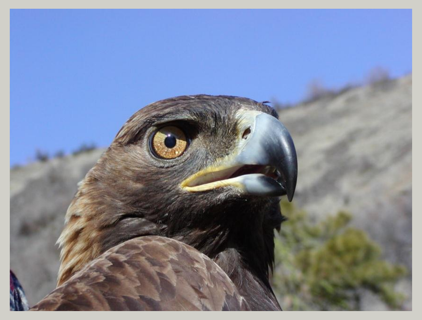
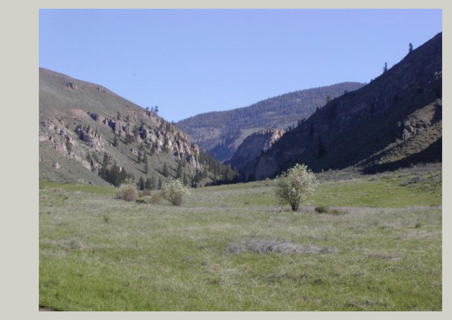


A COMPARISON OF HOME RANGE MAPPING TECHNIQUES FOR GOLDEN EAGLES IN WASHINGTON



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INTRODUCTION

With the advent of highly accurate global positioning system (GPS) radio transmitters and advancements in resource selection analyses such as resource utilization functions (RUFs), it is important for wildlife managers to understand how different methods of home range analysis depict utilization distributions (UDs). While many analysis methods exist, none perform optimally in all situations (Millspaugh et al. 2006) and the choice of the UD estimator likely affects resource selection methods that use UDs to define space use (Long et al. 2009). To understand differences in UD estimators for Golden Eagles (*Aquila chrysaetos*), we analyzed breeding season (16 Jan–16 Aug) GPS satellite telemetry fixes for 9 birds collected during 2005–2010. We analyzed fixes with 5 methods including the Brownian Bridge Movement Model (BBMM) and 4 types of non-parametric fixed-kernel density (KDE) which differed only by the method used to select bandwidth (h) values (smoothing parameters) (i.e., reference or optimal [h_{REF}], likelihood cross-validation [h_{CV}], plug-in [h_{PI}], and least squares cross-validation [h_{LSCV}]).

METHODS

Microwave Telemetry PTT100 satellite radio-transmitters were programmed to collect fixes hourly from 0600h to 2000h during 16 Jan–16 Apr and from 0500h to 2100h during 16 Apr–16 Aug. Fixes were highly discretized (rounding errors introduced by satellite data processing) which can cause some bandwidth calculations to fail, so we introduced random errors into coordinate locations (<0.00001 decimal degrees in one of four directions [45°, 135°, 225°, or 315°]) using SAS software, version 9.2 (SAS Institute 2010).

Sixteen seasonal home ranges from 8 eagles were used in this analysis. We excluded 1 bird that drifted extensively, resulting in a very large home range area that imposed computer memory limitations. Animal Space Use (Horne and Garton 2009) was used to derive h_{CV} values and the ADEHABITAT, KS, and RASTER packages in R (R Core Development Team 2010) were used to analyze and plot the 5 UD types. Standard fixed-KDEs were computed using the data driven smoothing parameters and the bivariate normal kernel.

We used R and the ADEHABITAT package to map UDs and UD volume for generating BBMMs. BBMMs were limited to use of consecutive fixes (bursts) that were separated by 2 hr or less (89.1% of all fixes). We computed the first smoothing parameter value (σ^2, related to the speed of the bird) using maximum-likelihood by burst and calculated the mean value across all bursts for an eagle in a season. Manufacturer error specifications of ±22 m were used to define the second smoothing parameter (δ^2, related to the imprecision of fixes). Individual UDs were created by burst using the mean σ^2 and were combined so that the resulting seasonal UDs integrated to 1 (true PDF) by weighting each individual burst UD by the number of fixes used to define each burst during summation. Due to computational time constraints, BBMMs were developed at 90 m resolution and were resampled using bilinear interpolation to 30 m for comparison.

To understand differences in home range and core area estimates we calculated the volume of intersection statistic (VI) and Bhattacharyya's affinity (BA) (Fieberg and Kochanny 2005) for each method relative to h_{REF}; area of the 99%, 95%, and 50% UD boundaries by volume; and an index of home range fragmentation (frequency of small islands introduced by discretized data). We calculated mean (±SE) values for each method using SAS PROC MIXED to account for repeated home range measurements on individual eagles throughout time (home range method was used as a fixed effect and individual bird as a random effect).

METHOD	99% VOLUME CONTOUR		95% VOLUME CONTOUR		50% VOLUME CONTOUR	
	FRAGMENTS (SE)	AREA IN HA (SE)	FRAGMENTS (SE)	AREA IN HA (SE)	FRAGMENTS (SE)	AREA IN HA (SE)
FIXED KERNEL h_{REF}	9.4 (2.4)[a]	11,139.7 (2,143.2)[a]	2.0 (0.5)[a]	4,460.2 (1,019.9)[a]	1.7 (0.3)[a]	519.1 (141.8)[a]
BROWNIAN BRIDGE MOVEMENT MODEL	4.3 (0.7)[a]	8,229.7 (1,680.5)[a,b]	2.2 (0.5)[a]	3,338.0 (749.3)[a,b]	1.3 (0.1)[a]	401.6 (89.0)[a]
FIXED KERNEL h_{CV}	23.9 (4.2)[b]	5,942.0 (1,206.9)[b,c]	11.5 (5.0)[a]	2,589.1 (492.3)[b,c]	2.8 (0.5)[a]	255.8 (65.8)[b]
FIXED KERNEL h_{PI}	41.0 (4.7)[c]	3,310.7 (706.0)[c,d]	52.1 (10.0)[b]	1,714.1 (359.2)[c,d]	4.3 (0.6)[a]	118.9 (24.9)[b,c]
FIXED KERNEL 10% of h_{REF}	100.8 (13.4)[d]	1,506.9 (320.9)[d]	121.7 (21.2)[c]	885.0 (185.5)[d]	11.3 (2.1)[b]	60.2 (19.7)[c]

Table 1. Mean (±SE) area (ha) and number of fragments at three % volume contours for 5 different home range estimators developed using 16 breeding seasons of data for 8 golden eagles. Within a column, values for methods with the same letter are not significantly different (alpha=0.05) using the Tukey-Kramer multiple comparison procedure.

METHOD	BHATTACHARYYA'S AFFINITY (SE)	VOLUME OF INTERSECTION STATISTIC (SE)
FIXED KERNEL h_{REF}	1.000 (0.001)[a]	1.000 (0.001)[a]
BROWNIAN BRIDGE MOVEMENT MODEL	0.9607 (0.0194)[a]	0.8207 (0.0385)[b]
FIXED KERNEL h_{CV}	0.9071 (0.0205)[b]	0.6965 (0.0441)[c]
FIXED KERNEL h_{PI}	0.7971 (0.0149)[c]	0.5168 (0.0167)[d]
FIXED KERNEL 10% of h_{REF}	0.6188 (0.0115)[d]	0.3558 (0.0098)[e]

Table 2. Mean (±SE) overlap indices (compared to fixed kernel h_{REF}) for 5 different home range estimators developed using 16 breeding seasons of data for 8 golden eagles. Within a column, values for methods with the same letter are not significantly different (alpha=0.05) using the Tukey-Kramer multiple comparison procedure.

RESULTS

Fixed-KDE using h_{LSCV} failed to calculate a smoothing factor 100% of the time for our Golden eagle data. Even though h_{LSCV} failed to converge, we chose to include the default output from the ADEHABITAT h_{LSCV} function, 10% of h_{REF}.

For the 3 volume contours, h_{REF} had the largest area and for the 99% and 50% contours h_{REF} had the second lowest number of fragments (Table 1). BBMMs had the second highest area, and for the 99% and 50% contours BBMMs had the lowest number of fragments. The remaining 3 KDE methods decreased in size and increased in fragmentation in the following order, h_{CV}, h_{PI}, and 10% of h_{REF}.

BBMMs had the highest overlap relative to h_{REF} based on the BA and VI indices (Table 2). Overlap for the other KDE methods decreased in the following order, h_{CV}, h_{PI}, and 10% of h_{REF} (Table 2).

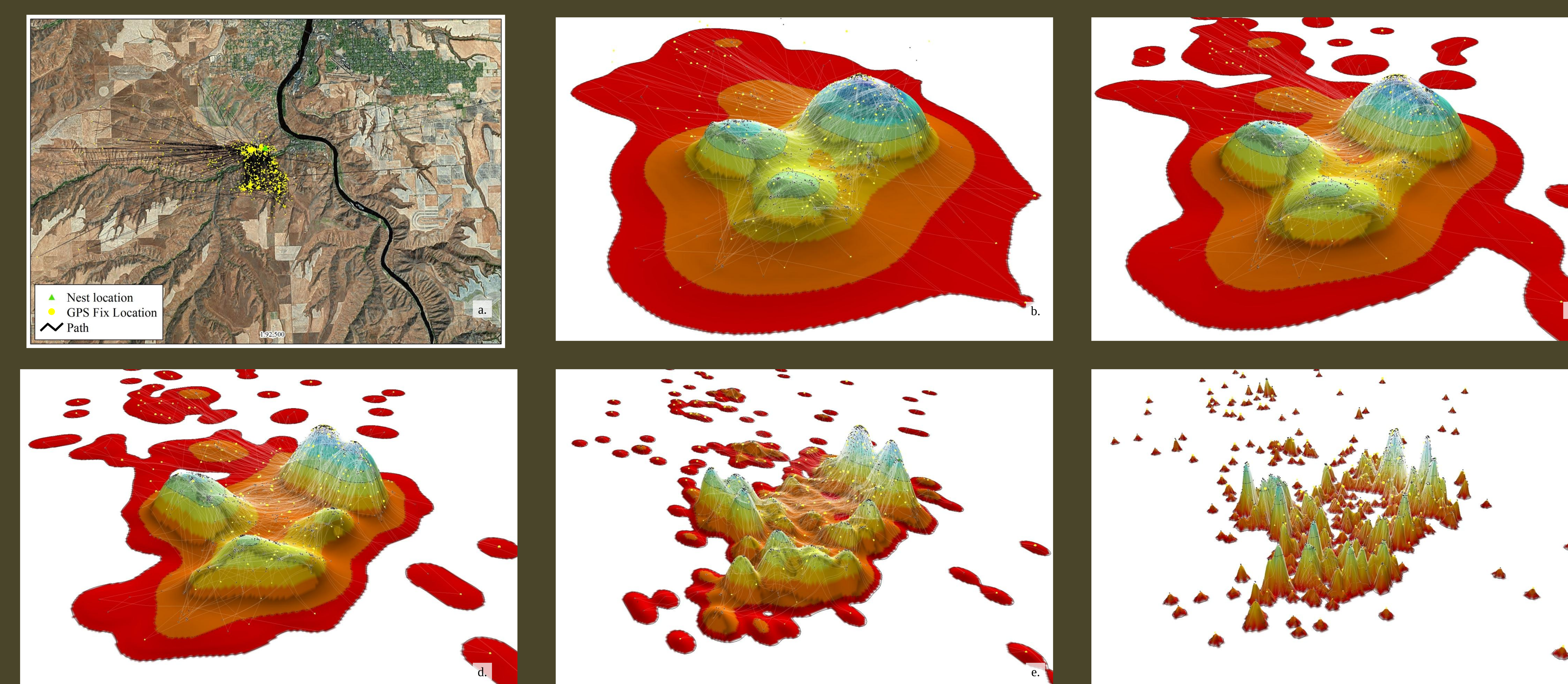

Figure 1. Aerial photo with fix locations and path and 3D volume surfaces of 5 home range methods for a golden eagle in Asotin county located in southeast Washington, during the 2010 breeding season. In order from upper left to lower right, a) path and fix locations, b) Brownian Bridge Movement Model, c) fixed kernel density estimate (KDE) h_{REF}, d) KDE h_{CV}, e) KDE h_{PI}, and f) KDE 10% h_{REF}.

DISCUSSION

Kernel density ranges were centered on the area with densest fixes and all KDEs produced similar UDs. However, the choice of smoothing parameter impacted both the area and fragmentation of the home range (Fig. 1). Kernel density based upon h_{PI} or 10% of h_{REF} had the potential to leave out important movement corridors between fixes at 99% and 95% volume contour levels but also provided the best definition for high use areas within the home range. Brownian Bridge Movement Models had the least fragmentation and intermediate to high home range size. These ranges were centered on the trajectory, which had the effect of stretching the core use area to include more of the area traversed when commuting from nesting to foraging locations.

While evaluation for other species and at finer resolutions is needed, we feel the mechanistic BBMM method provides an insightful alternative to fixed-KDE because it incorporates flight behavior into UDs for raptors. Brownian Bridge Movement Model 99% volume contours could be used to define the spatial extent for use-availability resource selection functions (RSFs) and may better represent available habitat for these types of models than fixed-KDE methods. Alternatively, we suggest that fixed-KDE using h_{PI} or 10% of h_{REF} for bandwidth selection emphasizes high-use nesting, perching, and foraging areas which may be useful in developing RUFs and maps that highlight the use of these areas. High fragmentation reduced the value of these bandwidth parameters in defining overall home range and volume contours.

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