3/20/2018

McCrea Cobb

U.S. Fish and Wildlife Service

Anchorage, AK 99516

907-786-3403

[mccrea\_cobb@fws.gov](mailto:mccrea_cobb@fws.gov)

RH: Cobb et al. ● Mountain Goat Resource Selection on Kodiak

**Resource Selection of an Introduced Mountain Goat Population**

MCCREA A. COBB, *U.S. Fish and Wildlife Service,* 1011 East Tudor Rd, Anchorage, AK 99615

BILL PYLE, *U.S. Fish and Wildlife Service*, Buskin River Rd, Kodiak, AK 99615

NATHAN SVOBODA, Alaska Department of Fish and Game, Kodiak, AK 99615

**ABSTRACT**

Mountain goats are one of the least studied ungulates in North America. Understanding resource selection of introduced large herbivores exhibiting rapid population growth is important because of their ecological and economic importance and their potential to negatively impact native flora and fauna. Animals interact with their environment differently across time and space, and this relationship is reflected in scale-dependent differential selection of habitats. To better understand the relative importance of landscape attributes to mountain goat space use patterns, we quantified summer and winter resource selection of GPS-collared mountain goats on Kodiak Island, Alaska during 2013-2017. We compared habitat covariates at used (GPS fixes) and available locations conditional mixed effects logistic regression models at multiple spatial scales, which account for temporal autocorrelation and mechanistically define available locations based on the distributions of movement parameters. Results indicated that mountain goats resource selection was scale dependent and varied between seasons. During the both seasons, mountain goats selected tundra habitats and avoided shrub habitats. During the summer, mountain goats selected high elevation south-facing rugged and avoided shrub habitats. During the winter, mountain goats selected for steep, south-facing, and rugged terrain in mid elevations with close proximity to water and avoided areas forested habitats. Water was an important predictor of mountain goat use, but models indicated that goats selected for water at smaller scales during the winter than summer. Random effects were larger in the top winter model than the top summer model, indicating greater individual variation in resource selection during the winter than during the summer.

**KEY WORDS** conditional mixed effects logistic regression, Kodiak Island, mountain goats, *Oreamnus americanus,* resource selection, RSF

***Journal Title 00(0): 000-000, 201X***

Mountain goats are one of the least studied ungulates in North America. We know less about mountain goat resource selection than other species partly because mountain goats inhabit steep, rugged mountainous environments characterized by extreme climate conditions. Monitoring mountain goat space use during nutritionally stressful periods, such as winter, and periodic events, such as parturition, is especially challenging, but understanding habitat requirements during these and other critical time periods is crucial to linking landscape needs to population dynamics.

Introduced ungulate populations often follow a general trend of rapidly increasing to peak abundances, crashing to low levels, and then increasing to a theoretical carrying capacity below peak abundance (Caughley 1970). During the initial growth phase, 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 found some evidence for impacts on native ecosystems (Houston et al. 1994 (Lemke 2004) (Aho and Weaver 2003), but these impacts could be more pronounced in northern population where habitat resiliency is lower because of shorter growing seasons. To better gauge the potential for impacts to native species and allow for informed management, detailed information on resource selection patterns of introduced ungulates is a critical.

Processes such as foraging, predator avoidance, and competition collectively manifest in differential resource selection patterns. Mountain goat resource selection is a balancing act between using landscape features that promote predator avoidance but also host high quality forage. Ecological theory states that each process has an appropriate spatial scale determined by the time scale appropriate (“ecological neighborhoods”) for each process (Addicott et al. 1987), resulting in animal resource selection that can be quantified hierarchically in scale (Johnson 1980). As such, multi-scale resource selection that seek to identify the optimal scales at which an animal interacts with its environment provide more complete information on how animals perceive and utilize their environment to maximize fitness (Laforge et al. 2015, Laforge et al. 2016). Despite the importance of multi-scale resource selection, few studies address multiple scales and fewer yet use scale-optimized models to assess the sensitivity of habitat relationships at the scale of analysis (Mayor et al. 2009, McGarigal et al. 2016).

The mountain goat population on Kodiak Island, Alaska, is unique in its history and available habitats. Since their introduction in 1952, the population has exhibited exponential population growth and range expansion (Cobb et al. 2012). This pattern has persisted despite continuous and liberal sport harvest pressure across the population’s range; approximately 10-15% of the population harvested annually on Kodiak Island (ADF&G report…). Although now economically valuable population, Kodiak’s high density mountain goat population has the potential to negatively impact sympatric native flora fauna. Information on their resource selection patterns will shed light on whether the population has expanded to all suitable habitats and the probably of spatial overlap with sympatric species of concern.

In northern climates, winter weather can drive large herbivore population dynamics by limiting availability to high quality forage and causing to poor physical condition. Because of this, understanding how animals interact with their environment in winter is an important step toward quantifying the link between habitat and carrying capacity. Nothing is known of mountain goat winter resource selection in regions where forested habitats are largely absent, such as Kodiak Island. Mountain goats inhabiting wet coastal climates typically select for lower elevation forested habitats during winter presumably because lower snow depths increase foraging opportunities and lower movement energetic expenditure (Fox and Smith 1988). Nothing is known of how spatial scale of selection changes with seasons in coastal populations. Data from proximate mountain goat populations show that even adjacent populations exhibit plasticity in their resource selection patterns due to difference in available habitats such as snow characteristics (Poole et al. 2009). Therefore, site-level information on resource selection in atypical habitats is therefore necessary to inform management.

1. Do goats select at different spatial grain between summer and winter?

Our objective was to quantify the annual and seasonal resource selection patterns of introduced mountain goats on Kodiak Island, Alaska. Using GPS collar data, we sought to identify which topographic and vegetative characteristics that mountain goats select.

**STUDY AREA**

Kodiak Island (8,975 km2), the largest island in the Kodiak Archipelago, is located in the western Gulf of Alaska (Fig. 1). Kodiak Island is 40 to 65 km from mainland Alaska, separated by the Shelikof Strait. Kodiak Island is approximately 160 km long and varies in width from 15 to 130 km. The topography of Kodiak Island is mainly mountainous, with elevations ranging from sea-level to 1,362 m. Kodiak Island has a sub-arctic maritime climate, which is characterized by long, cold winters and wet summers. Annual precipitation averages 195 cm (Kodiak city) and monthly temperatures range from -1.2o C (January) to 12.9o C (August).

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). Alpine 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*). Snow was generally present in alpine habitats until mid-July. 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.

Eighteenmountain goats (7 males and 11 females) were introduced to Kodiak Island from the Kenai Peninsula, in 1952 and 1953. The population has been growing since, and by 2017, over 4000 goats were well distributed across the island (\*\*insert recent goat survey report). Potential predators to mountain goats on Kodiak include the Kodiak brown bear (*Ursus arctos*) and humans. Mountain goats are open to sport hunting harvest throughout the island.

**METHODS**

*Capture and collar-* We captured mountain goats from a helicopter. We immobilized goats with carfentanil citrate delivered via a 2-cc barbed dart fired from a projector (Palmer Cap-Chur Equipment, Powder Springs, GA). We fitted each captured goat with either a single Globalstar GPS collar (W300 Wildlink-GTX, Advanced Telemetry Systems, Isanti, MN), or a spread-spectrum GPS collar (TGW-4590 Iridium, Telonics, Mesa, AZ) and a VHF collar (MOD-400-1, Telonics, Mesa, AZ). We programmed Globalstar collars to collect two daily fixes, each separated by 13 hrs. We programmed spread-spectrum collars to record a fix every three hours between 16 December and 16 May, and every six hours between 16 May and 16 December. Six hours of collar inactivity triggered a mortality alert in all collars. Globalstar collars transmitted fix and mortality status datasets daily to a website, where we accessed them. Alternatively, spread-spectrum collars required us to manually upload data to a laptop computer in a fixed-wing aircraft. We fitted goats with a numbered red tag on each ear for identification purposes. To reverse immobilization drug effects, we hand-injected 255 mg Naltrexone (5.1 cc) intramuscularly in the rump.

*Resource selection modeling*

We compared covariate values at GPS collar fixes (used) to those at available locations. We considered individual collared mountain goats as the sampling unit. For the population level analysis, we evaluated the relative probability of use using conditional logistic mixed effects models with a matched case-control design (Fortin et al. 2005, Duchesne et al. 2010). Models included a random intercept for each collared mountain goat to account for the unbalanced design and correlation among individuals and allow for population level inference. We quantify resource selection separately for summer and winter seasons. We defined the summer season as June-September and the winter season as December-April based on the typical presence of snow cover.

For every collared mountain goat, we draw 10 random steps in the study area for every used fix from an empirical distribution of step lengths and turning angles based on all other mountain goats with similarly programmed collars (i.e., separately for ATS and Telonics collars). We applied the sample of steps to each fix to generate 10 matched (case-control) available fixes for each used fix. We then extracted spatial covariates values to the used and available fixes. We withheld a random sample of 20% of the used and available dataset (“testing data”) for model validation (detailed below).

*Covariates*

Similar to other large herbivores, mountain goat select habitats that minimize predation pressure but maximize opportunities of high quality forage consumption (Gross et al. 2002, White 2006). With these needs in mind and using information on Kodiak mountain goat diets (Hjeljord 1973), we selected *a priori* terrain and vegetation covariates that we hypothesized affect mountain goat resource selection (Table X). We derived terrain covariates [slope, aspect and vector terrain ruggedness (VTR, Sappington et al. 2007)] from one arc-second (30-m) USGS National Elevation data (NED). We defined aspect as a continuous numeric index between 0 (north) and 1 (south). We obtained habitat covariates using a landscape cover classification of the Kodiak Archipelago derived from 30-m LandSat ETM+ imagery classification (Fleming and Spencer 2007). We selected six habitat classes from the coarsest hierarchical classification level that we hypothesized were most relevant to mountain goats: meadow (including forbs and graminoid dominant grassland and meadows), tundra (alpine tundra and lowland heath), shrub (dominated by alder, salmonberry and willow), forest (dominated by Sitka spruce, birch and cottonwoods), rock (solid and fragmented), and water (fresh). Based on field observations, we expected that females would select steeper slopes in more rugged terrain in the summer than males because of their unique need to provide proximate escape terrain for kids. Therefore, we included sex as an individual-level covariate.

We followed a multi-tiered approach to model selection (Lowrey et al. 2017). In the first tier, we fit univariate models of terrain covariates (slope and vector ruggedness measure) derived from USGS NEDs. We used AICc for model selection. In the second tier, we began with the top candidate terrain model as a base model and then evaluated all combinations of habitat type covariates, which included Forest, Shrubs, Tundra/Heath, Meadow, Water, Snow and Rock.

To assess the predictive performance of the most supported models, we evaluated the correlations between the frequencies of occurrence of the testing data and their relative RSF scores using Spearman’s rank correlation coefficients (Boyce et al. 2002). High correlation indicates a well performing model.

**RESULTS**

* -Goats selected high elevations during summer and mid-elevations during winter
* -The scale that goats selected some habitat covariates changed between summer and winter. For example, goats selected tundra during both seasons, but at a finer scale in the winter (small patches?) and selection was weaker. Alternatively, shrub is avoided at the same scale throughout the year.
* -Strong avoidance of forest during the winter, but forest was not in the final model in the summer.
* -Goats selected more rugged and steeper areas during the winter than the summer.
* -Goats strongly selected water at a large scale (1 km buffers) during the summer. Goats selected water less strongly and at a finer scale during the winter.
* -Goats selected southerly aspects throughout the year. Aspect had a slightly stronger effect on selection in winter though.
* -There was more individual variation in selection patterns among each collared goat during the winter than during the summer (larger random effect in winter).

**DISCUSSION**

Evaluating spatial scale in resource selection modeling is an important component that is often overlooked. Our results show that mountain goats generally selected for similar habitats between seasons, but the scales of selection varied. There are a number of possible reasons for this apparent difference. The needs of and stresses on mountain goats differ between seasons and these differences are exemplified in differential resource selection patterns between seasons. A particular habitat class is physically different during summer and winter and offers different benefits to mountain goats. For example, during summer mountain goats may be selecting steep and rugged alpine tundra because it offers high quality forage and escape terrain from predators. During winter, predation pressure is less (Kodiak bears are hibernating), moderate quality forage is more difficult to access and movement is constrained due to snow cover. Therefore, we suspect that selection for tundra habitat

This was the first study to evaluate scale affects using conditional mixed effects models. Past studies have evaluated covariates at multiple scales, but defined available habitats at the home range scale (Lowrey et al. 2017). Our approach defines availability explicitly for each fix and therefore provides a more realistic temporally varying representation of how mountain goats make decisions conditional on their previous location.

**MANAGEMENT IMPLICATIONS**

**ACKOWLEDGEMENTS**

Kodiak National Wildlife Refuge and the U.S. Fish and Wildlife Inventory and Monitoring Program provided financial support. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

**LITERATURE CITED**

Addicott, J. F., J. M. Aho, M. F. Antolin, D. K. Padilla, J. S. Richardson, and D. A. Soluk. 1987. Ecological neighborhoods : scaling environmental patterns. Oikos 49:340-346.

Aho, K., and T. Weaver. 2003. Classification of alpine plant communities of the Northern Rocky Mountain Volcanics. Report to Yellowstone National Park. YELL-NPS-5119. 82 pp.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281-300.

Caughley, G. 1970. Eruption of ungulate populations, with emphasis on Himalayan thar in New Zealand. Ecology 51:53-72.

Cobb, M. A., H. Helling, and B. Pyle. 2012. Summer diet and feeding site location patterns of an irrupting mountain goat population on Kodiak Island, Alaska. Biennual Symposium of the Northern Wild Sheep and Goat Council 18:122-135.

Courchamp, F., J. L. Chapuis, and M. Pascal. 2003. Mammal invaders on islands: impact, control and control impact. Biological Reviews 78:347-383.

Duchesne, T., D. Fortin, and N. Courbin. 2010. Mixed conditional logistic regression for habitat selection studies. Journal of Animal Ecology 79:548-555.

Fleming, M. D., and P. Spencer. 2007. Kodiak Archipelago Land Cover Classification Users Guide. USGS (Alaska Science Center) and National Park Service. 77 pp.

Fortin, D., H. L. Beyer, M. S. Boyce, D. W. Smith, T. Duchesne, and J. S. Mao. 2005. Wolves influence elk movements: Behavior shapes a trophic cascade in Yellowstone National Park. Ecology 86:1320-1330.

Fox, J. L., and C. A. Smith. 1988. Winter mountain goat diets in southeast Alaska. Journal of Wildlife Management 52:362-365.

Gross, J. E., M. C. Kneeland, D. F. Reed, and R. M. Reich. 2002. GIS-based habitat models for mountain goats. Journal of Mammalogy 83:218-228.

Hjeljord, O. 1973. Mountain goat forage and habitat preference in Alaska. Journal of Wildlife Management 37:353-362.

Hobbs, N. T. 1996. Modification of ecosystems by ungulates. Journal of Wildlife Management 60:695-713.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Laforge, M. P., R. K. Brook, F. M. van Beest, E. M. Bayne, and P. D. McLoughlin. 2016. Grain-dependent functional responses in habitat selection. Landscape Ecology 31:855-863.

Laforge, M. P., E. Vander Wal, R. K. Brook, E. M. Bayne, and P. D. McLoughlin. 2015. Process-focussed, multi-grain resource selection functions. Ecological Modelling 305:10-21.

Lemke, T. O. 2004. Origin, expansion, and status of mountain goats in Yellowstone National Park. Wildlife Society Bulletin 32:532-541.

Lowrey, B., R. A. Garrott, H. M. Miyasaki, G. Fralick, and S. R. Dewey. 2017. Seasonal resource selection by introduced mountain goats in the southwest Greater Yellowstone Area. Ecosphere 8:e01769-n/a.

Mayor, S. J., D. C. Schneider, J. A. Schaefer, and S. P. Mahoney. 2009. Habitat selection at multiple scales. Ecoscience 16:238-247.

McGarigal, K., H. Y. Wan, K. A. Zeller, B. C. Timm, and S. A. Cushman. 2016. Multi-scale habitat selection modeling: a review and outlook. Landscape Ecology 31:1161-1175.

Poole, K. G., K. Stuart-Smith, and I. E. Teske. 2009. Wintering strategies by mountain goats in interior mountains. Canadian Journal of Zoology-Revue Canadienne De Zoologie 87:273-283.

Sappington, J. M., K. M. Longshore, and D. B. Thompson. 2007. Quantifying landscape ruggedness for animal habitat analysis: A case study using bighorn sheep in the Mojave Desert. Journal of Wildlife Management 71:1419-1426.

Spear, D., and S. L. Chown. 2009. Non-indigenous ungulates as a threat to biodiversity. Journal of Zoology 279:1-17.

White, K. S. 2006. Seasonal and sex-specific variation in terrian use and movement patterns of mountain goats in southeastern Alaska. Biannual Symposium of the Northern Wild Sheep and Goat Council 15:183-193.