Identification of functional corridors with movement characteristics of brown bears on the Kenai Peninsula, Alaska

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Received: 11 August 2005/ Accepted: 6 February 2007
First published by - Springer Science +Business Media B.V. 2007

Abstract We identified primary habitat and functional corridors across a landscape using Global Positioning System (GPS) collar locations of brown bears (*Ursus arctos*). After deriving density, speed, and angular deviation of movement, we classified landscape function for a group of animals with a cluster analysis. We described areas with high amounts of sinuous movement as primary habitat patches and areas with high amounts of very directional, fast movement as highly functional bear corridors. The time between bear locations and scale of analysis influenced the number and size of corridors identified. Bear locations should be collected at intervals ≤ 6 hours to correctly identify travel corridors. Our corridor identification technique will help managers move beyond the theoretical discussion of corridors and linkage zones to active management of landscape features that will preserve connectivity.

Keywords: connectivity, fragmentation, habitat, highways, linkage zones, *Ursus arctos*

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Introduction

Habitat conservation and maintenance of connectivity are issues of increasing concern for wildlife populations. This is especially true for small populations, animals with large home ranges, and in areas fragmented by human development (Proctor et al. 2005, Ward 2005). Large, continuous tracts of high quality habitat are the biological ideal for maintaining genetic and demographic connectivity, because animals that live in areas with patches of poor quality habitat must expend effort to navigate around them, whether natural or human-caused. Identification of areas that are currently used as 1) high quality habitat, hereafter primary habitat, and 2) corridors can help us to predict the effect of land development, restoration, or preservation by enabling managers to see the value and function of specific land areas in the context of the whole landscape.

Previous attempts to identify high quality habitat have relied on analyses of habitat characteristics representing food and shelter at point locations used by animals, usually in comparison to unused or available locations (e.g. Mueller et al. 2004, Manly et al. 2002). Corridors are typically defined as areas with the same characteristics as high quality habitat, but also possessing additional landscape characteristics (e.g. Haddad et al. 2003). Corridors have vegetation that provides better food or cover than the surrounding habitat matrix, are composed of patches that are longer than wide, and are often aligned to an internal entity like a river that may form a natural travel route (Forman 1995). However, few studies have tested whether putative corridors (based on vegetation type and structure) are functionally used as corridors by animals (Aars and Ims 1999, Sutcliffe and Thomas 1996). Another little-tested, but important theoretical characteristic of corridors is movement efficiency. Within a corridor, animals move more quickly than in the surrounding matrix or primary habitat (Forman 1995). Few studies have examined this thoroughly and few methods exist that distinguish patterns of landscape use based on movement characteristics (Johnson et al. 2002). Here we use movement characteristics, rather than vegetation and landscape structure, to determine landscape functionality for a subpopulation of brown bears on the Kenai Peninsula, Alaska.

Landscape functionality varies from primary habitat, which can meet all of an animal's needs (food and cover), to lower quality habitat, which can support travel but little else, to non-habitat, which has few resources and little safety. We expect movement paths in primary habitat to be dense (because animals are often there), slow (because animals stop to eat or rest), and sinuous (because animals search for food; Fig. 1A).

In areas with greater fragmentation, additional hazards, or fewer resources (lower quality habitat), animal movement will be constrained, linear, and faster. When behaviors are limited to travel rather than feeding or resting, the area

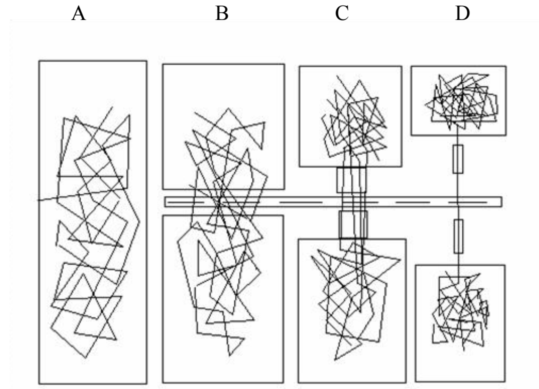

Fig 1. A) Primary habitat with high amounts of move-ment, high angular deviation, and little fragmentation. B) Linkage zone with potential fragmentation, but movement similar to primary habitat. C) Highly functional corridor with fragmentation but high amounts of directional (low angular deviation) movement. D) Minimally functional corridor with high fragmentation and little movement.

is called a corridor. We therefore define highly functional corridors as places where animals exhibit large amounts of rapid and highly directional movement (Fig. 1C) and minimally functional corridors as areas where animals exhibit long, rapid, and infrequent movements (Fig. 1D). As corridors become narrower and less continuous, risk increases and probability of use decreases, until the area is no longer a conduit for animals and can not be considered suitable habitat (i.e., non-habitat). Our definition is based on the movement efficiency characteristic of corridors and is more appropriate for generalist species like bears that respond to factors with visually indistinct boundaries, such as proximity to human activity. Defining corridors with this approach eliminates the assumption that we can correctly identify all habitat factors to which animals respond and replaces the intermediate step of modeling resource selection when corridor identification is the only objective. This method does not require classification of remotely sensed images, and thereby avoids the potential to misidentify suitable habitat for travel.

With GPS collars we can now track animals across a large landscape (100s of km) at fine temporal and spatial scales (e.g. ~10m positional accuracy, every 15 minutes). We can derive highly descriptive movement parameters from these large datasets of frequent locations to determine whether animals are using fragmented areas as highly functional corridors, minimally functional corridors, or not at all.

We developed a technique for identifying primary habitat and corridors based on animal movement patterns. We demonstrate the application of our technique with locations of brown bears on the Kenai Peninsula.

Methods

Data were collected with Global Positioning System (GPS) collars for several brown bear studies conducted on the Kenai Peninsula, Alaska between 1995 and 2002 (e.g. Schwartz et al. 1999, Suring and DelFrate 2002, Suring et al. 2004). The Kenai population was designated by the State of Alaska as a population of special concern in 1998 in recognition of increased levels of human activity. Most location data are from female bears. Unless otherwise noted, spatial analyses were conducted with ArcGIS 8.3 or 9.0 (ESRI, Redlands, CA, USA) and statistical analyses were conducted with SPSS 11.0 (SPSS Inc, Chicago, IL, USA).

Effect of Scale

As battery life in GPS collars has improved, collars have been programmed to collect locations at more frequent intervals. The full Kenai Peninsula brown bear dataset included bear locations collected at <0.25, 0.5, 1, 6, 13, and 23 h intervals. To permit inclusion of as many bears as possible at the finest appropriate spatial scale, we assessed the influence of time interval between animal locations and the effect of scale on corridor and primary habitat classification. We examined data from 5 bears with collars programmed to record locations at a frequency of ≤ 0.5 hrs. From this dataset we extracted locations at 1, 6, 13, and 23-hr intervals. We calculated movement path density, mean movement speed, and angular deviation of movement at 4 different scales: 1) 500 m cell size with a 250 m search radius, 2) 500 m cell size with a 1000 m search radius, 3) 1000 m cell size with a 3000 m search radius, and 4) 1000 m cell size with a 5000 m search radius. The search radius defines the area used in calculation of the parameter. For instance, the choice of a 500 m cell size with a 250 m search radius will assign a cell that is 500 m X 500 m a density based on all paths within a circle of radius 250 m around the cell center.

We estimated movement paths as straight lines between consecutive locations. We calculated movement path density within each cell, and defined all areas containing one or less movement paths per cell as non-habitat areas. This allowed us to focus our efforts on primary habitat and highly functional corridors. Therefore, this analysis defined only areas that were heavily used. To distinguish between non-habitat and areas in which no bears had GPS collars, we identified regions outside 95% kernel home ranges of all bears (Hawth's Tools; Beyer 2004) as non-sampled (Fig. 2). We used kernel home ranges because minimum convex polygons would greatly overestimate the area considered to be sampled. We used the movement path density raster as the extent for calculations of other movement parameters so cells were perfectly aligned.

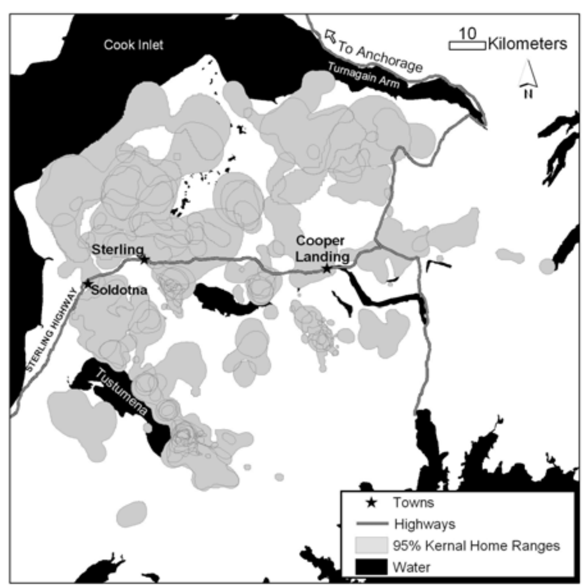

Figure 2. 95% kernel home ranges for 35 bears included in Peninsula-wide classification of the landscape into corridors and primary habitat. Kernal home ranges are used to delineate areas that were sampled.

We calculated movement speed across the landscape with Trajectory Analyst Extension (Miller Mountain Consulting, Durango, Colorado, USA). We examined the spatial and temporal effects of scale within the movement speed parameter. We created spatial utilization distributions (UD) by sampling movement paths at 1) 500 m, 2) 1000 m, and 3) 3000 m intervals and calculating the density of locations at each scale. We created temporal UDs by sampling the movement path at 60 and 15 minute intervals and then calculating the density of locations at each time scale. We divided spatial UDs by temporal UDs for the final landscape movement speed.

To examine directionality, we determined the length and bearing for each path in each cell. We computed each path's axial bearing (0-180 degrees) by multiplying the bearing (0-360 degrees) by 2 and if the result was greater than 360, subtracting it from 360 (Zar 1999). We calculated the axial angular deviation for a cell as in Zar (1999), but weighted each bearing by the length of its path in the cell using the following formulas:

X= ∑ for each path in cell (Cos(axial bearing)*Path length) / ∑ all path lengths

Y= ∑ for each path in cell (Sin(axial bearing)*Path length) / ∑ all path lengths

Low axial angular deviation indicates highly directional travel paths, or low tortuosity (Turchin 1998), but at a landscape scale.

Landscape function classification

We defined areas with high path densities and highly sinuous movement as primary habitat patches and areas with high path densities and very directional movement as highly functional bear corridors. To classify these areas we applied a K-means cluster analysis with a 2-cluster solution (Hartigan and Wong 1979) for each location interval and scale combination. We standardized all variables to a mean of 0 and a standard deviation of 1. Since animal movement patterns show high sinuosity (high angular deviation) in high quality habitat (Ward and Saltz 1994, Nolet and Mooij 2002), we surmised highly directional movement would most clearly distinguish corridors from primary habitat and linkage zones. Therefore, we weighted the angular deviation 3X as important as movement density and speed.

From this preliminary analysis we determined the location frequency and scale combinations that 1) identified cells with the centers of highest location densities as primary habitat, 2) divided the landscape into the largest number of primary habitat patches, and 3) described continuous corridors among most primary habitat patches. Using the best combination of location frequency and scale, we repeated the analysis to identify primary habitat patches and corridors across the entire Peninsula. Movement characteristics observed along the edges of some primary habitats were similar to movement characteristics observed in corridors between primary habitat patches, so we included only patches with ≥ 3 contiguous cells in our final map.

Results

Effect of Scale

Location frequency, scale of search radius, and scale of cell size influenced the number and size of primary habitat patches identified and the number of continuous corridors among them. Analysis at intervals of 6 and 13 hours between locations, a 1000 m search radius, and a 500 m cell size identified all centers of high location densities as primary habitat (Table 1). Analysis with one hour location intervals, a 5000 m search radius, and a 1000 m cell size also identified all centers of high location densities as primary habitat. However the latter analysis grouped all high density locations into one large habitat patch. The clearest discrimination between patches (Table 1) and the best corridor continuity (Table 2) resulted when locations were sampled at 6 hour intervals with a search radius of 1000 m and a cell size of 500 m. Thus, for Peninsula-wide analyses we used a 1000 m search radius and a 500 m cell size and included only bears with location attempts that

Table 1. Mean percent and number of primary habitat patches identified for combinations of location frequency and scale.

Hours between locations	Percent				Number			
	Search Radius (m)				Search Radius (m)			
	250 [a]	1000 [a]	3000 [b]	5000 [b]	250 [a]	1000 [a]	3000 [b]	5000 [b]
1	0.17	0.44	0.67	1.00	1.0	2.3	3.0	1.0
6	0.25	0.94	0.56	0.61	1.5	4.5	1.8	1.3
13	0.17	1.00	0.62	0.56	1.0	4.1	1.2	1.3
23	0.17	0.89	0.46	0.44	1.0	3.7	1.3	1.0

Analysis included data from 5 bears on the Kenai Peninsula with locations recorded at intervals <0.5 hours.
[a] 500 m cell size
[b] 1000 m cell size

Table 2. Mean number of continuous corridors connecting primary habitat patches for combinations of location frequency and scale.

Hours between locations	Search Radius (m)			
	250 [a]	1000 [a]	3000 [b]	5000 [b]
1	0.0	1.8	3.0	2.0
6	4.0	13.6	6.2	6.6
13	0.3	13.3	5.5	5.8
23	0.0	11.2	5.6	4.1

Analysis included data from 5 bears on the Kenai Peninsula with locations recorded at intervals <0.5 hours.
[a] 500 m cell size
[b] 1000 m cell size

were ≤ 6 hours apart. This permitted inclusion of 19,017 locations from 35 bears.

The UDs used to calculate mean movement speed are sensitive to the frequency of sampling along bear paths. When we calculated the temporal UD on points from hourly intervals, many cells in the mean movement speed layer showed no use (cell value = 0) if bears traveled through the area quickly. Thus, we recalculated movement speed by sampling bear paths at 15 minute intervals. Bear paths had to be sampled at a fine temporal scale to keep all relevant cells in the analysis. Similarly, when we sampled bear paths at 3000 m intervals to calculate the spatial UD, the movement speed grid was patchy in areas where bears moved quickly. To identify corridors as contiguous units, and to adequately represent speed through time, bear paths were sampled at a fine spatial interval, 500 m in the Peninsula-wide analysis.

Peninsula-wide analysis

We identified 179 primary habitat patches and 170 corridor patches larger than 3 contiguous grid cells. Patches of non-habitat and non-sampled areas were interspersed among primary habitat and corridor patches (Fig. 3).

In our initial assessment of the effect of location frequency and scale on corridor identification, we used a 2-cluster solution to the K-means cluster analysis that classified areas as habitat vs. corridors. However a 2-cluster analysis at a peninsula-wide scale identified one small area of exceptionally good habitat and combined all other areas together, so we used a

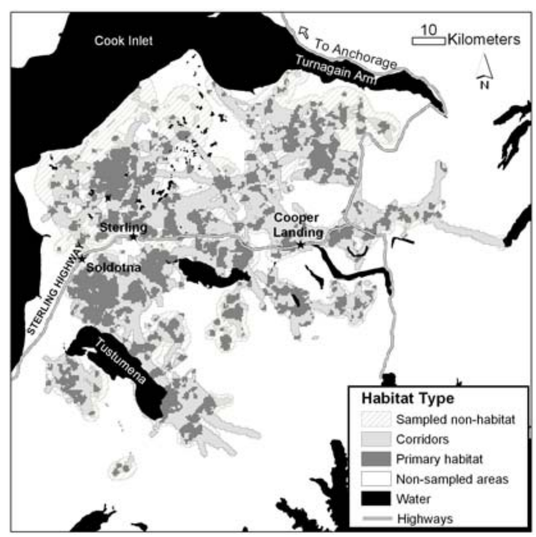

Fig. 3. Corridors, primary habitat and sampled non-habitat (based on 95% kernel home ranges). The Sterling Highway bisects the Kenai Peninsula.

3-cluster analysis for the final peninsula-wide analysis. The 2 clusters with high quality habitat were combined to define primary habitat.

Discussion

We demonstrate that movement characteristics, rather than vegetation and landscape structure, can be used to determine landscape functionality. This technique requires a large, frequently sampled dataset of locations from a representative set of animals distributed across the geographic area of interest. As in any study, results of this study on the Kenai Peninsula must be carefully interpreted as some areas important to bears may not have been identified solely because bear collaring operations did not occur uniformly across the Peninsula. However, this technique is robust; it clearly identifies primary habitat and travel corridors within areas used by GPS–collared bears. Many areas along the highway were categorized as non-sampled, but none of the 74 bears with > 15 locations obtained with GPS collars used these areas. Although it is possible that we did not capture bears that used those areas, it seems more likely that bears were displaced, although the reasons for displacement are not identified by this analysis. Completion of additional analyses into differences between primary habitat, corridors, non-habitat and non-sampled areas may shed additional light on this issue.

The areas identified as corridors or habitat are scale dependent. We recommend that researchers assess the appropriate search radius and cell size for their dataset. The appropriate radius and cell size depend on the frequency at which animal locations were collected. If locations are infrequent (≥ 6 hours apart) the scale at which researchers will need to assess movement may be so large that the assumption that the animal moved in a direct line is unrealistic. For locations recorded at more frequent intervals, a smaller cell size and search radius will correctly identify habitat and corridors at a finer scale. Because the estimated distance moved increases with more frequent locations, path length and thus movement density also increases with frequency of locations, so it is important to use locations at equal intervals in the analysis. Also, error can occur in movement parameters if locations are very close together and measurement error in locations is large (Jerde and Visscher 2005). Researchers should assess a range of cluster sizes using characteristics like we used to assess location frequency and scale (e.g. number and percent of primary habitat patches, number of continuous corridors). Examining multiple cluster sizes would also be appropriate for species with seasonal variations in movement intensity, such as migrating caribou (Johnson et al. 2002).

This technique can be used to address practical management issues. On the Kenai Peninsula, the Sterling Highway has been posited as a potential barrier to brown bear movement. Because dispersal of young bears occurs very gradually, and because human activities directly increase mortality risk of such dispersers, particularly for females (McLellan and Hovey 2001), researchers have predicted that areas with seasonal habitat importance and low levels of human activities are required to maintain sufficient dispersal success and prevent habitat fragmentation (Servheen and Sandstrom 1993; Fig. 1B). Such areas have been termed linkage zones. Because linkage zones should have movement char-acteristics that are equivalent to primary habitat, we identified primary habitat patches intersecting with the Sterling highway as linkage zones. Linkage zones were present along the highway in 4 areas: north of Skilak Lake near the East Fork of Moose River, north of Skilak Lake near Hidden Creek, west of Cooper Landing near Juneau Creek, and east of Kenai Lake (Fig. 4).

The technique we described here can be used to test aspects of the linkage zone prediction model currently used by the U.S. Fish and Wildlife Service to manage habitat fragmentation within the northern Rocky Mountains. The method can determine whether the influence zones around various types of human development are appropriate and can be

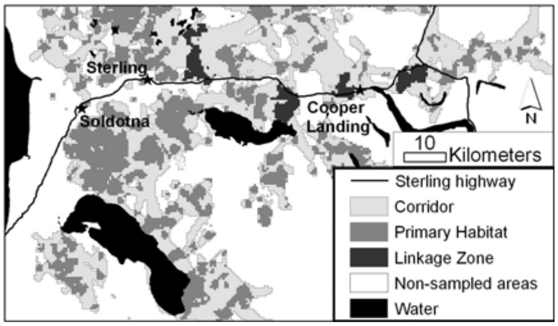

Fig. 4. Corridors and linkage zones identified along the Sterling Highway, a potential source of fragmentation, bisecting the Kenai Peninsula, Alaska.

used to estimate the minimum width necessary for land to function as a linkage zone versus a corridor. In addition, this type of analysis is the first of two analyses implemented to understand why animals are using areas as corridors. It is possible that those areas provide food or cover, but have some characteristic, such as the presence of humans, that makes bears move quickly through the area. It is also possible that bears move quickly through areas because these corridors are the fastest route between patches of high quality habitat. While some corridors may not contain much food or cover, these routes may be perceived as relatively safe by the animals. A regression tree analysis using landscape function as the response variable would help determine which of these hypotheses best explain why animals move quickly and frequently through an area.

This technique can further our understanding of animal use of fragmented landscapes. It will help biologists identify landscape features like primary habitat, linkage zones, and corridors based on real data. Using this technique, managers may move beyond the theoretical discussion of corridors and linkage zones to active management of landscape features that preserve connectivity.

Acknowledgements This analysis was supported by the USDA Forest Service Chugach National Forest, the Alaska Department of Fish and Game, the USFWS Kenai National Wildlife Refuge, UNOCAL Alaska, and Audubon Alaska. We thank Steve Arthur and Chuck Schwartz for input on early drafts. We also thank Rolf Peterson, an anonymous editor, and 3 anonymous reviewers for comments.

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