Implementation and Comparison of Home Range Estimators for Grizzly Bears in Alberta, Canada, based on GPS data

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1. Introduction

Grizzly bear (*Ursus arctos horribilis*) population studies have shown that the area inhabited by grizzly bears has shrunk over the past century (Mattson and Merrill 2002). The Alberta (CA) and Montana (USA) foothills now form the eastern and southern fringe of grizzly bear distribution. As a result of this reduction the Foothills Research Institute (FRI) Grizzly Bear Program was initiated to assess the effects of anthropogenic influences on population size and distribution of grizzly bears in Alberta. While the wider goal is to ensure long-term conservation of grizzly bears in Alberta (Stenhouse and Munro 2000), a specific objective of the program is to understand how grizzly bear health is related to landscape and environmental parameters. This requires mapping of the (natural) landscape and its characteristics, and the study of grizzly bear behaviour.

An important component of this research is to identify the home range of the individual bears to be able to assess the influence of natural resources (e.g. food resources) and anthropogenic factors on home range location, shape, structure, and size. An animal's home range has been defined by Burt (1943) as "[the] *area traversed by the individual in its normal activities of food gathering, mating, and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered as part of the home range.*"

The objective of our research was to implement several established and new methods that estimate an animal's home range and to compare these methods and results for grizzly bear GPS data. Although other comparisons have been undertaken before (see for instance Seaman et al. 1998, Horne and Garton 2006, Laver and Kelly 2008) these comparisons (i) do not cover newer estimation techniques, (ii) have used artificial data or real data from other species, (iii) used data that had different characteristics (e.g. GPS vs. radio telemetry points, number of points), and (iv) only apply quantitative measures and do not consider contextual landscape information. In particular issues (ii) and (iv) are important, since home range characteristics depend on the species movement patterns, foraging strategies and resource needs - and home ranges of individuals are influenced furthermore by food resources, topographic constraints, competition, etc. (Stephens et al. 2007). Hence, these previous studies can only indicate possible approaches to home range estimation.

2. Computational home range estimation methods

In general we can distinguish between two groups of home range estimation methods with respect to the input data: point-based methods and line-based methods. Point-based methods take single points of observation (occurrence) as input, e.g. mapped points of visual observation, points from GPS collars, and points retrieved through radio telemetry (radio collars). Besides parametric mathematical models (e.g. a bivariate elliptic home range model) well known non-parametric estimation methods are Minimum Convex Polygon (MCP), Kernel Density Estimation (KDE), Harmonic Mean, and Local Convex Hull (LoCoH) (see Laver and Kelly 2008, Getz et al. 2007, Worton 1987 and others).

Line-based models use the base-line between two point observations to estimate the home range. Usually the lines are based on successive points from GPS collars. One such model is the Brownian-bridge model, which has been applied for home range estimation by Horne et al. (2007). A second approach, which has been developed in our research, is based on buffering the base-lines with the average daily travel distance.

3. Grizzly bear life and home ranges

As outlined earlier, the size and shape of home ranges is on the one hand species dependent (influenced by locomotor mode - Nathan et al. 2008, velocity and acceleration - Turchin 1998, foraging strategy - Stephens et al. 2007, etc.) and on the other hand dependent on an individual's environmental context (e.g. topography, food resources, anthropogenic influences, competitors, predators – Stephens et al. 2007). Hence, the home range we derive for each grizzly bear will be affected by the following facts (Munro et al. 2006, Ross 2002, McLellan 1989): (i) Grizzly bears are omnivorous - but most eat vegetation primarily, (ii) they sometimes roam widely to search for berries and food sources in late summer and autumn, (iii) they are not territorial, (iv) males have home ranges several times larger than females, (v) home range is influenced by population density, (vi) grizzlies may move over hundreds of kilometres during dispersal, (vii) they avoid some environments such as high elevations consisting of snow, rock and glaciers since they provide no food - however, they may cross them, and (viii) they are slow to mature and reproduce.

Based on the information given above, we can expect a GPS point distribution with multiple centres of activity (multi-modal Gaussian distribution) over large areas. We expect to see GPS points that exhibit patch-based foraging behaviour (Stephens and Krebs 1986) and we expect that the majority of GPS points will be within land-cover classes that are associated with grizzly bear food (Burt 1943). We do not expect to see many GPS points on glaciers, few GPS tracks that cross mountain ridges, nor GPS points within lakes.

4. Experiment

4.1 Data

We obtained GPS point data from collars of four grizzly bears. Each point dataset covers only one year (April to November), and contains 600-900 points. Time information is given for each day. Hence, point ordering for base-line/track calculation and visualisation, as well as grouping per day is possible (1...6 points/day). The four bears have been chosen such that the area covered by the GPS points includes hilly areas, mountains, and lakes and rivers to allow a qualitative evaluation of the calculated home ranges. The FRI program has made GPS data, land-use/land-cover data and remote sensing images available for this work.

4.2 Methods

Several existing methods have been implemented and one method was developed for this work. Table 1 lists the methods, which also includes four Kernel Density Estimation (KDE) approaches that use different kernels (Biweight and Gaussian Kernel) and bandwidth estimation methods (h_{ref}, h_{LSCV}, $h_{ad\text{-}hoc}$). Although it is emphasized in the literature that different kernels show not much different results – it has never been demonstrated, and hence we tested two different kernel functions. All approaches have been implemented with the free GIS OpenJUMP and the Sextante Toolbox (Steiniger and Bocher 2009).

Table 1. Evaluated home range (HR) estimators.

Method	Principle	Parameters
KDE	A weighted kernel function is moved over a raster and point values summed	Smoothing bandwidth *h* for kernel, Seaman et al. 1998
- $h_{ref,Gaussian}$	Gaussian kernel, $h_{ref} = A\ \sigma_{xy}\ n^{-1/6}$	σ_{xy}: variance in x,y
- $h_{ref,Biweight}$	Biweight kernel, $h_{ref} = A\ \sigma_{xy}\ n^{-1/6}$	*A*: kernel constant
- $h_{LSCV,Biweight}$	*h* from Least Square Cross Validation	Assumes Gaussian PDF
- $h_{ad\text{-}hoc,\ Gaussian}$	*h* if HR splits into two regions	Berger and Gese 2007
MCP	Convex hull of points	---
Line-buffer	±Buffering and union of the lines between two subsequent GPS points	Radius from median daily travel distance
LoCoH	Union of Local Convex Hulls	Size *s* of convex hull
- LoCoH-a	s_a sum of distances of points ≤ *a*	Getz et al. 2007
- LoCoH-k	s_k using k-1 points of root point	
- LoCoH-r	s_r using points within distance r	

4.3 Evaluation approach

Quantitative and qualitative evaluation of home ranges was undertaken. Quantitatively we looked at area, perimeter, and the number of home range patches. Qualitatively we looked at the shape of the home range polygons and compared it to the GPS data, land-cover, and remote sensing data. In particular, we were interested if mountains ridges, lakes, and rivers were included or "observed" as part of a home range.

5. Results

The qualitative and quantitative results, i.e., derived home range characteristics are presented in Figure 1 and Tables 2 and 3. Due to limitations in space we give results for only two of four bears.

6. Discussion

When comparing the results, one method does not appear clearly superior to another since some methods perform better for different (topographic) contexts. However, notably two methods can be excluded: First, the Minimum Convex Polygon, since it tends to cover an area much larger than that used by the bears, possibly areas that are impossible to visit - as seen in Figure 1, top; Second, Kernel Density Estimation (KDE) with the bandwidth *h* estimated using Least Squares Cross Validation (LSCV), since LSCV failed in all cases. This problem, of LSCV failing for large point datasets

Table 2. Evaluation results for bear 268, covering a mountain area. Note that the LSCV method failed.

Method	Area [km^2]	Perimeter [km]	Patches [number]	Holes in HR [y/n]	Context (e.g. mountain ridges, river etc.)	Parameter
KDE						
- $h_{ref,Gaussian}$	898	339	5	Yes	ok, but complex shape	h=2673m
- $h_{ref,Biweight}$	1698	200	1	No	covers ridge completely	h=7431m
- $h_{LSCV,Biweight}$	---	---	134	---	---	h=180m
- $h_{ad\text{-}hoc,\ Gaussian}$	1263	262	1	Yes	covers ridge largely	h=4548m
MCP	1260	162	1	No	covers ridge completely	---
Line-buffer	1360	217	1	Yes	covers ridge largely	r=3223m
LoCoH						
- LoCoH-a	630	310	1	Yes	ok, doesn't cover ridge	a=40km
- LoCoH-k	365	278	1	Yes	ok, leaves out regions	k=18pts
- LoCoH-r	453	313	2	Yes	ok, doesn't cover ridge	r=3500m

Table 3. Evaluation results for bear 265, covering a hilly area. Note that the LSCV method failed.

Method	Area [km^2]	Perimeter [km]	Patches [number]	Holes in HR [y/n]	Context (e.g. mountain ridges, river etc.)	Parameter
KDE						
- $h_{ref,Gaussian}$	2586	467	2	Yes	Ok	h=5700m
- $h_{ref,Biweight}$	5225	333	1	No	not good at river	h=15860m
- $h_{LSCV,Biweight}$	---	---	142	---	---	h=622m
- $h_{ad\text{-}hoc,\ Gaussian}$	2799	441	1	Yes	Ok	h=6409m
MCP	3643	250	1	No	not good at river	---
Line-buffer	2291	391	3	Yes	Ok	r=3624m
LoCoH						
- LoCoH-a	1531	464	1	Yes	Ok	a=110km
- LoCoH-k	2144	361	1	Yes	holes in wrong spot	k=40pts
- LoCoH-r	1309	416	4	Yes	too many regions	r=7500m

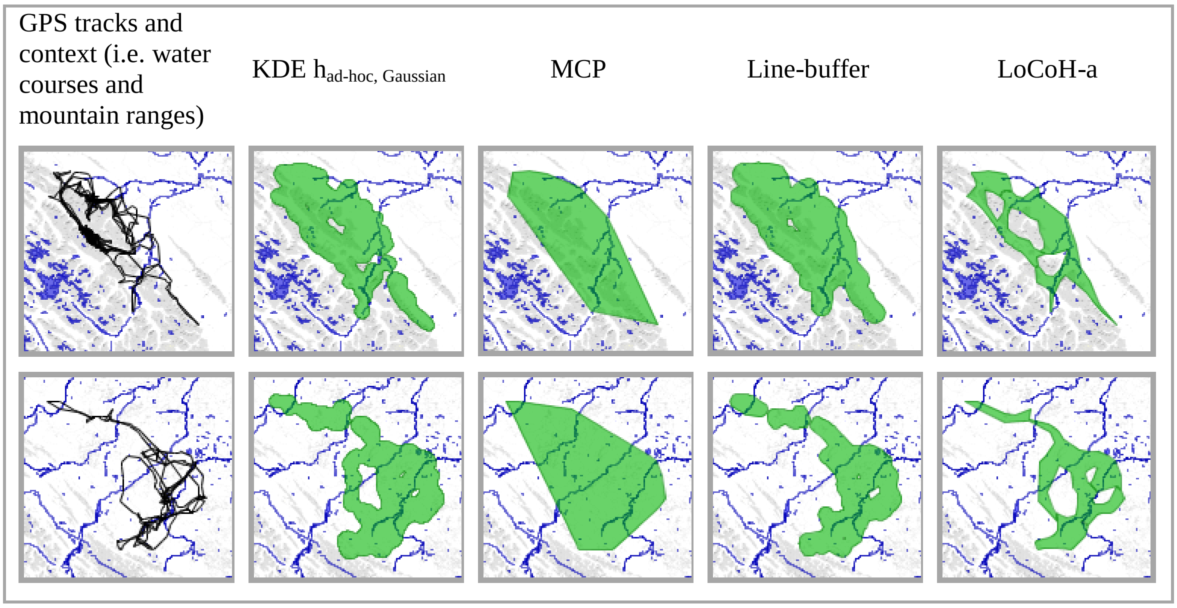

Figure 1. Example home ranges generated with four different methods for bear 268 (top) and bear 265 (bottom).

(> 100), has also been reported by other authors recently (Hemson et al. 2005). In addition, the KDE with *h* obtained via the ad-hoc approach failed two out of four times resulting in $2 \cdot h_{ref}$ being used. But despite the failures of the ad-hoc approach, the result in one case was visually (and quantitatively) acceptable when compared with the results of the other methods. We also note that the regions created using LoCoH appear un-natural due to its angular shape, and in comparison with the other methods, parameters for LoCoH have to be chosen manually. It is possible, however, to exclude areas where the bears clearly do not go, such as mountain ranges, as can be seen with bear 268. The line buffer approach produces comparable results to LoCoH, KDE-$h_{ref,Gaussian}$, and KDE-$h_{ad\text{-}hoc,Gaussian}$, however it does have one limitation in common with MCPs, they provide no indication of high use areas within the resulting home range.

We recommend the use of LoCoH, KDE-$h_{ref,Gaussian}$, KDE-$h_{ad\text{-}hoc,Gaussian}$ and the line-buffer-based approach for home range estimation. A decision with regard to the best approach should be undertaken on a case-by-case basis giving due consideration to a species' life history traits and their environmental context. We note that an advantage of KDE based methods is the production of a utilization distribution surface. Hence, home ranges for different probabilities of utilization can be developed. This is important if the so-called 'core' (Samuel et al. 1985) of a home range is of interest for wildlife management decisions. Future work should focus on improving existing home range estimators, and developing new estimators to (i) utilize the additional (time) information that comes with GPS point data, and (ii) utilize context information, e.g. topographic and or land cover information.

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