flying at altitudes >760 m. However, we suspect the threshold altitude for no response by staging brant is similar to or higher than the 1,070-m altitude of no response for molting brant (Jensen 1990) because staging brant responded with flight to 61% (n = 28 overflights) of the helicopters flying at altitudes between 915 and 1,220 m. Nevertheless, aircraft at Izembek Lagoon are unlikely to regularly fly at an altitude where flocks of brant and Canada geese do not respond. Low clouds are a common occurrence at Izembek Lagoon in fall (J. Painter, National Weather Service, Cold Bay, Alaska, personal communication) and will likely prevent aircraft using VFR from flying above 760 m altitude in the vicinity of staging geese.

Brant and Canada geese were more sensitive to helicopters than propeller planes at most combinations of altitude and lateral distance. Only at low (≤152 m) altitudes or great (≥1.6 km) lateral distances did geese respond similarly to these 2 types of aircraft. Flocks of fall-staging lesser snow geese (*Chen caerulescens caerulescens*) also were equally prone to fly in response to fixed- (Cessna 185) and rotary-wing (Bell 206-B helicopter) aircraft flying at a low (152 m) altitude; however, they flushed at greater distances to the helicopter (Davis and Wiseley 1974). These data support the general consensus that helicopters cause more disturbance of wildlife than other types of aircraft (Gollop et al. 1974*b*, Bleich et al. 1994).

During some overflights, flocks of brant and Canada geese took flight before aircraft were visible to the birds, which suggests aircraft noise was a cue for escape behaviors. Aircraft noise was believed a primary factor in response of molting pink-footed (*Anser brachyrhynchus*) and barnacle (*B. leucopsis*) geese to helicopter overflights in Greenland (Mosbech and Glahder 1991). Our data indicated intensity of noise may be important because geese reacted to high-noise aircraft at greater distances. Geese also may be disturbed by a particular spectral characteristic of aircraft noise. Although both propeller planes and helicopters generate a broad band of continuous noise, helicopters produce a low-frequency impulse noise from the rotor blades that is unique (Newman and Beattie 1985, Larkin et al. 1996) and may cause the greater response of geese to these aircraft.

The increased response of geese to aircraft at intermediate altitudes may be a result of the windy conditions that are typical of Izembek Lagoon. Wind can cause upward refraction of aircraft noise and shadow zones that reduce noise transmission of aircraft at low altitudes (Harrison et al. 1980). When aircraft altitude increases, the shadow-zone effect is diminished and the perceived noise may become louder even though the distance between the aircraft and flock increases (Harrison et al. 1980). Windy conditions can also cause waves on the lagoon that enhance refraction of aircraft noise.

Repetitive disturbances may have a cumulative effect to which waterfowl may habituate over time. Our tests of accommodation to helicopter overflights were inconclusive, although there was some evidence for a reduction in response of brant. The ability of waterfowl to accommodate likely depends in part on predictability of the location and constancy of the stimulus. For example, in a study where captive American black ducks (*Anas rubripes*) were exposed to playbacks of aircraft noise, the percentage of time spent reacting declined from 25 to 8% over a 4-day period (Conomy et al. 1998). Brant nesting near oil production sites in northern Alaska accommodated to relatively predictable sources of activity (i.e., vehicle traffic) but reacted more strongly to less predictable sources of disturbance (i.e., human foot traffic; S. M. Murphy and B. A. Anderson. 1993. Lisburne terrestrial monitoring program: the effects of the Lisburne development project on geese and swans 1985–1989, unpublished report. Alaska Biological Research, Fairbanks, Alaska, USA). At Izembek Lagoon, where disturbance is infrequent, brant have not accomodated to sporadic and unpredictable sources of disturbance such as boats and aircraft (Ward et al. 1994).

MANAGEMENT IMPLICATIONS

Although response to aircraft is likely to vary among waterfowl species (Burger 1991, Conomy et al. 1998, this study), models from this study should be useful in predicting the response of staging geese to aircraft overflights. Predicted responses can be combined with spatial data describing the distribution and abundance of birds to identify flight corridors that minimize aircraft disturbance of waterfowl (Miller 1994, Miller et al. 1994).

At Izembek Lagoon and other areas where waterfowl respond to aircraft overflights, managers should consider lateral distance from the birds as the primary criterion for establishing local flight recommendations, especially for helicopters. This contrasts with standard Federal Aviation Administration advisory or aeronautical maps for the United States that recommend aircraft fly above 610 m when crossing sensitive wildlife areas. Increasing aircraft altitude may in some circumstances increase rather than reduce disturbance to waterfowl. We recommend aircraft flying near Izembek Lagoon travel outside and >1.6 km from the shoreline of the lagoon.

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LITERATURE CITED

AKAIKE, H. 1973. Information theory as an extension of the maximum likelihood principle. Pages 267–281 *in* B. N. Petran and F. Cáski, editors. International symposium on information theory. Second edition. Akadémiai Kiadi, Budapest, Hungary.

BÉLANGER, L., AND J. BÉDARD. 1989. Responses of staging greater snow geese to human disturbance. Journal of Wildlife Management 53:713–719.

———, AND ———. 1990. Energetic cost of man-induced disturbance to staging snow geese. Journal of Wildlife Management 54:36–41.

BELLROSE, F. C. 1980. Ducks, geese and swans of North America. Stackpole Books, Harrisburg, Pennsylvania, USA.

BLEICH, V. C., R. T. BOWYER, A. M. PAULI, M. C. NICHOLSON, AND R. W. ANTHES. 1994. Mountain sheep *Ovis canadensis* and helicopter surveys: ramifications for the conservation of large mammals. Biological Conservation 70:1–7.

BURGER, J. 1991. The effects of human activity on birds at a coastal bay. Biological Conservation 21: 231–241.

CONOMY, J. T., J. A. DUBOVSKY, J. A. COLLAZO, AND W. J. FLEMING. 1998. Do black ducks and wood ducks habituate to aircraft disturbance? Journal of Wildlife Management 62:1135–1142. .

DAHLGREN, R. B., AND C. E. KORSHGEN. 1992. Human disturbances to waterfowl: an annotated bibliography. U.S. Fish and Wildlife Service Biological Report 188.

DAVIS, R. A., AND A. N. WISELEY. 1974. Normal behavior of snow geese on the Yukon–Alaska North Slope and the effects of aircraft-induced disturbance on this behavior, September, 1973. Pages 1–85 *in* W. W. H. Gunn, W. J. Richardson, R. E. Schweinsburg, and T. D. Wright, editors. Studies of snow geese and other waterfowl in the Northwest Territories, Yukon Territory and Alaska, 1973. Arctic Gas Biological Report Series 27.

DERKSEN, D. V., M. W. WELLER, AND W. D. ELDRIDGE. 1979. Distributional ecology of geese molting near Teshekpuk Lake, National Petroleum Reserve-Alaska. Pages 189–207 *in* R. L. Jarvis and J. C. Bartonek, editors. Management and biology of Pacific Flyway geese: a symposium. OSU Book Stores, Corvallis, Oregon, USA.

GOLLOP, M. A., J. E. BLACK, B. E. FELSKE, AND R. A. DAVIS. 1974*a*. Disturbance studies of breeding black brant, common eiders, glaucous gulls, and arctic terns at Nunaluk Spit and Phillips Bay, Yukon Territory, July, 1972. Pages 153–203 *in* W. W. H. Gunn and J. A. Livingston, editors. Disturbance to birds by gas compressor noise simulators, aircraft and human activity in the Mackenzie Valley and the North Slope, 1972. Arctic Gas Biological Report Series 14.

———, J. R. GOLDSBERRY, AND R. A. DAVIS. 1974*b*.

Aircraft disturbance to molting sea ducks, Herschel Island, Yukon Territory, August 1972. Pages 202–232 *in* W. W. H. Gunn and J. A. Livingston, editors. Disturbance to birds by gas compressor noise simulators, aircraft and human activity in the Mackenzie Valley and the North Slope, 1972. Arctic Gas Biological Report Series 14.

HARAMIS, G. M., J. D. NICHOLS, K. H. POLLOCK, AND J. E. HINES. 1986. The relationship between body mass and survival of wintering canvasbacks. Auk 103:506–514.

HARRISON, R. T., R. N. CLARK, AND G. H. STANKEY. 1980. Predicting impact of noise on recreationists. U.S. Forest Service Project 2688.

HENRY, W. G. 1980. Populations and behavior of black brant at Humboldt Bay, California. Thesis, Humboldt State University, Arcata, California, USA.

HENSCHER, D., AND L. W. JOHNSON. 1981. Applied discrete choice modelling. Croom Helm, London, United Kingdom.

HOSMER, D. W., AND S. LEMESHOW. 1989. Applied logistic regression. John Wiley & Sons, New York, New York, USA.

JENSEN, K. C. 1990. Responses of molting Pacific black brant to experimental aircraft disturbance in the Teshekpuk Lake Special Area, Alaska. Dissertation, Texas A&M University, College Station, Texas, USA.

JONES, R. D., JR., AND D. M. JONES. 1966. The process of family disintegration in black brant. Wildfowl 17:55–78.

KORSCHGEN, C. E., L. S. GEORGE, AND W. L. GREEN. 1985. Disturbance of diving ducks by boaters on a migrational staging area. Wildlife Society Bulletin 13:290–296.

KRAMER, G. W., L. R. RAUEN, AND S. W. HARRIS. 1979. Populations, hunting mortality, and habitat use of black brant at San Quintin Bay, Baja California, Mexico. Pages 242–254 *in* R. L. Jarvis and J. C. Bartonek, editors. Management and biology of Pacific Flyway geese: a symposium. OSU Book Stores, Corvallis, Oregon, USA.

LAING, K. K. 1991. Habitat and food selection, behavior, and body composition of nesting emperor geese. Thesis, University of California, Davis, California, USA.

LARKIN, R. P., L. L. PATER, AND D. J. TAZIK. 1996. Effects of military noise on wildlife: a literature review. U.S. Army Corps of Engineers Technical Report 96/21.

MADSEN, J. 1985. Impact of disturbance on field utilization of pink-footed geese in west Jutland, Denmark. Biological Conservation 33:53–63.

MANCI, K. M., D. N. GLADWIN, R. VILLELLA, AND M. G. CAVENDISH. 1988. Effects of aircraft noise and sonic booms on domestic animals and wildlife: a literature synthesis. U.S. Fish and Wildlife Service Report 88/29.

MANLY, B. F. J. 1991. Randomization and Monte Carlo methods in biology. Chapman & Hall, New York, New York, USA.

MILLER, M. W. 1994. Route selection to minimize helicopter disturbance of molting Pacific black brant: a simulation. Arctic 47:341–349.

———, K. C. JENSEN, W. E. GRANT, AND M. W. WELLER. 1994. A simulation model of helicopter disturbance of molting Pacific black brant. Ecological Modelling 73:293–309.

MOSBECH, A., AND C. GLAHDER. 1991. Assessment of the impact of helicopter disturbance on moulting pink-footed geese *Anser brachyrhynchus* and barnacle geese *Branta leucopsis* in Jameson Land, Greenland. Ardea 79:233–238.

NEWMAN, J. S., AND K. R. BEATTIE. 1985. Aviation noise effects. U.S. Department of Transportation Report FAA-EE85-2.

OWEN, M., AND J. BLACK. 1989. Factors affecting the survival of barnacle geese on migration from the breeding grounds. Journal of Animal Ecology 58: 603–617.

OWENS, N. W. 1977. Responses of wintering brent geese to human disturbance. Wildfowl 28:5–14.

TAYLOR, E. J. 1993. Molt and bioenergetics of Pacific black brant (*Branta bernicla nigricans*) on the Arctic Coastal Plain, Alaska. Dissertation, Texas A&M University, College Station, Texas, USA.

———. 1995. Molt of black brant (*Branta bernicla nigricans*) on the Arctic Coastal Plain, Alaska. Auk 112:904–919.

TEMPLE, E. R., JR. 1993. Black duck reproduction in high and low noise level environments in the Pamlico Sound region of North Carolina. Thesis, North Carolina State University, Raleigh, North Carolina, USA.

WARD, D. H., C. J. MARKON, AND D. A. DOUGLAS. 1997. Distribution and stability of eelgrass beds at Izembek Lagoon, Alaska. Aquatic Botany 58: 229–240.

———, R. A. STEHN, AND D. V. DERKSEN. 1994. Response of staging brant to disturbance at the Izembek Lagoon, Alaska. Wildlife Society Bulletin 22:220–228.

WHITE-ROBINSON, R. 1982. Inland and saltmarsh feeding of wintering brent geese in Essex. Wildfowl 33:113–118.

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