Differences in home-range size computed in commonly used software programs

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Abstract: With the advancement of radiotracking techniques, there has been a dramatic increase in the quantity and quality of locational and movement data obtained for a variety of wildlife species. Automated tracking systems, in particular, produce enormous amounts of data. These data help researchers determine movements, home ranges, and habitat use by individuals and populations. One of many challenges is determining not only which home-range estimators to use, but also which home-range program will best fulfill study objectives. We used data from a moose (Alces alces) fitted with a test Global Positioning System (GPS) collar to compare home-range sizes estimated by 5 commonly used software packages (CALHOME, HOME RANGE, RANGES IV, RANGES V, TRACKER). We found large differences in calculated home-range sizes using minimum convex polygon, harmonic mean, and kernel estimators at 3 levels of resolution (95%, 75%, and 50% of locations). Comparing home ranges among different research studies can be misleading unless researchers report choices for software program, home-range estimators, user-selected options, and input values of required parameters.

Key words: adaptive kernel, harmonic mean, home range, home-range software programs, minimum convex polygon, moose, radiotracking.

For nearly 30 years wildlife researchers have relied a great deal on radiotracking for the collection of animal movement and range data. At first, VHF transmitters were fitted to animals and signals received by the observer were used to determine the animal's location. In the past 15 years satellites have also been used for wildlife tracking. In particular, TIROS/ARGOS has been widely used to report on gross movements of highly mobile animals (Harris RB et al. 1990, White and Garrott 1990). More recently, GPS has been used for wildlife tracking (Rodgers et al. 1996). The spatial and temporal resolution of GPS data allows researchers to study interactions of animals and their habitat at an unprecedented level of detail (Rempel et al. 1995, Rempel and Rodgers 1997). The use of both GPS and ARGOS has greatly increased the volume of locational data accumulated by researchers.

A variety of techniques and software are available to evaluate home-range size and determine patterns of home-range use (Harris S et al. 1990, White and Garrott 1990). A large challenge in wildlife research lies in deciding which home-range estimators and home-range-analysis software to use (Kenward 1992). Larkin and Halkin (1994) summarized the functionality, user interfaces, and other characteristics of 11 software programs used to estimate animal home ranges. Although there have been many studies evaluating different home-range estimators (e.g., Garton et al. 1985, Boulanger and White 1990, Harris S et al. 1990, White and Garrott 1990, Worton 1995), few studies have compared the home-range sizes computed by different computer software packages. Instead, it appears that most researchers have assumed that different home-range programs will yield similar and comparable results if the values of parameters in user-defined algorithms are held constant. However, Larkin and Halkin (1994) showed that different home-range values were calculated by the software packages they reviewed. To further investigate these differences, we used data from a GPS collar fitted to a free-ranging moose to compare results from 5 different home-range software programs. We also determined the suitability of these home-range programs for analyses of large data sets obtained from automated tracking systems.

GPS collar data

In late-February/early-March 1994 a pilot study was undertaken to test the first commercially available GPS-based animal location system under field conditions (Rodgers et al. 1995, Rodgers et al. 1996). GPS collars (Lotek Engineering, Inc., Newmarket, ON L3Y 7B5, CANADA) were deployed on 8 free-ranging adult, cow moose (Alces alces) in northwestern Ontario. Collars were pre-programmed to obtain a position estimate (latitude, longitude) every 3 hours. Data stored on each collar were downloaded through a UHF radio-modem communication link at monthly intervals. We selected the data set which contained the closest to, but not over, 500 GPS locations to use in comparisons of home-range estimates computed by different computer software packages. These test data consisted of 483 position estimates obtained from 27 February to 20 May 1994.

Selection of home-range estimators

Moose locations were imported to a Geographic Information System (GIS) and plotted on an interpreted and expanded view of a
Landsat-5 TM satellite image (Rodgers et al. 1996). As in 2 other studies of collared moose, these data showed a consistent pattern of habitat patch use. The moose resided in a small area (< 1 km²) for < 2 weeks, then moved directly to a new patch < 10 km away, on a continuous basis (Fig. 1). From these preliminary observations, as well as a review of current literature, we chose minimum convex polygon (MCP), harmonic mean, and kernel estimators for comparison among home-range software programs. We selected these 3 methods primarily because they use nonparametric approaches to estimate home-range size, thereby eliminating the need to make assumptions about the distribution of home-range locations (e.g., bivariate normality).

Many papers suggest using > 1 home-range estimator and that 1 of these be MCP which is easy to compare between studies and is the most frequently used (Harris S et al. 1990, White and Garrott 1990). However, when all points are included, the MCP does not indicate how intensively different parts of an animal's range are used, and the estimate of home-range size is strongly related to the distribution of the outermost points (Kenward 1987). On the other hand, both the harmonic mean and kernel analyses allow determination of more than 1 center of activity or core-activity area (Dixon and Chapman 1980, Worton 19X9, Harris S et al. 1990). Although the harmonic mean approach has been the one most often used, Worton (1989, 1995) and Kie (1996) advocated the use of kernel methods over other estimators because kernels are less biased by the chosen scale or grid density and could produce more consistent results.

Selection of home-range analysis software

Based on our preliminary explorations of GPS collar data, and keeping in mind future research plans and objectives, we compared various features of home-range analysis software programs: (1) maximum number of input locations; (2) types of home-range estimators; (3) variations in algorithms used to calculate home-range estimators; (4) ability to export polygon edge coordinates for use in GIS applications; and (5) ability to perform autocorrelation analyses. We did not compare features discussed by Larkin and Halkin (1994) such as cost, system requirements, support, and ease of use.

Of 13 home-range programs we initially reviewed, 5 could be used to compare all 3 home-range estimators we selected. Our test data consist of almost 500 locations collected in < 3 months. Many home-range programs handle a maximum of 500 locations. Therefore, a larger data set would have to be analyzed over a short time frame, or subset, and this may not be biologically reasonable. Since automated tracking systems, such as GPS collars, can record large quantities of data in short time periods, home-range programs should allow for > 500 locations.

Three of the 13 programs provided autocorrelation analyses which may be particularly important to those using tracking systems that provide continuous monitoring of animals (Swihart and Slade 1985, Harris S et al. 1990, White and Garrott 1990:147). Although data could be tested for autocorrelation in a separate statistical software program (e.g., SAS, SPSS, etc.), this would result in a multistage procedure that is time consuming, cumbersome, and has the potential for error at each processing step.

Of increasing importance to future needs is the ability to export polygon edge coordinates to a GIS in which maps have already been prepared for analyses of habitat use. Several home-range programs can input simplified maps, but do not retain and use other attribute data as effectively as in a GIS. Most of the programs we examined allow data to be exported for habitat analysis, but in all cases reformatting is necessary before import to a GIS.

After a thorough literature review and numerous personal communications, we selected 5 home-range-analysis programs for comparisons; CALHOME (Kie et al. 1994), HOME RANGE (Ackerman et al. 1990), RANGES IV (Kenward 1990), TRACKER (Camponotus AB and Radio Location Systems AB 1994), and a pre-release version of RANGES V (Kenward and Hodder 1996). We have summarized the main features of the selected home-range programs with respect to our selection criteria (Table 1).

Table 1. Main features of software programs used for comparison of home-range estimates, including input parameters and available options for each estimator.
### Home-range software programs

<table>
<thead>
<tr>
<th>Home-range software programs</th>
<th>Maximum locations (XY)</th>
<th>Export polygons</th>
<th>Autocorrelation</th>
<th>Minimum convex polygon (MCP)</th>
<th>Harmonic mean</th>
<th>Adaptive kernel</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALHOME ver. 1.0</td>
<td>500</td>
<td>Yes</td>
<td>No</td>
<td>Smallest area MCP</td>
<td>Number of grid cells; % of locations</td>
<td>Number of grid cells; % of locations; smoothing factor</td>
</tr>
<tr>
<td>HOME RANGE 2nd ed.</td>
<td>1,000</td>
<td>Yes</td>
<td>Yes</td>
<td>Re-calculated arithmetic mean</td>
<td>Scale; number of grid cells % of locations</td>
<td>Not available</td>
</tr>
<tr>
<td>RANGES IV</td>
<td>500</td>
<td>Yes</td>
<td>No</td>
<td>Arithmetic mean, recalculated arithmetic mean, harmonic mean, or user defined</td>
<td>Number of grid cells; center fixes in grid squares or unmodified fixes</td>
<td>Number of grid cells; multiplication of default smoothing factor (.5-1.5)</td>
</tr>
<tr>
<td>RANGES V</td>
<td>3,000a</td>
<td>Yes</td>
<td>Yes</td>
<td>Arithmetic mean, recalculated arithmetic mean, harmonic mean, kernel, or user defined</td>
<td>Number of grid cells; contours fitted to fixes or fix density; center fixes in grid intersections or unmodified fixes; freeze grid or edge detection and rescaling</td>
<td>Number of grid cells; multiple of default smoothing factor (.5-2); fixed, tailed-weighted or core-weighted kernels; contours fitted to fixes or fix density; freeze grid edge detection and rescaling</td>
</tr>
<tr>
<td>TRACKER ver. 1.1</td>
<td>3,000</td>
<td>No</td>
<td>Yes</td>
<td>Median</td>
<td>Grid spacing; margin</td>
<td>Type of kernel; density coefficient of variation; grid spacing; margin</td>
</tr>
</tbody>
</table>

*a Ranges V can allow for more than 3,000 locations. The number of locations Ranges V can run depends on the RAM of the computer.*

### Comparisons of home-range estimates

All 5 software programs operated on personal computers under the DOS or Windows environment. Location data for all programs were input as Universal Transverse Mercator (UTM) coordinates. Area was reported in m², ha, or km², depending on the program. The programs varied widely in interface, operation, and output (Larkin and Halkin 1994).

Although not intended as a method of identifying centers of activity or core areas of animal home ranges, the MCP approach can be used to identify regions with the highest density of animal locations (Michener 1979, Kenward 1987). This is accomplished by continually recalculating the MCP after excluding a percentage of the outermost position estimates. In spite of its limitations (White and Garrott 1990), this approach has been widely used, particularly for eliminating occasional locations that occur well outside the "normal" home range of an individual (i.e., "outliers") as defined by Burt (1943). We compared calculated values of 50%, 75%, and 95% MCPs (i.e., after eliminating 50%, 25%, and 5% of outermost locations, respectively) among the 5 home-range-analysis programs. Similarly, we compared 50%, 75%, and 95% harmonic mean home-range estimates using each of the 5 programs. We ran 50%, 75%, and 95% kernel analyses in only 4 of the 5 programs, because the HOME RANGE program does not compute kernels. Wherever possible, we kept the values of parameters in user defined algorithms equivalent.

### Sources of home-range programs reviewed and other internet sites

MCP is often considered a relatively more comparable home-range estimate among different studies and different home-range programs (Harris S et al. 1990), despite being less suitable biologically as a descriptive statistic (White and Garrott 1990:148). As expected, all programs reported the same MCP home-range size (80.12 km²) using 100% of the moose locations. However, results varied when running the analyses with less than 100% of the fixes (Table 2). Home-range areas using 95% of the locations ranged from 39.96 km² to 65.37 km², those using 75% of the locations ranged from 23.86 km² to 58.25 km², and those using 50% of the locations ranged from 8.63 km² to 16.97 km². These differences occur because each program has a different algorithm for determining core MCP areas; with the exception of RANGES IV and RANGES V, which do use the same algorithms and give identical results.

Table 2. Minimum convex polygon estimates of home-range size (km²) computed by 5 software programs at 3 levels of resolution for a moose fitted with a test GPS collar (n = 483 fixes).
In comparisons of harmonic mean analyses, there are even greater differences in reported home-range size among the 5 home-range programs (Table 3). Home-range areas using 95% of the locations ranged from 31.60 km$^2$ to 90.98 km$^2$, those using 75% ranged from 10.66 km$^2$ to 50.21 km$^2$, and those using 50% ranged from 3.08 km$^2$ to 19.26 km$^2$. Once again, differences among computed values are accounted for by the different algorithms used by each program to calculate harmonic mean areas. All 5 programs provide unique combinations of the default number of grid cells, the maximum number of grid cells, and the placement of X and Y locations within grid cells (Table 4). Our preliminary testing showed that in all the home-range programs, differences in the number of grid cells greatly influenced the reported home-range size. Although we attempted to use the same number of grid cells (i.e., 40 x 40) in making final comparisons, the maximum number of grid cells allowed by the HOME RANGE program did not meet our requirements, and the TRACKER program uses grid spacing and the grid margin to determine the appropriate scale. RANGES V translocates position estimates to the intersections of grid cells, RANGES IV and TRACKER place locations at the center of the grid cells, and CALHOME and HOME RANGE do not shift the location of data points. Except for RANGES IV and RANGES V which provide the option of not translocating fixes, users do not have control of the algorithm used to place locations within grid cells.

Table 3. Harmonic mean estimates of home-range size (km$^2$) computed by 5 software programs at 3 levels of resolution for a moose fitted with a test GPS collar (n = 483 fixes).

<table>
<thead>
<tr>
<th>Home-range software programs</th>
<th>Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95%</td>
</tr>
<tr>
<td>CALHOME (smallest area of polygon)</td>
<td>31.60</td>
</tr>
<tr>
<td>HOME RANGE (72 x 32, scale = 1500)</td>
<td>90.98</td>
</tr>
<tr>
<td>RANGES IV (40 x 40, fixes centered in grid cells)</td>
<td>46.44</td>
</tr>
<tr>
<td>RANGES V (40 x 40, fixes placed at grid intersections)</td>
<td>41.70</td>
</tr>
<tr>
<td>TRACKER (grid spacing = 157.08, margin % = 30)$a</td>
<td>49.23</td>
</tr>
</tbody>
</table>

$a$ Default grid spacing and margin determined by TRACKER program.
Table 4. Parameters and algorithms used to compute harmonic mean estimates of home-range size in 5 software programs.

<table>
<thead>
<tr>
<th>Home-range software program</th>
<th>Default number of grid cells</th>
<th>Maximum number of grid cells</th>
<th>Movement of location on the grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALHOME</td>
<td>30 x 30</td>
<td>50 x 50</td>
<td>Fixes unmodified in the grid</td>
</tr>
<tr>
<td>HOME RANGE</td>
<td>48 x 21</td>
<td>72 x 32</td>
<td>Fixes unmodified in the grid</td>
</tr>
<tr>
<td>RANGES IV</td>
<td>40 x 40</td>
<td>40 x 40</td>
<td>Center of the grid cells</td>
</tr>
<tr>
<td>RANGES V</td>
<td>40 x 40</td>
<td>50 x 50</td>
<td>Intersection of the grid cells</td>
</tr>
<tr>
<td>TRACKER</td>
<td>N/A b</td>
<td>N/A</td>
<td>Center of the grid cells</td>
</tr>
</tbody>
</table>

a RANGES IV and V give the user the option of unmodifying the fixes in the grid.

b TRACKER does not allow the user to specify the number of grid cells—only grid spacing and the grid margin.

Lastly, we compared kernel analyses (Table 5). Home-range areas using 95% of the locations ranged from 14.45 km² to 39.95 km², those using 75% ranged from 4.58 km² to 17.00 km², and those using 50% ranged from 1.43 km² to 6.65 km². As with the MCP and harmonic mean estimators, the 4 programs have different algorithms for determining the home-range area. Unlike the harmonic mean estimator, differences in the number of grid cells has little influence on kernel estimates of home-range size (Worton 1995, Kie et al. 1996). Instead, the kernel approach is sensitive to changes in the value of the bandwidth (Harris S et al. 1990) which is more commonly referred to as the “smoothing parameter” (Worton 1989). RANGES IV provides a fixed kernel approach in which the smoothing parameter is assumed to be constant throughout the plane of the estimated bivariate probability density function (Worton 1989). The default smoothing parameter is calculated from the estimated variances of the X and Y location data (Worton 1989, Kenward 1990) and may be modified in RANGES IV by a user-selected multiplication factor of 0.5 to 1.5. The other 3 programs examined use the adaptive kernel method of estimating home-range areas as discussed in Worton (1989). In this approach, the value of the smoothing parameter is assumed to vary, particularly in the tails of the estimated bivariate probability density function, such that areas with a low concentration of fix locations are smoothed more than areas with a high concentration (Worton 1989). RANGES V provides the additional option of using a core-weighted smoothing parameter (i.e., the inverse of the tail-weighted function) that emphasizes the area of the distribution with the highest concentration of fixes (Kenward and Hodder 1996). Both CALHOME and RANGES V use the approach of least-squares cross-validation to choose the appropriate smoothing parameter for adaptive kernel estimates; i.e., the value of the smoothing parameter used is that which results in the smallest least-squares cross-validation score (Worton 1989, Kie et al. 1994, Kenward and Hodder 1996). However, in some cases where there is more than one core area, the least-squares cross-validation score cannot be minimized, and RANGES V automatically reverts to the default smoothing parameter (Kenward and Hodder 1996). TRACKER does not provide any methods to estimate a smoothing parameter, but gives an initial value of the density coefficient of variation for the bivariate probability density function which the user can then modify to a limited extent.

Table 5. Kernel estimates of home-range size (km²) computed by 4 software programs at 3 levels of resolution for a moose fitted with a test GPS collar (n = 483 fixes)
<table>
<thead>
<tr>
<th>Home-range software program</th>
<th>Locations</th>
</tr>
</thead>
</table>
| CALHOME (adaptive kernel); 40 x 40 grid  
  \(h^a = 7.95\) | 95% 75% 50% |
| 32.99 9.23 3.45 |
| RANGES IV (fixed kernel); 40 x 40 grid | 39.95 17.00 6.65 |
| RANGES V (fixed kernel); 40 x 40 grid  
  \(h = 7.95\) | 32.96 16.21 4.02 |
| RANGES V (core-weighting adaptive); 40 x 40 grid  
  \(h = 7.95\) | 29.81 11.50 4.25 |
| RANGES V (tail-weighting adaptive); 40 x 40 grid  
  \(h = 7.95\) | 37.32 16.97 3.91 |
| TRACKER (adaptive kernel)b;  
  grid spacing = 377.06  
  margin % = 30  
  density CV = 0.15 | 14.45 4.58 1.43 |

\(a\) "\(h\)" is the smoothing parameter (Worton 1989)

\(b\) Default parameter values determined by the TRACKER program.

The 4 programs also use different functions to estimate the bivariate normal density distribution. CALHOME uses the Epanechnikov kernel function, RANGES IV and RANGES V use the Gaussian kernel, and TRACKER allows the user to select Gaussian or Epanechnikov kernels. Although the choice of the kernel estimator is expected to have less effect on home-range size calculations than the choice of smoothing parameter (Worton 1989, Camponotus AB and Radio Location Systems AB 1994), differences can occur. For example, variation of home-range size between CALHOME and RANGES V is partly accounted for by the different kernel estimators employed by each program.

For the most part, differences in home-range areas estimated by the software programs can be accounted for by the algorithms of the kernel methods. To further demonstrate these effects, we analyzed our test data with RANGES V, using each of the fixed, tail-weighted, and core-weighted kernel methods and specified identical values for the required input parameters (i.e., 100 m resolution, 40 x 40 grid, smoothing factor multiple equal to 1, contours fitted to fixes rather than modeled on fix density, and freezing of grid rather than edge detection and rescaling). For our test data, the fixed and core-weighted methods provided similar estimates of home-range size when 95% of the locations were included in the analysis (Table 6), but fixed and tail-weighted methods were most similar when 50% or 75% of locations were used. Given these differences, selection of kernel method cannot be made indiscriminately and requires preliminary examination of the location data. The large number and highly clumped moose locations that we observed (Fig. 1) suggest that the fixed kernel method is the most appropriate for our test data.

Fig. 1. **UTM locations** (n=483) of a free range moose fitted with a test GPS collar from 27 February to 20 May, 1994.
Discussion

Based on a single data set, our results have shown large differences in the reported home range using several home-range estimators computed by 5 different computer software packages. These differences are largely the result of decisions made with regard to the various options offered by each program in the calculations of the estimators and values input for various parameters. Based on the differences we observed, comparisons of home-range size and habitat use of a particular species between different research studies could be very misleading. This is particularly true if the different studies do not report the home-range estimator used, user-selected options for calculating the estimator, the input values of parameters, and the home-range program used.

Although most studies do report the number of locations, the type of home-range estimator, and home-range program, very few indicate values of input parameters or user-selected options. In all the home-range programs, the harmonic mean estimate has been criticized as being strongly dependent on the grid spacing and scale (Worton 1989, Ackerman et al. 1990, Harris S et al. 1990, Kenward and Hodder 1996). Too fine grid spacing produces jagged and fragmented curves, and too coarse grid spacing includes large areas where the animal did not travel. Kenward and Hodder (1996) pointed out that all implementations of harmonic mean analysis were likely to give slightly different results for the same set of data. We examined all studies that reported home-range sizes using the harmonic mean estimator in the Journal of Wildlife Management over the last 5 years (1991-1996). Only 6 of 16 studies reported the number of grid cells or scale chosen.

Although the adaptive kernel estimator does not have the same inherent problems as the harmonic mean approach, Harris S et al. (1990) noted that relatively minor changes in the smoothing parameter value had a large effect on overall range size. This is especially true for small sample sizes (Worton 1996). Very few studies to date have used the adaptive kernel estimator for determining home-range size, because it is more recent than the harmonic mean method. However, as it comes into greater use, researchers should report the type of kernel method, grid-cell size, smoothing parameter, sample size, and home-range analysis software.

Consistency is crucial when running home-range analyses. In carrying out harmonic mean or kernel analyses, for example, it is important to decide on an ideal grid spacing and number of grid cells based on a preliminary examination of the data. Once selected, these variables should be used for the duration of the study, and reported in final reports or publications.

Likewise, it may also be necessary to employ the same home-range program throughout a study. We attempted to run our analyses using the same options for calculating each estimator and identical values of input parameters. However, each home-range program had different methods for selecting <100% of the locations in MCP analyses. When doing harmonic mean analyses we could choose the same number of grid cells (i.e., 40 x 40) in only 3 of the 5 programs. In HOME RANGE, we could only choose a rectangular, not a square grid. Moreover, TRACKER allows the user to choose scale only, not the number of grid cells. Similarly, when running adaptive kernel home-range analyses we chose the same values of input parameters (i.e., number of grid cells and initial smoothing parameter), but each of the 4 programs we compared used a different method to implement the smoothing parameter and contour routine. Thus, our attempts to repeat the results were thwarted by the options offered. Changing home-range analysis software during a research project could thus invalidate comparisons within a single study. Comparisons between studies may also be invalid if home-range area or habitat use are derived from different software programs.

Of the 5 home-range analysis software packages we used, RANGES V may be the most suitable program for analyses of large data sets obtained from automated tracking systems: up to (and over) 3000 locations can be input; it will perform an autocorrelation analysis that determines the time to independence; and polygon coordinates from home-range analyses can be exported for use in GIS.
applications. RANGES V also provides the widest variety of algorithms for calculating home-range estimators and the greatest number of user-selected options for calculating each estimator.

Each of the 5 home-range programs we examined, as well as many others, may have their own niche, and individual researchers must assess which program will best meet project requirements. However, we are concerned that valid comparisons among studies may not be possible with the ongoing proliferation of computer software programs to meet the specific needs of individual research projects. At present, there is no generally accepted computer program for analysis of animal location data. As advocated by White and Garrott (1990) and Larkin and Halkin (1994), there is still need for a comprehensive analysis program to provide standards and handle all phases of animal location data analysis.

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Literature cited


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