Home range structure in a space-time cube: an example of White-tailed Deer

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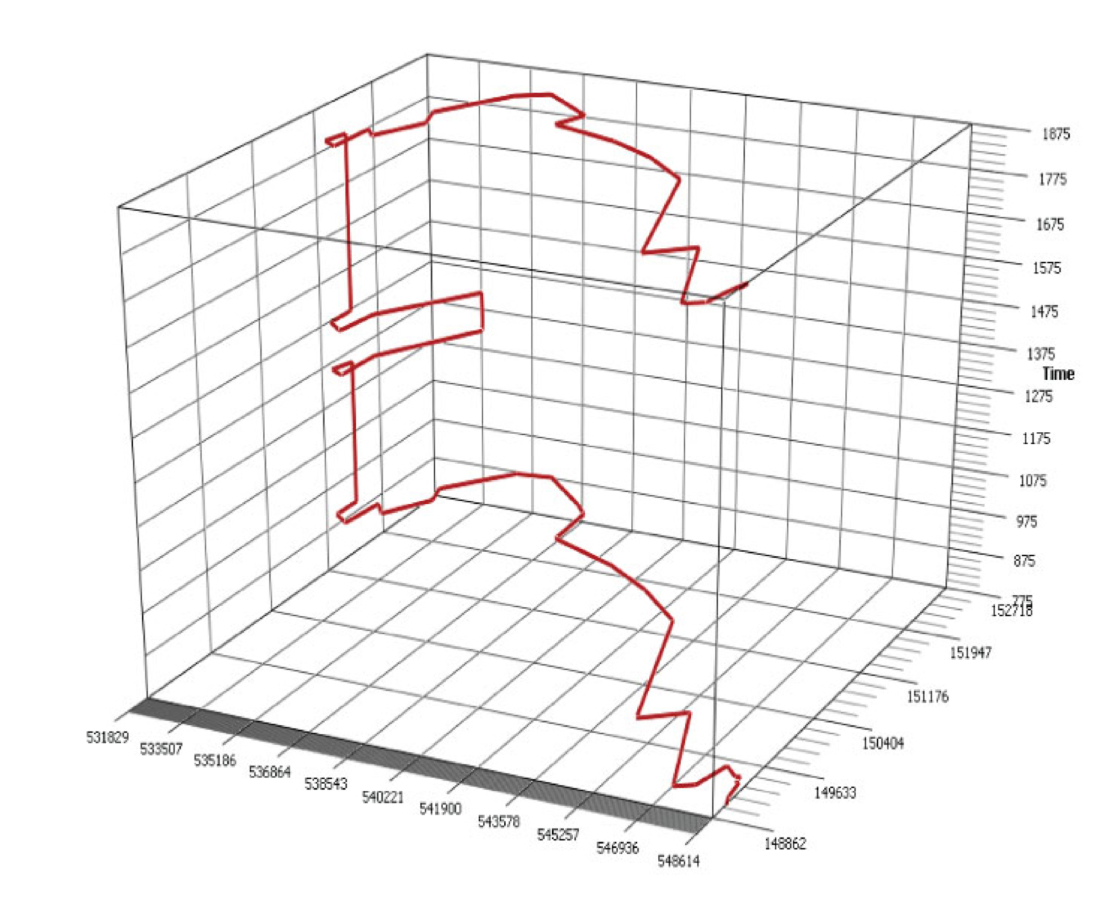

Figure 1. A schematic representation of the 3D cube. Horizontal plane shows spatial relocations, the vertical axis shows time. Steady vertical lines indicate places with no movements.

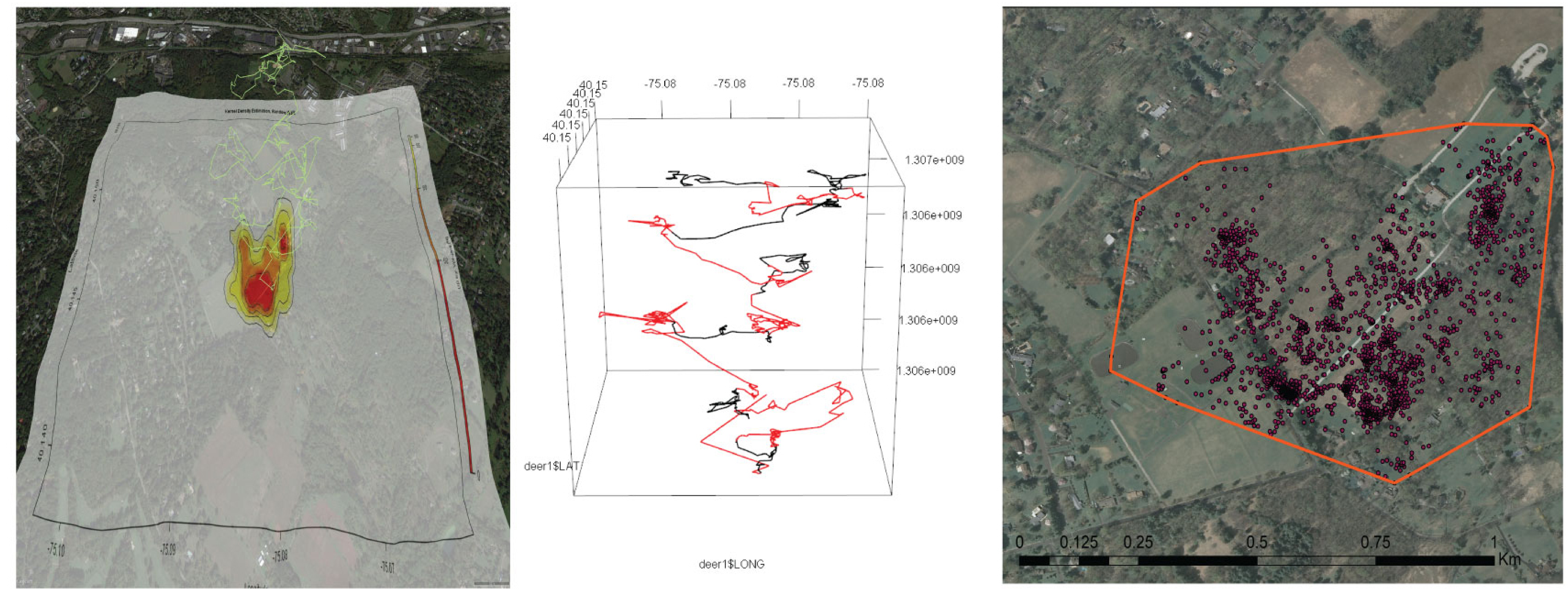

Figure 2. Left: Bare-bones 3D space-time cube representation of four day movement of a male deer (Magnus) in the period 6/19-6/24 .Center: Traditional MCP of the same animal with all fixes available. Right: Google-Earth representation of the 3D space-time cube. Kernel home range is plotted at the spatial plane.

Abstract

We analyzed daily trajectories of 34 deer instrumented with GPS/GSM radio-collars which transmitted spatial and temporal data at high-frequency intervals (5 min) for the observation period of 1 to 6 months. The deer trajectories were then converted into a space-time object (two spatial dimensions and one temporal dimension). This approach clearly separated the three types of movements. The first type included trajectory sections with stable spatial dimensions and regular diurnal and nocturnal timing, which corresponded to movements within daytime and night-time bedding areas. The second type was comprised of feeding trips characterized by non-repeatable spatial dimensions and regular time distributions. The third type consisted of social trips that had non-repeatable spatial dimensions and were non-regular in time. Separation of the animal movement modes in a space-time cube appears to be a trivial task, since extracting subparts of space-time trajectories, flattening the cube across space or time, or transforming the cube geometry or content are equivalent to re-projecting the space-time along one of the 3 axis. Overall, the structure of the home range projected onto a conceptual space-time cube manifold provides a promising approach and visualization tool for spatial utilization of habitat during different behavioral modes.

Introduction

Traditionally in animal ecology, movements of animals were represented with the MCP (minimum convex polygon) technique, which is, essentially, a border of the distribution of fixes. Naturally such a method is effective in a small dataset, whereas with a large dataset such an approach is missing the reach of information in dense spatial data. Dealing with large spatial datasets resulting from tracking studies always leads to problems with presenting the data. The solution is to separate the time and spatial components of animal relocation. This would allow for the differentiation of the animal's spatial behaviour into seasons (breeding, rut, lactation) and present the data in a more detailed form. The 3D space cube method appears to be a good candidate to achieve such goals.

The 3D space-time cube, or hyper-cube, or space aquarium, was suggested for visualization of social behaviour in humans as early as 1970 (Hägerstrand 1970). Essentially, the 3D space-cube is a 3-dimensional space, where spatial coordinates are represented on a X-Y plane and the time on the vertical Z-axis (Figure 1). Later it was adapted for visualization and analysis of transportation systems in urban environments, earthquake studies, medical research, and even social networking analysis (Kwan, 2004, Qi & Du. 2013 and references therein). In this study, we used the 3D space-time cube to visualize the trajectories of free-roaming white-tailed deer (Figure 2).

Methods

The location of 34 individual white-tailed deer (*Odocoileus virginianus*) was monitored in a natural area preserve located about 25 km (15 miles) northeast of central Philadelphia, Pennsylvania, at the grounds of the Pennypack Ecological Restoration Trust (PERT). PERT manages 3.3 km^2 (809 acres) of mature forests, regenerating woodlands, riparian forests, and fields of cool- and warm-season grasses in the Pennypack Creek valley with a network of trails. Adjacent areas represent a variety of building densities ranging from homes on large lots with mature woodland vegetation to densely-populated residential and commercial areas that merge with towns. The study area includes several schools with large institutional campuses, and industrial office parks. These areas are also intersected by a variety of roads ranging from a limited access highway (Pennsylvania Turnpike) to small unpaved roads and footpaths.

Thirteen female and 21 male deer were individually trapped in a modified Clover trap (Clover, 1954) under Pennsylvania Game Commission permits, and fitted with Tellus GPS/GSM collars (Followit, Sweden), which transmitted spatial and temporal data at 5 min intervals for periods of 1 to 6 months. Some individuals had collars collecting 5 min fixes for 2 wk periods interrupted by 2-4 wk periods during which fixes were collected at 6 h intervals. In such instances, only the 5 min fix intervals were used for this study. A total of 468,146 GPS fixes were collected from the monitored deer, with an average of 15,146 fixes per individual. Data were remotely collected and processed in the ArcGIS 9.4 and 10.0 (GIS Development Team, 2015) using the protocol from Potapov et al. (2012, 2013). Statistical analysis and visualisation was done in R software environment (R Core Team 2014) using packages RGEOS, Geosphere, RGDAL, maptools, rgl, plot3d, adehabitatLT, insol, rgdal, spacetime and a dedicated set of scripts developed by us for the purpose of this study. We used an approach known as Time-Space Cube or "Space-Time Aquarium" (Kwan 2000) to visualise movement and interactions of white-tailed Deer.

Results

White-tailed deer in the study area are mostly nocturnal (Potapov et al. 2013), and spend most of the time in encamped positions hidden from the view of humans. This behaviour generates many stationary fixes, which out-weigh the movement fixes. Nevertheless, separation of day and night fixes did not make any significant effect on the total density of points. The deer also cover larger distances by night than by day (Figure 3).

The space-time cube is a very effective tool to understand seasonal changes in home ranges. In Figure 4, depicting the daily movements of a female deer, one can clearly distinguish daily home ranges, the shrinkage of the daily home ranges at the time when the deer gave birth to a fawn, much smaller daily home ranges at the nursing period, shift of the home range after the fawn started to walk freely, and two reconnaissance tours across the neighbouring areas.

The 3D space-time cube turned out to be a very effective tool to visualize the interactions between 2 neighbouring deer (Figure 5). One can clearly see that occasionally the trajectory of the two animals came close to each other, while the individual home ranges of neighbouring individuals are mostly disjunct.

There is a high degree of synchrony between the movements of neighbouring individuals (Figure 6). During both day and night, relocations were made in the same directions, however the distances travelled were different between individuals. The figure also demonstrates a contact between the deer occurring on one of the nights.

There is also a high degree of seasonal synchrony (Figure 7). The figure shows movement of the dominant female Aven and subdominant Kerstin. The spring daily home ranges of both females overlapped; they were overlapping during the period of giving birth to fawns and nursing in early June. During this period, the home ranges of both females shrunk. When the fawns started to walk freely, the home ranges expanded, while the subdominant female (Kerstin) was pushed away from the home range of Aven. Interestingly enough, both females used the same route to escape from the disturbance. There is a significant likelihood that these animals are related (mother and daughter).

Interactions between 3 individuals are also easy to present in the 3D space-cube (Figure 8). The parallel synchrony of movements is evident in the figure; however, the movement of some individuals occured in opposite directions. These animals tended to stay together overnight.

Synchronous movement of deer in time and space might be attributed to wind direction (see poster by M. Rodgers et al.) (Figure 9).

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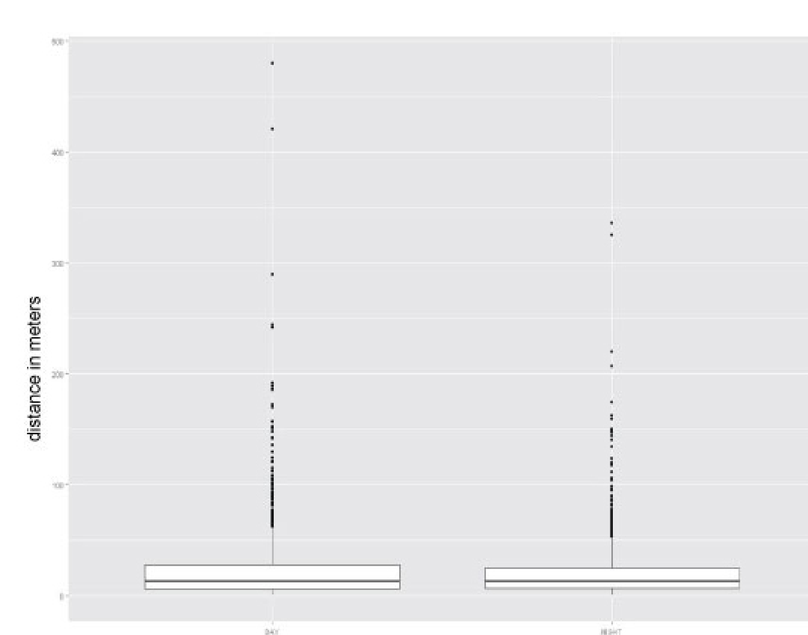

Figure 3. Distances covered by day and night. All individuals combined.

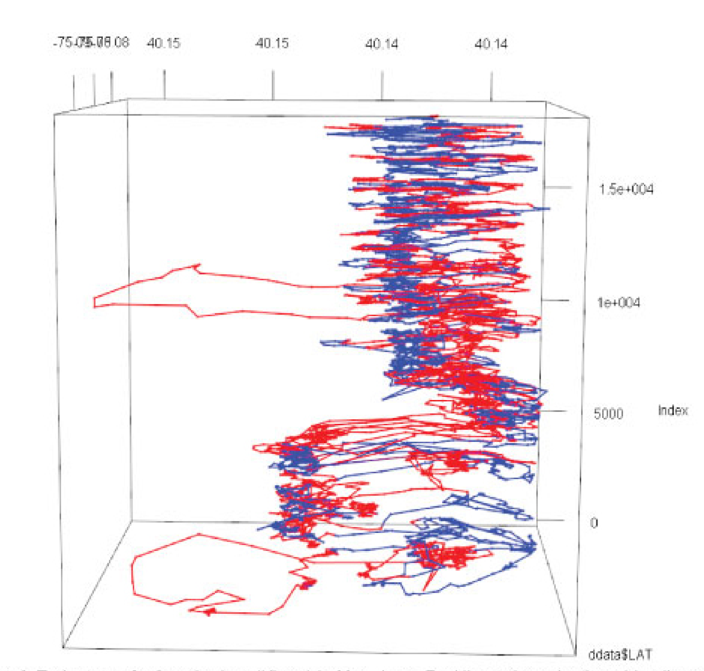

Figure 4. Trajectory of a female deer (Kiana) in May-June. Red lines show daytime, blue lines show night time. There was a significant shrinkage of the daily home ranges on June 23, when the animal gave birth to a fawn. There are two reconnaissance trips: one in May another in June, both made during daytime, and both had an identical route.

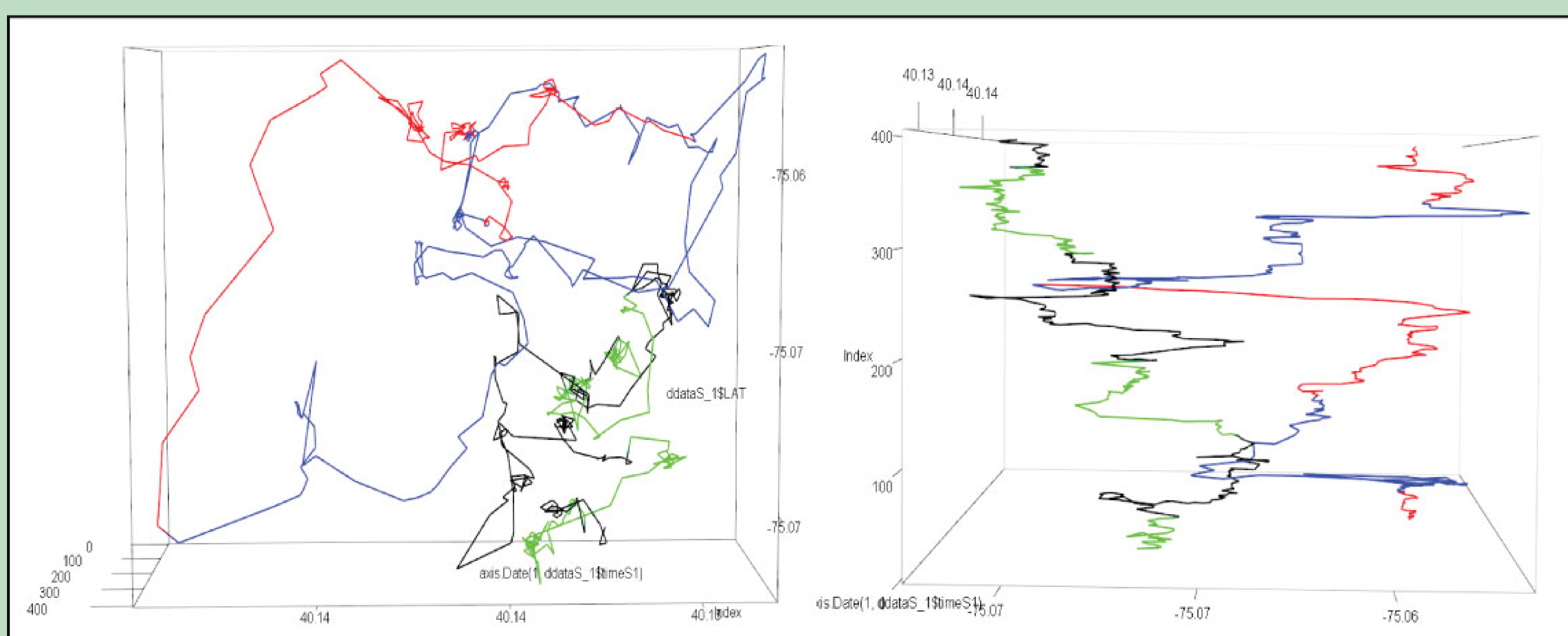

Figure 5. Interactions between Selena (female; red=day, blue=night) and Trevor (young male; green=day, black=night). http://ep.faculty.brynathyn.edu/Deer/ESA/GL1/

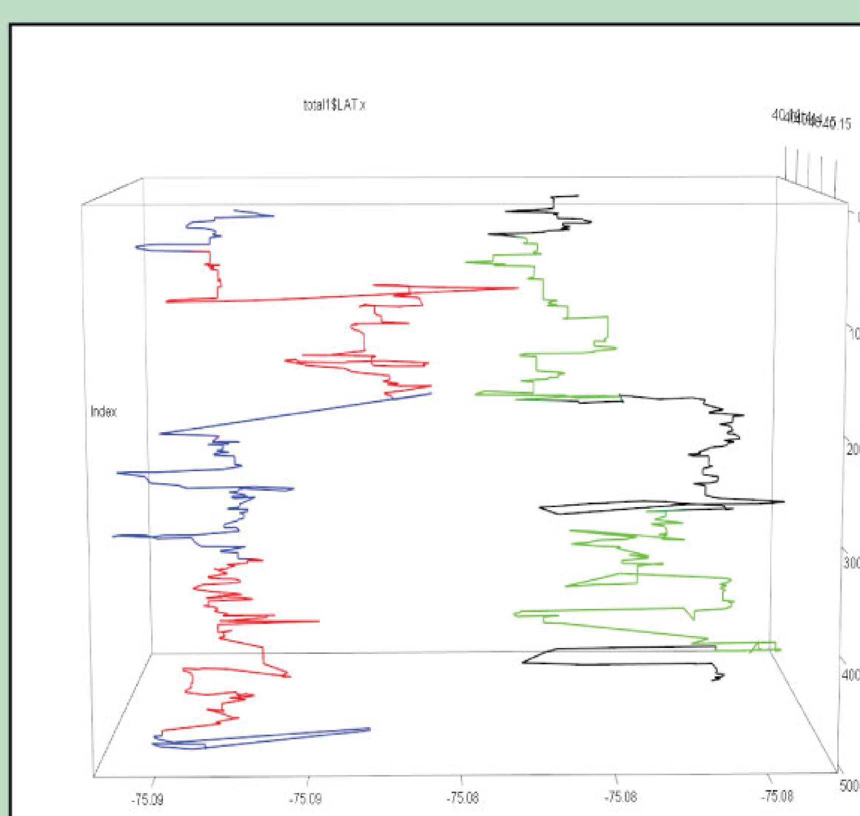

Figure 6. Interactions between Selena (female: (red=day, blue=night).) and Trevor (young male: (green=day, black=night) interacts with female. http://ep.faculty.brynathyn.edu/Deer/ESA/GL1/

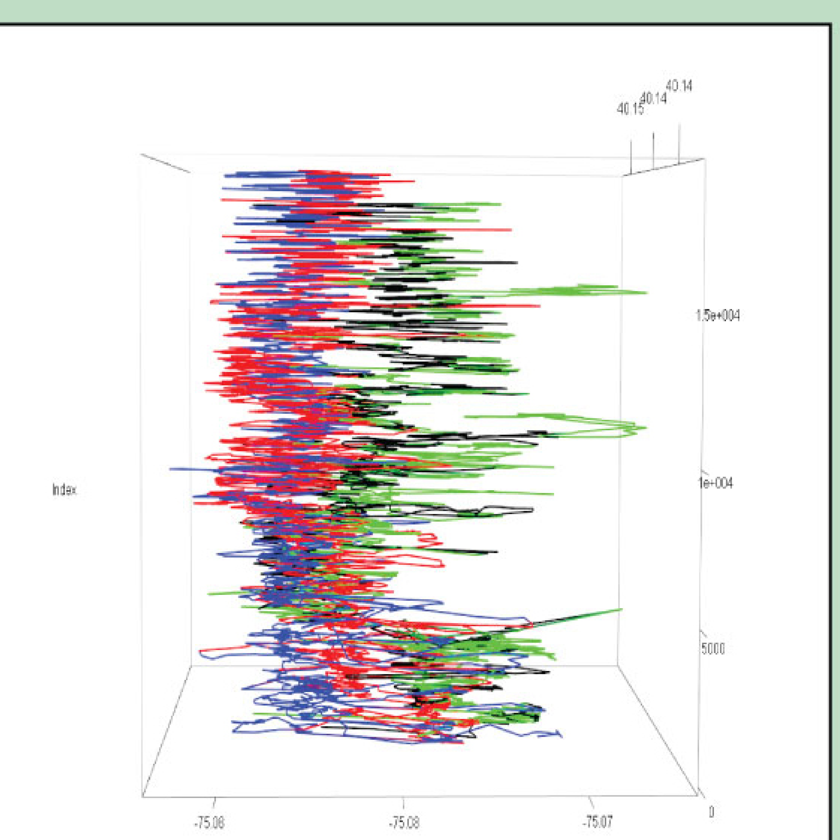

Figure 7. Trajectories of Aven (night: blue, day: red) and Kerstin (night: black, day: green). Both are female with fawns.

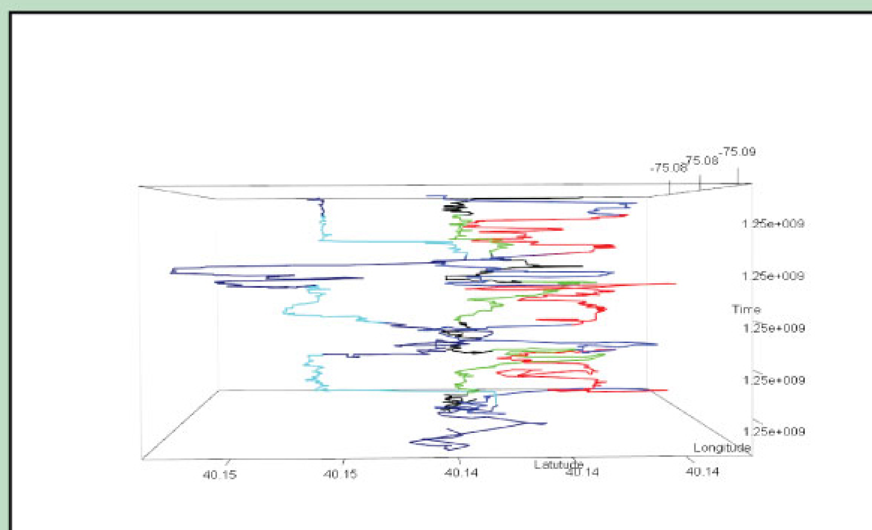

Figure 8. Movements of 3 females (Aven, night: blue, day: red), Kerstin (night: black: day: green) and Carina (night: cyan, day: dark blue).

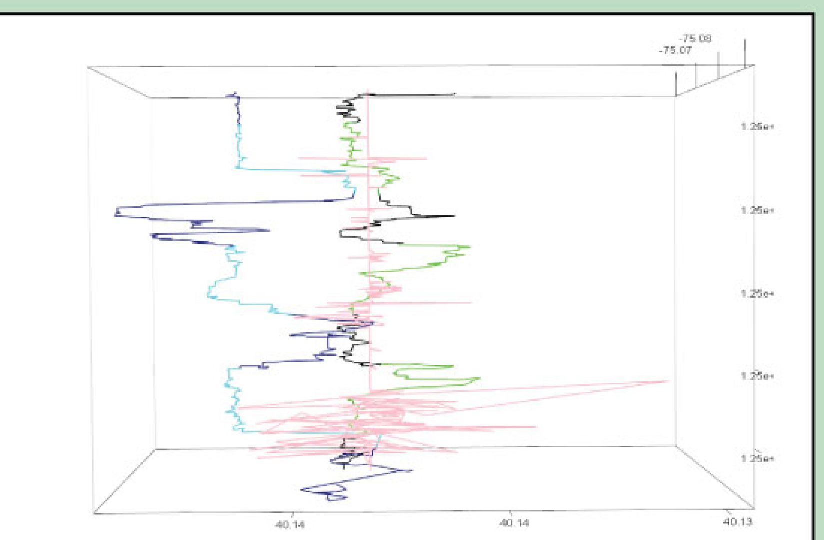

Figure 9. Movements of 2 females Aven (night: blue, day red, and Carina (day: cyan, night: dark blue) and wind direction and speed (pink).

This research project is funded by Bryn Athyn College, the Grant Doering Research and Study Trust Fund, and the Pennypack Ecological Restoration Trust