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Summer Diet, Feeding Site Selection, and Forage Resources of Mountain Goats on Kodiak Island, Alaska

McCrea Cobb, Bill Pyle, and Heidi Helling

Kodiak National Wildlife Refuge
August 2013

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Mountain Goat Diet, Feeding Site Selection, and Forage Resources on Kodiak Island, Alaska

McCrea Cobb[1], Bill Pyle[1], and Heidi Helling[2]

Abstract

Introduced mountain goats (*Oreamnus americanus*) on Kodiak Island have followed an irruptive population growth pattern, typified by low density ungulates that are free of predation pressure and have abundant forage resources. In response to concerns over potential impacts to native flora and fauna from a high density mountain goat population and to improve harvest management, we sought to quantify mountain goat summer diets, feeding site selection, and available forage resources across three subpopulations at different densities and durations of site occupancy. Between June and August, we collected fecal pellets from goat groups that were primarily composed of nannies, and to a lesser extent kids and billies. Microhistological analyses of the pellets revealed that diets (uncorrected for differential digestibility of forage components) were largely composed of fern rhizomes and grasses in early summer (June), and sedges and forbs later in the summer (July to mid-August). The proportion of forage in goat diets varied across subpopulation, but dietary differences among subpopulations were uncorrelated with subpopulation density or duration of occupancy. Mountain goats selectively used sites with abundant sedge, rush, and moss on south-facing slopes close ($\bar{x}$ = 57 m) to escape terrain (slopes >33°). Forage quality, measured as digestible protein and dry matter digestibility, of primary goat forage classes that composed more than 5% of their diets, varied among forage classes, according to sequential fiber analyses. Digestible protein content declined by an average of 5% between early and late summer across all study sites. In contrast, dry matter digestibility did not vary over the summer or between study sites. Forage biomass varied by aspect, day of the year, slope, and study site We found no evidence that forage biomass differed between feeding and random sites, suggesting that goats did not select feeding sites based on forage biomass. This study was the first to quantify mountain goat diets, feeding site selection, and forage resources on Kodiak Island. These findings will guide management of the Kodiak mountain goat population and likely apply more generally to mountain goat populations in coastal Alaska.

Introduction

The mountain goat (*Oreamnus americanus*) population on Kodiak Island, Alaska has increased dramatically in number and range since its introduction in 1952. Kodiak has since firmly established itself as leading destination for recreational sport hunting of mountain goat in North

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America. In Alaska, more mountain goats were harvested from Kodiak than any other management area in 2012. Hunting is a popular and potentially effective means of regulating mountain goat abundances, but the impact of harvests on annual changes in population abundance have been unclear on Kodiak. If the Kodiak mountain goat population exceeds its carrying capacity, ecological theory predicts that the population will over utilize its resources and decline to a new lower carrying capacity. This process would result in reduced hunter harvest opportunities and potentially adverse impacts to Kodiak's natural resources.

The long-term management goal of the Kodiak National Wildlife Refuge and the Alaska Department of Fish and Game (ADF&G) is to maintain mountain goat abundances at levels that satisfy hunter harvest expectations while avoiding irreversible resource damage. Introduced ungulates can cause detrimental landscape-level effects by altering vegetation structure and composition, soil system functioning, and chemical processes (Hobbs 1996, Spear and Chown 2009). Impacts can be especially severe on island and alpine ecosystems that are less resilient to disturbance (Courchamp et al. 2003). Studies on the effects of introduced mountain goats have generally found evidence for impacts on native ecosystems. Houston et al. (1994) concluded that mountain goats modified native plant communities and reduced abundances of several rare and endemic plants in Olympic National Park, Washington. Mountain goats introduced to the Greater Yellowstone Area of Montana and Wyoming expanded in range and size (Lemke 2004), and were associated with reduced vegetation cover along intensively used alpine ridges (Aho and Weaver 2003). To understand potential impacts of mountain goats on Kodiak's flora, managers need to understand the relationships between Kodiak mountain goats and their habitat. Quantifying these relationships requires detailed empirical data on mountain goat resource selection patterns.

Managing mountain goats and their habitats on Kodiak is a high priority to federal and state agencies. The importance of this goal has been well documented and is supported by agency policies and plans. Managing Kodiak's mountain goats was recognized as a primary concern during an interagency meeting on Kodiak Island's nonnative species (Clough 2000). ADF&G has identified four explicit goals related to mountain goats on Kodiak: developing low cost methods to index annual population trends, gaining a better understanding of movements and habitat selection, developing a harvest plan to provide ample hunter opportunities while maintaining habitat conditions, and gaining a better understanding of mountain goat impacts on habitats (Van Daele and Crye 2008). Managing mountain goats is an essential ungulate management goal for the Refuge, as highlighted in the Refuge's Comprehensive Conservation Plan (CCP). Specifically, the CCP stresses the importance of evaluating and reporting habitat use and preferences of mountain goats and improving the understanding of goat influence on habitat conditions (U.S. Fish and Wildlife Service 2006). Research on Kodiak mountain goats directly addresses other Refuge objectives; including increasing knowledge of fish and wildlife populations, their habitats, and their interrelationships (CCP Goal 1); managing nonnative species to minimize impacts on native resources, while continuing to provide opportunities for harvest (CCP Goal 3); and maintaining native plant populations, communities, and habitats (CCP Goal 6) These goals, objectives, and concerns are additionally supported by the Fish and Wildlife Service's overarching Biological Integrity, Diversity and Environmental Health Policy (U.S. Fish and Wildlife Service 2001).

Empirical data on mountain goat foraging ecology on Kodiak Island is needed to understand potential impacts to native flora, and focus future research priorities. For example, it is unclear how mountain goat diets on Kodiak compare to other regions in coastal Alaska that contain sub-alpine coniferous forest (absent on Kodiak), and different alpine plant community assemblages. Microhistological analysis of fecal pellets is a common technique for estimating mountain goat diets, but has yet to be applied. An observational study conducted in the 1970's at the initial site of introduction (Hjeljord 1973) provides baseline dietary information and, through comparison with contemporary study, an opportunity to understand whether diets have changed in response to subsequent variation in population density, and whether the mountain goat diets might differ spatially across the island.

Mountain goat densities and relative duration of site occupancy vary spatially across Kodiak Island as a function of distance to the initial site of introduction (Cobb 2011). This unusual ecological state offers a rare research opportunity to quantify variation in diet and feeding site selection patterns among spatially distinct mountain goat sub-populations at different densities and varying histories of occupancy. The subpopulation near the initial site of introduction has exhibited a complete irruptive population growth cycle (sensu Caughley 1970), including an initial growth phase (phase 1), a subsequent decline to a lower abundance (phase 2), and a final "post-decline" population stabilization to a lower abundance (phase 3). During the 1970s (approximately 10-20 years following introduction), subpopulations surrounding the initial introduction site were colonized and have increased in density (phase 1), and are predicted to follow the same trend of decline and stabilization (phases 2 and 3) exhibited at the initial colonization site (Cobb 2012). Subpopulations located further from the initial introduction site were established in the 1990s, and are currently at low densities but predicted to follow a similar pattern as the other regions. If the irruptive growth cycle observed on Kodiak Island has lead to declines in plant diversity and preferred forage abundance, as predicted, then we expect to observe differential diet and feeding site selection patterns and differences in plant community composition across a spatial gradient linked to distance from the initial introduction site.

Quantifying the availabilities, distributions, and nutritional contents of preferred forage at mountain goat feeding sites provides a crucial link between diets and spatial use patterns, and is a critical first step toward developing an understanding of nutritional-based carrying capacity. At the scale of seasonal home range, mountain goats generally select high elevation steep rugged terrain with abundant high quality forage (i.e. grasses, sedges and forbs) (Gross et al. 2002, Poole and Heard 2003, White et al. 2012). Selection patterns at a more fine scale, however, are not well understood. Additionally, mountain goat habitat selection has only once been examined relative to feeding behavior (but see Hjeljord 1973). As a ruminant with a limited gut capacity, mountain goats likely select feeding sites that have an abundance of immature, highly digestible protein-rich plants. However, feeding site selection is also likely a trade-off between security from predators and access to preferred forage. Vascular plants, including species potentially preferred as forage, can vary in biomass and relative nutritional content due to environmental factors such as slope, aspect, elevation, and time of year. Additionally, forage biomass might be greater at feeding site due to selection or may be lower at feeding sites as a result of grazing pressure. Forage biomass and nutritional contents may differ between different regions of Kodiak due to different geologies or histories of grazing.

Our primary objectives were to quantify and compare summer diets and feeding site selection of mountain goats, and to determine whether they vary as a function of population densities and history of occupancy. We expected that mountain goat would select feeding sites that contain more abundant forage of high nutritional content and were closer to escape terrain than expected from random. As a result of potential overgrazing and trampling, we hypothesized that forage diversity, cover, and biomass would be lower in sites containing higher density subpopulations. Our secondary objectives were to quantify site level biomass and nutritional contents of preferred forage, and determine whether forage biomass and nutritional content varied with environmental factors and mountain goat site selection.

Study Area

Kodiak Island (8,975 km^2), the largest island in the Kodiak Archipelago, is located in the western Gulf of Alaska. Kodiak is 40 to 65 km from mainland Alaska, separated by the Shelikof Strait. Kodiak is approximately 160 km long and varies in width from 15 to 130 km. The topography of Kodiak is mainly mountainous, with elevations ranging from sea-level to 1,362 m. Kodiak has a sub-arctic maritime climate, which is characterized by long, cold winters and wet summers. Kodiak receives an average of 195 cm of precipitation annually (Kodiak city). Average monthly temperatures ranged from -0.6^o C (January) to 13.0^o C (August), between 1973 and 2012 (Kodiak Airport). Average summer temperatures are 10.0 ^{o} C in June, 12.5 ^{o} C in July, and 13.0 ^{o} C in August. Average temperatures during the study (2011 and 2012) were normal in 10.2^o C in June, 12.0^o C in July, and 12.3 ^{o} C in August.

We conducted field work at three study sites (Hidden Terror, Uyak, and Hepburn) on Kodiak Island (Figure 1), which we selected based on our understanding of historical mountain goat occupancy from annual aerial surveys (unpublished data). The Hidden Terror study site (76 km^2) was on northeastern Kodiak Island, between Hidden Basin and Terror Lake. Elevations ranged from sea-level to 1,130 m. Mountain goats have occupied Hidden Terror since 1952 (the initial mountain goat introduction), their densities peaked in the 1985 (2.09/km^2), and then steadily declined to 1.21 goats/km^2 by 2011. During the 2011 field season, the Hidden Terror study site encompassed two regions: a ridge north of Hidden Basin (22 km^2) and a region surrounding Terror Lake (54 km^2). In 2012, we constrained the Hidden Terror study site to the Hidden Basin region to alleviate budget constraints and to increase data collection efficiency. The second study site, Uyak (48 km^2), was centrally-located on Kodiak Island between Uyak Bay and Zachar River. Elevations ranged from sea-level to 1,320 m. Mountain goats colonized Uyak in the 1970s and the subpopulation, had been increasing in abundance since, and was at record densities in 2011 (2.54 goats/km^2). During the 2011 field season, Uyak encompassed two regions: mountains surrounding Lake 629 (37 km^2), and mountains surrounding an unnamed valley to the northeast of Amook Bay, which we termed “Brosis Valley” (11 km^2). In 2012, we limited the Uyak study site to just Brosis Valley, for the same reasons listed above for Hidden Terror. The third study site, Hepburn (62 km^2), covered a mountainous peninsula on southeastern Kodiak Island, between Deadman and Sulua Bays. Elevations ranged from sea-level to 700 m. Mountain goats colonized this site in the mid-1990s and were still at low densities in 2011 (0.75 goat/km^2).

Lower elevation habitats (sea level to 300 m) consisted of a matrix of mixed forb meadows composed of lupine (*Lupinus nootkatensis*), fireweed *(Epilobium angustifolium)*, goldenrod (*Solidago lepida*), Jacob's ladder (*Polemonium acutiflorum*), paintbrush (*Caltilleja unalaschcensis*), and burnett (*Sanguisorba stipulate*); open alder with forb meadows composed of patches of dense alder (*Alnus crispa*), often mixed with salmonberry (*Rubus spectabilis*) and elderberry (*Sambucus racemosa*), and patchy of forbs including fireweed, lupine, and cow parsnip (*Heraculem lanatum*); and dense alder habitats dominated by a tall mature alder (*Alnus crispa*) over story and a ground cover of litter and scattered maidenhair ferns, grasses (numerous *spp*.), and salmonberry (Fleming and Spencer 2007). In general, lower elevation habitats in Hepburn and Hidden Terror contained a greater proportion of forbs and less alder compared to Uyak. Higher elevation habitats (≥300 m) were dominated by alpine tundra, alpine forb meadow, alpine heath, prostrate shrub tundra, exposed bedrock, talus slopes, and snow-covered habitat types (Fleming and Spencer 2007). Common plants included long-awned sedge (*Carex macrochaeta*), mosses, lichens, partridgefoot (*Luetkea pectinata*), and black crowberry (*Empetrum nigrum*). Hepburn contained less exposed bedrock and inaccessible cliffs than the other study sites. Snow was present at the Hidden Terror and Uyak sites until mid-July, but absent from Hepburn by 1 June. The primary bedrock at all sites is Kodiak Formation (late Cretaceous), which consists of surficial deposits and sedimentary rocks (Wilson et al. 2005). A band of granitic bedrock (Paleocene) underlies northwestern portions of Hepburn.

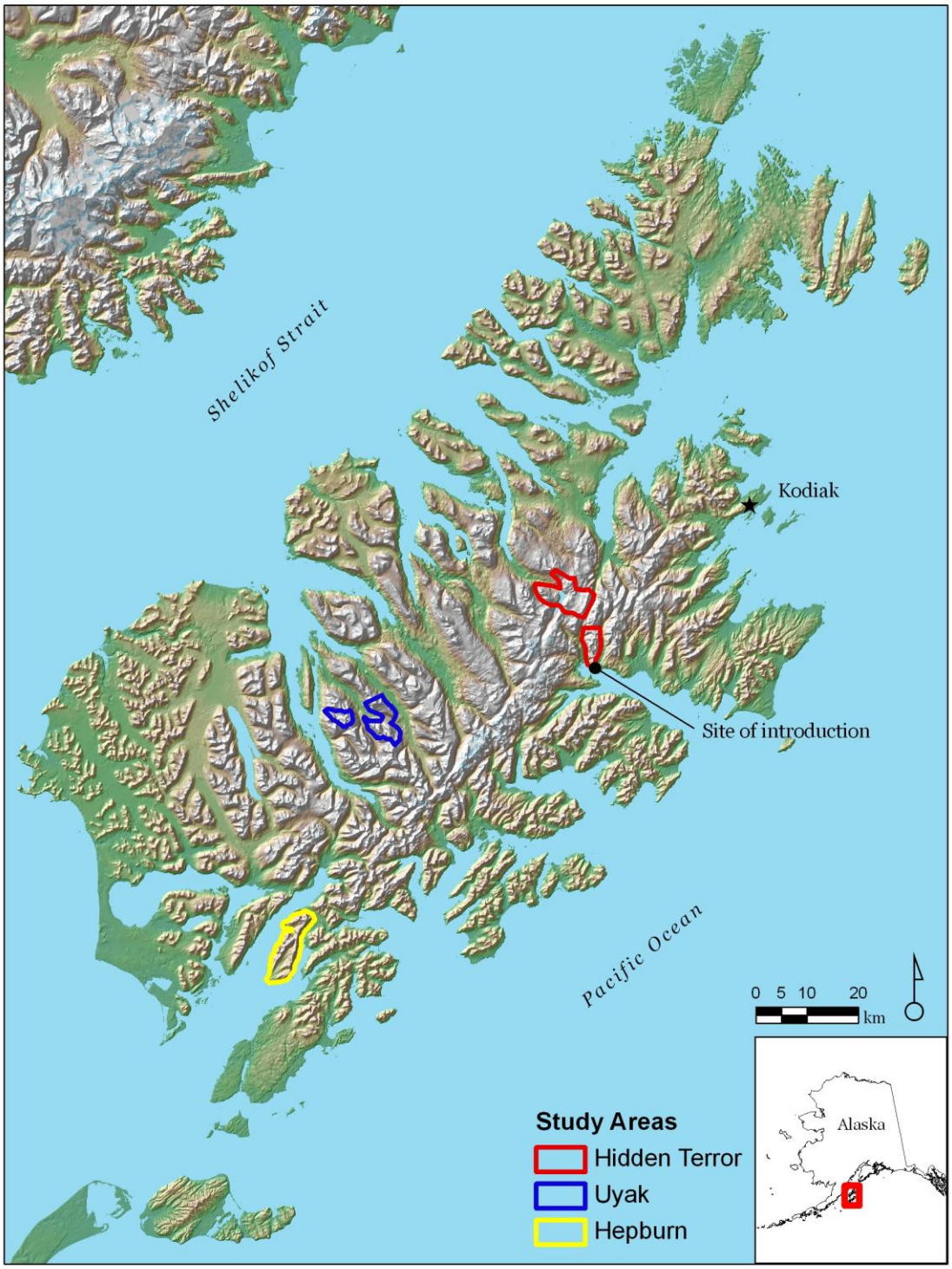


Figure 1. Mountain goat study sites, Kodiak Island, Alaska.

Methods

We visited each study site twice during the growing season: once in the early summer (June – early July) and once in the mid- summer (late July – August). During each occasion, our goals were to sample fecal pellets, primarily from adults affiliated with nursery groups, and to compare vegetation diversity and abundance between sites where goat groups sampled for fecal pellets were observed feeding ("feeding sites") and randomly selected sites in the alpine ("available sites"). In 2012, we sampled vegetation at feeding and random sites to measure vegetation biomass, and we collected samples of known mountain goat forage species to assess their nutritional contents.

Diet

We quantified mountain goat diets using microhistological analyses of fecal pellet samples (Hinnant and Kothmann 1988). To collect samples of fecal pellets, we observed a nursery group (composed of primarily nannies, and to a lesser extent kids and subadults) until at least one goat defecated. In 2011, we classified the group's size and individuals into age/sex classes (adults, billies, nannies, and kids). We then slowly approached the center of the group's location, and searched for fresh pellet groups. We considered fecal pellets as fresh if they were moist, soft, had a slimy sheen, and were free of mold and insects. We collected approximately 25 mg (15 pellets) from each pile of pellets and stored each sample in a WhirlPak (Nasco, Ft. Atkinson, WI). We kept pellet samples cool and dry in the field and then froze them upon returning to the office (<12 days later). We randomly selected nine to 10 pellet samples from each occasion that we visited the study sites, with only one sample (i.e. from one individual goat) from each group observation to avoid spatial autocorrelation, and submitted the samples to the Wildlife Habitat Nutrition Lab at Washington State University (Pullman, WA) at the conclusion of the field season for microhistological analyses to estimate the relative percent composition of forage classes that were estimated to comprise >5% of the sample (Level B, 50 views/sample). We did not correct diet composition data for differential digestibility.

We quantified the influence of the date (day of the year), study site, and year on goat diets using linear regression (Zar 2009). We tested for annual differences in the percent composition of individual forage classes using Mann-Whitney *U* tests.

Feeding Site Selection

We initially located mountain goat groups by conducting ground-based and fixed-wing aerial surveys of the study sites. We defined feeding sites as the centroid of a site where a nursery group of mountain goats was observed feeding. We constrained selection of random sites to available habitats in typical mountain goat summer ranges (Hjeljord 1970, Von Elsner-Schack 1986, Fox et al. 1989, Poole and Heard 2003), which were composed of low willow, alpine tundra, heath, forb-graminoid meadows, snow and ice, and fragmented rock habitat types. We used a GIS land cover classification map of Kodiak to delineate the extent of these habitats within each study site (Fleming and Spencer 2007). Additionally, we limited available habitats to areas over 150 m above sea level because we did not expect mountain goats to occupy areas below this elevation during the summer (Hjeljord 1973). We designated random sites by creating 100 random waypoints in available habitats, for each study site visit, using Geospatial

Modeling Environment. We included an inhibition distance (minimum allowable distance between random waypoints) of 100 m to eliminate potential overlap between adjacent transects (below) and to insure a more even sampling distribution across study sites. We uploaded random waypoints into portable GPS units (Garmin GPSmap 76CSx), which we used to locate random sites in the field.

We followed the same method for conducting plant surveys at feeding and random sites. We inserted an aluminum stake into the ground at the site, selected a random compass bearing using a random number table, and extended a tape measure from the stake along the compass bearing for 16 m in both directions. Starting from the stake, we placed a 50 by 20 cm plot frame to the right side of the tape measure at 2-m intervals, for a total of 17 plots per site (Daubenmire 1959). Within each plot, we defined cover as the percentage of the plot that was encompassed by the sum of imaginary minimum convex polygons drawn on leaf tips of undisturbed canopies (ignoring inflorescences) and projected onto the ground (Kent 2012). We classified cover into 12 classes based on their relative percentages of a plot, following a modified Domin scale (Currall 1987) (Table 1). For each plot, we estimated cover for forb and sedge species, and plant classes for other plants (grasses, rushes, ferns, lichens, mosses and willow).

To summarize available forage at each site, we quantified forage diversity and cover. We defined forage diversity as the sum of unique plant species and habitat classes observed in all plots at a site. We quantified forage cover (relative spatial cover of a plant species or class at a site) as the median percent value for a particular plant's cover class within a plot, averaged across all plots at a site.

Since mountain goats are associated with steep terrain that they use to escape from predators (Hamel and Cote 2007), we included a measure of distance to escape terrain as a predictor of feeding site selection. Escape terrain has been described as steep rocky slopes ranging from $>25^{o}$ to $>33^{o}$ (Adams and Bailey 1982, Gross et al. 2002). To be conservative, we considered escape terrain as slopes $\geq 33^{o}$. We defined the distance to escape terrain as the distance (m) from random and feeding sites to the edge of the closest pixel of escape terrain, defined by a 30-m pixel USGS Digital Elevation Model (DEM) in GIS (ESRI 2012).

Habitat selection of northern ungulates such as mountain goats is affected by many factors, including forage accessibility, forage quality, and thermodynamics, which are collectively influenced by relative solar radiation (Keating et al. 2007). To determine if mountain goat feeding site selection was correlated with solar radiation, we estimated hypothetical solar illumination (1200 hrs, 1 July) across Kodiak Island using the ArcGIS's Hillshade function applied to the DEM. We then standardized hillshade values by converting to *z*-scores (Zar 2009), and then extracted standardized hillshade values at random and feeding sites.

We considered random and feeding sites as the sampling unit for statistical analyses. To avoid overfitting models and to simplify results, our predictors included forage cover estimates for the top eight forage classes in goat summer diets, as determined from pellet microhistological analysis in 2011, and five additional habitat predictors (slope, forage diversity, distance to escape terrain, hillshade, and study site) in statistical tests. The top eight forage classes composed 96% of fecal pellet samples.

We tested for differences in available (random sites) forage cover for each of the eight forage classes, and differences in total available forage cover (sum of all eight classes of available forage cover within a site), among study sites using Kruskal Wallis tests (Zar 2009).

We quantified feeding site selection with logistic regression models using the 13 predictors. To assess relative correlation among the predictors, we computed a Pearson product-moment correlation matrix. For pairs of highly correlated predictors (>0.30), we kept the predictor that was most biologically relevant to goat feeding site selection (Zar 2009). To evaluate competing candidate models, we examined differences in ΔAIC_c using a backwards, step-wise approach (Burnham and Anderson 2002). Finally, we calculated AIC_c weights (*w*) to determine relative support for each of the top models. We model averaged parameter estimates among the top candidate models to compute unconditional standard errors (Burnham and Anderson 2002). We tested the final model fit with a Hosmer-Lemeshow goodness-of-fit (GOF) test and Nagelkerke's pseudo R^2.

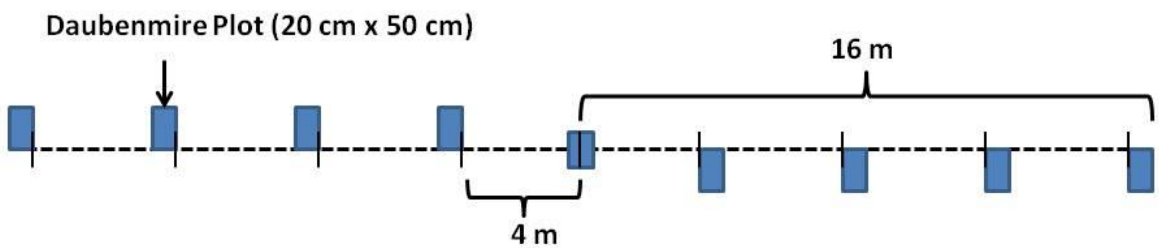
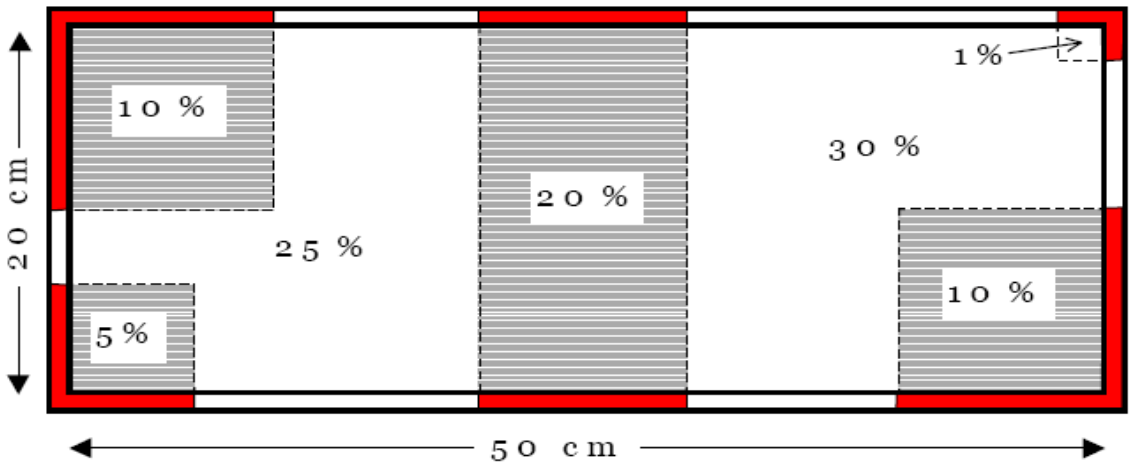


Figure 2. Vegetation survey transects and locations of Daubenmire plots used to quantify the plant diversity and canopy cover at mountain goat feeding sites and random sites, Kodiak Island.

a.



b.

% Cover Classes					
Code	Range	Mean	Code	Range	Mean
T	0-1%	0.50%	**5**	45-55%	50%
0	1-5%	3%	**6**	55-65%	60%
1	5-15%	10%	**7**	65-75%	70%
2	15-25%	20%	**8**	75-85%	80%
3	25-35%	30%	**9**	85-95%	90%
4	35-45%	40%	**X**	95-100%	97.5%

Figure 3. Daubenmire plot with a guide for quantifying percentage vegetation canopy cover (a) and canopy cover classes with associated range of percent canopy covers (b) used to quantify vegetation cover at mountain goat feeding sites and random available sites, Kodiak Island.

Forage Nutritional Content

In 2012, during each sampling occasion, we collected 5 g samples of above-ground vegetation that comprised ≥ 5% of mountain goat summer diets (uncorrected for differential digestibility), as determined from 2011 fecal microhistological results (Cobb 2012). Forage items sampled included: long-awned sedge, lady fern rhizomes, wooly geranium, grass *spp*., Nootka lupine, moss *spp*., Potentilla genus (cinquefoil *spp*.), willow *spp*., and woody rush *spp*. We collected samples opportunistically while walking between random and feeding site sites. Each sample originated from a variety of sites within the study site and therefore we considered them to be representative samples.

We dried samples in a drying oven for 12 hrs at 150° C and submitted them to WHNL to be analyzed for percent crude protein, neutral detergent fiber, acid detergent fiber, and acid insoluble ash using sequential fiber analyses corrected for indigestible tannins (Martin and Martin 1982). We calculated percent digestible protein (% DP) and dry matter digestibility (% DMD) for each sample (Hanley et al. 1992).

We tested for differences in % DP and % DMD among forage items using Kruskall-Wallis χ^2 tests. We quantified the effect of study site and sampling occasion (early versus mid-summer) on % DP and % DMD of forage items using generalized linear regression models (Gaussian identity link). We followed a information-theoretic approach to model selection, as described above (Burnham and Anderson 2002).

Forage Biomass

In 2012, we randomly selected one plot from each random and feeding site and collected all above-ground vegetation from within it. We sorted the plant material to species (vascular plants) or forage class (nonvascular plants) at the office, and then dried the sorted samples following the same process as above. We then weighed (Model L-125 Escali scale, calibrated and accurate to 0.01 g) the sorted samples.

We tested for a difference in forage biomass between feeding and random sites with a Kruskal Wallis χ^2 test. We quantified the correlation between forage biomass and forage cover using linear regression. We quantified the effect of site (random or feeding), study site, day of the year, elevation (m), slope (degrees), and aspect (8 classes) on forage biomass using generalized linear regression models. To evaluate competing candidate models, we examined differences in ΔAIC_c using a backwards, step-wise approach (Burnham and Anderson 2002). We calculated AIC_c weights (*w*) to determine relative support for each of the top models.

Results

We visited each study site twice, between 2 June and 19 August, 2011, and again between 3 June and 11 August, 2012 (Table 1). Visits averaged 9 days (ranged 4 to 12 days). Four researchers visited each study site, but to maximize efficiency, we split into two groups daily to cover more ground.

Table 1. Duration (days) of study site visits for mountain goat research, 2011 and 2012, Kodiak Island.

	Trip 1		Trip 2	
Study Site	2011	2012	2011	2012
Hepburn	7	11	9	9
Uyak	4	6	10	8
Hidden Terror	10	12	10	8

Diet

We collected 325 pellet samples (200 in 2011, and 125 in 2012) from mountain goats (Table 2). From these samples, we sub-sampled 119 pellet samples (59 in 2011, and 60 in 2012) for microhistological analyses. We selected 10 pellet samples annually per study site per visit, except for the first Hepburn sampling occasion in 2011, for which we were only able to collect 9 samples because of foul weather (n = 59).

Goat groups that we collected pellets from in 2011 (n = 28) averaged 9 individuals (SE = 1.76). Group sizes did not statistically differ among study sites (KW x^2 = 0.19, p = 0.91). We were

unable to classify 13 (48%) groups by sex because of far distances between the groups and the observers, and because of inclement weather (fog, low clouds, or heavy rain). Groups that we could classify by sex (n = 15) were composed primarily of nannies (69%) and to a lesser extent of kids (23%) and billies (8%).

Microhistological analyses revealed that goats largely consumed sedges (39%), followed by forbs (22%), grasses (13%), rushes (10%), and fern rhizomes (6%) (Table 3). In contrast, goats consumed few lichens (2%), mosses (3%), and shrubs (4%).

Table 2. Number of fecal pellet samples collected at each study site, Kodiak Island.

Study Site	2011	2012
Hepburn	38	49
Uyak	65	35
Hidden Terror	97	42
TOTAL	200	125

Table 3. Average percent dietary composition of mountain goats, Kodiak Island.

Forage class	Average		2011		2012	
	%	SE	%	SE	%	SE
Sedge	39%	1.43	34%	1.63	44%	2.17
Forb	22%	0.88	22%	1.12	21%	1.36
Grass	13%	1.13	12%	1.43	15%	1.74
Rush	10%	0.73	13%	1.19	7%	0.64
Fern	6%	1.02	8%	1.74	4%	1.03
Shrub	4%	0.48	1%	0.36	6%	0.79
Moss	3%	0.38	4%	0.63	2%	0.43
Lichen	2%	0.40	2%	0.58	2%	0.56

Linear regression models indicated that mountain goat diets varied by year, day of the year, and study site (Table 4). In 2012, goat pellets were composed of 9% (SE = 2.40) more sedge, of 3% (SE = 1.70) more grass, and of 5% (SE = 0.84) more shrubs than in 2011. On the other hand, in 2012, goats pellets contained 7% (SE = 1.07) less rushes, 4% (SE = 1.67) less ferns, and 2% (SE = 0.66) less moss.

Sedges, forbs, and rushes were increasingly consumed over the summer and the place of grasses, ferns, mosses, lichens, and shrubs (Figure 4). In June, diets were largely composed of sedges (31%, SE = 1.97), grasses (21%, SE = 1.77), forbs (19%, SE = 1.21), and ferns (11%, SE = 1.83, primarily rhizomes). Ferns declined to only 1% (SE = 0.53) of pellets in June and 0.08% (SE = 0.05) in August. Pellets contained few shrubs (1%), mosses (3.8%) and lichens (2%) in June, and composition of these forage in pellets declined over the summer.

Goats at Hidden Terror consumed 5% more forbs (SE = 2.06) than at Uyak, and 4% more forbs (SE = 2.20) than at Hepburn. Most of the variation within the forb class was due to Nootka lupine, which was consumed almost twice as much at Hidden Terror (18%, SE = 1.78) than at Uyak (9%, SE = 1.15), and three times more than at Hepburn (5%, SE = 1.17).

Table 4. Results of the most parsimonious linear regression models for estimating the relationship between individual mountain goat forage classes and year, day of year, and study site at Kodiak Island. Separate candidate linear models were run for each forage class. Values are the percent change in forage class composition with one unit change in each predictor, assuming all other predictors are held constant. A "--" indicates that the predictor was not in the most parsimonious model and there was no statistically significant relationship (α = 0.05).

Model	Predictor estimates (SE)			
	Year	Day of the year	Uyak	Hepburn
Sedge	9.17% (2.40)	0.29% (0.05)	--	--
Forb	--	0.11% (0.04)	-4.79% (2.06)	-3.59% (2.20)
Grass	2.56% (1.70)	-0.33% (.04)	4.61% (2.13)	--
Rush	-6.55% (1.07)	0.18% (0.02)	--	--
Fern	-3.94% (1.67)	-0.26% (0.04)	--	--
Shrub	4.67% (0.84)	-0.03% (0.02)	1.08% (1.05)	-2.20% (1.13)
Moss	-1.82% (0.66)	-0.07% (0.02)	--	-1.82% (0.66)
Lichen	--	-0.04% (0.02)	2.35 % (0.95)	--

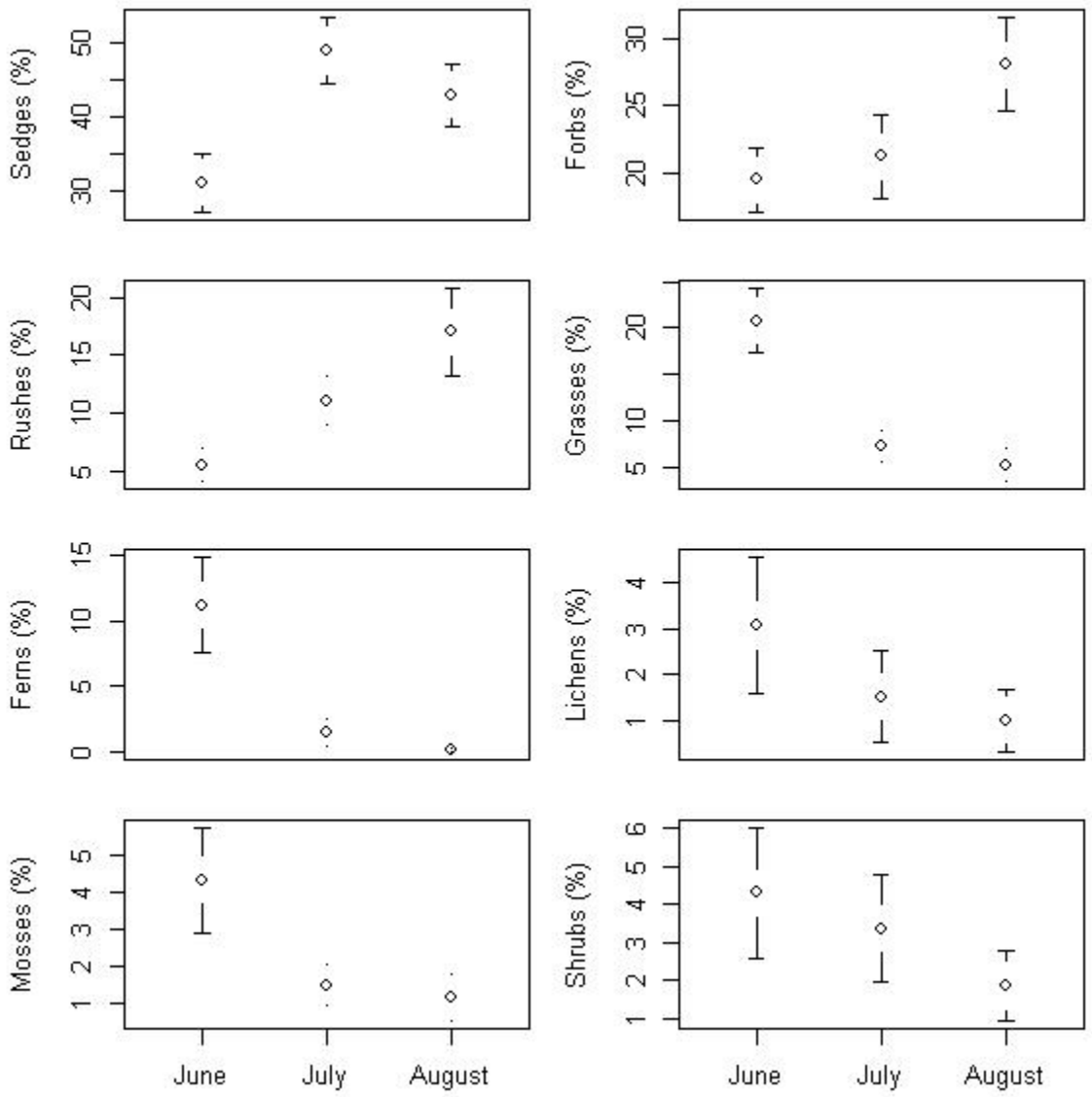


Figure 4. Monthly percent composition of forage items in mountain goat pellet samples, Kodiak Island. Circles indicate averages and bars extend to 95% confidence intervals.

Table 5. Number of vegetation transects and Daubenmire plots per survey site, Kodiak Island.

	2011		2012		Total	
Survey site	Transects	Plots	Transects	Plots	Transects	Plots
Hepburn	59	1,110	143	2,517	202	3,627
Uyak	83	1,918	125	1,974	208	3,892
Hidden Terror	156	2,166	123	1,780	279	3,946
TOTAL	298	5,194	391	6271	689	11,465

Feeding Site Selection

In 2011 and 2012, we surveyed forage cover and diversity in 11,465 plots at 689 sites (198 feeding sites and 491 random sites) (Table 5, Figures 5 – 7). We quantified 181 forage classes (plant species and classes). Moss was the most common forage, averaging 25.69% cover across all sites. The most common plant species was long-awned sedge (*Carex macrochaeta*), which occurred averaged 4% cover. Other common plants included: patridgefoot (*Luetkea pectinata*), arctic daisy (*Arctanthemum arcticum*), black crowberry (*Empetrum nigrum*), and variegated sedge (*Carex stylosa*). During the first sampling occasion, ferns, grasses, willows, and sedges were in early growth stages, so we could not identify them all to species.

We included the most common forage classes in mountain goat diets as candidate predictors in feeding site selection models; which were long-awned sedge, Nootka lupine, wooly geranium, grass, rush, fern, willow, and moss. We also included slope, distance to escape terrain, hillshade, and study site as candidate predictors. We excluded forage diversity as a candidate predictor, because it was highly correlated (>0.30) with numerous other predictors.

Available forage cover was statistically different among study sites for all forage classes considered ($p < 0.05$), except long-awned sedge ($p = 0.20$) and rush ($p = 0.06$), according to KW tests (Figure 8). Hidden Terror contained the least wooly geranium, grass, fern, and moss cover. Uyak contained the most long-awned sedge, wooly geranium, and willow cover. Hepburn contained the least Nootka lupine and the most moss cover. Total available forage cover (sum of all eight forage class covers at available sites) also significantly differed among study sites (KW $\chi^2 = 99.53$, $p < 0.01$). Hidden Terror had approximately 30% less total available forage cover than Uyak and Hepburn (Figure 9) (Hamel et al. 2009).

Hepburn

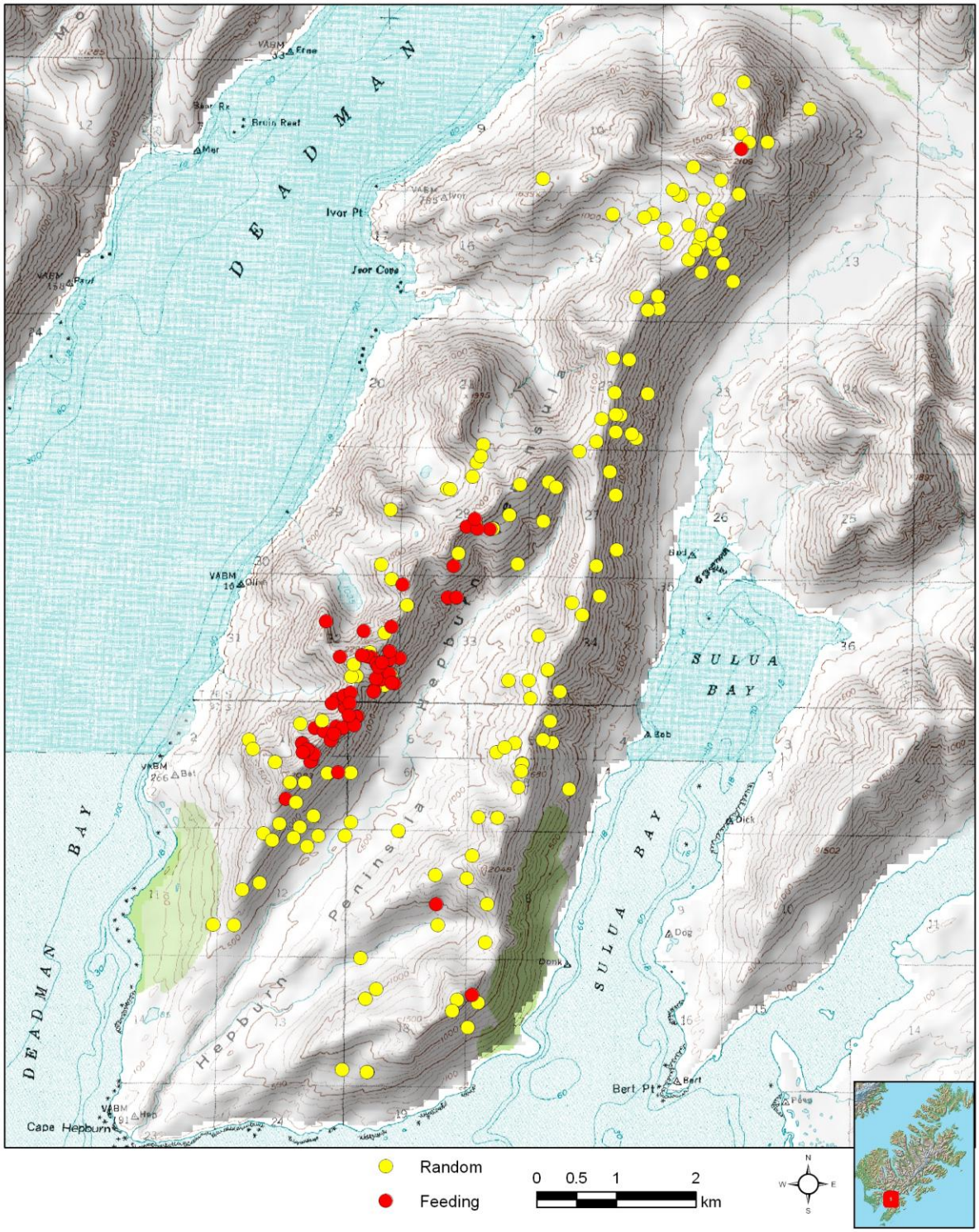


Figure 5. Locations of vegetation surveys (feeding and random sites) at the Hepburn study site, Kodiak Island.

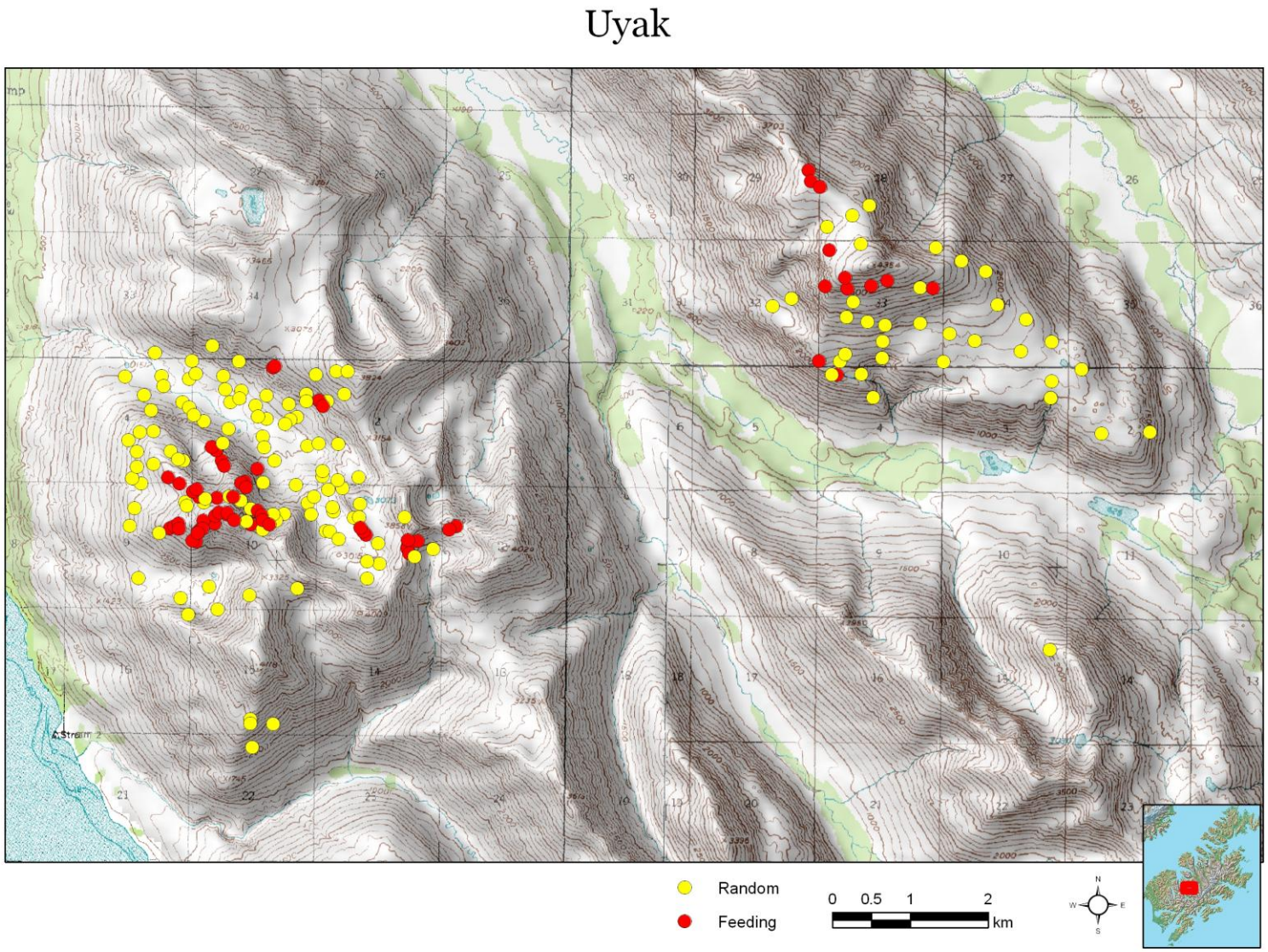


Figure 6. Locations of vegetation surveys (feeding and random sites) at the Uyak study site, Kodiak Island.

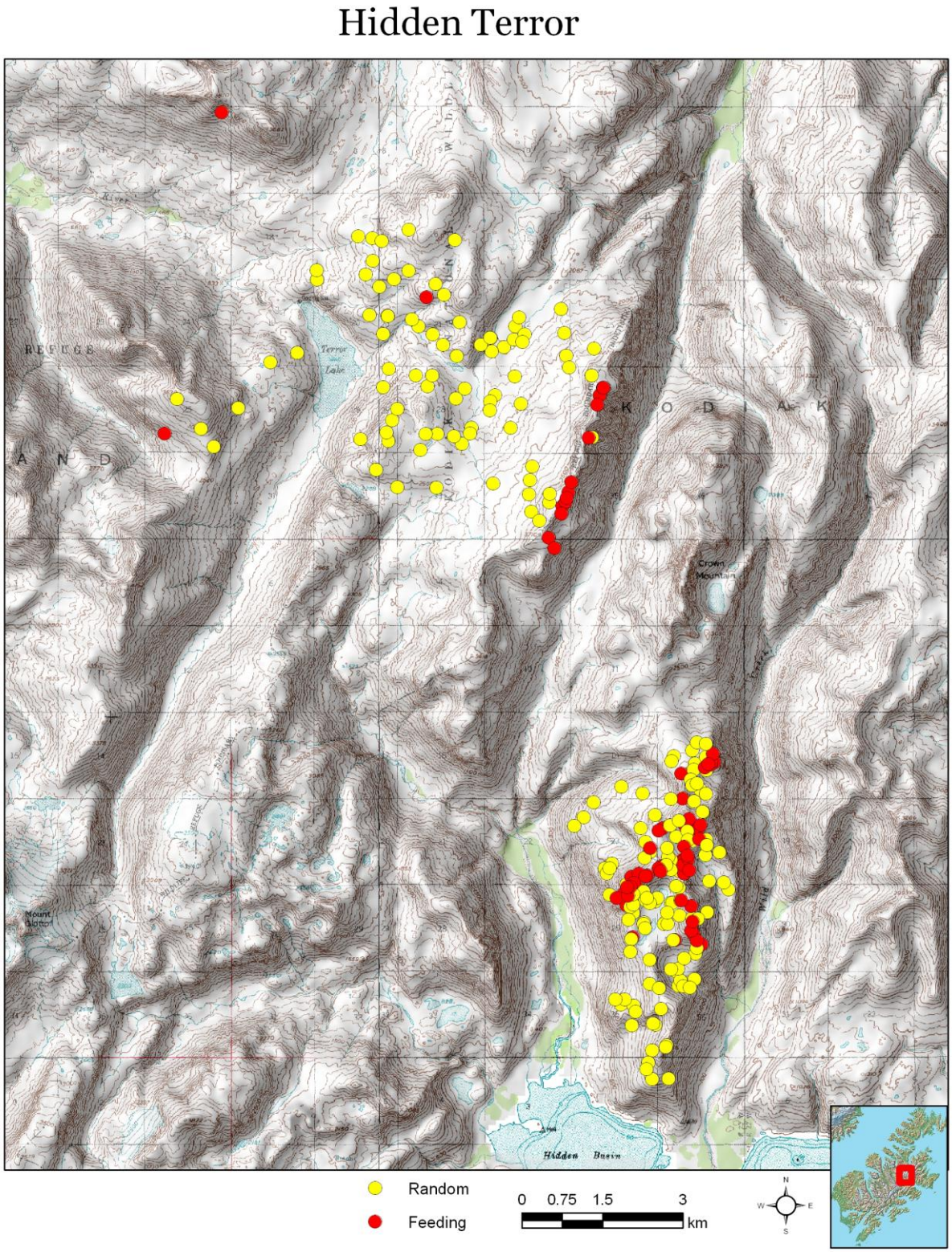


Figure 7. Locations of vegetation surveys (feeding and random sites) at the Hidden Terror study site, Kodiak Island.

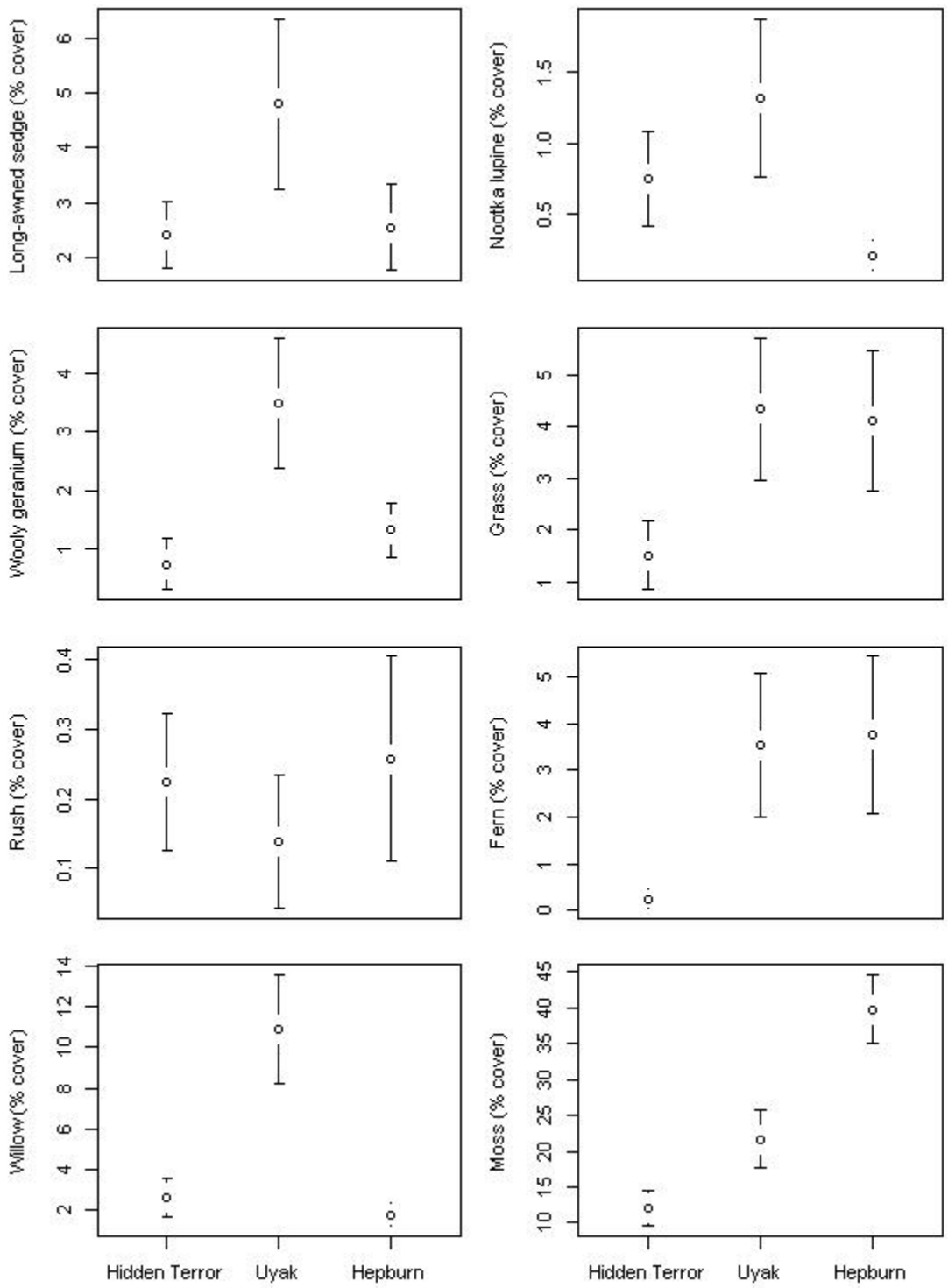


Figure 8. Available mountain goat forage cover by study site, Kodiak Island. Open circles represent percent forage cover averages at random alpine locations. Lines extend to 95% confidence intervals.

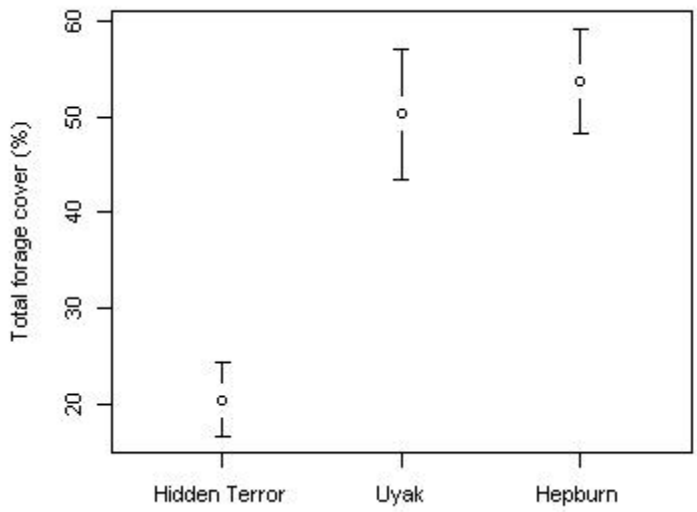


Figure 9. Total available mountain goat forage cover by study site, Kodiak Island. Total available cover is the sum of all eight forage cover classes within each random site. Open circles represent percent forage cover averages at random alpine locations. Lines extend to 95% confidence intervals.

The most parsimonious feeding site selection model included all candidate predictors except willow, slope, and grass (AICc = 487.60). This model was two-times more likely to be the best approximating candidate model, based on the evidence ratio of Akaike weights. The most parsimonious model showed good model fit (Hosmer-Lemeshow $\chi^2 = 4.77$, $p = 0.78$) and explanatory power ($R^2 = 0.57$).

Mountain goats selected feeding sites that had abundant long-awned sedge, rush, and moss; were close to escape terrain; and were on sunny slopes, according to the most parsimonious model (Table 7). Logistic regression indicated that the odds of mountain goats feeding at a given site were 75% higher for every 1% increase in rush cover (ß = 0.56, SE = 0.13) and 19% higher for every 1% increase in long-awned sedge cover (ß = 0.17, SE = 0.02) (Figures 10 and 11). Alternatively, the odds of a mountain goat feeding at a site were 23% lower for every 1% increase in Nootka lupine (ß = -0.26, SE = 0.07) wooly geranium (ß = -0.26, SE = 0.06), and fern cover (ß = -0.26, SE = 0.10). Feeding sites averaged 57 m from escape terrain, as opposed to random sites, which averaged 241 m from escape terrain (Figure 10). Mountain goats were approximately 1% less likely to feed at a site for every meter further from escape terrain. Sites at Hidden Terror were 80% more likely to be feeding sites than those at Hepburn, and sites at Uyak were 90% more likely to be feeding sites than at Hepburn.

Figure 10. Average distance to escape terrain at mountain goat feeding sites and random sites, Kodiak Island. Bars extend to 95% CI.

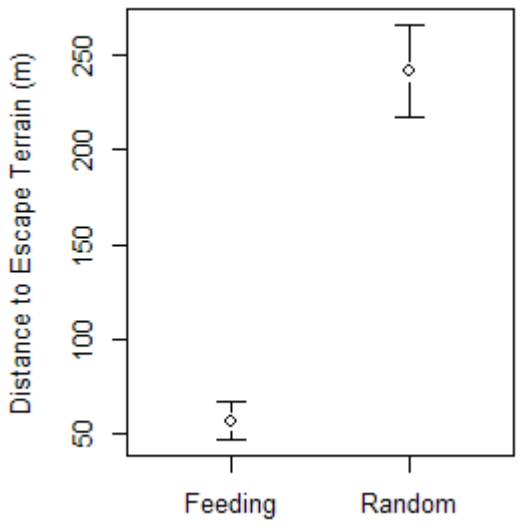


Table 6. Top candidate models for mountain goat feeding site selection, Kodiak Island. The most parsimonious model included all predictors except willow, slope and grass.

Model	K	AIC_c	Delta AIC_c	*w*
(- willow, slope and grass)	11	497.6	0	0.57
(- willow and slope)	12	499.04	1.44	0.28
(- willow)	13	500.79	3.19	0.11
Global model	14	502.84	5.23	0.04

Table 7. Model-averaged predictor estimates of mountain goat feeding site selection based on top candidate logistic regression models, Kodiak Island.

Predictor	Estimate	SE	Lower 95% CI	Upper 95% CI
(Intercept)	-1.79	0.38	-2.53	-1.05
Long-awned sedge	0.17	0.02	0.13	0.21
Nootka lupine	-0.26	0.07	-0.41	-0.12
Wooly geranium	-0.26	0.06	-0.37	-0.15
Rush	0.56	0.13	0.29	0.82
Fern	-0.26	0.10	-0.46	-0.06
Moss	0.02	0.01	0.01	0.03
Distance to escape terrain (m)	-0.01	<0.01	-0.01	-0.01
Hillshade	-0.20	0.05	-0.30	-0.10
Hidden Terror	0.59	0.33	-0.06	1.24
Uyak	0.64	0.34	-0.02	1.29

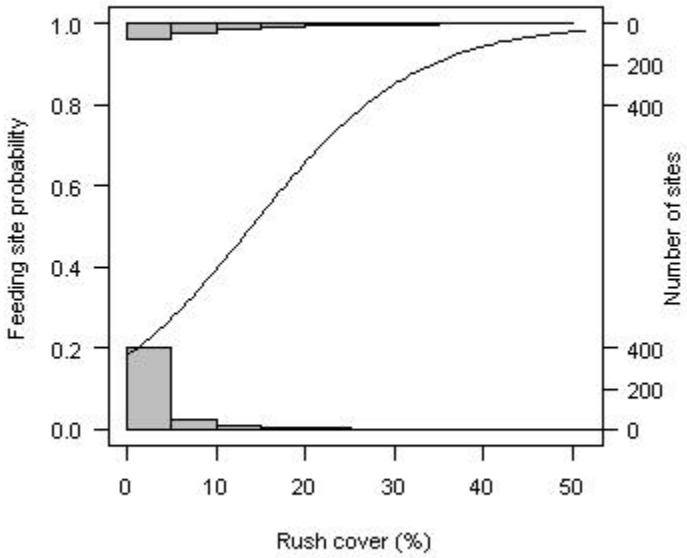


Figure 11. Mountain goat feeding site selection relative to rush cover (%), Kodiak Island. The line represents that probability (0 – 1) of a particular site being selected as a mountain goat feeding site, given rush cover. Bars represent the number of random sites (bottom) and feeding sites (top) containing given percentages of rush cover, displayed at 5% intervals.

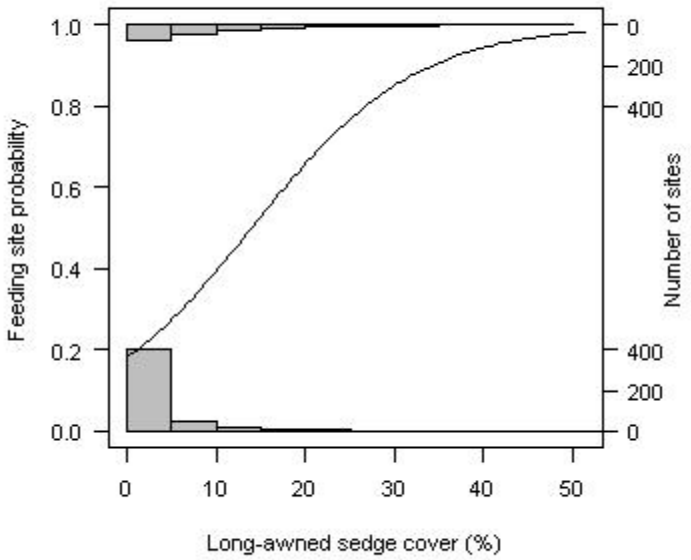


Figure 12. Mountain goat feeding site selection relative to long-awned sedge cover (%), Kodiak Island. The line represents that probability (0 – 1) of a particular site being selected as a mountain goat feeding site, given long-awned sedge cover. Bars represent the number of random sites (bottom) and feeding sites (top) containing given percentages of long-awned sedge cover, displayed at 5% intervals.

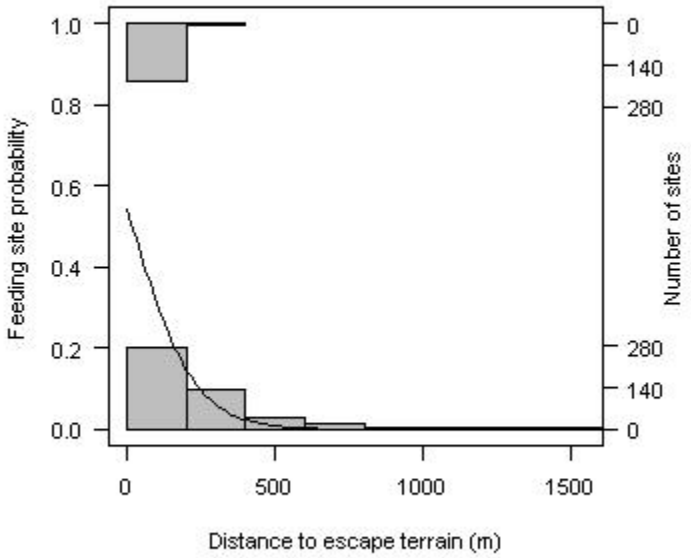


Figure 13. Mountain goat feeding site selection relative to distance to escape terrain (m), Kodiak Island. The line represents that probability (0 – 1) of a particular site being selected as a mountain goat feeding site, given distances to escape terrain. Bars represent the number of random (bottom) and feeding sites (top) at given distances to escape terrain, displayed at 300 m intervals.

Forage Nutritional Content

Digestible protein and dry matter digestibility values differed significantly among individual preferred mountain goat forage classes, according to Kruskal-Wallis tests (KW $\chi^2 = 28.59$, $p < 0.01$ and KW $\chi^2 = 31.77$, $p < 0.01$, respectively). Lupine contained the most digestible protein (23%), and ferns and moss contained the least (3% and 4%, respectively) (Figure 14). Dry matter digestibility was similar for lupine (69%), geranium (67%), grass (66%), and sedge (65%), and lowest for moss (39%) (Figure 15).

Digestible protein in preferred mountain goat forage varied between sampling occasions but was similar between study sites, according to the most parsimonious linear regression model. The model predicted that forage contained 5.25% (SE = 2.20) less digestible protein in the second sampling occasion (late July to August) than the first occasion (June to early July) ($R^2 = 0.13$, $p = 0.02$) (Table 8 Table 9). On the other hand, dry matter digestibility did not change between sampling occasions ($R^2 < 0.01$, $p = 0.81$) or vary among study sites ($R^2 = 0.01$, $p = 0.79$), according to linear regression models.

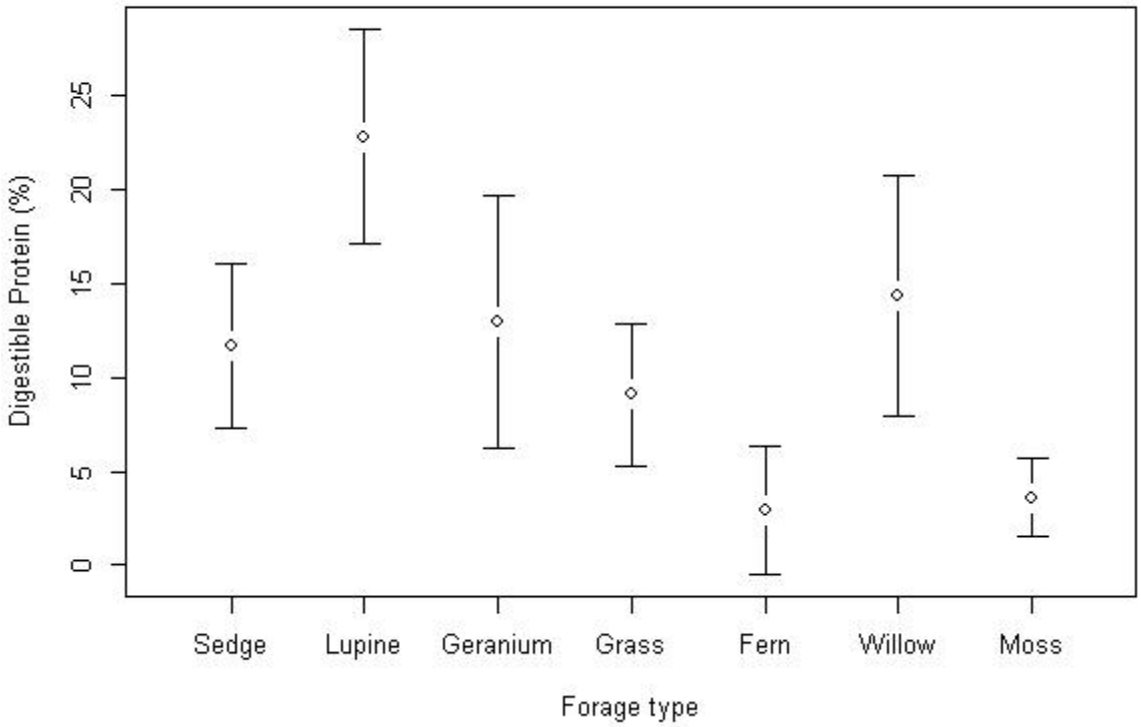


Figure 14. Percent digestible protein by mountain goat forage type, Kodiak Island, 2012. Points are means and lines extend to 95% CI.

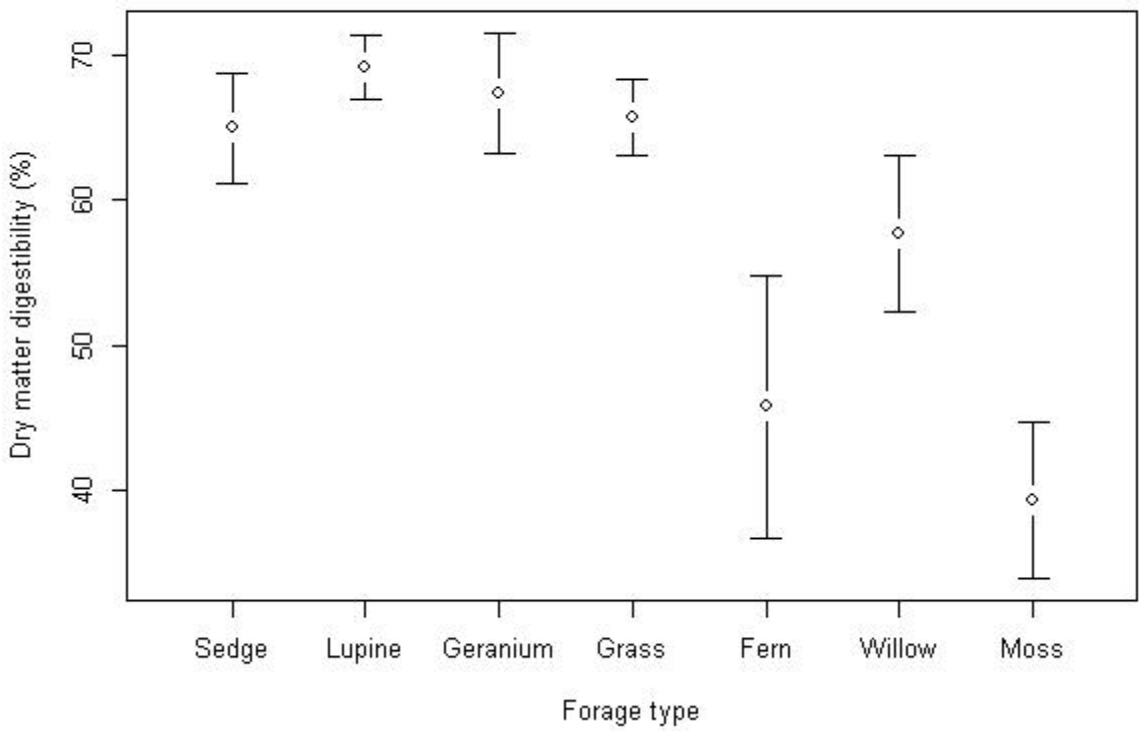


Figure 15. Percent dry matter digestibility by mountain goat forage type, Kodiak Island, 2012. Points are means and lines extend to 95% CI.

Table 8. Results of model selection for percent digestible protein in mountain goat forage, 2012.

Model	K	AICc	ΔAICc	w
Visit	3	279.62	0	0.88
Visit + Study Site	5	283.99	4.37	0.1
Study Site	4	287.26	7.64	0.02

Table 9. Output from the most parsimonious linear regression model describing the relationship between percent digestible protein in mountain goat forage (%) and sampling occasion, Kodiak Island, 2012.

Predictor	Estimate	SE	p
(Intercept)	13.37	1.55	<0.01
Sampling occasion (2nd)	-5.32	2.16	0.02

Forage Biomass

Moss was the most common forage class that composed greater than 5% of mountain goat diets, averaging 10.25 g/plot (SE = 6.15). After moss, the most common forage class that composed

greater than 5% of mountain goat diet was willow (0.90 g/plot, SE = 0.14) (Figure 16). The least common forage classes were lupine (0.07 g/plot, SE = 0.02) and rush (0.08 g/plot, SE = 0.02). Feeding sites (1.52 g/plot, SE = 0.33) contained less forage than random sites (1.91 g/plot, SE = 0.36), but the difference was not statistically significant (KW $\chi^2 = 0.02$, $p = 0.89$).

Linear regression models indicated that forage biomass varied with aspect, day of the year, slope, and study site (Table 10 and Table 11). Elevation and the type of site (random versus feeding site) were not included in the most parsimonious model, and therefore, were not good predictors of forage biomass. The model predicted a 0.5 g/plot (SE = 0.19) decline in forage biomass for every one degree increase in slope (Figure 17). North-facing sites were predicted to have higher biomass than any other aspect. The model predicted a 0.15 g/day/plot increase in biomass over the summer. Sites at the Hidden Terror study site were predicted to have 9.64 g/plot less biomass than the other study sites, but this difference was not statistically significant ($\alpha = 0.05$).

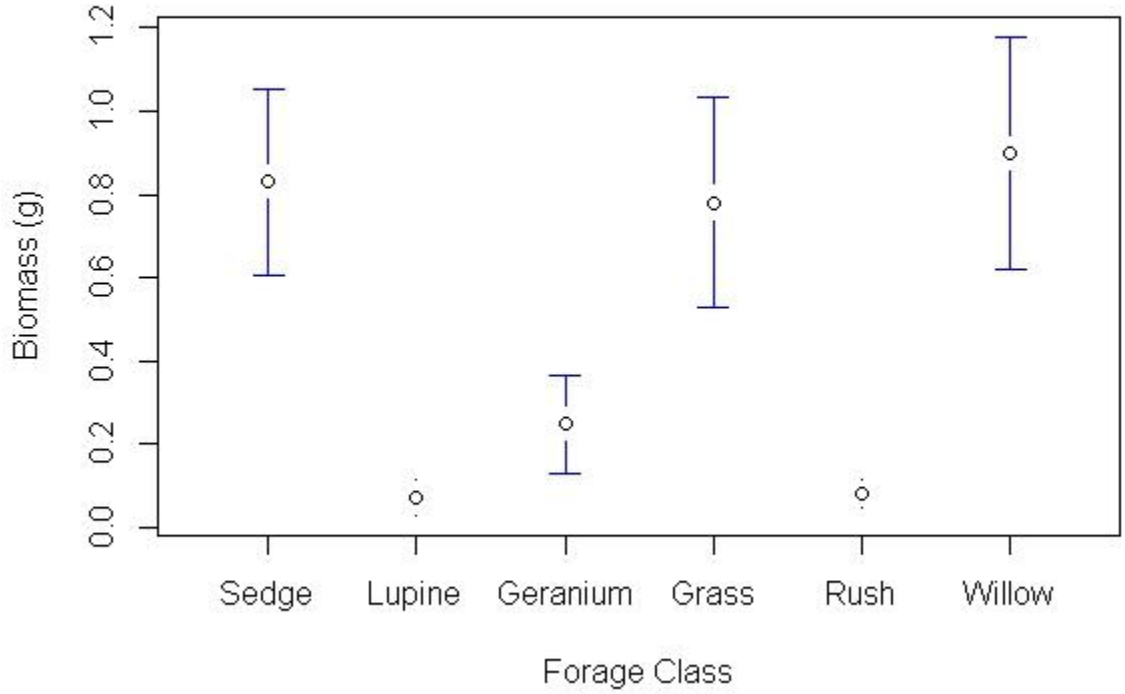


Figure 16. Biomass per plot (±95% CI) by forage class, Kodiak Island, 2012. Moss was excluded for clarity (averaged 10.25 g/site) and fern was excluded because we only collected above ground material.

Table 10. Candidate model set for linear regression models of mountain goat forage biomass, Kodiak Island, 2012.

Model	K	AICc	ΔAICc	*w*
Aspect + Day of year + Slope + Study site	13	2677.36	0	0.55
Aspect + Day of year + Slope + Study site + Elevation	14	2679.36	2	0.2
Aspect + Day of year + Slope + Study site + Type of site	14	2679.58	2.22	0.18
Aspect + Day of year + Slope + Study site + Elevation + Type of site	15	2681.52	4.17	0.07

Table 11. Output from the most parsimonious linear regression model predicting forage biomass (g) at feeding and random sites, Kodiak Island, 2012.

Predictor	Estimate	SE	p
(Intercept)	27.09	20.90	0.20
Aspect[NE]	-26.76	9.57	0.01
Aspect[E]	-20.61	9.47	0.03
Aspect[SE]	-16.61	8.86	0.06
Aspect[S]	-14.38	9.03	0.11
Aspect[SW]	-23.93	8.11	0.00
Aspect[W]	-12.16	8.04	0.13
Aspect[NW]	-25.87	9.44	0.01
Day of year	0.15	0.10	0.13
Study site [Hidden Terror]	-9.64	5.14	0.06
Study site [Uyak]	-0.06	4.96	0.99
Slope	-0.50	0.19	0.01

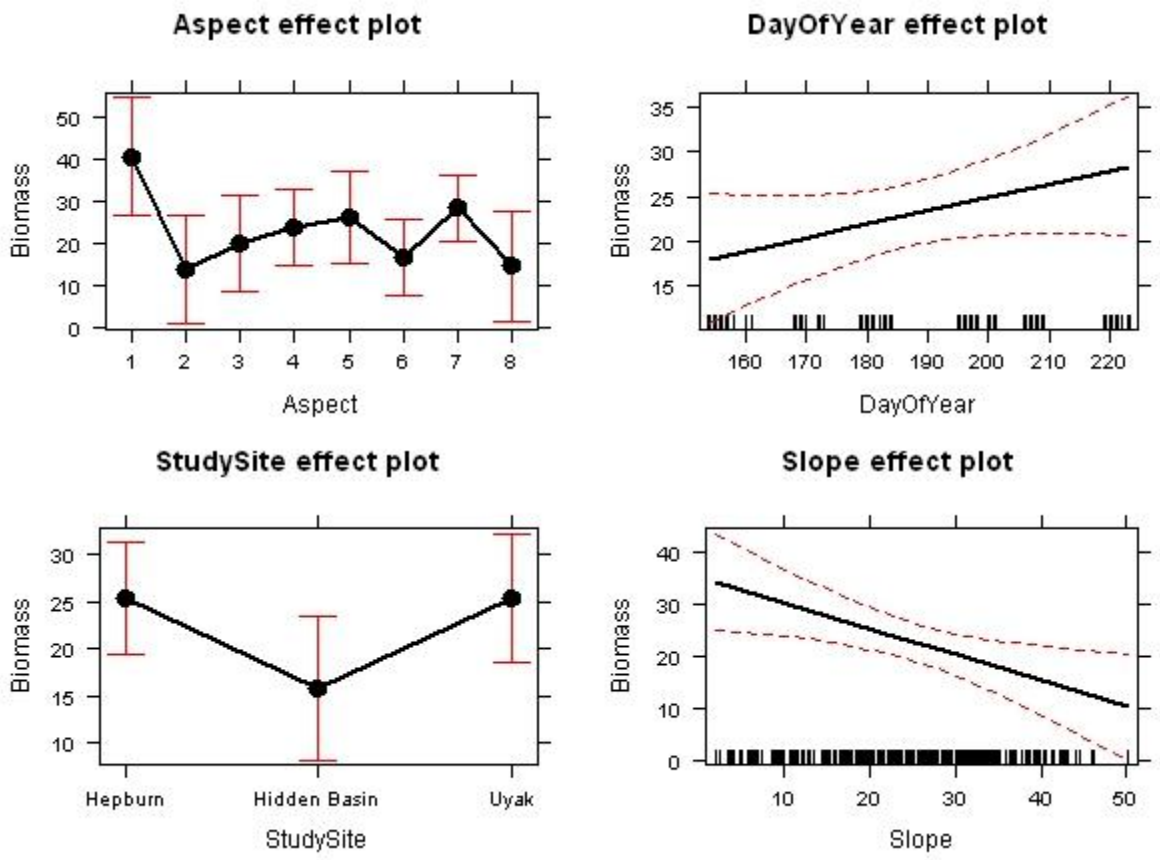


Figure 17. Effects plots (± 95% CI) based on the linear regression model of forage biomass, Kodiak Island, 2012. Plots display the relative changes in biomass predicted to occur with changes in aspect, day of year, slope, and study site, assuming all other covariates are held constant.

Discussion

The uncorrected summer diets of mountain goats on Kodiak Island consisted largely of alpine sedges and forbs, as reported elsewhere in coastal Alaska (Hjeljord 1973, Fox et al. 1989, White et al. 2012). This result was also consistent with results described for other introduced goat populations in Montana and Colorado, which primarily consumed grasses, sedges and rushes in the summer (Saunders and Saunders 1955, Hibbs 1967) and fall (Varley 1994). Introduced goats on the Olympic Peninsula, WA, grazed mainly on grasses and sedges, but also relied on forbs such as aster (*Aster paucicapitatus*) and western sweet vetch (*Hedysarum occidentale*) (Pfitsch and Bliss 1985). Collectively these results seemingly indicate a consistent preference for grasses and sedges on summer range but also accommodation to variation in vegetation composition and availability of preferred forage among regions. Shrubs were a dominant part of summer diet of goats in Montana and South Dakota (Casebeer 1948, Richardson 1971). At Chopaka Mountain, WA, summer diets included over 30% shrubs such as *Artemisia* spp. and soapberry. As an ungulate that inhabits northern seasonal climates, forage intake is largely driven by the need for rapid growth and weight gain to counterbalance annual weight loss over the winter due to

nutritional deprivation. The apparent pattern of summer dietary intake by mountain goats of Kodiak Island likely reflected this strategy of physiological optimization by focusing on high quality newly emergent sedges and grasses with high cellular content, little cell wall material, and minimal secondary compounds (Fox et al. 1989). Alpine plants contain more nitrogen (i.e. higher quality) than their counterparts at lower elevations and continue to emerge from areas adjacent to receding snow banks throughout much of the summer (Fox 1991), thereby providing goats with highly nutritious new growth over an extended time period.

As summer progressed, Kodiak's mountain goats consumed more sedges and forbs, and less ferns and grasses. This dietary shift, most pronounced between June and July, was consistent across all study sites and was likely linked to increased availability of new alpine vegetative growth following snowmelt. Higher elevations of Kodiak Island were still largely snow-covered throughout most of June, which presented limited forage availability similar to winter conditions. Seasonal dietary shifts by mountain goats have been previously observed on Kodiak Island (Hjeljord 1971) and elsewhere (Hjeljord 1973, Varley 1994, Degano and Catan 2002), and have been correlated with changes in forage availability and quality (Pfitsch and Bliss 1985). Twenty years after they were introduced, goats at Hidden Basin utilized tall rigid grasses and sedges during the winter, especially Altai fescue (*Festuca altaica*) and coiled sedge (*Carex circinata*), It was believed that these plants were selected by goats because they maintain an upright structure and green tissue, even on snow-covered slopes (Hjeljord 1971). Hjeljord also observed mountain goats spending much of their feeding time digging through litter to consume lady fern (*Athyrium filix-femina)* rhizomes in winter, and blue joint grass (*Calamagrostis canadensis*) and fern rhizomes in early spring (May). Our results expand upon Hjeljord's findings by showing that ferns and grasses were still important components of Kodiak's mountain goat diets into early summer (late June), which appeared to be the independent of population density or history of irruptive growth.

We identified differences in goat diets between subpopulations at different densities and with different occupancy histories. However, our findings did not clearly show that diet selection was density dependent or based on occupancy history. We did, however, find that goats at the study site with the longest history of goat occupancy, Hidden Terror, consumed more forbs than those in the other study sites. This site-level difference in diets was primarily a result of goats at Hidden Terror consuming approximately four-times more Nootka lupine than goats from other study sites. Interestingly, lupine cover was not greater at Hidden Terror than other sites. However, total forage cover at Hidden Terror was substantially lower than other sites and may have led goats to focus more on lupine. Although lupine contained the highest nutritional quality (measured as digestible protein and dry matter) of any of the primary diet components examined, parts of the lupine plant contain secondary compounds that inhibit digestion and detract herbivory. Goats on Kodiak might have avoided these compounds by eating portions of the plant with lower concentrations of these compounds, like other ungulates (Stolter et al. 2005), but our diet analyses did not distinguish what parts of lupine were consumed.

Our diet results were uncorrected for differential digestibility of each forage class. Therefore, they are conditional since the true proportions of forage classes that goats consumed may have differed some because of differences in the ability of mountain goats to digest various plants. In general, proportions of forbs in diets can be underestimated, and grasses overestimated, but there

can also be variations among plant species within a forage class and there can be temporal variation in the digestibility of a single forage type as it grows and senesces (Bartolome et al. 1995). Correcting for differential digestibility can be obtained *in vitro* by introducing plants to rumen fluid of various big game ruminants or by multiplying the percent composition of forage classes in pellets by an empirically calculated dry matter digestibility values (Hanley et al. 1992). Our dry matter digestibility results became available after having completed our diet analyses, but we plan to adjust our results in future work.

Mountain goats of Kodiak Island selected feeding sites on summer range by balancing their need for predator protection with their need for high quality forage. Proximity to escape terrain was the most critical predictor of selection of feeding sites on Kodiak Island and is commonly identified as an important component of mountain goat habitat selection (Gross et al. 2002, Poole and Heard 2003, Hamel and Cote 2007). Typical predators of goats include wolves, black bear, brown bears, golden eagles (*Aquila chrysaetos*), and humans (Fox and Streveler 1986, Cote and Beaudoin 1997, Cote et al. 1997, Hamel and Cote 2009); of which only the later three inhabited Kodiak Island. Levels of bear and eagle predation on Kodiak's goats were unknown, but likely minimal because observed interactions between the species and discoveries of goat predation events were rare. Also, it is unlikely that the observed 60 years of exponential growth of mountain goat population would have been possible under heavy bear and eagle predation and an increasingly liberal hunter harvest pressure (e.g., 5 – 10 % targeted kill rates in 2012).

Forage cover was an important predictor of goat summer feeding site selection on Kodiak and reflected their dietary preferences. Goats apparently selected feeding sites with abundant sedge and rush cover, which were highly nutritious forage throughout the summer (Fox 1991). Moss cover was also a strong determinant feeding site selection, which was another preferred forage class but lower in nutritional value. In general, mountain goat feeding sites have been described as alpine meadows near cliffs (Von Elsner-Schack 1986). Like other northern ungulates, goats are considered selective feeders (Festa-Bianchet and Cote 2008). Hjeljord (1971) also concluded that goats at Hidden Basin (part of the Hidden Terror study site) seemingly selected sedge meadows and slopes as feeding locations during the summer, where their preferred forage was long-awned sedge. These results suggest that mountain goat feeding site selection patterns on Kodiak have not changed noticeably, despite substantial differences in the distribution and abundances of the population over the 40 years between studies.

Goats of Kodiak Island were more likely to select feeding sites on sunny (i.e. south-facing) slopes for summer feeding sites. The additional sunlight at these sites probably promoted plant growth, which presents additional available forage. In addition, sunny slopes were warmer and may have provided goats with an energetic saving by helping them to meet their thermoregulatory needs. Reports are conflicting as to which aspect goats generally prefer during the summer in other regions. Goats in Colorado and were found to prefer south-facing slopes (Gross et al. 2002). Goats at the Olympic Peninsula of Washington preference for south-facing slopes in early summer during snow melt and then north-facing slopes later in summer when it is hotter and drier (Pfitsch and Bliss 1985). Within season changes in mountain goat uses of different aspects was not apparent at Kodiak, possibly because the cooler and wetter climate may better support plant growth across all slope aspects or because our study seasons ended before differences in slope selection could be observed. Our study did not evaluate selection after mid-

August, after which seasonal climate changes may have driven changes in mountain goat site use and dietary composition.

We expected to see a positive correlation between the nutritional value of each preferred goat forage class and their relative preferences by mountain goats, but our results were inconclusive. In support of our prediction, dry matter digestibility (DMD) was highest for the four most common preferred forage classes (sedge, Nootka lupine, wooly geranium, and grass). However, we found no clear difference in digestibility among these four forage classes, despite large differences in their level of consumption by goats. Also, unexpectedly, mountain goats did not select forage classes in the order of their digestible protein concentrations. Lupine and willow had the highest concentrations of protein but they were not the most common forage items in goat diets. One possible explanation for this discrepancy is that lupine and willow also have secondary compounds (Adler et al. 2001, Pfister et al. 2001) that inhibit digestibility and thus are avoided by ungulates (Bergvall and Leimar 2005). Levels of tolerance of these secondary compounds by mountain goats are unknown.

Although we saw an increase in preferred forage biomass across all study sites between June and August by approximately 60%. However, we also documented a decline by over 5% in digestible protein concentration in preferred forage over the same time period. This inverse relationship between forage quantity and quality are likely what drove the temporally dynamic diet selection patterns of goats on Kodiak. In June and early July, goats focused on emerging sedges and grasses that were nutritionally rich, but sparse. They also continued their pattern of winter diet selection, as documented by Hjeljord (1972), by eating fern rhizomes and senescent grasses that provided a comparably low, but more consistently accessible source of nutrition. As higher quality forage plants such as sedges and forbs became increasingly available later in the summer, goats progressively focused on them and reduced their intake of lower quality forage (ferns and grasses). The physiological need for a temporally dynamic and selective feeding was likely a product of their digestive efficiency. In general, smaller ruminants have more selective diets than larger ones because digestive efficiency (longer gut is more efficient) is sacrificed for faster digestive processing (shorter gut processes faster) (i.e. the Jarman/Bell principle). As medium-sized ruminants, goats on Kodiak appear to display a greater level of selective behavior in mid/late summer when high quality forage are available, and less selective feeding during the winter to early summer when only lower quality forage are available. Because this study extended from green-up conditions in early summer to mid-summer conditions, the results appear to have documented the switch between the two phases of diet selection.

Understanding the diet, feeding site selection and behavioral patterns of a rapidly growing mountain goat population was a critical first step toward empirically-driven harvest management on Kodiak Island. Our results showed that summer diets did not vary by subpopulation, even though densities varied from 0.75 to 2.54 goats/km^2. Although irruptive growth commonly results in reduced forage abundance, diversity, and distributions (Hobbs 1996), the diets did not vary across subpopulation with occupancy histories ranged from 10 to 60 years. Apparently, selection of feeding sites was driven by access to high quality sedges and forbs and proximity to escape terrain. Like diet selection, feeding site selection was also independent of population density or history. If the population continues to grow and exceeds its nutritional carrying capacity, it will likely cause a reduction in their preferred forage species, which could in turn

affect other species, such as brown bear, that apparently also rely on these species (Atwell et al. 1980). Additional work is therefore needed to further understand the relationship between the resource selection patterns, population dynamics, and harvest management options for mountain goats on Kodiak Island.

Management Implications

Mountain goats of Kodiak Island exhibited selective feeding behaviors observed in goat populations elsewhere in Alaska. They focused primarily on sedges, and to a lesser extent forbs (Nootka lupine and wooly geranium), grasses and rushes. As such, these plants would be those most likely impacted by a high density non-native population in sites showing continued herd growth such as Uyak and Hepburn. Long-awned sedge is a common alpine plant that is known to be extensively foraged by brown bear of Kodiak Island in spring before other resources such as salmon are available (Atwell et al. 1980). The impacts of long-term and intensive foraging by goats on this important bear food resource are unclear, but should not be dismissed.

We observed differences in the compositions and abundances of preferred goat forage between study sites with different histories of goat occupancy. However, these differences are not necessarily clearly related to overgrazing by goats and could be the result of inherent site-level differences in geology or other environmental factors. Future efforts aimed at understanding long-term mountain goat impacts should consider constructing exclosures for study of goat influence on vegetation in habitats known to be used heavily by goats in summer and winter. These areas were not known during this study, but will be quantified with habitat use data from GPS collared goats. ADF&G deployed 15 GPS collars on goats during summer 2013.

We plan to use the data from this study to drive a modified version of the Forest Service's Forage Resource Evaluation System for Habitat (FRESH) model, which employs a linear programming approach to calculating nutritional carrying capacity. This model will answer the basic question: "what is the maximum number of goats (or goat days) that can be supported by a given food resource at a given level of metabolic requirement?" It will also provide a better understanding of the number of goats that can be sustained within a particular habitat over the summer. More importantly, the carrying capacity estimates from this model will provide refuge and ADF&G managers with a population size that can be targeted through harvest management.

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Appendix A. Mountain goat vegetation survey datasheet, Kodiak Island.

Mountain Goat Habitat Site Description

Study Area: *Hepburn Uyak Hidden* **Site:** *Random Used* **Site ID:**_____ (eg. YYYYMMDDPlot##)

Date: _____ **Observer** *(initials)*:_____

UTM E: _____ N:_____ **+/-Error** *(m)*:_____ **Biomass ID**:_____
(Site ID/Quad#)

Aspect (^{0}):_____ **Slope** (^{0}):_____

Biomass weight:_____

KLCC class: _____ **Feces in plots?** *Goat Deer Bear Unknown*

Bag weight: Plastic / Paper

Camera ID:

Site Description:

T1 Camera Pic #:

T2 Camera Pic #:

T1 BEARING:

Species	16	●	12	8	4
	1		2	3	4

0
5

T2 BEARING:

4	8	12	16
6	7	8	9

Species	16	●	12		8		4	
	1		*2*		*3*		*4*	

0	
5	

4		8		12		16	
6		*7*		*8*		*9*	

NOTES:

Appendix B. Results of microhistological analyses of mountain goat pellets, Kodiak Island. Each row shows the percent composition of forage classes for an individual pellet sample.

Study Site	Date	Year	Month	Day of Year	Visit	Sedges	Geranium	Lupine	Forbs	Rushes	Grasses	Ferns	Mosses	Lichens	Shrubs
Hepburn	6/4/11	2011	June	153	1	37.4	10.7	0.1	14.8	4.2	18.4	4.1	19.7	1.4	0.0
Hepburn	6/4/11	2011	June	153	1	32.9	13.3	0	15.4	3.6	12.4	21.8	13.3	0.6	0.0
Hepburn	6/4/11	2011	June	153	1	23.8	19	0	24.3	3.7	15.0	11.8	10.2	11.2	0.0
Hepburn	6/4/11	2011	June	153	1	32.6	8.8	0	11.2	7.4	22.0	2.4	15.6	2.6	0.0
Hepburn	6/4/11	2011	June	153	1	28.1	17.9	3.9	26.0	5.4	22.5	9.9	6.9	0.0	0.0
Hepburn	6/5/11	2011	June	154	1	26.9	0.1	0.1	8.3	8.3	20.5	25.2	8.0	0.0	0.0
Hepburn	6/5/11	2011	June	154	1	14.4	6.4	0	9.1	0.01	36.3	22.3	14.4	0.0	0.9
Hepburn	6/5/11	2011	June	154	1	19.7	0.1	0	3.5	0	26.5	22.6	12.9	14.8	0.0
Hepburn	6/5/11	2011	June	154	1	4	8.3	0.1	14.0	0.1	0.8	66.1	14.1	0.0	0.0
Hepburn	6/5/11	2011	June	154	1	7.3	10.6	0	19.3	0.1	4.5	47.9	16.5	3.1	0.0
Uyak	6/15/11	2011	June	164	1	43.8	7	11.1	26.3	9.4	24.4	29.2	0.6	0.6	0.0
Uyak	6/15/11	2011	June	164	1	63.1	0.1	8.6	17.9	5.2	41.2	12.1	3.6	3.4	0.0
Uyak	6/15/11	2011	June	164	1	42.3	0.1	17.4	29.7	7.9	19.7	23.3	1.6	0.0	1.2
Uyak	6/15/11	2011	June	164	1	46.4	0	5.1	20.7	22.2	15.6	21.9	1.5	11.1	0.0
Uyak	6/15/11	2011	June	164	1	36.5	0.1	18.4	22.3	15.3	40.2	7.4	1.0	1.4	2.4
Uyak	6/15/11	2011	June	164	1	47.4	0.1	0.1	16.2	12	17.7	25.9	1.5	0.0	0.9
Uyak	6/15/11	2011	June	164	1	41.2	4.1	12.4	17.2	12	34.7	26.3	1.3	0.7	0.0
Uyak	6/15/11	2011	June	164	1	40.3	3.1	11.3	12.0	23.9	19.5	32.9	0.0	0.0	0.0
Uyak	6/15/11	2011	June	164	1	41.4	3.7	20.7	15.4	11.9	47.5	7.2	1.1	4.0	0.0
Hidden Terror	6/26/11	2011	June	175	1	50.2	5.4	21.6	16.4	11.2	6.3	0.0	0.0	0.0	0.0
Hidden Terror	6/26/11	2011	June	175	1	14.4	11.5	11.5	32.9	4.5	8.2	0.0	0.0	0.0	0.0
Hidden Terror	6/26/11	2011	June	175	1	19.9	12.9	3.6	30.0	0.1	7.4	0.8	1.9	0.0	0.0
Hidden Terror	6/26/11	2011	June	175	1	15.3	4.4	21.7	20.5	9.2	3.4	0.0	3.8	0.0	0.0
Hidden Terror	6/26/11	2011	June	175	1	24.8	12.2	7.8	24.5	4.4	11.0	10.6	2.2	25.6	3.3
Hidden Terror	6/29/11	2011	June	178	1	17.2	14.5	5.8	14.8	7.1	12.4	4.0	6.5	0.3	0.0
Hidden Terror	6/29/11	2011	June	178	1	32.6	12.2	0.1	16.6	5.2	10.1	5.1	3.0	0.0	0.9
Hidden Terror	6/29/11	2011	June	178	1	15.8	7.1	6.4	38.0	3	9.2	2.5	2.1	0.0	1.4
Hidden Terror	6/29/11	2011	June	178	1	32.2	10	0.1	17.5	0.1	11.4	18.6	2.5	0.0	0.0
Hidden Terror	6/29/11	2011	June	178	1	22.7	11.5	0.1	13.7	0.1	24.2	8.9	4.0	0.3	2.7
Hepburn	7/16/11	2011	July	195	2	52.1	0.1	26.8	28.3	7.9	13.0	1.6	0.0	0.0	0.0
Hepburn	7/16/11	2011	July	195	2	37.2	0	13.5	20.5	12	2.6	0.0	0.0	0.0	0.0
Hepburn	7/16/11	2011	July	195	2	56	0	9.9	33.6	9.6	7.2	0.0	3.1	0.0	0.0
Hepburn	7/16/11	2011	July	195	2	33.3	0	10.8	10.6	24.2	7.0	3.1	5.1	0.0	0.0

Study Site	Date	Year	Month	Day of Year	Visit	Sedges	Geranium	Lupine	Forbs	Rushes	Grasses	Ferns	Mosses	Lichens	Shrubs
Hepburn	7/16/11	2011	July	195	2	40.6	0	26.8	31.6	9.9	4.8	0.0	2.4	0.0	0.0
Hepburn	7/16/11	2011	July	195	2	48.2	0.1	12.5	10.3	23.2	17.9	0.0	2.2	0.0	5.1
Hepburn	7/16/11	2011	July	195	2	31	12.3	16.4	32.3	24.7	9.7	0.0	2.6	0.0	0.0
Hepburn	7/16/11	2011	July	195	2	40.4	17.5	10.1	23.9	11.3	6.8	1.0	4.1	0.0	0.0
Hepburn	7/19/11	2011	July	198	2	60.1	4.6	14.8	34.5	10.3	2.7	0.7	5.1	2.0	1.7
Hepburn	7/19/11	2011	July	198	2	12.5	0.1	18.7	32.8	10.3	0.8	0.0	0.7	0.0	0.8
Uyak	7/30/11	2011	July	209	2	36.2	10.2	4	34.4	24.8	0.0	0.0	0.0	0.6	2.8
Uyak	7/30/11	2011	July	209	2	42.1	15.7	0.1	17.2	17.9	4.4	0.0	1.1	0.0	18.6
Uyak	7/30/11	2011	July	209	2	37.2	24.1	7.1	13.9	6.8	11.3	0.0	0.7	6.5	2.0
Uyak	7/30/11	2011	July	209	2	35.7	13.6	0.1	17.0	12.9	8.4	0.0	0.7	8.4	1.0
Uyak	7/30/11	2011	July	209	2	25.7	4.9	7.3	31.0	15	3.6	0.0	0.0	3.9	0.0
Uyak	8/5/11	2011	August	214	2	32.2	0.1	19.1	24.7	19.7	12.2	1.2	2.5	3.4	1.9
Uyak	8/5/11	2011	August	214	2	37.3	0.1	0.1	3.9	31.1	7.4	0.0	1.6	0.8	1.9
Uyak	8/5/11	2011	August	214	2	39.5	0.1	22.8	29.0	16	6.8	0.0	1.6	2.5	4.6
Uyak	8/5/11	2011	August	214	2	31.3	0	13.4	21.2	20.9	19.5	0.0	3.7	2.4	0.0
Uyak	8/6/11	2011	August	215	2	27.3	3.4	15	29.0	12.3	4.8	0.0	6.5	6.8	2.4
Hidden Terror	8/12/11	2011	August	221	2	34.7	0.1	36.6	21.7	14.2	2.1	0.0	1.8	0.0	0.0
Hidden Terror	8/12/11	2011	August	221	2	49.8	0	17.1	33.2	21	2.4	0.0	0.0	0.0	0.0
Hidden Terror	8/12/11	2011	August	221	2	39.6	0	32.5	28.0	23.7	4.9	0.0	1.7	0.0	0.0
Hidden Terror	8/12/11	2011	August	221	2	43.4	0	25	27.7	19.4	4.0	0.7	2.3	0.0	0.0
Hidden Terror	8/13/11	2011	August	222	2	38.5	0	21.4	39.1	18.1	7.2	0.0	0.0	1.6	0.0
Hidden Terror	8/16/11	2011	August	225	2	30.2	0	23.7	25.5	38.9	0.9	0.0	0.3	0.0	0.0
Hidden Terror	8/16/11	2011	August	225	2	36.7	0	25.3	28.3	16.9	7.1	0.0	1.3	0.0	8.1
Hidden Terror	8/16/11	2011	August	225	2	41.6	0	19.3	19.3	26.9	6.1	0.0	0.0	0.0	0.9
Hidden Terror	8/17/11	2011	August	226	2	43.4	0	21.3	25.3	27.3	1.4	0.0	0.6	0.0	0.9
Hidden Terror	8/17/11	2011	August	226	2	25.9	0	31.2	32.1	28.4	2.8	0.0	0.0	0.0	2.2
Hepburn	6/3/12	2012	June	155	1	49.7	13.2	0.1	16.8	0.1	27.1	1.3	2.0	0.0	2.1
Hepburn	6/3/12	2012	June	155	1	17.5	5.2	3.3	8.5	5.7	46.2	1.4	2.8	8.0	10.0
Hepburn	6/3/12	2012	June	155	1	32.6	20.4	0.1	22.5	0.0	32.0	0.0	10.0	0.0	1.3
Hepburn	6/6/12	2012	June	158	1	21.7	10.2	0.1	14.0	0.0	35.8	25.6	0.0	0.0	3.4
Hepburn	6/6/12	2012	June	158	1	35.8	7.8	0.0	10.6	0.1	23.9	27.5	0.9	0.0	0.0
Hepburn	6/6/12	2012	June	158	1	30.0	24.6	0.0	24.6	0.1	36.8	4.7	2.0	0.0	0.0
Hepburn	6/6/12	2012	June	158	1	0.1	26.7	0.1	32.7	0.1	5.7	44.9	9.1	1.1	3.4
Hepburn	6/6/12	2012	June	158	1	16.3	16.7	0.1	25.3	4.9	41.8	4.4	1.0	0.0	6.5
Hepburn	6/7/12	2012	June	159	1	18.9	12.3	0.1	17.5	5.8	43.6	9.9	2.1	0.0	2.6

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Hepburn	6/7/12	2012	June	159	1	14.8	19.0	0.0	22.0	10.6	24.8	21.1	1.4	3.5	2.2
Uyak	6/17/12	2012	June	169	1	47.2	0.1	0.1	4.8	10.5	29.9	0.0	2.8	2.7	2.4
Uyak	6/17/12	2012	June	169	1	55.6	5.1	9.1	16.4	4.5	18.3	0.0	0.0	1.0	4.5
Uyak	6/17/12	2012	June	169	1	28.8	15.6	0.1	23.4	0.1	33.3	3.1	0.6	0.0	9.3
Uyak	6/17/12	2012	June	169	1	15.5	21.6	17.4	43.5	0.0	0.0	9.8	0.0	19.2	12.2
Uyak	6/17/12	2012	June	169	1	18.0	4.1	6.7	10.8	0.1	49.0	5.7	2.6	1.0	10.3
Uyak	6/18/12	2012	June	170	1	43.3	0.1	0.1	4.4	10.4	17.7	2.4	0.0	11.0	11.0
Uyak	6/18/12	2012	June	170	1	41.3	5.1	9.7	23.4	4.1	9.4	0.0	1.5	18.9	2.1
Uyak	6/18/12	2012	June	170	1	37.6	6.4	5.0	12.0	0.0	17.9	5.4	2.0	2.0	23.3
Uyak	6/18/12	2012	June	170	1	4.1	17.3	14.1	38.5	0.0	11.1	0.0	4.5	9.5	32.8
Uyak	6/18/12	2012	June	170	1	10.4	0.0	0.1	1.9	6.8	46.7	0.0	22.1	7.4	5.2
Hidden Terror	6/28/12	2012	June	180	1	56.1	3.5	15.3	20.4	4.7	1.3	0.8	0.0	0.8	16.1
Hidden Terror	6/28/12	2012	June	180	1	47.5	5.1	12.0	17.1	3.2	20.9	1.9	1.9	0.0	7.7
Hidden Terror	6/28/12	2012	June	180	1	37.7	7.4	21.6	30.2	10.5	10.6	1.2	2.5	0.0	7.4
Hidden Terror	6/28/12	2012	June	180	1	25.6	7.4	3.9	15.7	3.9	32.5	2.5	2.5	7.9	9.4
Hidden Terror	6/28/12	2012	June	180	1	36.2	7.2	13.9	25.4	11.5	12.1	1.8	3.6	3.0	6.7
Hidden Terror	6/28/12	2012	June	180	1	52.9	3.9	7.1	14.2	8.4	13.7	0.0	0.0	0.0	10.9
Hidden Terror	6/29/12	2012	June	181	1	35.4	5.2	22.9	38.8	0.1	11.0	2.1	1.6	0.0	9.9
Hidden Terror	6/29/12	2012	June	181	1	53.9	5.6	6.1	11.7	6.1	7.8	0.0	0.0	0.0	20.5
Hidden Terror	6/30/12	2012	June	182	1	50.6	12.8	16.5	31.8	9.8	3.8	1.8	0.0	0.0	2.5
Hidden Terror	7/2/12	2012	July	184	1	51.9	4.2	6.6	12.7	10.3	18.7	2.3	0.0	0.0	4.3
Hepburn	7/16/12	2012	July	198	2	39.9	5.9	7.8	34.6	8.5	6.6	5.9	0.0	1.9	1.4
Hepburn	7/16/12	2012	July	198	2	47.7	0.1	5.0	13.5	12.2	2.4	17.6	0.9	0.0	4.6
Hepburn	7/16/12	2012	July	198	2	67.7	6.2	0.1	14.0	15.9	2.7	0.0	0.0	0.0	0.0
Hepburn	7/16/12	2012	July	198	2	61.1	3.8	3.8	16.7	12.1	7.9	1.3	1.3	0.0	0.0
Hepburn	7/16/12	2012	July	198	2	67.9	0.1	3.5	12.7	0.1	3.8	1.5	2.0	2.0	9.7
Hepburn	7/16/12	2012	July	198	2	57.5	0.1	0.1	9.8	6.1	13.6	3.3	0.0	0.0	10.4
Hepburn	7/16/12	2012	July	198	2	53.5	0.1	5.0	15.5	9.4	14.1	0.0	2.0	3.3	2.9
Hepburn	7/16/12	2012	July	198	2	66.7	7.2	0.1	13.5	0.1	12.5	0.0	0.0	0.0	0.0
Hepburn	7/19/12	2012	July	201	2	52.6	4.3	10.4	27.2	9.1	1.0	3.9	0.9	0.0	5.7
Hepburn	7/19/12	2012	July	201	2	46.7	4.0	9.2	26.7	3.9	13.5	2.0	0.0	0.0	7.9
Uyak	7/25/12	2012	July	207	2	52.4	0.1	7.9	17.2	14.4	12.1	0.0	1.3	0.4	3.2
Uyak	7/25/12	2012	July	207	2	54.0	0.1	17.4	30.9	0.1	11.7	0.0	0.5	1.1	0.0
Uyak	7/25/12	2012	July	207	2	38.0	7.5	23.5	36.4	12.5	4.2	5.5	0.0	0.0	4.0
Uyak	7/25/12	2012	July	207	2	52.9	0.1	14.5	27.2	7.6	3.0	0.0	1.2	4.6	4.1

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Uyak	7/27/12	2012	July	209	2	63.0	3.2	3.9	14.9	9.7	11.8	0.0	0.0	0.0	1.4
Uyak	7/27/12	2012	July	209	2	64.5	6.4	6.8	15.5	10.2	4.8	0.9	0.0	0.4	4.2
Uyak	7/27/12	2012	July	209	2	64.8	0.1	0.1	4.3	8.4	6.2	0.0	3.5	3.5	9.7
Uyak	7/28/12	2012	July	210	2	57.6	0.1	8.8	17.3	12.8	7.8	1.6	3.6	0.0	0.0
Uyak	7/28/12	2012	July	210	2	55.9	0.1	17.3	22.8	6.6	1.6	0.0	5.1	2.0	6.6
Uyak	7/28/12	2012	July	210	2	54.7	0.1	6.2	7.8	7.3	4.8	0.0	2.6	14.1	8.9
Hidden Terror	8/8/12	2012	August	221	2	51.8	0.1	25.3	28.3	12.1	2.8	0.0	2.7	0.0	2.7
Hidden Terror	8/8/12	2012	August	221	2	52.9	3.8	23.2	28.5	6.1	10.8	0.0	0.0	1.9	0.0
Hidden Terror	8/8/12	2012	August	221	2	45.7	0.0	26.6	30.7	8.1	8.8	0.0	1.1	0.0	5.8
Hidden Terror	8/8/12	2012	August	221	2	56.4	0.0	21.8	26.0	7.4	4.8	0.0	0.0	0.0	5.9
Hidden Terror	8/9/12	2012	August	222	2	54.2	0.0	19.3	19.3	22.9	0.7	0.0	0.0	3.0	0.0
Hidden Terror	8/10/12	2012	August	223	2	57.4	0.1	31.6	34.1	7.6	0.0	0.0	0.0	1.0	0.0
Hidden Terror	8/10/12	2012	August	223	2	56.6	0.1	33.5	36.0	7.1	0.0	0.0	0.5	0.0	0.0
Hidden Terror	8/10/12	2012	August	223	2	40.3	0.1	45.1	46.9	8.7	2.7	0.0	0.0	0.0	2.0
Hidden Terror	8/10/12	2012	August	223	2	61.7	0.0	13.2	20.8	8.2	4.2	0.0	0.0	1.8	3.7
Hidden Terror	8/10/12	2012	August	223	2	44.7	0.1	38.4	42.2	3.5	6.4	0.0	0.0	0.0	3.5