



Short communication

Improving the realism of random walk movement analyses through the incorporation of habitat bias



Catherine L. Proulx*, Lorraine Proulx, Gabriel Blouin-Demers

Department of Biology, University of Ottawa, 30 Marie Curie Private, Ottawa, Ontario, Canada K1N9A4

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ABSTRACT

The removal and fragmentation of natural landscapes by anthropogenic features have led to a decrease in biodiversity throughout the world. Spatial tools that use animal movement data are becoming increasingly important to determine the effects of landscape modifications on various processes related to population persistence. Several studies have found that the correlated random walk model is useful to investigate the spatial dynamics of animal populations. Here we present an Animal Movement Analysis program that uses a derivation of the random walk to model animal movement. Our Random Walk Generator allows the user to incorporate habitat bias in movement for an organism. The incorporation of habitat bias greatly improves the realism of the analysis of movement patterns via random walks, making it a better model to inform management decisions.

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1. Introduction

Documenting the spatial dynamics of animal populations and their relationships with environmental variables is crucial to biodiversity conservation (Skidmore et al., 2011). The continuing loss and fragmentation of natural landscapes is considered a major cause of species decline (Fahrig, 2003), reducing distributions and isolating populations that subsequently become more vulnerable to extinction (Forman and Alexander, 1998; Lode, 2000). Several processes influencing animal fitness are often directly related to movement, such as foraging, predator avoidance, mate searching, and seasonal migrations (Gurarie, 2008; McIntire and Rompré, 2013). As a result, movement data are used increasingly to investigate how human modifications of the landscape impact animals (Proulx et al., in press; Robson and Blouin-Demers, 2013; Row et al., 2007), which allows making more informed management decisions.

Animal movements result from interactions between behavioral responses to an organism's internal state, environmental cues, and constraints (Gurarie, 2008). The continuing improvement of remote sensing technology, various forms of telemetry, global positioning systems (GPS), and geographical information systems (GIS) now make the collection of detailed animal movement data possible. Although animal movements are difficult to model mathematically, many studies employ derivations of the random walk (RW) or

correlated random walk (CRW) to study individual animal movement and population level spatial patterns (Bergman et al., 2000; Johnson et al., 2008; Kareiva and Shigesada, 1983; Row et al., 2007; Shepard et al., 2008). In general, a CRW assumes that animals move at a more or less constant rate over time and consists of independent distributions of move lengths (i.e., displacement events) separated by successive reorientation events (i.e., turning angles) (Bartumeus et al., 2005; Gurarie, 2008; Johnson et al., 2008). The degree of correlation of the random walk is controlled by the probability distribution of the turning angles: symmetrically clustering turning angles around zero degrees allows for persistent directionality in movement (Bartumeus et al., 2005; Gurarie, 2008). The random walk model serves as a null hypothesis, allowing researchers to quantify the impacts of anthropogenic stressors, such as habitat fragmentation and road networks, on animal movement patterns by comparing the observed movements of the animals to the null hypothesis generated from the random walk model.

Several modeling software packages are available for the analysis of movement data with a CRW. The Geospatial Modeling Environment (Spatial Ecology LLC, Hawthorne L. Beyer, 2001–2012) has a “movement.simplecrw” command that “simulates a simple correlated random walk by randomly drawing from a specified step length and turn angle distribution, based on a set of start locations, the number of steps per path to simulate, and the number of simulation paths per start location”. This package also allows the user to set a home range boundary constraint. The Spatial Analyst Tools (ArcView 3.0–3.3, 2000) has an “Animal Movement” extension that uses a “Monte Carlo simulation and parameters from the original data to determine whether the observed movements patterns

* Corresponding author. Tel.: +1 613 599 5122.

E-mail addresses: cprou100@uottawa.ca (C.L. Proulx), lorraine.proulx@rogers.com (L. Proulx), gblouin@uottawa.ca (G. Blouin-Demers).

has more site fidelity than should occur randomly, is a random pattern or is overly dispersed". Lastly, the Cran-R Project for Statistical Computing has a "CRAWL" package (Johnson, 2013) that "fits continuous-time correlated random walk models to animal movement data which has been collected at irregular intervals".

Although the CRW method has been used to study movement of many species, it is a major simplification of real animal movements. Animals move from one habitat to another in search of certain attributes required for survival and reproduction. Habitat selection is primarily determined by habitat availability (i.e., access), required resources, and environmental characteristics (Hall et al., 1997). Preference for a certain habitat type (e.g., wetland, forest, agricultural land) can be assessed by comparing its use by an animal versus its availability (Hall et al., 1997). While a simple CRW approach may be appropriate in instances where we do not expect strong habitat biases in movements (e.g., Row et al., 2007; Robson and Blouin-Demers, 2013), it is clearly inappropriate when there are clear habitat biases in movements (e.g., Proulx et al., in press). For instance, Proulx et al. (in press) studied the movement patterns of semi-aquatic Blanding's turtles (*Emydoidea blandingii*) where, clearly, movements in water should be much more likely than movements overland. Our modified CRW program allows for a habitat bias in movement, which will render most analyses of movement patterns via CRW much more realistic. By classifying each observed animal movement by habitat type, a habitat type movement proportion (number of movements within a habitat/total number movements) can be calculated to restrict the randomization. This restriction ensures that the proportion of movements within the various habitat types respects the proportions observed for each individual animal. In this paper, we provide the details of this novel modeling procedure and provide a program that implements CRW with user-specified habitat proportions. We start with a simple CRW and then show how to incorporate habitat bias.

2. Program architecture

The Animal Movement Analysis (AMA) program is a Java application (version 1.7.0-01) that was developed and tested on a Windows 7 platform. Because Java can be implemented in other operating systems, our program should be easily portable to these other operating systems, such as Mac OS or Unix. The primary function of the AMA program is the Random Movement Generator (RMG). RMG requires an input file containing, for each animal, its ID and the x- and y-coordinates for each of its recorded locations (see Appendix A.1 for format and details). An optional input file containing the east, west, north, and south restrictions, in the same coordinate system as the movements, for all or for some of the individuals can also be provided. The user can specify the number of movement legs they wish to generate for each iteration.

2.1. Random walk

From the input file, the RMG calculates the distances traveled between successive points using the simple Euclidian distance formula:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

Starting with an individual's initial location, RMG generates a random walk path using the sequence of observed distances moved (legs), but by randomizing the direction (i.e., turning angle) between each movement leg. Depending on the turning angle, each new location (x, y) is calculated from the previous location (x_0, y_0) as demonstrated in Table 1. After each randomization, boundary

Table 1

Equations used when determining a new location (x, y) using the observed distance (d), a previous location (x_0, y_0), and a randomized angle (θ).

Angle	Equations
$\theta < 90^\circ$	$a = (\sin \theta) d$ $b = \sqrt{d^2 - a^2}$ $x = x_0 + b$ $y = y_0 + a$
$\theta = 90^\circ$	$x = x_0$ $y = y_0 + d$ $a = [\sin(180 - \theta)] d$
$90^\circ < \theta < 180^\circ$	$b = \sqrt{d^2 - a^2}$ $x = x_0 - b$ $y = y_0 + a$ $x = x_0 - d$ $y = y_0 - a$ $a = [\sin(\theta - 180)] d$
$180^\circ < \theta < 270^\circ$	$b = \sqrt{d^2 - a^2}$ $x = x_0 - b$ $y = y_0 - a$
$\theta = 270^\circ$	$x = x_0$ $y = y_0 - d$ $a = [\sin(360 - \theta)] d$
$270^\circ < \theta < 360^\circ$	$b = \sqrt{d^2 - a^2}$ $x = x_0 + b$ $y = y_0 - a$ $x = x_0 + d$
$\theta = 360^\circ$	$y = y_0$

requirements are assessed; if the requirements are not met, the randomization is discarded and a new one is generated.

2.2. Random walk corrected for habitat bias

Optionally, the RMG allows the user to perform a RW correcting for habitat bias. An input file containing a habitat type raster of the area of study must be provided for this analysis. This habitat type raster file is a matrix of cells in which each cell contains a numerical value representing the type of habitat. The user must then specify the scale of the raster map, the preferred habitat type(s), the desired habitat type proportion error, as well as the x-coordinates of the left and right borders and y-coordinates of the top and bottom borders of the raster.

From the input, the RMG calculates the habitat type proportion for each individual. The raster information is contained in a matrix, the number of squares determined by:

$$SQ = \left[\frac{X_R - X_L}{r} \right] \times \left[\frac{Y_T - Y_B}{r} \right] \quad (2)$$

where r is the raster scale, X_R is the x-coordinate of the right border of the raster, X_L is the x-coordinate of the left border of the raster, Y_T is the y-coordinate of the top border of the raster, and Y_B is the y-coordinate of the bottom border of the raster. The x-coordinate range of the squares in the matrix, starting from the top-left and moving right, are given by;

$$(X_L) \text{ to } (X_L - 1 + r), (X_L + r) \text{ to } (X_L - 1 + 2r), \dots, (X_L + nr) \text{ to } (X_R - 1) \quad (3)$$

Similarly, the y-coordinate range of the squares in the matrix, starting from the bottom-left and moving up, are given by:

$$(Y_z + 1) \text{ to } (Y_z + r), (Y_z + 1 + r) \text{ to } (Y_z + 2r), \dots, (Y_z + 1 + mr) \text{ to } (Y_T) \quad (4)$$

Each coordinate of type (x, y) can be mapped to a certain square in the raster, and then associated with a habitat type. After each randomization, a habitat type proportion is calculated; if it differs

from the observed habitat type proportion (\pm proportion error), the randomization is discarded and another one is generated.

2.3. Habitat Type Mapper

An additional function of the AMA program is the Habitat Type Mapper (HTM). HTM requires an input raster file containing the habitat types for the area of study. In addition to the raster file, one or several coordinates are listed in the form of (x, y) for which the habitat type needs to be determined (see Appendix A.2 for format and details). The user must also specify the scale of the raster map and the x-coordinates of the left and right borders and y-coordinates of the top and bottom borders of the raster. This function is useful to validate the accuracy of the RMG.

2.4. Intersect Point Finder

Another additional function of the AMA program is the Intersect Point Finder (ITP). ITP requires an input file containing the animal movement paths and an input file containing the intersecting points between the paths and another linear feature such as roads (see Appendix A.3 for format and details). The program associates each intersecting point to an individual. The output files created provide a count of the intersections for each animal walk, as well as the average, median, minimum, and maximum number of intersections for each individual. This function is useful to analyze the results of a random walk.

2.5. XY to path

The final function of the AMA program is the XY to path (XYP) creator. XYP requires an input file containing ordered animal locations and creates a file containing sequences of distance legs (see Appendix A.4 for format and details). This function is useful to create linear movements in a GIS to visualize the movement of animals.

3. Implementation

We used the RWG to investigate the impact of roads on the movement patterns of the semi-aquatic Blanding's Turtle (*Emydoidea blandingii*) in southern Québec, Canada (Proulx et al., in press). Using radio-telemetry data on 52 individuals, we tested the hypothesis that roads act as a barrier to movement. The data were analyzed using a random walk with and without a habitat type movement bias. The habitat type raster was created using the "Create Raster Dataset" tool in ArcMap10 (Environmental Systems Research Institute, Redlands, California) from a layer of habitat types. The generated paths from the random walks were intersected with a shape file of roads using the "isectfeatures" command from the Geospatial Modeling Environment. The IPF command was then used to associate each intersection to an individual, and produce summary statistics on road crossings. The results of both types of random walk demonstrated that, at the population level, Blanding's Turtles crossed roads significantly less than expected if moving randomly in relation to roads (regular RW paired $t = 5.736$ and habitat-restricted RW paired $t = 4.966$, $df = 51$, $P < 0.001$). At the individual level, roads were a significant barrier to movement for 6 of the 52 turtles with the regular random walk and for 3 of the 52 turtles with the habitat-restricted random walk. The results from the habitat-restricted random walk, although qualitatively similar to those of the regular RW, demonstrated a reduced number of expected road crossings compared to the unrestricted random walk, which is more realistic for this species.

4. Conclusion

The main objective of the Animal Movement Analysis program is to provide a tool with improved realism for analyzing animal movement. The Random Movement Generator allows the user to run a random walk with and without a raster file containing habitat types for the area of study and that correct for habitat bias in movements. Taking into account habitat bias in movements will improve several studies, for instances studies of habitat selection, autocorrelation, dispersal and distribution, and road avoidance. Although several packages are available for the analysis of movement data, to the best of our knowledge none readily incorporates habitat bias in movements. More realistic modeling frameworks in animal spatial ecology will allow to make better informed management decisions.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.ecolmodel.2013.08.009>.

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