Spatial Analysis of Plateau Pika Habitat Use

by

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Abstract

The habitat occupied by animals during their normal activities is referred to as their home range. This physical space contains limited resources that are necessary for reproduction and survival. Using spatial analysis techniques, we studied the habitat use of adult plateau pikas (*Ochotona curzoniae*) based on their home ranges and burrow locations on the Tibetan plateau. This was done for pikas exclusively within their own families, which is referred to as the family data, and also for individuals without taking their families into account, which is referred to as the individual data. We used spatial models to identify the microhabitat characteristics that influenced pika activity and to measure the spatial autocorrelation between the areas of home range overlap. We hypothesized that edges between microhabitats are most beneficial to pikas because there is access to food and cover from predators available. The edges between sedge and black sand microhabitats had a small effect on the level of pika activity for the family data. The edges between sedge and black sand, and the edge between sedge and small depressions, both had a large effect on the level of pika activity for the individual data. The burrows, which pikas can use to hide from predators, had a small effect on the level of pika activity for the individual data and a trivial effect for the family data. We found that the amount of sedge, which pikas feed on, had a trivial effect on pika activity for both the individual and family data. It seems that the edges, which provide a combination of food and cover from predators, had a larger effect than food, as sedge, and cover, as burrows, did individually. Neither the individual nor family data were significantly influenced by spatial autocorrelation.

Acknowledgments

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List of Abbreviations

ER1	Ratio of sedge-black sand edge to overlap area
ER1	Ratio of sedge-small depression edge to overlap area
BR	Ratio of the number of burrows to overlap area
SAR	Simultaneous autoregressive model

Introduction

The habitat that is occupied by animals is important to their ecology and evolution. Animals rely on a variety of resources in order to survive and reproduce. The behavior that results from seeking out these resources can be represented spatially with animal movement. Animal movement is determined not only by the heterogeneous distribution of resources, but also the presence of other animals, the mechanics of movement, and the distance or scale of perceptual range (Lima and Zollner, 1996; Horne et al., 2008). Studying the movement of animals can reveal which limited resources are prioritized and the social behaviors that aid in acquiring those resources (Osterwalder et al., 2004; Börger et al., 2008). These factors can change significantly based on the spatial and temporal scales that are being used for observations (Börger et al., 2008). One method of simplifying the study of movement is to focus on movement around home or nest sites. The summation of this restricted movement that an animal normally takes part in is referred to as its home range (Burt, 1943).

Competition for food, mates and cover from predators are a few factors that can influence home range locations, sizes and shapes (San Jose and Lovari, 1998, Börger et al., 2008). GIS techniques can provide a means to combine habitat data with animal location data to analyze these spatial patterns. We studied the home ranges of *Ochotona curzoniae*, also known as the black-lipped pika or plateau pika. Pikas are small, semi-fossorial mammals in the order Lagomorpha. Small mammals such as pikas often have very high metabolic rates and require high food intake relative to their bodyweight. Seemingly small differences in activity can result in very different energy returns (Wang and Wang, 1996). Plateau pikas can reproduce multiple times within a short summer breeding season (Dobson et al., 1998). For males, breeding involves frequent movement for mate-seeking. For females, breeding involves weaning multiple litters. In order to satisfy the energy demands for investing in these fitness traits, pikas must feed throughout the day. Male pikas engage in alarm calling to warn those nearby of danger such as predators (Ivins and Smith, 1983). Male plateau pikas may spend more time in a state of vigilance in the presence of females and young. While this can result in higher survival rates for females and their young, males are at higher risk for predation by remaining visible for longer. This is a good species for study of habitat use because individuals and their locations can be identified and observed from a distance. Individual pikas tend to be aggressive towards individuals in different families (Dobson et al., 2000). The territorial nature of pikas means that their individual and family home ranges tend to be restricted relative to the movement abilities of the individuals.

These behaviors can be influenced by the habitat that individuals and families occupy (Smith, 1978). Unlike pika species that live in crevices in talus deposits, plateau pikas live in burrows in sedge meadows. These semi-fossorial animals have a series of connected burrows with multiple entrances and exits. As a result, several individuals can occupy an extensive burrow system. Creating burrows can mix and aerate soil which may benefit local plant populations (Bagchi et al., 2006; Smith and Foggin, 1999; Yanshu et al., 2013). Plateau pikas are considered a keystone species of the alpine steppe habitat, partly because their burrow networks provide ecosystem wide benefits.

Plateau pikas can live in complex family structures with distinct home ranges and burrow systems (Smith and Wang, 1991). On the Tibetan plateau where these animals live, food in the form of grasses and sedges is available in large continuous meadows. There are multiple microhabitats within these meadows. The microhabitats include sedge meadow, large often barren depressions in the sedge meadow known locally as “black sand” (sometimes containing a species of mint), and areas of “small depression” where the sedge has started to break down (Dobson et al., 1998). While the sedge meadows offer food resources, the black sand and small depressions do not. However, the black sand and small depressions microhabitats can provide cover from predators because there is a difference in height of the vegetation and soil in these areas compared to the sedge meadow (Smith and Foggin, 1999). There is a larger difference in height between the black sand habitat and sedge compared to small depressions and sedge. At the end of the breeding season, the density of pikas can reach 300/ha (Smith and Wang, 1991). Individuals are highly mobile, and are capable of traveling from one end of the study area to the other. However, individuals within families are territorial and this can restrict their movements. So individuals within the same family may share space, because they’re in the same family and not necessarily because of the habitat characteristics.

We separated datasets into family groups and individuals. We analyzed individual home ranges within those family groups and individuals without the consideration of family structure. We measured the rank of overlap within portions of the study area as a measure of activity or density. In other words, a higher overlap area meant there are more individual home ranges overlapping. Small mammal home ranges usually include both food sources and cover from predators (Hayes, 2007). We expected home ranges to contain several burrow openings, as there can be multiple entrances and exits to the burrow network. Pikas face several avian and mammalian predators on the Tibetan Plateau such as the black kite (*Milvus migrans*), upland buzzard (*Buteo hemilasius*), and Asian polecat (*Mustela eversmanni*) (Smith et al., 1986). Harris et al. (2014) even suggest that Tibetan foxes (*Vulpes ferrilata*) are obligate predators on plateau pikas. This means that pikas have to fulfill their high energy requirements while also being subjected to high predation pressure. As a result, the edges between sedge and black sand or sedge and small depressions may provide an important balance between access to food and cover from predators. This may explain why burrow openings are often close to the edges between habitats. In this study, we want to determine whether the edges between habitats are valuable to pikas. We want to determine whether sedge-black sand edges are as beneficial to pikas as sedge-small depression edges. We also want to determine, if edges are valuable, whether they are valuable because of the cover they provide from avian predators or because of burrow locations

We hypothesized that edges between microhabitats are most beneficial to pikas because there is access to food and cover from predators available. We predicted that the edge lengths had a significantly large positive effect on the number of pikas utilizing the habitat. We predicted that the sedge-black sand edges had a greater effect size than sedge-small depression edges in this model. We predicted that each edge types had a greater effect size than burrows in this model. We predicted that each edge types had a greater effect size than sedge in this model.

Methods

Field Methods

We studied pikas on 2 hectare of the Tibetan Plateau (35 30’ N, 101 10’ E, elevation 3500m) in Guinan County, Qinghai Province, People’s Republic of China. A Cartesian grid system was marked off with flagging in 5m x 5m squares. Cells in the grid were labeled alphanumerically so that they could be uniquely identified. This grid system was used for documenting pika behavior and location through scan sampling with the help of Earthwatch volunteers. These observations took place from April 2 to August 31 in 1990. Subsequent to the collection of behavioral observations, professional artists were enlisted to accurately draw microhabitat patch location, shape and size, along with burrow locations within the grid system from May 25 – June 9 in 1992 (microhabitats did not exhibit noticeable change during the intervening years; F.S. Dobson and A.T. Smith, personal observations). This was done on 2.54mm x 2.54mm cell grid paper pages. The 2-hectare study site was depicted on 100 grid pages with each page representing 200 m^2.

Pikas were captured by placing string nooses and live traps near burrows. They were first anesthetized with Metofane and then subsequently weighed, examined for sex and reproductive status, and tagged with numbered ear tags. Different combinations of colored ear tag washers were used to enable identification of individual adult pikas. Juveniles from the same burrow were considered to be from one litter and were given the same ear tag colors so they could be grouped together. However, since females can produce multiple litters per season, juveniles from the same litter were grouped together based on when they emerged. Observations were mostly conducted from the edge of the study area, which was about 2m higher in elevation than the adjacent meadowland of the study grid. Pikas became habituated to observers and there appeared to be minimal influence on their behavior. A focal animal was chosen and observed for a 15-minute session, with behavior and grid location recorded in 5-minute intervals. During the focal sampling, scan sampling of nearby pikas on the study grid were recorded. Then another nearby focal animal was chosen and observed for a subsequent session. Individuals were observed multiple times throughout the day and on separate days. Family groups were first identified based on clustering of centers of activity (Smith and Dobson, 1994). Then behavioral observations corroborated the validity of these groups. Adults displayed affiliative behavior towards adults in the same family and aggressive behavior towards adults in different families in the vast majority of recorded observations (Dobson et al., 1998).

Spatial Data Methods

We scanned the grid sheets as TIFF files so they could be edited and analyzed with GIS software. We used the raster analysis software ERDAS Imagine 2015 to assign appropriate grid coordinates to each grid sheet file. We then used the Mosaic function in Imagine to stitch the 100 grid sheets into one TIFF file that displays the entire 2-hectare study site. Using the modeling function in Imagine, we removed the gridlines and assigned a raster value to the dark ink marks that were drawn on the maps. This essentially provided a digitized outline for each microhabitat patch on the map. These patches were filled and assigned different raster values based on their microhabitat type. If a patch was not labeled and could not be identified based on proximity of identified patches, it was removed. The resulting TIFF was then projected in UTM WGS 84 South and edited using ESRI ArcMap 10.3. We converted this raster file to vector format to simplify analyses. In ArcMap, we used the Editor tool to drop points for burrow locations as an additional shapefile to overlay on the habitat patches. Edges were characterized as a separate shapefile by converting habitat patch polygons to polylines.

We used the scan samples to construct home ranges in ArcMap 10.3. Point layers were created from coordinates and enclosed by a minimum convex polygon. Minimum convex polygons require at least 3 observations, so individuals with fewer than 3 observations were removed. This resulted in 114 different adults categorized into 28 families. Kernel density contours are often used for home range mapping. However, the sample sizes for many individuals were too low for kernel density measurements (Seaman et al., 1999; Swihart and Slade, 1997). Home ranges created from minimum convex polygons contain every observation of individuals. However, a limitation of this approach is that the density of observations points is treated as if it is uniform throughout the home range. This means that an individual may be active in certain parts of their home range more than others but those differences cannot be measured with minimum convex polygons.

The overlap of home ranges was measured for individuals and for individuals within each family. Individual overlap was measured by overlaying all individual home ranges. Overlap within families was measured by only overlaying individual home ranges with others within their family (Figure 1). This means that family range dataset does not include overlap of individual ranges from different families. In contrast, the individual range dataset contains overlap of individual ranges regardless of their family. The output of these two separate overlaying procedures was overlap polygons with pika burrow counts and edge length measurements assigned as attributes. Because burrow counts and edge lengths will depend on the size of the polygon, we divided these measurements by the area of the polygon. This was a way of measuring the density of the habitat features for each overlap polygon. Each of these polygons was also assigned a value indicating the rank of overlap, which is the number of home ranges that overlapped in that area. For within family overlap, the rank of overlap was restricted to individuals within each family. Overlap between different families was not measured in the family dataset. A limitation with this approach was that patches of habitat could be shared by several individuals in different families, but this would not count as multiple layers of overlap for the family dataset. Instead those individual ranges would be counted separately respective to the family those adult pikas belong to. For individual overlap measurements, the family spatial structure is removed and so overlap was measured regardless of family categories.

Statistical Methods

We used the R statistical software (core team 2016) for data analysis. Juvenile pikas were excluded, as individuals within the same litter were not differentiated. Adults with fewer than 3 observations were excluded because their home ranges could not be created with a minimum convex polygon. After creating and overlaying home ranges, our datasets consisted of 328 overlap polygons for the family data and 717 overlap polygons for the individual data. Polygons smaller than $5m^2$ were removed so that imperceptibly small GIS artifacts known as slivers were not included. Overlap values were skewed towards fewer individuals and so were log transformed. Each overlap polygon also contained a sedge meadow area, burrow count, black sand – sedge meadow edge length value, and small depression – sedge meadow edge length value. We used the packages 'sp' (Bivand et al., 2013), 'GISTools' (Brunsdon and Chen, 2014), 'rgdal' (Bivand et al., 2016) and 'maptools' (Bivand and Lewin-Koh, 2017) to import the map shapefiles into R. We used the package 'spdep' (Bivand and Piras, 2015) to run simultaneous autoregressive (SAR) error models for both individual and family data. These models take the form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \lambda W \mu + \varepsilon$$

$\mathbf{Y}$ is the rank of overlap within family or for individuals, $\mathbf{X_1}$ is black sand – sedge meadow edge, $\mathbf{X_2}$ is small depressions – sedge meadow edge, $\mathbf{X_3}$ is burrow density, $\boldsymbol{\lambda}$ is spatial autoregression coefficient, $\mathbf{W}$ is the queen's contiguous spatial weight matrix and $\boldsymbol{\mu}$ is the spatially dependent error. In addition to these variables, sedge density which is a measure of food availability, family size measures, and the interaction between each edge type and burrows were also included separately. This approach was chosen in order to allow us to measure the spatial autocorrelation present in the models. Spatial error models have been found to account for autocorrelation more effectively than other spatial regression models (Kissling and Carl, 2008). We chose to use queen's contiguity for the weight matrix in the SAR models. Queen's contiguity refers to the analogy of adjacency to movements on a chessboard. This means that polygons that are adjacent to each other in all directions can be autocorrelated. We chose this adjacency category because pika movement and therefore their home ranges are not restricted by direction. Similar methods have been used to study the large range sizes of birds (Jetz and Rahbek, 2002). One possible issue is that this model could be biased by the edges of the study site in that individual ranges occasionally extended outside the site boundaries. However, we did not record habitat attribute data outside the boundary of the study site and so some home ranges were reduced in size. Nagelkerke R^2 values were used to compare strength of models. Cohen's f^2 was used to measure effect size for variables (Cohen, 1992). Moran's I was used to quantify spatial autocorrelation for comparison between different models.

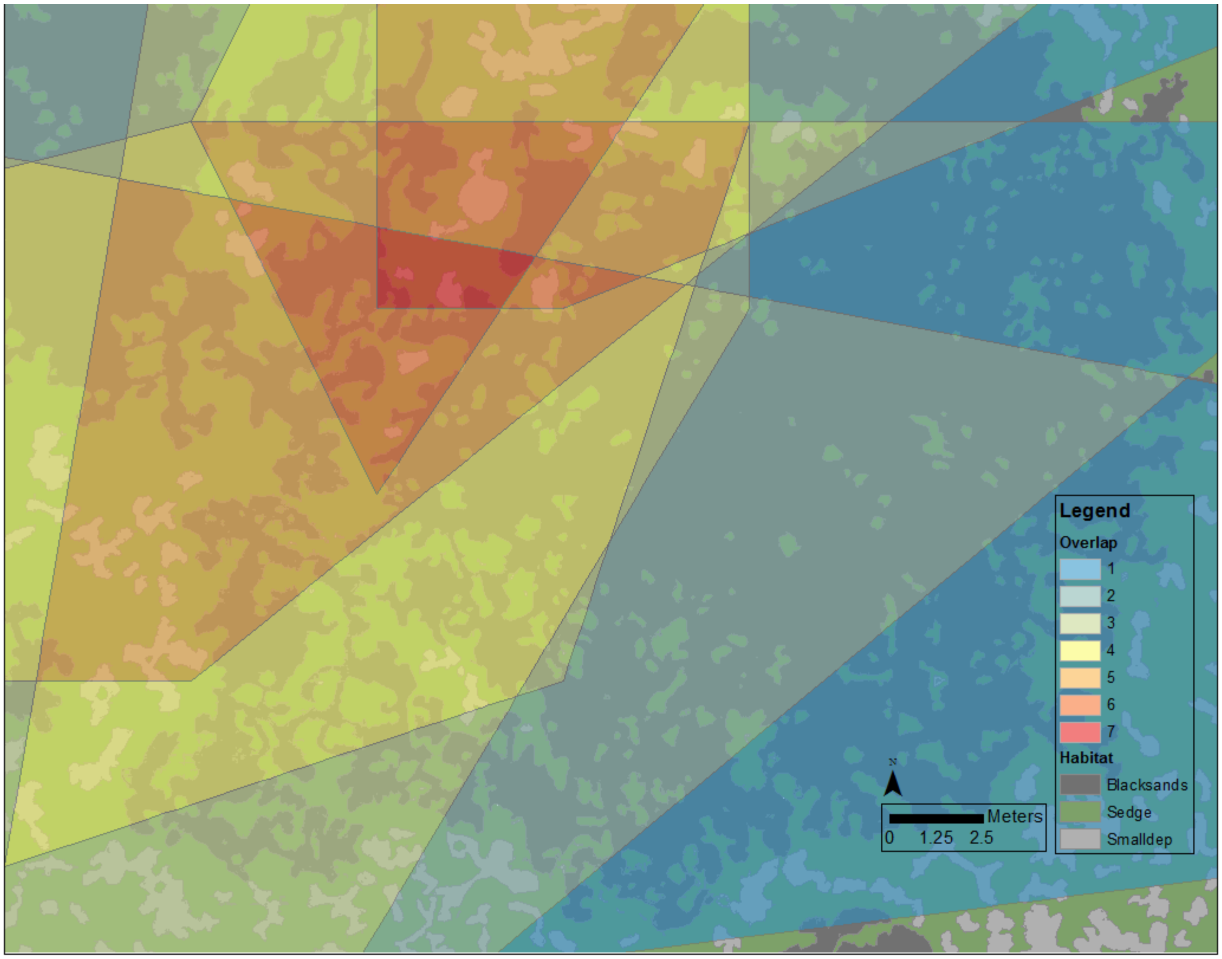

Figure 1: Example of individual home ranges overlapping within families with habitat in the background.

Results

Microhabitats were digitized as polygons and edges were depicted as polylines (Figure 2). Due to the way that home ranges were created, individual ranges measured from 25m^2 to 7450m^2. Family home ranges spanned from 87.5m^2 to 9300 m^2. The number of individual pikas per family spanned from 1 to 11. Rank of overlap indicates how many home ranges occur in the same location (Figure 3). The highest rank of overlap of home ranges within families was 7. The highest rank of overlap of individual home ranges was 15. The rank of overlapping polygons was log-transformed and referred to as "log overlap". The effect size of the correlation between family size and rank of overlap was small for the overlap within families ($r = 0.29$, d.f. = 326). For individuals, when an overlap polygon represented the overlapping ranges of pikas from different families, we calculated the average and the maximum family size from the families that individuals belong to. The effect size of the correlation between the maximum family size and rank of individual overlap was trivial ($r = -0.02$, d.f. = 715). The effect size of the correlation between the average family size and rank of individual overlap was trivial ($r = -0.01$, d.f. = 715).

The number of burrows was calculated for each overlap polygon. There were as few as 0 and as many as 1661 burrows per family overlap polygon. The ratio of the number of burrows to overlap area, referred to as "BR", ranged from 0 to 0.68 burrows/m^2 for family overlap polygons. There were as few as 0 and as many as 68 burrows per individual overlap polygon. The BR for individual overlap polygons ranged from 0 to 1.28 burrows/m^2. The length of edge between habitats was calculated for each overlap polygon. The ratio of sedge-black sand edge to overlap area is referred to as "ER1". The ratio of sedge-small depressions edge to overlap area is referred to as "ER2". The ER2 values were more evenly distributed than ER1 values though both were right skewed (Figure 4). ER1 values appear to increase as the rank of overlap within families increases while there doesn't seem to be a clear pattern with ER2 values (Figure 5). For individual overlap, both ER1 and ER2 appear to increase as the rank of overlap increases. There are more outliers for ER1 than ER2 for individual overlap.

Results of the simultaneous autoregression (SAR) spatial error model show that the edges between sedge meadow and black sand microhabitats (ER1) has a significant positive effect on the rank of overlap in home ranges within families (Table 1). The edges between sedge meadow and small depressions microhabitats (ER2) did not have a significant effect on the rank of overlap within families. Burrow ratio (BR) did not have a significant effect on the rank of overlap within families (Table 1). The ratio of sedge meadow to overlap area had a trivial effect on the rank of overlap within families ($f^2 = 0.00$). We found that the effect size of the correlation between ER1 and BR was trivial for the overlap within families (r = -0.07, d.f. = 326). We found that the effect size of the correlation between ER2 and BR was small for the overlap within families (r = 0.25, d.f. = 326). The interaction term between ER1 and BR had a trivial effect on the rank of overlap ($f^2 = 0.00$). The interaction term between ER2 and BR also had a trivial effect on the rank of overlap ($f^2 = 0.00$). Nagelkerke pseudo R^2 values indicate that this SAR model explained 34.9% of the variation in the data. ER1 and ER2 had a small effect, and BR had a trivial effect on the rank of overlap within families.

The SAR spatial error model was also used for the individual overlap data. The results show that the edges between sedge meadow and black sand microhabitats (ER1) has a significant positive effect on the rank of overlap (Table 1). The edges between sedge meadow and small depressions microhabitats (ER2) also had a significant positive effect on the rank of overlap (Table 1). Burrow ratio (BR) had a significant positive effect on the rank of overlap (Table 1). The ratio of sedge meadow to overlap area had a trivial effect on the rank of individual overlap ($f^2 = 0.01$). We found that the effect size of the correlation between ER1 and BR was small for the individual overlap (r = 0.19 , d.f. = 715). We found that the effect size of the correlation between ER2 and BR was large for the individual overlap (r = 0.77, d.f. = 715). The interaction term between ER1 and BR had a small effect on the rank of overlap ($f^2 = 0.13$). The interaction term between ER2 and BR also had a trivial effect on the rank of overlap ($f^2 = 0.03$). The effect sizes of average family size ($f^2 = 0.00$) and maximum family size ($f^2 = 0.01$) on individual overlap were both trivial. Nagelkerke pseudo R^2 values indicate that this SAR model explained 73.1% of the variation in the data. ER1 and ER2 had a large effect, and BR had a small effect on the rank of individual overlap (Table 1).

The SAR model for overlap within families indicated that positive spatial autocorrelation accounted for some of the residual variance ($\lambda = 0.85$). We calculated Moran's I, which is a commonly used spatial autocorrelation index, and found that there was not a significant amount of positive spatial autocorrelation in the residuals in the model (I = 0.024, p = 0.11). The SAR model for individual overlap indicated that positive spatial autocorrelation accounted for some of the variance that was not accounted for by the variables ($\lambda = 0.55$). We found that there was not a significant amount of positive spatial autocorrelation in the residuals in this model (I = -0.025, p

= 0.98). To visualize these pattern, we plotted residual map of the home range overlap polygons (Figure 6). Strong clustering of values was not present in these residual maps.

Table 1. Results of SAR models (logoverlap ~ ER1 + ER2 + BR) with Nagelkerke pseudo R^2, Moran's I of residuals, p-value associated with Moran's I and effect sizes of predictor variables. Individual results refer to home range overlap for individuals and family results refer to home range overlap within families.

Individual	**Estimate**	**Std. Error**	**z value**	**p value**
Intercept	0.021	0.009	2.323	0.020
ER1 (sedge-black sand edge ratio)	0.331	0.010	31.855	< 2.2e-16
ER2 (sedge-small depression edge ratio)	0.331	0.009	33.948	< 2.2e-16
BR (burrow ratio)	0.294	0.043	6.845	7.631e-12
Moran's I statistic for residuals	-0.025	0.011	-2.292	0.98
Nagelkerke pseudo R-squared	0.731			
Variable	**Cohen's f^2**		**Effect size**	
ER1	0.489		Large	
ER2	0.975		Large	
BR	0.022		Small	
Family	**Estimate**	**Std. Error**	**z value**	**p value**
Intercept	0.635	0.079	8.008	1.11e-15
ER1 (sedge-black sand edge ratio)	0.052	0.024	2.150	0.032
ER2 (sedge-small depression edge ratio)	0.004	0.024	0.149	0.881
BR (burrow ratio)	0.001	0.009	0.147	0.882
Moran's I statistic for residuals	0.024	0.023	1.207	0.113
Nagelkerke pseudo R-squared	0.349			
Variable	**Cohen's f^2**		**Effect size**	
ER1	0.022		small	
ER2	0.003		trivial	
BR	0.000		trivial	

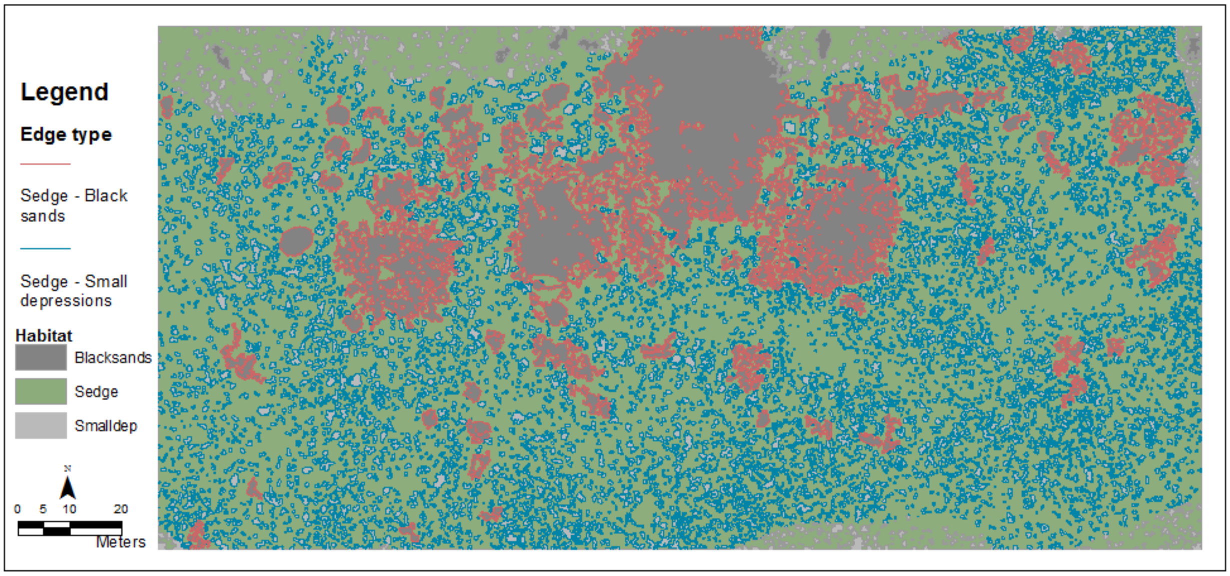

Figure 2. Microhabitats and edges in 2-ha study area on Tibetan plateau. Edge habitats that are not highlighted did not have individual home ranges covering that region.

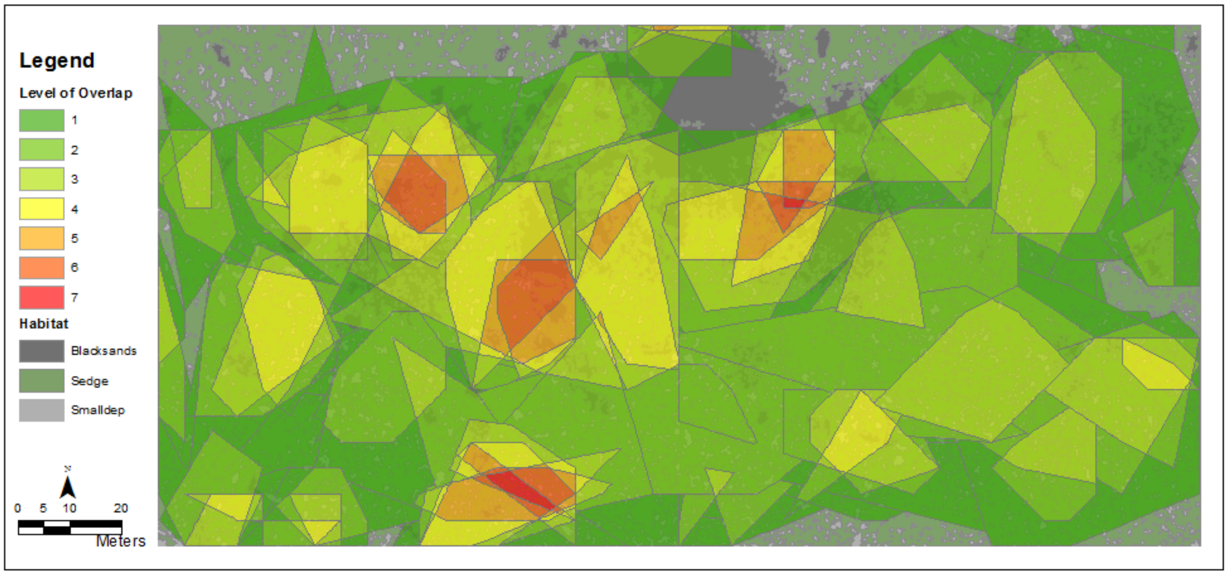

Figure 3. Example of minimum convex home range polygons showing where individuals among the same family overlap with each other. Rank of overlap refers to the count of individuals present in each polygon.

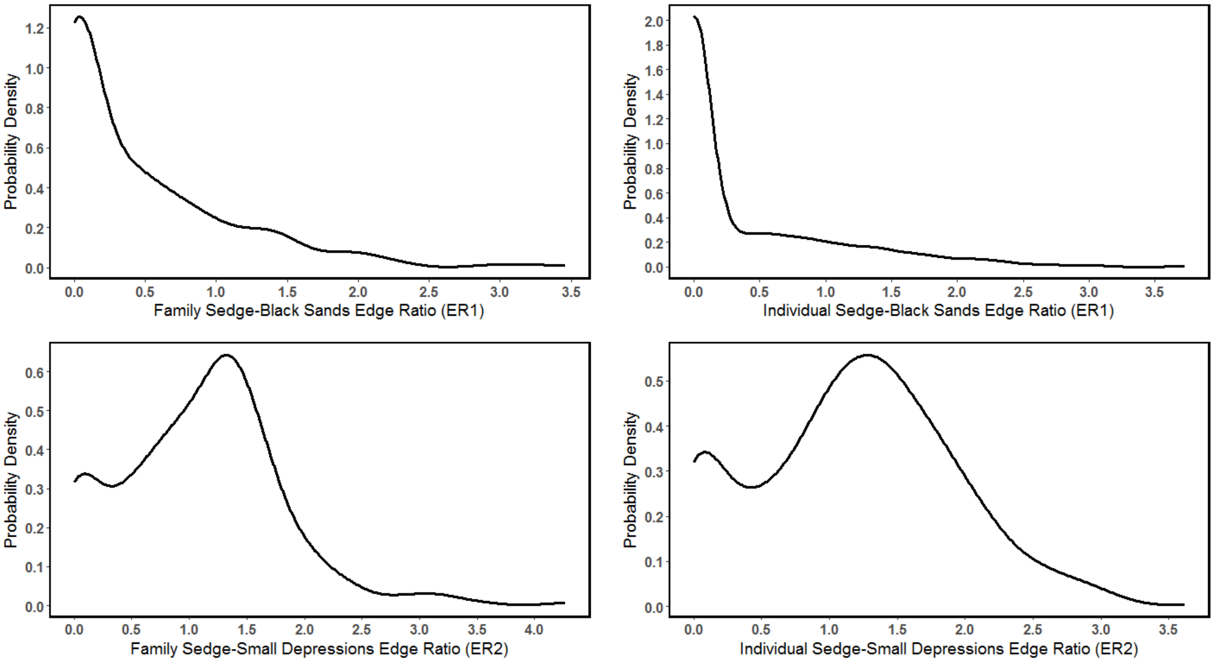

Figure 4. Probability density plots showing distribution of the sedge-black sand edge ratio (ER1) and the sedge-small depressions edge ratio (ER2) within home range overlap polygons. Individual refers to home range overlap for individuals (n = 717 polygons) and family refers to home range overlap within families (n = 328 polygons).

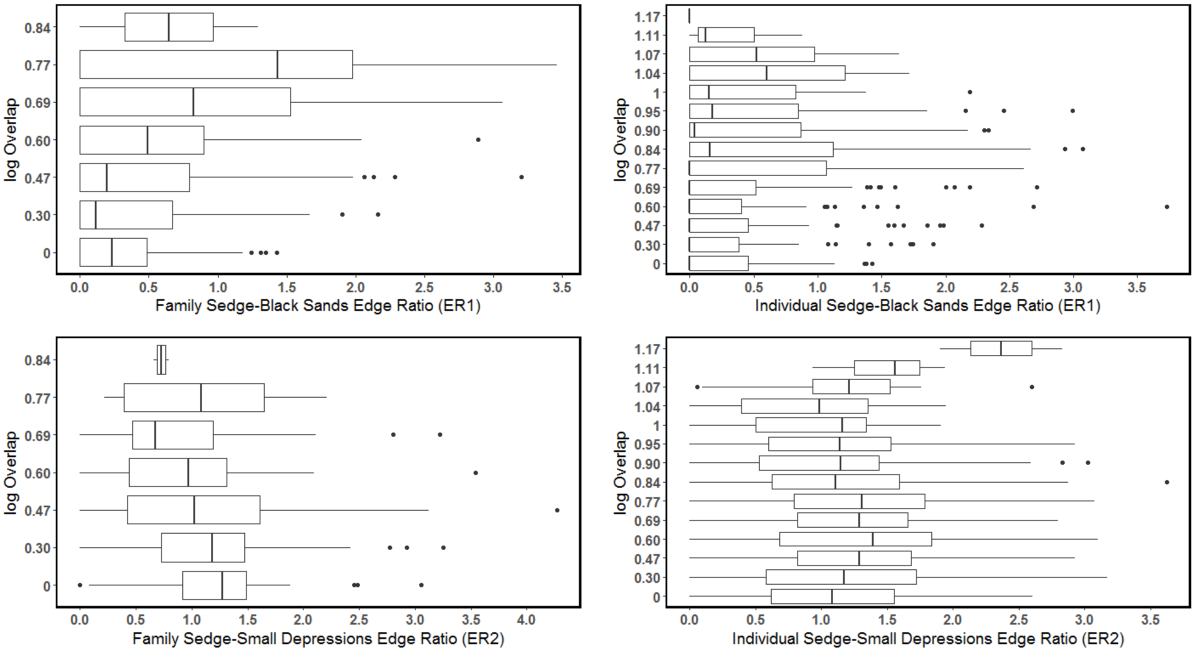

Figure 5. Box plots of ratio of sedge-black sand edge (ER1) and ratio of sedge-small depression edge (ER2) in home range overlap polygons for each rank of log overlap. Individual refers to home range overlap for individuals (n = 717 polygons) and family refers to home range overlap within families (n = 328 polygons).

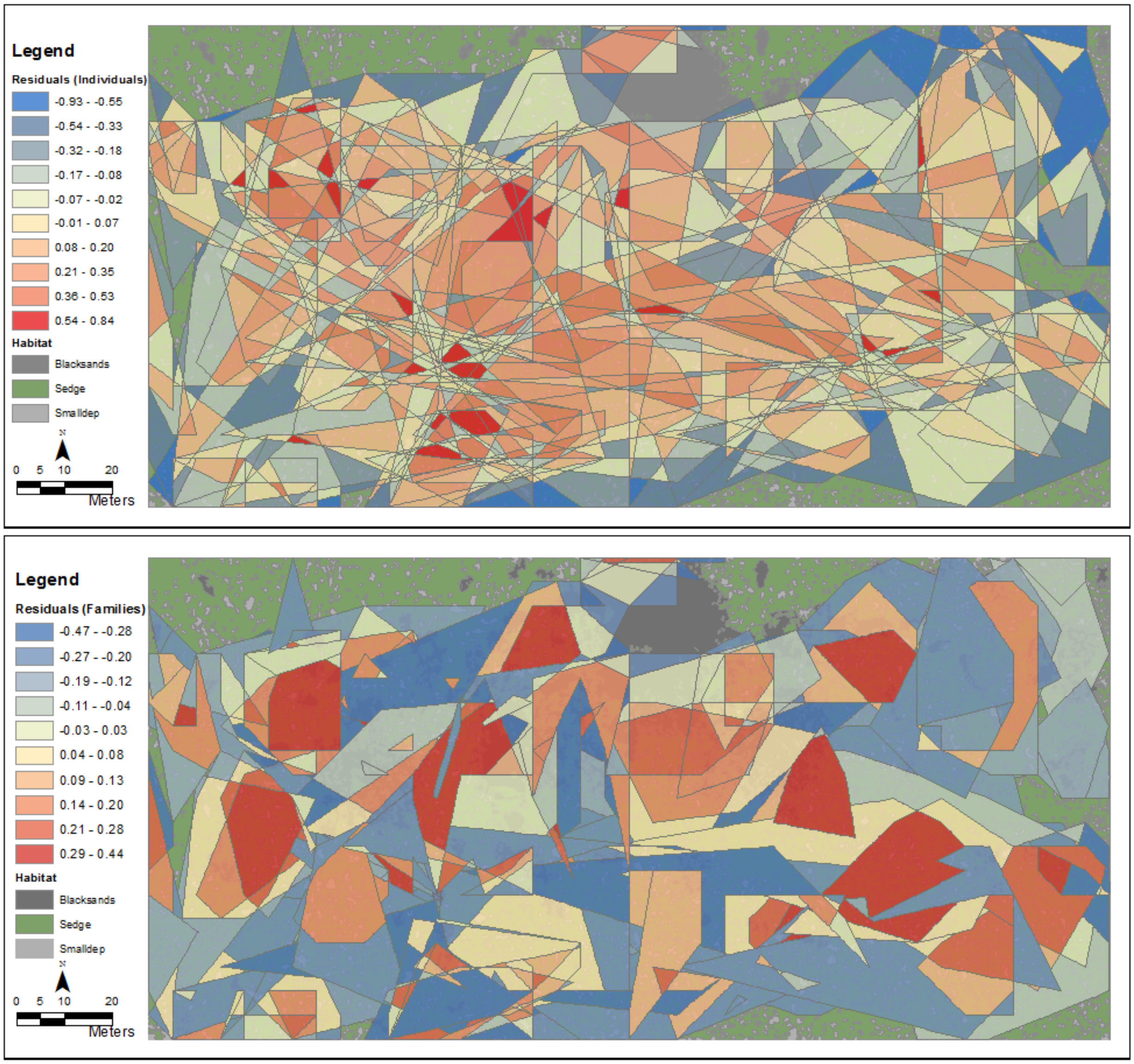

Figure 6. Residual maps for home range overlap polygons based on the SAR model (logoverlap ~ ER1 + ER2 + BR). Individual refers to home range overlap for individuals (n = 717 polygons) and family refers to home range overlap within families (n = 328 polygons). The result of Moran's test on the residuals in the family SAR model showed that there was not a significant amount of spatial autocorrelation present (I = 0.024, p = 0.11). The result of Moran's test on the residuals in the individual SAR model showed that there was not a significant amount of spatial autocorrelation present (I = -0.025, p = 0.98). Range of residuals are not clustered in this map. This visually depicts that there was neither positive nor negative spatial autocorrelation accounting for a significant portion of the unexplained variance in this model.

Discussion

We measured how home ranges overlapped as a way of measuring pika activity and then analyzed the variables affecting the rank of overlap. We found that the results for the family and individual overlap datasets differed. Sedge-black sand edge (ER1) had a significant positive effect on the rank of overlap for both datasets. Sedge-small depression edge (ER2) and burrows (BR) had a significant positive effect for individual overlap but not for family overlap. There was also a noticeable difference between the effect sizes of the variables for the individual and family overlap data. For individual overlap, ER1 had a large effect, ER2 had a large effect, and BR had a small effect. For family overlap, ER1 had a small effect, and ER2 and BR both had essentially no effect. ER2 had a larger effect than ER1 for the individual data. Though pikas seem to make burrows near edges, there was not a strong interaction between either edge type and the burrow ratio in both the family and individual data. There was also not a strong association between the number of individuals in a family and the rank of overlap in both family and individual data. The amount of sedge available, which pikas feed on, had a trivial effect on the rank of overlap for both family and individual data. So it appears that edges are more important than the number of burrows, food availability and family size in terms of the overlap of pika home ranges. Spatial autocorrelation significantly affected neither individual nor family overlap datasets. One issue is that multiple families could be sharing space in the study area but this was not counted in the family overlap data. Several families could have home ranges that overlap in certain areas which are not being counted. The overlap of different family ranges is not included in this dataset. Rather, only overlap of individuals within their own families is counted. Pikas are territorial and display aggressive behavior towards individuals in different families (Smith and Wang, 1991; Dobson et al., 1998). So individuals tend to share habitat space within their own families. Smith et al (1986) found 91% of pika interactions that were observed were between individuals within their family.

The data for this study were collected during the summer breeding season. Home ranges of small mammals can change significantly during breeding seasons (Erlinge et al., 1990). During the breeding season, adult males can engage in chasing away males from other families for the purpose of mate guarding (Smith and Wang, 1991). By doing this, males may be observed outside their normal home ranges. During the breeding season, males have been observed expanding their home ranges to include other adjacent families (Smith and Wang, 1991). Though those individuals occupied distinct home ranges, Smith and Wang (1991) found that they were not competing for food. This may be because males engage in territorial behavior during the breeding season and in this situation the individuals in separate families are allowed to move between ranges. Groups that are categorized as separate families could have overlapping ranges for this reason. However, this seems to be an uncommon occurrence. Individuals in separate families can overlap because the high energy demands during the breeding season cause pikas to travel further to consume enough vegetation. During the breeding season, in addition to mate guarding and aggressive territorial behavior, adult males also engage in alarm calling and paternal care (Smith et al., 1986; Smith and Wang, 1991). Females spend the vast majority of this time feeding in order to have the energy necessary to produce multiple litters (Smith and Wang, 1991). When multiple litters are produced throughout the breeding season, the population density increases. So individuals within each family may increase their home range to feed more and as a result, have ranges that overlap with individuals in other families. Smith and Wang (1991) found that juveniles and adult females become more territorial at the conclusion of the breeding season. The patterns of home range overlap among individuals in different families may change at the end of the breeding season.

Our hypothesis that edges between microhabitats are beneficial to pikas was supported in the individual data but not the family data. For individual overlap, both ER1 and ER2 had a large effect size on the rank of overlap. Pikas have been observed foraging along the edges between microhabitats (Dobson et al., 1998; Smith and Foggin, 1999). We found that the ratio of sedge to overlap area had a trivial effect on the rank of overlap. This means that the availability of food alone may not affect pikas' home range locations. This could be attributed to the fact that sedge is super abundant on the study site. Edges between habitats can be more important to animals than each habitat type individually (Tufto et al., 1996). Both ER1 and ER2 edge types can offer cover from avian predators in addition to sedge for feeding. Tufto et al. (1996) found that roe deer (*Capreolus capreolus*) home ranges are influenced by forest edges due to the presence of vegetation and cover. A study of meerkat (*Suricata suricatta*) home ranges showed that they sometimes prefer the edges between dunes and river beds (Bateman et al, 2015). Dune-river bed edges allow meerkats to feed on prey and have access to holes to bolt down if predators are present. There is a steeper edge between sedge-black sand than between sedge-small depressions. So we expected the sedge-black sand edge to be more important to pikas because it can more effectively provide cover. However, sedge-small depression edge (ER2) had a larger effect size than sedge-black sand edge (ER1) in our individual overlap model which did not match our prediction. Parts of the study site did not contain black sand while small depression patches were more numerous and evenly distributed. Multiple individuals' home ranges did not contain sedge-black sand edges. ER1 and ER2 may serve a similar purpose. However, if ER1 is not available, pikas may be including the more common ER2 in their home ranges instead.

Burrows (BR) had a smaller effect size than both ER1 and ER2 edge types for individual overlap data, which supports our hypothesis. There were thousands of burrow openings spread across the study site. Burrows tend to be located relatively close to both edge types. However, since there were so many burrows available, the effect on individual overlap is low. A study of home ranges of degus (*Octodon degus*), a small burrowing mammal, found that burrow openings didn't have as strong of an effect on home range size compared to vegetative cover (Hayes et al., 2007). Some studies suggest that burrowing mammals may not flee to their burrows upon detection of a predator if the risk of losing feeding opportunities is high (Bonenfant and Kramer, 1996; Lagos et al., 2009). Both edge types may provide adequate cover from avian predators while simultaneously allowing pikas to feed. Since the energy requirements during the breeding season are high, burrows may not be as important as sources of cover because they do not allow the same feeding opportunities as edges. Burrows are likely more beneficial in hiding from non-avian predators because pikas may be noticed on the ground even alongside an edge.

Swihart and Slade (1997) suggest that there is considerable potential for bias in home range estimates created from data such as the scan sampling observations we used in this study. Furthermore, because of a relatively low sample size in terms of number of observations, we used minimum convex polygons to measure home ranges. Compared to kernel density measures, minimum convex polygons tend to produce biased stationary home ranges (Swihart and Slade, 1997). Since we are analyzing at how pika home ranges overlap, we needed to account for the fact that the rank overlap in one polygon could be spatially autocorrelated with the overlap in an adjacent polygon. SAR models can be used for this purpose and have only recently been used in ecological studies (Kissling and Carl, 2008; Lou et al., 2016). We used Moran's I to calculate the extent to which the residuals in the model are spatially autocorrelated. Neither the individual nor family overlap models' residuals were significantly autocorrelated. This essentially means that the rank of overlap in one region of the habitat isn't just determined by the overlap in a nearby region. The main issue with this approach is that the overlap among home ranges in different families is not being counted in the family overlap data. This is likely the reason why the results for individual and family overlap differ.

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