Computing Animal Habitat Use at the Population Level: A Time-Geographic Approach

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Abstract

Analysis of movement patterns at a fine temporal scale can lead to greater understanding of how animals interact with their surrounding habitat; particularly where researchers are interested not only in determining where animals spend their time, but when and how likely are they to interact with available habitat types throughout the day. For practical conservation concerns, these animal interactions summarized at the population level may be valuable as a view into greater behavioural processes. This paper extends two geocomputational approaches, a voxel based space-time prism and a comprehensive probability surface, to quantify the probability of habitat cover type interaction for multiple individuals within a specific space at a given time throughout the day. We evaluate the use of this approach using tracking data for a Black skimmer (*Rynchops niger*) population in the Amazon region in South America. A habitat interaction graph was constructed to summarize interaction by habitat type and by time of day for all individuals tracked.

Keywords: animal interactions, movement, mobile objects, habitat use

1. Introduction

Developing an understanding of how mobile objects traverse space is of particular interest to a number of fields, including but not limited to GIScience and Ecology (Long et. al., 2015). In the context of wildlife movement research, it is important to understand how an animal uses its habitat throughout the day. Fine-scale movement patterns can provide insight to this daily habitat use activity. Recent advancements in time-geographic analysis provide a means to evaluate probable locations of moving objects (Long and Nelson 2013, Winter and Yin 2011). Specifically, a probabilistic space-time geocomputational approach can be used to map which spatial locations are most probable for an entity's location at a given time, where known constraints limit their movements. Previous research has modelled known locations of habitat use (Byrne et. al. 2014, Lewis et. al. 2011, Web et. al. 2010) but few if any have quantified which areas are more probable for potential use. Downs (et. al. 2014) examines fine temporal scale movement patterns for individual animals, however this research did not extend the concept toward practical conservation use at the population level. This paper extends two geocomputational approaches, the voxel based space-time prism (Downs et. al. 2014) and the comprehensive probability surface (Loraamm and Downs 2015), to quantify the probability for particular habitat cover type interactions for multiple individuals within a specific space at a given time throughout the day.

2. Study Area and Data

Black Skimmers are piscivorous waterbirds found in the Americas, India and Africa. For one South American subspecies, the Amazonian black skimmer, large populations can be found particularly between the months of September and April along the Pacific coast regions in Peru and Chile. While previous studies have revealed broad-scale, long distance migration movement patterns, little is known about how these birds use the complex inland landscape of the Amazon region seasonally (Davenport et. al. 2016). To quantify habitat use using a time-geographic approach, a total of seven Black Skimmers were tracked in this region from August to December of 2014 from capture and tagging at two Manu National Park locations in the Amazon region. Each bird was outfitted with a 5g ARGOS PTT 100 transmitter (Microwave Telemetry, Inc.—MTI) attached using a backpack harness. Transmitters enabled capture of GPS fix locations at reasonably regular intervals. Each individual was tracked on a daily basis on a 90 minute average time interval between fix locations, with roughly 48-hour downtime periods between tracked days, for transmitter recharge. In total, the extent of fix locations covered 863,000 square miles with over 750 location fixes collected. Coordinate positions spanned from offshore locations west of metropolitan Lima, east through Manu National Park, and south to Paraguay in the case of one tracked individual.

These seven skimmer individuals were tagged inside Manu National Park, Peru. Habitat type (land cover) information used in this analysis was collected from the European Space Agency Climate Change Initiative's (ESA CCI) *Annual Land Cover Map 2015 (v2.0.7)*. This dataset reflects 22 land cover classifications corresponding to the UN Land Cover Classification System, at a 300m cellular resolution globally.

3. Computation of Population Level Habitat Interaction Probabilities

This paper demonstrates a time-geographic approach quantifying habitat use for a sample of a black skimmer population who were fitted with GPS transmitters in Manu National Park, Peru during August to December 2014. Once respective GPS fix datasets for each skimmer (hereafter, trajectories) were collected, coordinates in each trajectory were ordered in sequence by ascending date/time and preprocessed for time, distance, and velocity elapsed between each sequential fix pair. Next, these time, distance and velocity measures were specified as input parameters for the iterative calculation of probabilistic space-time prisms (PSTP) using an implementation of PSTP designed for use with ArcPy under ArcGIS (10.4). While formalisms associated with PSTP are available in (Downs et al. 2014), the core notion of PSTP involves a discretization of locations in space (X, Y) and time (Z) as *voxels* and the assignment of a probability of animal presence for each *voxel* accessible to the animal along its space-time path. *Voxels* are determined to be accessible at a given time-step (step-length determines height Z) given known animal movement characteristics (velocity, time elapsed etc.) between a coordinate fix location *A* relative to the next location *B*. Once determined to be accessible to the animal during the time-step, a probability of presence is assigned to each accessible *voxel* based on a distance-weighting function. A collection of *voxels* representing a particular time-step of the analyzed trajectory is called a *space-time disk*. The sequence of *space-time* disks describing a trajectory is referred to as the *probabilistic space-time prism* (Figure 1).

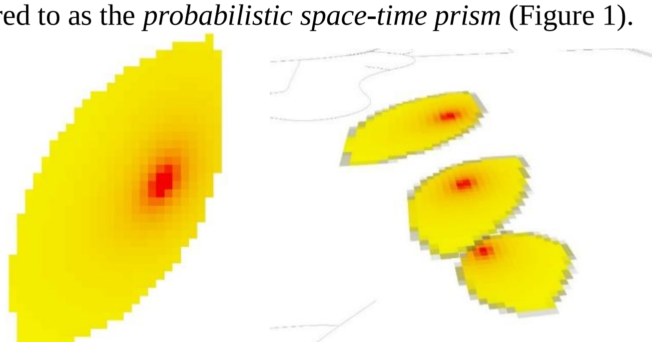

Figure 1. Left: A single space-time disk, comprised of voxels recording animal location probability values. Right: A sequence of disks, constituting part of a probabilistic space-time prism (Loraamm, et al, 2017 (under review)).

For this research, PSTP prisms were calculated from input trajectory data at a 50m voxel spatial resolution with a 5-minute time step length. Prism raster datasets were labeled with their corresponding time of day based on this 5-minute interval. For each 30-minute interval occurring in a 24-hour day, prisms falling with in the 30-minute interval were collected and a comprehensive probability surface for the 30-minute interval was calculated. The comprehensive probability surface (Loraamm and Downs 2015) is a method for summarizing a total probability of animal presence across a timeframe larger than the time-step length of input prisms; it is often used for subsequent overlay analyses providing environmental context to prism information. Based on generic formulations for the logical "OR" operation, *P(A) OR P(B) = P(A)+P(B)-P(A)P(B)*, the comprehensive probability surface (CPS) approach recursively performs the logical "OR" for overlaid space-time disks until the entire prism is considered.

$$R_1 = T_1 + T_2 - T_1 * T_2$$

$$R_2 = R_1 + T_3 - R_1 * T_3$$

$$R_n = (R_{n-1}) + (T_{n-1}) - [(R_{n-1}) * (T_{n+1})]$$

Equation 1. Recursive calculation of the CPS. At initialization, the first comprehensive surface result R_1, is the logical "OR" result for the first two input space-time disks in the space-time prism, T_1 and T_2. For all following iterations R_n, the previous R result is applied to the calculation (Loraamm and Downs 2015).

The resulting set of 48 CPS surfaces, each representing the probability of animal presence at a specific 30-minute window in the study area, were overlaid with the ESA CCI land cover dataset. For each 30 minute window, the set of voxels having nonzero probabilities overlaying each respective cover type were collected and a mean probability value was calculated. Results indicate the mean probability of animal presence in a particular cover type at a particular time of day, at a 30-minute resolution. A ranking was applied to the results isolating the top 10 cover types visited by tracked individuals.

4. Results

For the seven individuals tracked, 19 of ESA CCI's 22 global land cover classification types were visited at some point during the collection period. Most prevalent among cover types visited/utilized were *Mosaic Natural Vegetation (Tree, Shrub or Herbaceous >50%, <50% cropland)* and *Shrub or Herbaceous Cover, Flooded, Fresh/Saline/Brackish Water*, these types also represent significant land area in the study region. Flooded Shrub or Herbaceous cover strongly spatially co-locates with river bank areas, and other wetland areas, by visual interpretation of corresponding aerial imagery at the study site. Mosaic Natural Vegetation corresponded with a range of land configurations; for the study area, Mosaic Natural Vegetation is generally upland of Flooded Shrub or Herbaceous cover; it often exists at the periphery of agricultural developments.

Examined along the timeframe of a 24-hour day, Mosaic Natural Vegetation was most likely to be visited by individuals tracked between the hours of 5:00 AM and 8:00 AM, study area local time. Flooded Shrub or Herbaceous cover activity increases as Mosaic Natural Vegetation likelihood decreased over the course of the morning hours, from 7:30 AM to 10:30 AM, study area local time. A period where inhabited cover types do not appear particularly specialized follows between 10:30 AM and 12:30 PM. For individuals exposed to urban cover, the most active periods ran from 12:30 PM to 2:00 PM. Generally, animals were more likely to favour fewer cover types during daylight hours, while evening and night hours did not appear to display this kind of specialization.

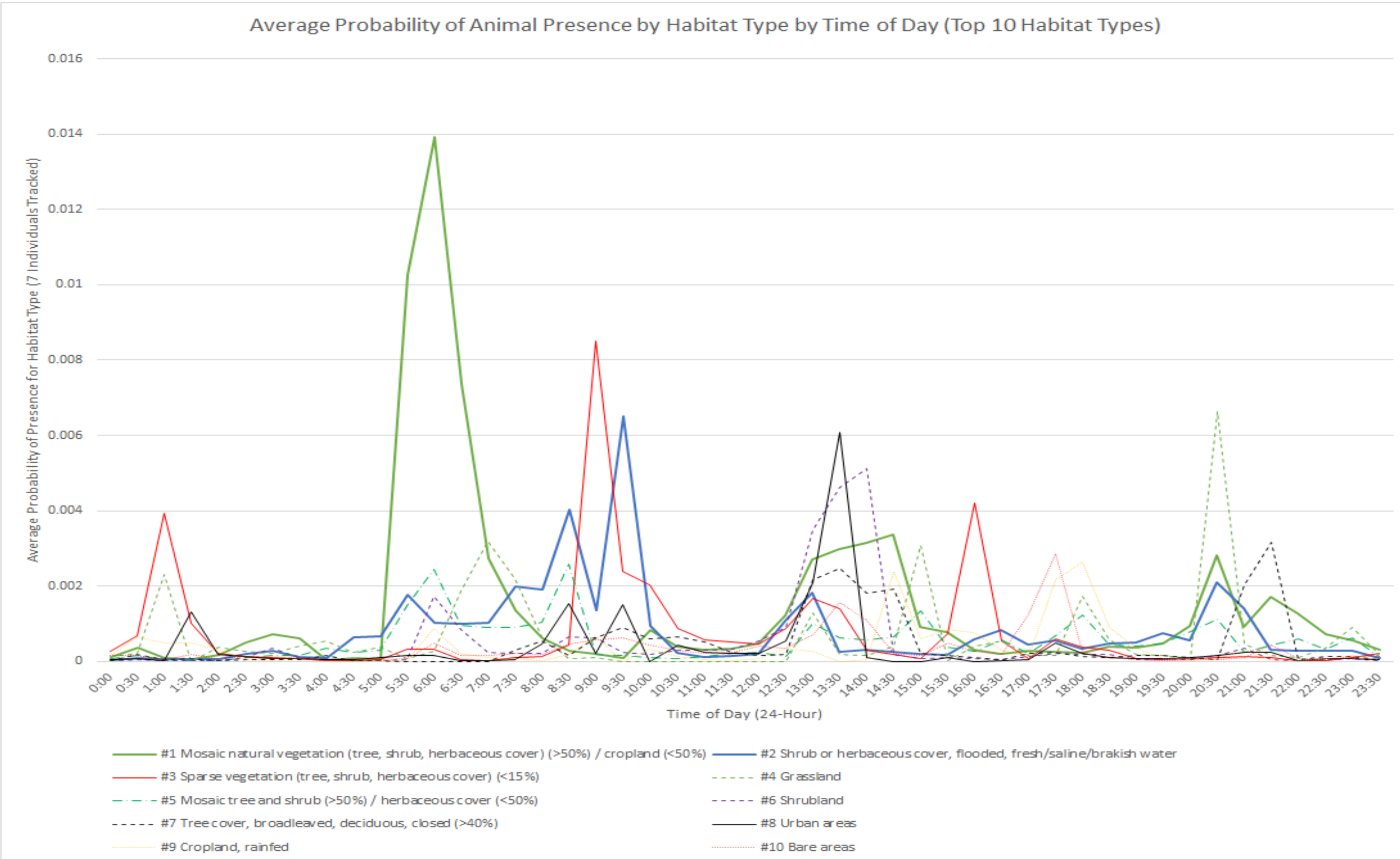

Figure 2. Comprehensive habitat utilization graph for the population of individuals tracked. Each line on the graph summarizes probability of interaction for each habitat type by time of day. Results indicate the average probability for all voxels of cover type that a tracked individual came in contact with, at a 30 minute temporal resolution for all days tracked.

Discussion

It should be noted also that user selections for spatial and temporal resolution values, for both the PSTP and CPS construction, have a considerable effect on the level of computational effort required to produce results. Future research investigating these results should focus on establishing causal relationships between patterns revealed under PSTP/CPS application, and the greater ecological processes they represent. For example, the PSTP/CPS approach might assist researchers in the construction of preliminary activity budgets for species of interest, or in the identification of specific behaviours occurring at particular times of day across particular types of land cover. Expert interpretation and ground-truthing by field observation could provide validation for result sets generated by the PSTP/CPS method described in this research. Additional investigation into possible serial correlation in animal visitation probability between cover type pairs over the course of a day is warranted. Further, application of these method to larger samples of animal trajectories should be explored. Practical goals for methods described here centre on a reduction of field effort in movement ecology research, and developments with respect to present themes associating pattern with process in the ecology literature (Long and Nelson, 2015b).

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