Mountain goat response to helicopter overflights in Alaska

Michael I. Goldstein, Aaron J. Poe, Erin Cooper, Don Youkey, Bridget A. Brown, and Trent L. McDonald

Abstract The number of helicopter flights used to gain access to backcountry has increased in recent years. Biologists, land managers, and the public have expressed concern about disturbance impacts to mountain goats (*Oreamnos americanus*) resulting from helicopter activity. We recorded behavioral responses of 122 groups of mountain goats from 347 helicopter overflights at 4 geographic areas in Alaska and analyzed responses in relation to distance and angle from helicopters to mountain goats, reproductive class, season, and area of study. We used multinomial logistic regression modeling combined with a bootstrap randomization procedure to identify factors associated with increased probability of mountain goats being in 1 of the 4 behavioral response categories during helicopter overflights. The probability of a goat group being disturbed was inversely related to distance of the helicopter from the group. Odds of disturbance increased by a factor of 1.25 for every 100-m reduction in approach distance. Approach distances resulting in >90% probability of maintenance were significantly larger where mountain goats had received less prior exposure to helicopters. When mountain goats were disturbed during overflights, a second analysis (i.e., gamma regression model with inverse link function) estimated elapsed time until mountain goats returned to maintenance behavior. The length of time that a goat remained in a disturbed state following overflight did not depend upon any of the covariates; mountain goats remained in a disturbed state for an average of 30.7 seconds (95% CI, 25.7–35.9 seconds). The results offer land managers an opportunity to evaluate risk for permitting helicopter activity.

Key words Alaska, behavior, disturbance, helicopter, mountain goats, *Oreamnos americanus*

The national forests of Alaska cover 8,900,000 ha, with approximately 6,900,000 ha on the Tongass National Forest (TNF) and 2,000,000 ha on the Chugach National Forest (CNF) (Figure 1). Helicopter access activities on the national forests include sightseeing, heli-skiing, heli-hiking, dogsled mushing, icefield landing tours, mechanized snow vehicle expeditions, and Army National Guard training. Permitted helicopter operations on the TNF in southeast Alaska are primarily related to sightseeing and heli-hiking tours. Summer icefield tours began on the TNF in 1984, and operations have increased since then, with approximately 19,000 landings on the Juneau Icefield in 2004. Generally, helicopter operations on the CNF are associated with winter recreation. Permitted helicopter-skiing operations began on CNF in 1997 and have steadily increased. The CNF currently hosts 2 helicopter-skiing opera-

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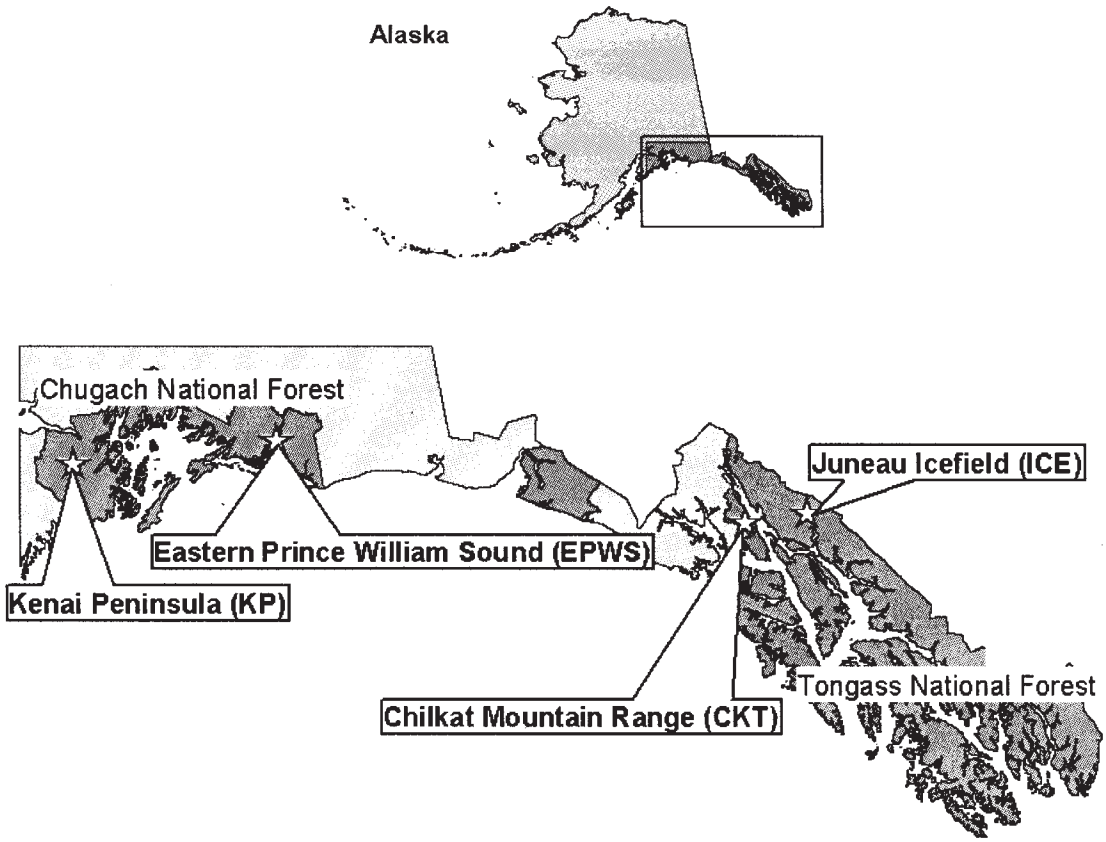


Figure 1. The locations of mountain goat disturbance study areas in Alaska, 2001–2002.

tions, which reported a total of 1,952 landings in winter of 2004. As helicopter activity increases in the backcountry, the potential for impacts to wildlife populations may increase.

The degree to which overflights influence wildlife depends on characteristics of the aircraft and flight activities, as well as species or individual specific factors including life history, habitat associations, season, sex, age, and prior experience with aircraft (National Park Service 1994; Maier 1996). The relationships between overflights and impacts to wildlife are complex, but generally, the closer the disturbance stimulus, the more likely an animal will be disturbed (Berger et al. 1983, Krausman and Hervert 1983, Knight and Knight 1984, Stockwell et al. 1991). Additionally, helicopter overflights are thought to elicit greater responses than fixed-wing overflights (Bleich et al. 1994, National Park Service 1994, Born et al. 1999, Ward et al. 1999, Frid 2003).

Mountain goat (*Oreamnos americanus*) viewing is an important recreational wildlife activity in the state of Alaska. Mountain goats also are an important game species. Since 1992 approximately 3,000 goats were harvested in south-central and southeast Alaska. Mountain goats exhibit a variety of responses to aircraft, many of which duplicate their response to predators, such as rapid retreat to escape cover, which could disrupt foraging and care of young and may result in injury or death (Berger et al. 1983, Chadwick 1983, Côté 1996, Sutherland 1996).

Mountain goats may be susceptible to disturbance resulting from helicopter overflights (Foster and Rahs 1983, Côté 1996). Immediate responses of mountain goats to helicopter disturbance likely are influenced by sex, age, season, prior experience, habitat, and characteristics of the helicopter activity (e.g., sling loads, flight-seeing, landings for passenger pickup and dropoff), and are therefore multifaceted and difficult to predict. This complexity has contributed to inconsistencies between recommended mitigations and regulations intended to minimize disturbance impacts.

We characterized disturbance behavior in

response to commercial and experimental helicopter overflights similar to recreational flight-seeing and commuter activities on national forests in Alaska. We then evaluated the importance of variables that affected the behavioral response by mountain goats. This study represented a unique opportunity to study differences between areas with differing levels of helicopter activity and possibly mountain goat habituation. We quantified the behavioral responses of mountain goats under regular sustained helicopter activity and compared those to the responses of mountain goats unaccustomed to helicopter activity. Our goal was to predict the levels of disturbance helicopter operations would have on mountains goats on national forest lands and to provide managers with a way to measure risk of disturbance when considering permit-specific conditions for helicopter traffic.

Study area

We sampled goat behavior at 4 study areas in south-central and southeast Alaska in 2001 and 2002 (Figure 1). Study areas were similar in topography, physical condition, and vegetation. Sites were located on rough, rocky, steep terrain containing glaciers and permanent snowfields, yet under a maritime climate with high precipitation. Vegetation cover consisted of alpine shrubs, grasses, and forbs. Groups of mountain goats occurred in discrete areas separated by intersecting glacial valleys. The discrete distribution of groups of mountain goats allowed for experimental evaluation of disturbance response, as individuals occurring at sampled locations had limited opportunity to migrate into or out of other sample areas during the relatively short sampling periods. Potential predators of goats within study areas included: wolves (*Canis lupus*), wolverines (*Gulo gulo*), lynx (*Lynx lynx*), black bears (*Ursus americanus*), brown bears (*Ursus arctos*), golden eagles (*Aquila chrysaetos*), and bald eagles (*Haliaeetus leucocephalus*).

We sampled mountain goats in winter, spring, and summer. We sampled the Kenai Peninsula–Turnagain Arm study area (KP) during winter (i.e., late March–April), the Eastern Prince William Sound study area (EPWS) during spring (i.e., late May–early June), the Chilkat Mountain Range study area (CKT) in summer (i.e., August), and the Juneau Icefield study area (ICE) during spring (i.e., June) and summer (i.e., July). Sampling areas during different seasons were based on 1) climatic constraints, 2) a priori determination of which sites could receive future human activity during a particular season, and 3) logistical constraints of personnel and aircraft availability.

We sought to assess whether behavioral responses by mountain goats accustomed to chronic overflight activity were different from those of goats at sites with less helicopter activity, and used this criterion to select sampling areas. Based on permitted helicopter activity and known flight corridors, mountain goats were presumed to have prior exposure to helicopter ranked from least to greatest: EPWS, KP, CKT, and ICE. Fixed-wing aircraft activity occurred in all areas. Hunting was permitted in all areas except most sites sampled at ICE.

Data collection

We used existing mountain goat survey and sighting records to identify locations where ground-based observers would be able to evaluate mountain goat responses to helicopter overflights. We positioned 2 observers approximately 1.6 km away from the group of mountain goats. This distance was far enough away to not cause noticeable responses by mountain goats to humans on the ground, but close enough to record behaviors. One person used a 15–60X spotting scope to observe behaviors while the second person recorded data. We targeted a 25X video camera on the most complete view of the group of mountain goats. We synchronized time with the behavioral sampling, which was displayed on the video screen and recorded. This time-stamped footage provided a continuous audiovisual log that was available for verification of behavior data.

We sampled groups of 1–17 individuals, but simultaneous behavioral data were collected on only 9 individuals, selected by random number table. We defined 8 categories of behavior: fleeing; defense–hide; alert (i.e., agitated or head tilted in direction of the stimulus); foraging (including small bouts of locomotion from one feeding site to another); nursing; walking; standing; and lying. When we could not observe animals, we recorded them as out-of-sight. We collected scan samples on each animal at 1-minute intervals for 15 minutes prior to and 15 minute following a 3-minute intercept period (as defined below). We took scan samples once every 10 seconds when helicopters were approximately 3 km (or 1 minute, at a speed of 100 knots) away from groups of mountain goats until 2 minutes after the helicopter passed over each group.

This resulted in a minimum of 33 minutes of data collection for each flight. We recorded sex and age of mountain goats.

Experimental overflights

Helicopters flew past groups of mountain goats at a constant speed (~51 m/sec) and direction at distances between 143 m and 1,911 m. At KP, EPWS, and CKT we contracted experimental overflights of A-Star AS-350 helicopters (American Eurocopter, Grand Prairie, Tex.) to fly over groups of mountain goats at distances between 250 m and 2,000 m as directed by ground observers. At ICE, A-Star helicopters operated regular flight lines during sightseeing tours under federal special-use permits. Commercial operators were not permitted to fly <500 m from groups of mountain goats, although, based on the results of the overflight data, it was evident the restrictions did not confine the operations. The occasional close proximity of helicopters to goats (<500 m) was opportunistic, not designed. Within the restrictions of flight safety, weather, and topography, pilots reduced variability by designing flight routes that avoided substantial turns or changes in elevation, avoided topographic features that could block mountain-goat-to-helicopter lines-of-sight, and maintained consistent aircraft speed within 4 km of an animal or group.

We recorded helicopter flight lines, time, and 3-dimensional coordinates at KP, EPWS, and CKT using onboard Trimble GeoExplorer 3 (Sunnyvale, Calif.) Global Positioning System (GPS) units. We mapped mountain goats into geographic information systems using air photos and topographic maps and determined distance from helicopter to mountain goat by analyses of GPS data. We synchronized behavioral data with GPS data collected during each helicopter overflight so that behaviors elicited could be evaluated with regard to helicopter position. Ground observers measured distances from helicopters to mountain goats at ICE by using laser rangefinders (distances ±10 m and angles ±1°). A single disturbance trial at ICE consisted of a group of 4 or 5 helicopters, with approximately 20 seconds between each aircraft.

Classifying and modeling response data

We classified each group of mountain goats into 1 of 3 reproductive classes (female–kid, female–subadult, or adult) and 1 of 3 seasons (winter, spring, or summer). We summarized behavioral responses from each overflight by distance, angle, reproductive class, and season. These variables are characteristically identified as important relative to disturbance caused by helicopter overflights (Foster and Rahs 1983, Côté 1996, Frid 2003), and many mitigation measures developed to minimize aircraft disturbance of mountain goats rely on controlling >1 of these variables.

We stratified observations into 3 time categories based on the point the helicopter reached its closest distance to the observed mountain goats, called the intercept center point (ICP): 1) before (15 minutes prior to the intercept period), 2) intercept period (i.e., 1 minute prior to the ICP and 2 minutes after), and 3) after (i.e., 15 minutes after the intercept period). We chose an intercept period of 3 minutes because it encompassed all immediate overt disturbance events associated with all helicopter overflights. At 1 minute prior to the ICP, the helicopter was approximately 3 km away from the goats and therefore outside the audiovisual range expected to influence their behavior (Foster and Rahs 1983, Côté 1996). Two minutes after the ICP provided enough time to capture all latent disturbance behavior and allowed for a time lag in initial disturbance response.

We summarized behavior as the proportion of time all mountain goats within the observed group spent fleeing, defense–hide, alert, feeding, nursing, walking, standing, lying, or were out-of-sight during the disturbance period. If one mountain goat in a group directly responded to the stimulus, we coded the group with eliciting that response. On rare occasions, when the mountain goat was alert or running for reasons other than the stimulus, we did not include the behavior in the disturbance analysis. We categorized behavioral response as maintenance, alert, vigilant, or fleeing: 1) Maintenance was recorded when all mountain goats within the group maintained feeding, nursing, walking, standing, and lying behavior during the entire intercept period; 2) Alert included alert behavior exhibited by any individual in the group for <10% of the time; 3) Vigilance was alert behavior exhibited by any individual in the group for >10% of time or any defense–hide response; and 4) Fleeing included running by any individual.

We first identified factors associated with increased probability of mountain goats being in 1 of the 4 behavioral response categories during helicopter overflights. When individual goats entered 1 of 3 nonmaintenance categories (i.e., alert, vigilance, or fleeing) during overflights, a second analy-

sis estimated elapsed time until goats returned to maintenance behavior.

In the first analysis, we fit a multinomial logistic regression model (Hosmer and Lemeshow 2000) to the data. We used the multinomial regression analysis to identify a model containing study variables that best described variation in the probability of groups of mountain goats being in each of the 4 behavioral categories. The multinomial regression model was a generalization of binomial logistic regression (Hosmer and Lemeshow 2000) and related the logarithm of probability ratios for 3 types of behavior to measured study covariates. The 3 multinomial regression equations involved the probability of a goat group being alert during the overflight (π_a), the probability of a goat group being vigilant during the overflight (π_v), the probability of a goat group fleeing during the overflight (π_f), and the probability of a goat group displaying maintenance behavior during the overflight (π_m). For convenience, we chose to use π_m as the reference category in the denominator of the ratios, given that we would have obtained the same model and results had we chosen a different reference category. Because of the 4 response categories, $3(p+1)$ total coefficients were estimated in the model, 1 for each covariate and equation, when p explanatory variables were included in the model.

We estimated coefficients (i.e., β) of the model by maximizing the 4 category conditional multinomial likelihood of the data (Mood et al. 1974). Assuming the observed disturbance responses are coded (Table 1), the likelihood of the data is conditional on the covariates (Hosmer and Lemeshow 2000). This likelihood was maximized iteratively to obtain estimates of the β coefficients using S-Plus (Venables and Ripley 1999). We discarded standard errors of the coefficients because they were potentially biased by dependencies in the data. We established confidence intervals for the coefficients using the bootstrap method described below. Once coefficients were estimated, we calculated predicted values for the probabilities of each disturbance class as,

$$\hat{\pi}_a = \frac{\exp\left(\hat{\beta}_{a0} + \hat{\beta}_{a1}x_1 + \ldots + \hat{\beta}_{ap}x_p\right)}{1 + \exp\left(\hat{\beta}_{a0} + \hat{\beta}_{a1}x_1 + \ldots + \hat{\beta}_{ap}x_p\right) + \exp\left(\hat{\beta}_{v0} + \hat{\beta}_{v1}x_1 + \ldots + \hat{\beta}_{vp}x_p\right) + \exp\left(\hat{\beta}_{f0} + \hat{\beta}_{f1}x_1 + \ldots + \hat{\beta}_{fp}x_p\right)}$$

$$\hat{\pi}_v = \frac{\exp\left(\hat{\beta}_{v0} + \hat{\beta}_{v1}x_1 + \ldots + \hat{\beta}_{vp}x_p\right)}{1 + \exp\left(\hat{\beta}_{a0} + \hat{\beta}_{a1}x_1 + \ldots + \hat{\beta}_{ap}x_p\right) + \exp\left(\hat{\beta}_{v0} + \hat{\beta}_{v1}x_1 + \ldots + \hat{\beta}_{vp}x_p\right) + \exp\left(\hat{\beta}_{f0} + \hat{\beta}_{f1}x_1 + \ldots + \hat{\beta}_{fp}x_p\right)}$$

$$\hat{\pi}_f = \frac{\exp\left(\hat{\beta}_{f0} + \hat{\beta}_{f1}x_1 + \ldots + \hat{\beta}_{fp}x_p\right)}{1 + \exp\left(\hat{\beta}_{a0} + \hat{\beta}_{a1}x_1 + \ldots + \hat{\beta}_{ap}x_p\right) + \exp\left(\hat{\beta}_{v0} + \hat{\beta}_{v1}x_1 + \ldots + \hat{\beta}_{vp}x_p\right) + \exp\left(\hat{\beta}_{f0} + \hat{\beta}_{f1}x_1 + \ldots + \hat{\beta}_{fp}x_p\right)}$$

$$\hat{\pi}_m = \frac{1}{1 + \exp\left(\hat{\beta}_{a0} + \hat{\beta}_{a1}x_1 + \ldots + \hat{\beta}_{ap}x_p\right) + \exp\left(\hat{\beta}_{v0} + \hat{\beta}_{v1}x_1 + \ldots + \hat{\beta}_{vp}x_p\right) + \exp\left(\hat{\beta}_{f0} + \hat{\beta}_{f1}x_1 + \ldots + \hat{\beta}_{fp}x_p\right)},$$

such that $\hat{\pi}_a + \hat{\pi}_v + \hat{\pi}_f + \hat{\pi}_m = 1$ for every unique set of covariate values.

The covariates of interest in the multinomial regression analysis were study area, reproductive class of the group of mountain goats, closest approach of the helicopter to the group of mountain goats, angle of the helicopter to the group of mountain goats, and season. We treated study area, reproductive class, and season as discrete factors containing 4, 3, and 3 levels, respectively. Distance and angle were continuous covariates. Pairwise interactions among these covariates also were of interest.

We used Schwarz's Bayesian Criterion (SBC) (Schwarz 1978) to select a set of covariates that

Table 1. Behavioral responses of groups of mountain goats to helicopter overflights at 4 study areas in Alaska during 2001 and 2002.

	Maintenance		Alert		Vigilant		Fleeing		
Site	*n*	%	*n*	%	*n*	%	*n*	%	Total
Chilkat Mountains	48	61.5	10	12.8	19	24.4	1	1.3	78
E. Prince William Sound	29	50.0	7	12.1	17	29.3	5	8.6	58
Kenai Peninsula	58	63.0	7	7.6	10	10.9	17	18.5	92
Juneau Icefield	92	77.3	11	9.2	7	5.9	9	7.6	119
Total	227	65.4	35	10.1	53	15.3	32	9.2	347

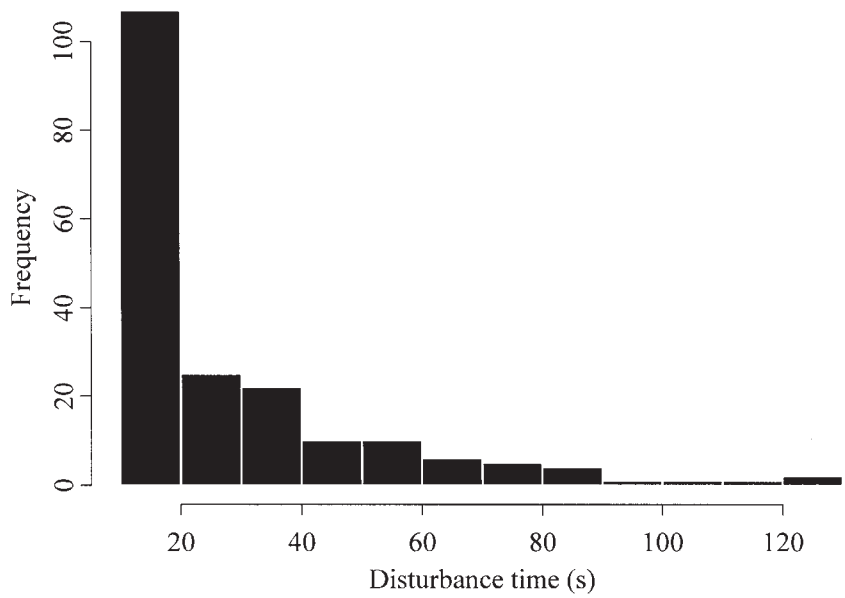


Figure 2. The observed distribution of disturbance time for individual mountain goats that entered one of the positive disturbance categories (vigilant, alert, or fleeing). Observations pooled from all areas, distances, angles, and seasons (n = 194) in Alaska, 2001–2002.

best explained variation in the probabilities of each response, by fitting and assessing all possible models containing the covariates of interest and their interactions.

We considered models with SBC close (< ~6.0) to the minimum SBC, obtained over all possible models, reasonable models and identical in fit as measured by SBC. We selected the final reported multinomial model from among this set of models with SBC close to the minimum. With 5 covariates and all pairwise interactions of interest, 1,449 models were possible. Once a final multinomial model was selected, confidence intervals for coefficients in the model were computed using a bootstrap method (Manly 1997) that accounted for the fact that multiple flights over a single group occurred on the same day at varying distances and angles. We assumed the influence of this type of dependency to be small because most groups (n = 76 of 122, 62.3%) received 1 or 2 overflights on the same day, 41 groups (33.6%) received between 3 and 7 overflights on the same day, and 5 groups (4.1%) received >7 overflights on the same day. Nonetheless, the bootstrap method accounted for potential dependencies among responses from the same group by resampling, with replacement, mountain goat group identifiers (Manly 1997). The process of resampling the original data and refitting coefficients was repeated 1,000 times, and variation in the refitted coefficients over these 1,000 iterations correctly represented variation of the original coefficients in the presence of whatever dependencies existed in the original data set. To quantify that variation, we constructed 95% confidence intervals for each coefficient by computing the 2.5th and 97.5th percentile of the 1,000 bootstrapped values for each coefficient. We considered a coefficient significantly different from 0 at the α = 0.05 level if its 95% confidence interval did not contain 0.

In the second analysis, we classified individual mountain goats as disturbed (i.e., alert, vigilant, fleeing) or not disturbed (i.e., maintenance) during their encounter with the helicopter. From observations of disturbed mountain goats, the total amount of time spent in a disturbed state prior to returning to the maintenance category was calculated. The amount of time a mountain goat spent in a disturbed state formed the response variable in a regression analysis that sought to identify factors associated with elongated states of disturbance and estimate average disturbance time. The overall distribution of disturbance time (Figure 2) was highly skewed toward small values and could not be transformed such that it followed an approximate normal distribution. Because disturbance time followed an approximate gamma distribution (Mood et al. 1974), a gamma regression model with inverse link function (McCullagh and Nelder 1989) was fit that related disturbance time to a function of the study covariates area, reproductive class, distance, and angle. Due to the reduced number of disturbed animals in the combinations of season and the other variables, season could not be considered in the gamma regression model. As in the first analysis, we considered study area and reproductive class discrete indicator variables, while we considered the angle and distance variables as continuous variables.

We selected the final gamma regression model the same way that the final multinomial model was

Table 2. Estimated coefficients from the top 4 multinomial models for helicopter overflight disturbance of mountains goats in Alaska during 2001 and 2002, as selected by Schwarz's Bayesian Criterion. Model 3 was selected for use as the final model to discuss habituation of mountain goats to helicopters.

Model no.	Schwarz's Bayesian Criterion	Variable	Coefficients in the logistic model		
			π_a/π_m	π_v/π_m	π_f/π_m
1	714.6	(Intercept)	–0.69552	–0.33478	–0.92113
		Distance	–0.00188	–0.00178	–0.00163
2	714.7	(Intercept)	–1.23242	–0.83683	–0.93034
		Distance	–0.00175	–0.00165	–0.00161
		Angle	0.01504	0.01420	–0.00009
3	717.1	(Intercept)	–0.97574	–1.38393	–0.92658
		Area.ckt [a]	0.42623	1.51822	–1.68300
		Area.epws [a]	1.02806	2.38028	0.96755
		Area.kp [a]	0.44507	1.27052	1.62840
		Distance	–0.00204	–0.00213	–0.00258
4	718.2	(Intercept)	–2.36855	–1.91885	–1.98490
		Angle	0.01673	0.01587	0.00129

[a] Indicator variables for Area. Area.ckt = 1 if overflight was conducted in the Chilkat Range study area, 0 otherwise. Area.epws = 1 if overflight was conducted in Eastern Prince William Sound study area, 0 otherwise. Area.kp = 1 if overflight was conducted in the Kenai Peninsula study area, 0 otherwise.

selected. All possible models containing the covariates of interest and their interactions were fit and assessed using SBC. Because we considered only 4 covariates for inclusion in the gamma model, there were 113 possible models to consider. We could not ignore correlation induced by observing multiple overflights for some individuals. Because multiple overflights of the same individual occurred at random and were not related to other factors, the magnitude of coefficients in the gamma model was not biased, but standard errors of those coefficients were potentially too small. As with the multinomial model, we computed 95% confidence intervals for coefficients in the final gamma model using the same bootstrap procedure outlined for the multinomial model.

Table 3. Confidence intervals (95%) for coefficients in the final multinomial model for helicopter disturbance of mountains goats in Alaska during 2001 and 2002, computed by the bootstrap method. Confidence intervals that do not contain 0 indicate a coefficient that was considered significantly different from 0 at the $\alpha = 0.05$ level. These intervals are denoted by "*".

	Model for π_a/π_m		Model for π_v/π_m		Model for π_f/π_m	
	Low limit	Upper limit	Low limit	Upper limit	Low limit	Upper limit
(Intercept)	–2.19266	0.53531	–2.39442	–0.27322*	–1.99062	0.19378
Area.ckt	–1.04700	2.04614	–0.28466	3.25171	–13.39977	0.48113
Area.epws	–0.62271	2.39648	1.16612	3.72196*	–0.95883	2.41139
Area.kp	–0.94182	1.79736	0.05901	2.55882*	0.44596	3.04200*
Distance	–0.00471	–0.00058*	–0.00381	–0.00130*	–0.00527	–0.00110*

Results

We analyzed mountain goat response data for 347 helicopter overflights on 122 groups in 4 study areas during 2001 and 2002. Overall, we observed maintenance behaviors in 65.4% (n = 227) of the flights and observed disturbance during 34.6% (n = 120) of the overflights (Table 1). Groups that we coded for disturbance collectively included 773 individual mountain goats. In those groups, 194 mountain goats (25.1%) had overt behavioral changes due to helicopters; 66% of those mountain goats were alert or vigilant and 34% fled.

Model selection

Among the 1,449 models fit during model selection, 4 had SBC values close to the minimum (Table 2). None of the top 4 models contained the variables reproductive class or season, nor did they contain any interactions. Distance appeared in 3 of the 4 models, angle appeared in 2 of the 4, and study area appeared in 1 of the 4 models. We chose to discuss model 3 as the final multinomial model because we have a unique opportunity to assess the question of habituation in an exploratory fashion. Model 3 contained the variables distance and study area. If mountain goats can become habituated to helicopter flights, then management of overflights may be implemented regionally or locally. Nonetheless, all 4 models have essentially the same amount of support, according to SBC. Bootstrap confidence intervals for coefficients in model 3 appear in Table 3.

Results of model 3 indicated that the probability of a goat group being in one of the disturbed classes (alert, vigilant, or flee-

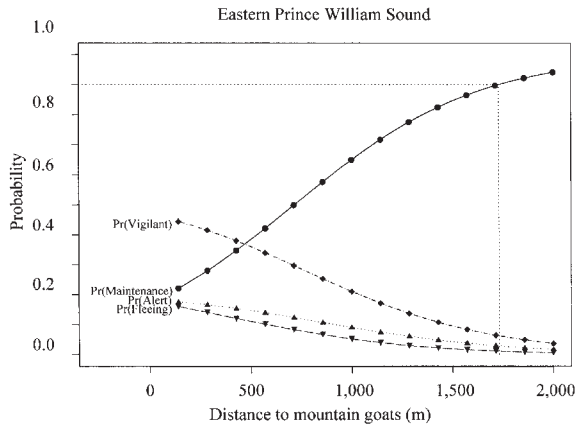


Figure 3a. Probabilities of each disturbance category (e.g., x, y, z) as a function of distance from the mountain goats in the Eastern Prince William Sound study area, Alaska, 2001–2002, as predicted by the final multinomial regression model. The probability of mountain goats being in the maintenance category is >90% if aircraft approach is >1,730 m.

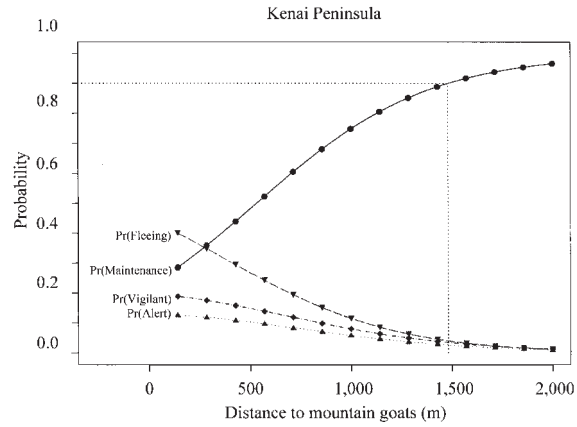


Figure 3b. Probabilities of each disturbance category (e.g., x, y, z) as a function of distance from the mountain goats in the Kenai Peninsula study area, Alaska, 2001–2002, as predicted by the final multinomial regression model. The probability of mountain goats being in the maintenance category is >90% if aircraft approach is >1,481 m.

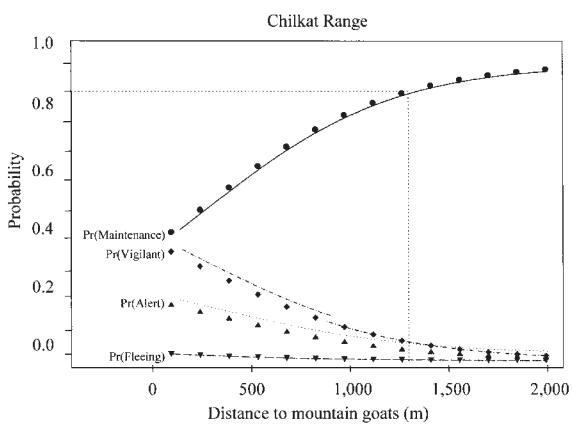


Figure 3c. Probabilities of each disturbance category (e.g., x, y, z) as a function of distance from the mountain goats in the Chilkat Range study area, Alaska, 2001–2002, as predicted by the final multinomial regression model. The probability of mountain goats being in the maintenance category is >90% if aircraft approach is >1,318 m.

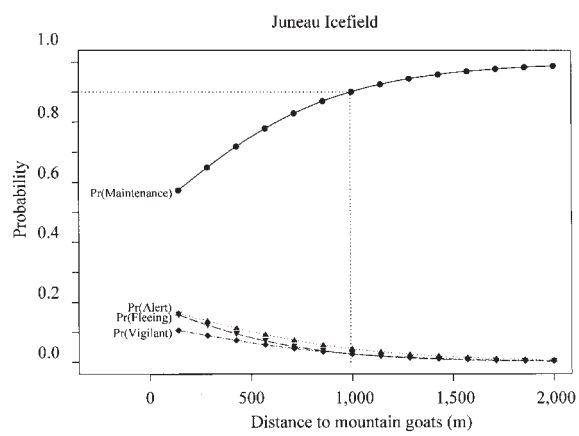


Figure 3d. Probabilities of each disturbance category (e.g., x, y, z) as a function of distance from the mountain goats in the Juneau Icefield study area, Alaska, 2001–2002, as predicted by the final multinomial regression model. The probability of mountain goats being in the maintenance category is >90% if aircraft approach is >991 m.

ing) was inversely related to distance of the helicopter from the group (Table 3, coefficients for distance in all 3 logistic models). Coefficients for distance in the model were similar for all 3 disturbance classes and, when averaged, indicated that the odds of disturbance increased by 25% (a factor of 1.25) for every 100-m reduction in approach distance. For an approach distance of 1,000-m, predicted probability of maintenance behavior was 0.65, 0.75, 0.82, and 0.90 in the EPWS, KP, CKT, and ICE study areas, respectively (Figure 3).

Predicted probability of each of the 4 disturbance responses, as a function of approach distance, was plotted for all study areas (Figure 3). From the predicted values, the probability of a group of mountain goats being in the maintenance category was >90% if distance to the group was >1,730 m in EPWS (Figure 3*a*), >1,481 m in KP (Figure 3*b*), >1,318 m in CKT (Figure 3*c*), and >991 m in ICE (Figure 3*d*). Confidence intervals for the

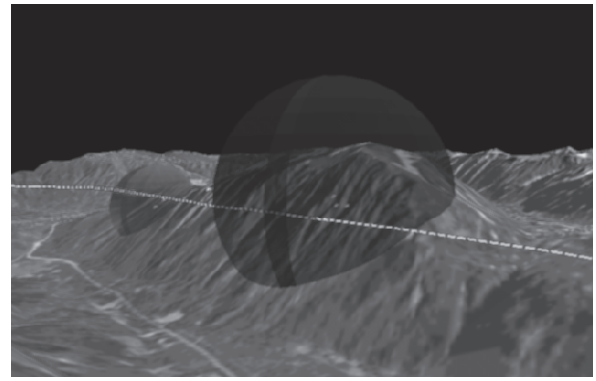
study area odds ratios for vigilant and fleeing behavior indicated that approach distances resulting in probability of remaining in maintenance >90% were significantly larger in EPWS and KP than in the CKT and ICE. Furthermore, the distance at which probability of remaining in maintenance was >90% was not significantly different between EPWS and KP, or between CKT and ICE.

Model 3 also indicated that the odds of fleeing and vigilance relative to maintenance in KP were significantly higher than the same odds in ICE (Table 3, coefficients for KP). For a given approach distance, the odds of vigilance relative to maintenance in EPWS area were higher than the same odds in ICE, but the odds of fleeing relative to maintenance were not significantly different between EPWS and ICE. No significant differences in any behavior existed in the response of goats in CKT and ICE.

For the 194 individual mountain goats that were disturbed, we related disturbance time to other factors. Three models yielded SBC values within 6 units of the minimum SBC, the null model (SBC = 122.4, intercept coefficient 0.03261, bootstrap SE = 0.002793113), a model with angle (SBC = 125.2, intercept coefficient 0.02955, angle coefficient 1.1035E-04, bootstrap SE = 0.91792E-04), and a model with distance (SBC = 126.8, intercept coefficient 0.03678, distance coefficient –7.7654E-06, bootstrap SE = 9.192265E-06). The CI for both angle and distance contained zero (by gamma distribution theory, a coefficient this size could have been selected by chance alone). The pre-bootstrap Wald *t*-test for angle resulted in $P = 0.051$, and after accounting for the dependency in the data, $P > 0.051$. For distance, the pre-bootstrap Wald *t*-test resulted in $P > 0.25$ (bootstrapping this data would have resulted in a less significant finding). The final gamma model also was the one with lowest SBC, the null model,

$$\hat{E}[y] = \frac{1}{0.03261},$$

where $\hat{E}[y]$ was the estimated average length of time an individual mountain goat stayed in a disturbed state following an overflight. The length of time that a goat remained in a disturbed state following overflight did not depend upon any of the covariates area, reproductive class, angle, or distance. The final gamma model estimated that goats remain in a disturbed state for an average of 30.7 seconds, with a 95% confidence interval from 25.7–35.9 seconds.



Three-dimensional computer graphic of helicopter overflight line on the Kenai Peninsula, with light 500-m and dark 1,000-m spheres surrounding the location of the goats.

Discussion

When disturbed by helicopter overflights, mountain goats can become alert, maintain a prolonged state of vigilance, seek cover, or run away. In Alberta (Côté 1996) and British Columbia (Foster and Rahs 1983), fleeing and hiding disturbance reactions were elicited at helicopter-to-goat distances of <500 m, maintenance behavior was altered at 500–1,500 m, and alerted head tilts occurred at distances >1,500 m. Disturbance responses in Alaska were muted in comparison; responses occurred in 33% of the overflights and changes in maintenance behaviors lasted <2 minutes (90% lasted <60 seconds and 55% lasted <20 seconds).

Topography may provide some explanation for the different magnitudes of response, due to terrain, noise levels, and proximity to escape cover. Mountain goats in open, undulating terrain in Alberta responded by running for long distances (>100 m) or remaining alert for extended periods of time (>10 min) (Côté 1996). On our study sites, steep terrain may have limited the ability of mountain goats to run long distances. Proximity to escape cover may have reduced the magnitude of the responses we detected. For example, Dall's sheep (*Ovis dalli dalli*) >20 m from rocky slopes always fled in response to helicopter passes, presumably because they were far from escape cover (Frid 2003). Because GIS analyses of goat group locations in Alaska showed that the vast majority of goats sampled during this study were either in or very close (<60 m) to escape cover, this parameter was not a covariate in our model.

Côté (1996) found no clear relationship between the reproductive composition of a mountain goat

group and their disturbance reactions. In contrast, Main et al. (1996) qualitatively proposed that in sexually dimorphic ungulates, adult males are greater risk takers and that disturbance reactions from such groups could be less in frequency and magnitude. This was supported by Ballard (1975), who found that female mountain goats with young showed more pronounced disturbance reactions to survey aircraft than did adults without kids in southeast Alaska. Reproductive class was not an important factor in the explanation of responses we observed.

The degree to which mountain goats are able to habituate to helicopter activity is not known. Little evidence exists of short-term habituation by mountain goats and other ungulates to aircraft overflights during the course of behavioral disturbance trials (Miller and Gunn 1980, Harrington and Veitch 1991, Bleich et al. 1994, Côté 1996, Frid 2003). Frid (2003) suggested that Dall's sheep responded more strongly to the first flight of the day than to subsequent overflights but found that after months of study the proportion of sheep fleeing from aircraft overflights did not change. Long-term habituation to sustained aircraft overflights has not been intensively studied, and the speculations are contradictory. Joslin (1986) suggested that goats were not able to habituate to sustained helicopter activity; however, other factors attributed to seismic exploration may have confounded these results. Bighorn sheep (*Ovis canadensis*) displayed milder reactions to helicopter overflights once they became habituated to regular helicopter traffic in the Grand Canyon (Stockwell et al. 1991). Bighorn sheep also habituated to simulated jet aircraft overflight noise and jet aircraft overflights (Weisenberger et al. 1996, Krausman et al. 1998). In our study areas, goats with greater prior exposure to helicopters seemed to have the most tolerance for helicopter overflights. The length of time that a goat remained in a disturbed state following an overflight, however, was not different between areas.

Management implications

The potential impact of helicopter traffic on mountain goats has generated several conflicting standards regarding separation distance. These standards have been developed based on either anecdotal information or published material from Alberta (Côté 1996) and British Columbia (Foster and Rahs 1983). Disturbance reactions from mountain goats in the rugged mountains of Alaska appear to be quite different than those from mountain goats in the terrain of Alberta and British Columbia and seem to allow closer helicopter approach distances.

Côté (1996) recommended a 2,000-m buffer between mountain goats and helicopter activities to minimize adverse impacts. Foster and Rahs (1983) analyzed mountain goat response to hydroelectric exploration in British Columbia and recommended a 2,000-m buffer to prevent an overt disturbance response to human activity. Aircraft on the TNF and CNF are expected to maintain a minimum landing distance of 805 m from all observed mountain goats (United States Department of Agriculture Forest Service 1997, 2002). While flying, aircraft are required to maintain a 500-m minimum vertical distance from all observed goats.

The probability of any mountain goat in a group becoming disturbed at 500 m was 62% in EPWS, 52% on the KP, 38% in the CKT, and 25% in the ICE. At 1,000 m, the probabilities decrease to 45% in EPWS, 25% on the KP, 18% in the CKT, and 10% in the ICE. Taken another way, if managers wish to consider a measure of risk of disturbance at <25% (an arbitrary delineation) when permitting helicopter traffic, then the helicopter approach distance could be 1,234 m in EPWS, 1,000 m on the KP, 771 m in the CKT, and 500 m in the ICE. Managers would need to consider whether pilots could effectively judge these distances or if a distance such as 805 m better facilitates judgment.

The distance an aircraft is to known mountain goat locations is a parameter that is fairly controllable by pilots and thus should be the focus of guidelines to reduce disturbance to mountain goats. An effective management strategy requires developing no-fly zones to surround known mountain goat locations, preferably accomplished through a validated habitat model. These zones can then be monitored if backcountry helicopter operators are required to submit flight lines recorded by on-board GPS systems.

Analyzing the impact of overflights by commuting helicopters is unlikely to provide the full answer to the mountain goat disturbance issue, and it is conceivable that helicopter landings that deliver recreational users to remote areas may impact goats differently. The impact of ground-based user groups may be more severe in Alaska as mountain goats in the state are generally from hunted populations and may react to all humans as hunter–predators. Rigorous quantification of the effects of helicopter disturbance on population dynamics

requires multi-year studies of radiocollared individuals exposed to experimentally determined disturbance rates. Future research should address population productivity and daily time expenditures under different levels of helicopter activity.

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