Home Range Methods for a Reintroduced Yearling Bull Elk in Virginia

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Abstract

In May 2012, the Virginia Department of Game and Inland Fisheries released 16 GPS satellite collared adult elk (C. c. nelson) on a reclaimed strip mine in Buchanan County, Virginia. Early 20th century reintroductions of elk in Virginia failed due to a lack of knowledge of elk ecology. One important aspect of elk ecology is obtaining estimates of an elk's home range. We compare methods to calculate the home range of a yearling bull elk, B-12. We calculate home range area estimates using the Minimum Convex Polygon method, Jennrich-Turner Ellipse method, and the Grid Cell Counts method. Finally, we construct a frequency plot and conduct a Kolmogorov-Smirnov goodness-of-fit test to gain insight into the core area of the home range of the yearling bull.

Keywords: Home Range, Elk, Virginia, Core Area

1 Introduction

In 2010, the Virginia Department of Game and Inland Fisheries created an operational plan to promote elk restoration in three counties in Virginia- Buchanan, Dickenson and Wise. The plan involved releasing up to 75 animals in Buchanan County with the goal of increasing the herd to 400 animals with sustained population control through selective hunting. The pilot program started in the Spring of 2012 by moving 16 adult elk from Kentucky to Buchanan County, VA. In Kentucky, the elk were fitted with GPS collars to collect geographic locations every eight hours. Once in Buchanan County, the elk remained in an acclamation pen for five days before being released into the wild. We studied the movements of a one-year-old bull elk, B-12. We received data locations from B-12 for three months and collected 253 geographic coordinate points before the collar malfunctioned and came off.

We examined three different methods to calculate the home range size of B-12 and one method of calculating the core area. Carl O. Mohr observed a series of studies conducted on small mammals in North America in the early 1940s which involved the first calculations used for the Minimum Convex Polygon (MCP) method [1]. Since that time, William Eddy computed an algorithm in 1977 for determining the area of a convex polygon by considering the coordinates in a clockwise fashion. While the MCP method was being modified, in 1949 Don Hayne suggested using a circle to calculate the home range of an animal which greatly influenced Robert Jennrich and Frederick Turner's approach with respect to an ellipse [2]. The Jennrich-Turner technique conducted in 1969 assumes that the coordinate locations are independently distributed with respect to the mean longitude (x) and mean latitude (y) locations [3]. The Jennrich-Turner estimate can be calculated based on a probability of finding the animal within the ellipse a given percent of the time. In 1969, Orrin Rongstad and John Tester examined a method to determine the home range area of white-tailed deer in Minnesota. The method required counting cells according to the observation locations of an animal and the size of the cells mapped. This method is carried out with no preconceived notions about the space the animal utilizes. In 1985, M. D. Samuel, D. J. Pierce and E. O. Garton used the bivariate histogram plot and included the frequency of observations in each cell to tabulate the animal's core area [4]. In essence, the grid cells were marked according to the high frequency that an animal appears to revisit a particular area to form a histogram plot. We use these methods to calculate the home range and core area of B-12. Home ranges and core areas of elk can be used in habitat selection studies and contribute to the information necessary for adequate elk management.

2 Minimum Convex Polygon Method

We plotted the longitude and latitude points for B-12 using ArcGIS, a Geographic Information System. Using the snapping tool we connected the outermost points with line segments to form a convex polygon enclosing the remaining points. The area of the minimum convex polygon constructed was $4,868,113m^2$.

From the polygon constructed in ArcGIS, we were able to determine that the polygon was constructed using eight points. In Microsoft Excel, the 253 observations were plotted and we constructed the minimum convex polygon by connecting the outermost points obtained from ArcGis with line segments as seen in Figure 1. It is important to note that due to the sensitivity of the ongoing restoration project, the axes on the graphs will not be labeled. Taking the eight points in a clockwise fashion around the polygon, we calculated the area of B-12's home range, denoted by $\hat{A}$, using the following formula where x_i represents the longitude coordinate and y_i represents the latitude coordinate:

$$\hat{A} = \frac{[x_i(y_n - y_2) + \sum_{i=0}^{n-1} x_i(y_{i-1} - y_{i+1}) + (x_n(y_{n-1} - y_1))]}{2}$$

$i = 1, \ldots, 253$. The area of the MCP was computed in Excel as $4,848,648m^2$.

While the MCP method was simple and required minimal mathematical calculations, it had several drawbacks. The area computed does not reflect B-12's normal movement pattern, but rather the total area utilized [1]. The MCP method created a larger polygon than desired because a huge portion of the upper central part of the MCP contained no observations.

3 Jennrich-Turner Method

The Jennrich-Turner ellipse is calculated based on a bivariate normal probability distribution. "That is, location vectors (x_i, y_i) are assumed to be identically and independently distributed according to a bivariate normal model" [1]. We assumed that B-12's movements were random within the home range and the majority of his movements would be found in the center of the ellipse. In our study, we used a 95% ellipse to obtain a region that contained 95% of the observations. Then, the area of the ellipse was determined to be another representation of the elk's home range.

In order to compute the home range ellipse, we had to calculate the mean, variance and covariance for both the longitude and latitude coordinates. The formulas are as follows with (x_i, y_i) representing the coordinate locations for $i = 1, \ldots, 253$:

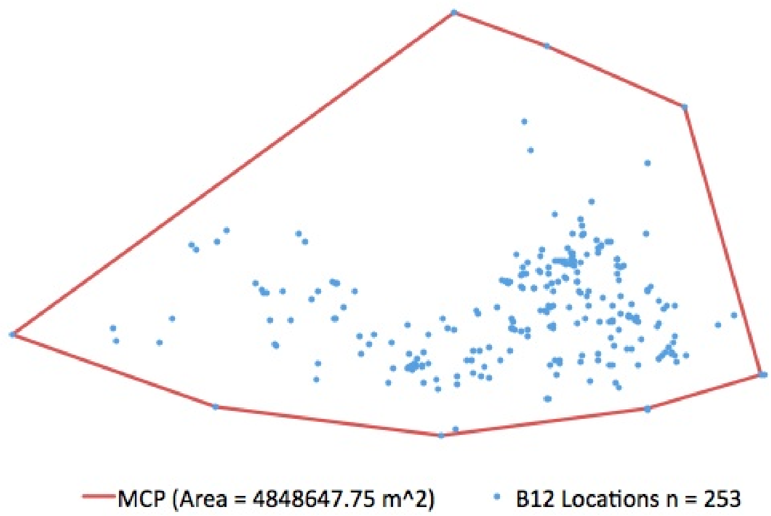

Figure 1: MCP Plotted in Excel (n = 253)

$$\bar{x} = \frac{\sum_{i=0}^{n} x_i}{n} \quad (1)$$

$$\bar{y} = \frac{\sum_{i=0}^{n} y_i}{n} \quad (2)$$

$$\sigma_x{}^2 = \frac{\sum_{i=0}^{n-1} (x_i - \bar{x})^2}{n} \quad (3)$$

$$\sigma_y{}^2 = \frac{\sum_{i=0}^{n-1} (y_i - \bar{y})^2}{n} \quad (4)$$

$$\sigma_{xy} = \frac{\sum_{i=0}^{n-1} (x_i - \bar{x_i})(y_i - \bar{y})}{n-1}. \quad (5)$$

Using Excel, we computed $\bar{x} = 398,440.319018m$, $\bar{y} = 4,117,628.231934m$, $\sigma_x{}^2 = 283,889.347524m^2$, $\sigma_y{}^2 = 117,452.1598967m^2$ and $\sigma_{xy} = 18,116.91382m^2$.

In order to plot the ellipse, we used the following formulas where a is the semi-major axis, b is the semi-minor axis ($a > b$), and θ is the angle of incline:

$$R = [(\sigma_y{}^2 - \sigma_x{}^2)^2 + 4(\sigma_{xy})^2]^{1/2} \quad (6)$$

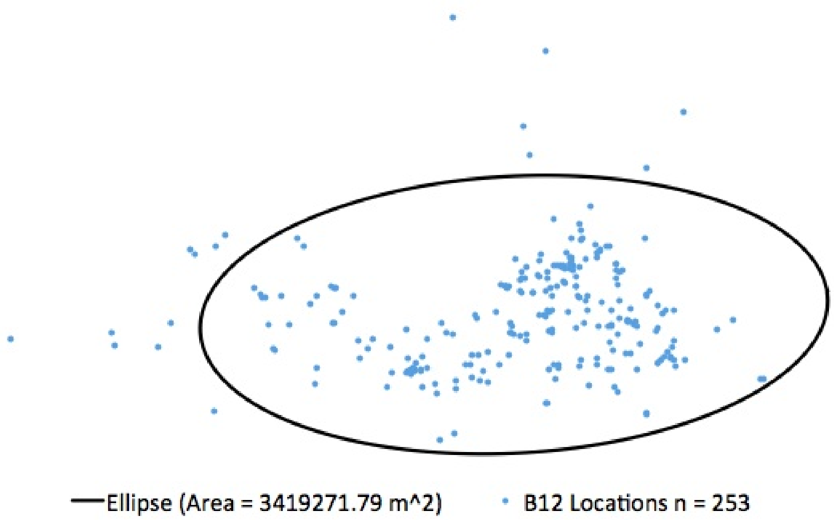

Figure 2: Jennrich-Turner Ellipse (n = 253)

$$a = \frac{({\sigma_y}^2 + {\sigma_x}^2 + R)\chi^2_{(1-a)(2)}}{2} \tag{7}$$

$$b = \frac{({\sigma_y}^2 + {\sigma_x}^2 - R)\chi^2_{(1-a)(2)}}{2} \tag{8}$$

$$\theta = arctan\frac{-2\sigma_{xy}}{{\sigma_y}^2 - {\sigma_x}^2 - R} \tag{9}$$

For our coordinate locations, $R = 170,335.6333, a = 1308.5003, b = 831.7828$, and $\theta = 6.1409°$. Using the parametric equations for an ellipse, we were able to evaluate 90-points on the ellipse with the following equations where ϕ is an angle from 0° to 360° increasing in intervals of 4°:

$$x = \bar{x} + a\cos\psi\cos\theta - b\sin\psi\sin\theta \tag{10}$$

$$y = \bar{y} + a\cos\psi\sin\theta + b\sin\psi\cos\theta \tag{11}$$

The 90 points of the ellipse were obtained and plotted using Excel. Figure 2 depicts the 95% Jennrich-Turner Ellipse estimate of the home range of B-12.

In order to calculate the area of the ellipse, we calculated the covariance matrix

$$\hat{E} = \begin{bmatrix} {\sigma_x}^2 & \sigma_{xy} \\ \sigma_{xy} & {\sigma_y}^2 \end{bmatrix} = \begin{bmatrix} 283,889.3475 & 18,116.91382 \\ 18,116.91382 & 117,452.1590. \end{bmatrix}$$

The correlation of the x-coordinates and y-coordinates were defined by

$$r = \frac{\sigma_{xy}}{({\sigma_x}^2{\sigma_y}^2)^{1/2}} \tag{12}$$

We calculated an r-value of 0.099, indicating that there is no significant relationship between the x and y coordinates. A 95% confidence ellipse is computed using a Chi-square random variable,

Table 1: "Burst Sample Set" for the t^2/r^2 Ratio Test

Interval between Locations (hr)	t^2/r^2 Ratio Test
8	0.60316
16	0.83346
24	1.04876
32	1.22845
40	1.11569
48	1.14112

$\chi^2_{(1-a)(2)}$, with two degrees of freedom. Thus, $a = 0.05$ and $\chi^2_{(1-a)(2)} = 5.99$. The formula for calculating the area of an ellipse is

$$\hat{A} = \pi \left|\hat{E}\right| \chi^2_{(1-a)(2)}. \tag{13}$$

The home range area based on the Jennrich-Turner ellipse technique was $\hat{A} = 3,419,271.79m^2$. The area of the ellipse was significantly smaller than the area calculated by the minimum convex polygon. However, the home range still has large areas with no observations present.

The Jennrich-Turner methods depends upon independent observations rather than autocorrelated ones. The independence between observations was based on a t^2/r^2 ratio test. A previous study conducted by Robert Swihart and Norman Slade suggested that t^2/r^2 is considered to be normally distributed with a ratio value of 2 [3]. The ratio of the mean squared distance between observations is represented by t^2 and the mean squared distance from what is considered to be the very center of activity is represented by r^2:

$$t^2 = \sum((X_{i+1} - X_i)^2/m + \sum((Y_{i+1} - Y_i)^2/m$$

$$r^2 = \sum((X_i - \bar{X})^2/(n-1) + \sum((Y_i - \bar{Y})^2/(n-1)$$

The t^2/r^2 ratio we calculated for the 253 data locations with an eight hour interval between observations was 0.60316. Clearly our observations were autocorrelated since this value was significantly smaller than 2.

In an attempt to have independent observations, we conducted a t^2/r^2 ratio test through a "burst sample" set. In other words, we increased the time interval between observations by deleting observations and conducted the t^2/r^2 ratio test. The "interburst intervals" were examined for intervals of 8, 16, 24, 32, 40 and 48 hours. Table 1 gives the values for each ratio test.

It was apparent that deleting observations and increasing the time interval between observations would not make our observations statistically independent. However, three researchers conducted a similar study in 1944 in which the locational coordinates of 28 Columbian black-tailed deer and 44 resident deer were examined. "They found that even when 6-week intervals were used between successive observations, 59% of resident deer and 82% of migratory deer exhibited significant levels of autocorrelation" [3].

We accepted our data as statistically dependent observations. However, we decided to eliminate the 18 data locations when B-12 was in the acclamation pen before his release, since these data point don't correspond to a free-ranging elk. Note that deleting these points does not affect the MCP estimate of home range since they were all in the interior of the polygon. After deleting the 18 points the t^2/r^2 ratio for the remaining 235 data locations was 1.2012. Figure 3 depicts the 95% Jennrich-Turner Ellipse updated estimate of the home range of B-12 at $\hat{A} = 3,482,025.551m^2$.

Although the home range area calculated with all 253 data locations was smaller, the ellipse calculated with only 235 data locations was more realistic since we eliminated points that were

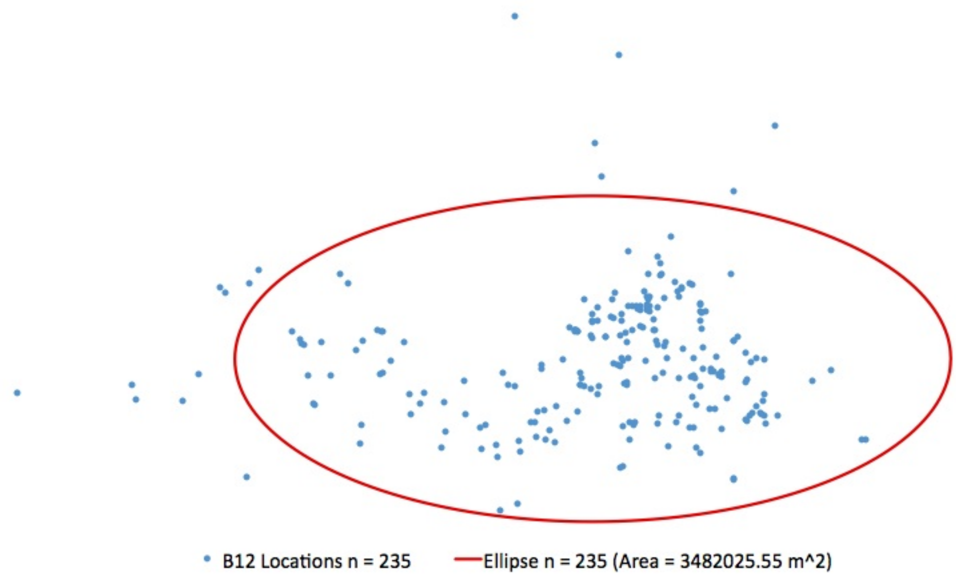

Figure 3: Jennrich-Turner Ellipse (n = 235)

Table 2: home range Estimates using the Grid Cell Method

Grid Cell Square Size (m)	home range Estimate (m^2)
100x100	1,380,000
200x200	2,000,000
300x300	3,780,000
400x400	4,640,000
500x500	5,500,000

potentially skewing the data. Figure 4 shows a comparison of the home range estimates using the two different n values.

4 Grid Cell Counts

The Grid Cell Counts method is a nonparametric approach to estimate home range size. For this method, an animal's movements are plotted and broken into a grid of cells of equal area. The sum of the areas of the cells containing observations is considered to be an estimate of the home range. Additionally, disjoint spaces, or cells not adjacent to cells containing observations, must be factored into the sum. We selected the least number of cells to adjoin disjoint cells in an attempt to achieve the most accurate estimate.

This approach is rather arbitrary due to the fact that the researcher decides the size of the grid cells. On the one hand, if the grid cell size is too coarse, extra area is included in the home range estimate. On the other hand, if the grid cell size is too fine, an underestimate of the home range will be determined [1]. We decided to use various sized grid cells and compare the area estimates. We computed estimates of the home range of B-12 using $100x100m$, $200x200m$, $300x300m$, $400x400m$ and $500x500m$ grid cell sizes. The areas of the home range estimate based upon the cell sizes are listed in Table 2.

The $100x100m$ and $200x200m$ grid cell sizes were considered to be too fine since there were

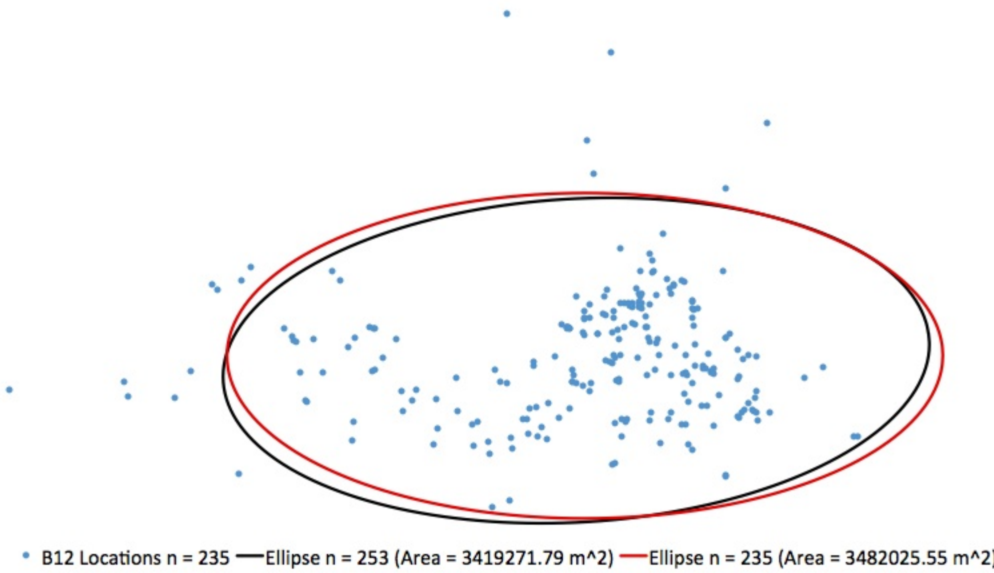

Figure 4: Jennrich-Turner Ellipse Comparison

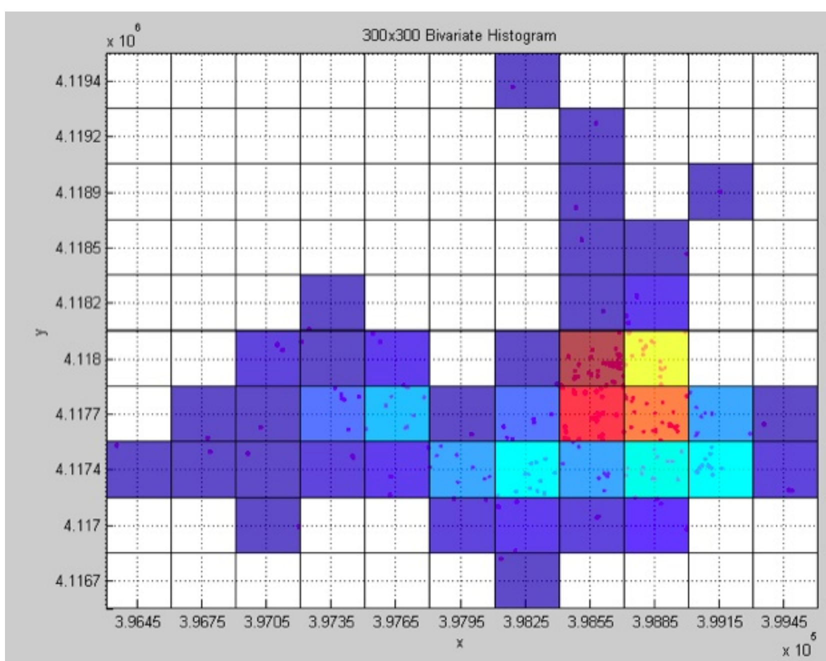

Figure 5: Grid Cell Count $300x300m$ (n = 235)

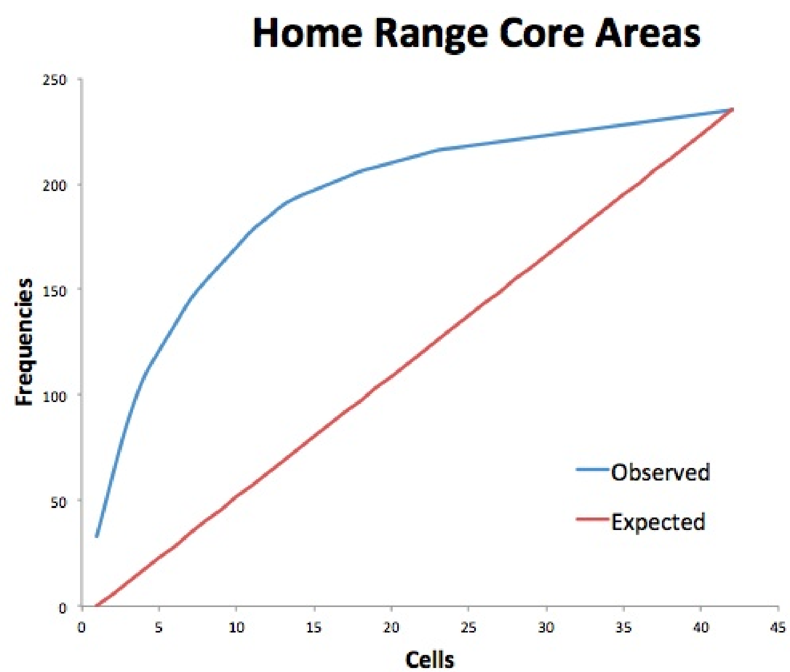

Figure 6: home range: core areas (n=235)

multiple disjointed cells. We considered the $400x400m$ and $500x500m$ grid cell sizes to be too coarse since many cells contained only one observation. The $300x300m$ grid cell size was considered adequate since no cells where disjoint and the home range estimate was fairly close to the Jennrich-Turner ellipse area estimate. The plot for the $300x300m$ grid cell size is given in Figure 5.

5 Core Area

The grid cell method gave us the opportunity to assess areas B-12 visited multiple times based on the frequency of observations in each grid cell. "Core areas are those areas used more frequently than any other areas and probably contain the homesites, refuges, and most dependable food source" [4]. We were able to differentiate between the equal-use patterns, represented by the home range, and areas used more intensely, represented by the core area.

To identify the potential core area, we tabulated the frequency of observations for each grid cell and ordered them cumulatively. We tested to see if B-12 used a core area of his home range by "comparing the value of the ordered observed cumulative distribution function with that hypothesized for the uniform distribution" [4]. Using a statistical analysis package, StatistiXL, we conducted a one-sided Kolmogorov-Smirnov goodness-of-fit test. The maximum difference, denoted D, between cumulative frequency values from observed observations and expected observations was 0.516 found at Cell 13 (Figure 6). Thus our distribution was significantly different from the uniform distribution ($D = 0.516, p < 0.001$). It is evident from Figure 5 that B-12's locations are not uniformly distributed over the home range. B-12's core area was estimated to be $1,170,000m^2$ centered in the eastern portion of his home range.

6 Conclusion

By examaining the home range of B-12 using the Minimum Convex Polygon method, Jennrich-Turner Ellipse method and Grid Cell Counts method, it was evident that each of the three methods offered valuable information. The Minimum Convex Polygon method was quite easy to implement, but provided a home range estimate that included areas with houses (in the upper central portion) know to be avoided by B-12. The Jennrich-Turner Ellipse method did not include as much of the avoided developed area, but shifted east to include areas without known B-12 locations. The Ellipse method required the most computations and our data did not satisfy the independence assumption. The Grid Cell Counts method included the least amount of space containing no observations and was considered the best estimate to the home range of B-12. Closer examination of the grid cells allowed us to isolate areas of concentrated use or core area within the home range. These methods provide insights into elk space use and can help make management decisions. To further our studies, we could evaluate a Kernel Density Estimation method.

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