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Research Paper

Measuring the use of green space with urban resource selection functions: An application using smartphone GPS locations

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ABSTRACT

Data describing how individuals use their urban environment is a valuable source of information in urban planning. In many cases, data used for these purposes have low spatial and temporal resolution, or sample size. Equally, comprehensive analytical approaches suitable for these data may be lacking. We present a statistical method borrowed from wildlife ecology and management called a resource selection function (RSF). We apply it to answer questions relating to the selection of urban green space by university students, using a dataset consisting of smartphone GPS location data volunteered by participants. We ask questions relating to urban greenspace selection by comparing used locations to a set of random locations at multiple spatial extents. We found that participants altered their selection of areas according to the surrounding recreational trail density and whether those areas were classified as green space. These relationships were also influenced by season. Our study also demonstrates how the design of an urban RSF can offer different insights by varying the extent of the domain: (1) to an individual's core area; or (2) by excluding from the domain areas that are physically unavailable. We emphasize the importance of matching availability to the research question and conclude by reviewing the opportunities presented by using RSFs combined with GPS location data in an urban context. We argue that RSFs have utility beyond wildlife ecology and management, and, given the increasing availability of smartphone GPS data, can successfully be applied to determine the use and selection of spaces by urban residents.

1. Introduction

Data describing behavioural patterns of city dwellers are fundamental to designing and quantifying the success of urban planning decisions (Gonzalez, Hidalgo, & Barabasi, 2008; Pettit, Lieske, & Leao, 2016). Movement through a road network informs traffic mitigation (Järv, Ahas, Saluveer, Derudder, & Witlox, 2012) and new road development and public transport design (O'Sullivan, Morrison, & Shearer, 2000). Data on green space is used to aid in promoting physical activity resulting in healthier communities (Brown, Schebella, & Weber, 2014). Evidence-based decision-making using observational data supported by statistical inferential procedures, can result in better planning policy and improve the way that we approach urban design (Krizek, Forysth, & Slotterback, 2009).

Self-reporting and survey-based studies dominate the literature pertaining to urban use and mobility (Brown et al., 2014), and such data are influenced by participants' levels of involvement, recollection and enthusiasm, creating bias (Isaacson, Shoval, Wahl, Oswald, & Auslander, 2016). Cellphone call detail records (CDRs) albeit at a coarse scale (Gonzalez et al., 2008; Kung, Greco, Sobolevsky, & Ratti, 2014), offer improved information on population-level urban use and movement patterns than most survey-based data. However, recent advances in GPS technology, specifically GPS-enabled smartphones, have significantly increased the frequency and quality of available spatio-temporal data. In these cases, location data can be recorded at one-minute intervals, and each location is tagged with corresponding estimate of accuracy (Galpern, Ladle, Alaniz Uribe, Sandalack, & Doyle-Baker, 2018), providing high resolution information on movement and urban use. Current applications of location history data to address questions relating to human behaviour are limited and studies that have used smartphone GPS data to ask this type of question have primarily adopted qualitative analysis or descriptive statistics (Kung et al., 2014; Palmer et al., 2013). For example, mapping the raw or filtered GPS data (e.g. Neuhaus, 2015) can be compelling for visualizing spatio-temporal patterns and may help to develop narratives that are broadly accessible to decision-making audiences.

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As a complementary approach, statistical methods capable of identifying non-random associations between urban resources and human behaviour have the potential to offer more robust generalizations at the population-level, for example by estimating the mean behavioural pattern and its uncertainty, or by estimating patters conditional on other urban environmental variables (e.g. Galpern et al., 2018; Hood, Sall, & Charlton, 2011; Vanky, Verma, Courtney, Santi, & Ratti, 2017; Vich, Marquet, & Miralles-Guasch, 2017). Collecting the longitudinally-recorded location histories archived automatically by smartphones presents an opportunity to obtain the sample sizes needed for such statistical estimation. We present an approach developed in a different research context specifically for understanding non-random patterns in the selection of areas when using spatio-temporal data of this type. We demonstrate its application for the identification of causal relationships between people and their urban environment.

1.1. Resource selection functions as ecological models

How and what individuals select within an environment is a long-running theme of research in animal behavioural ecology. In ecology, habitat selection is defined as a behavioural consequence of animals selecting where they spend time and therefore attributes that benefit the animal (Boyce & McDonald, 1999). The approach identifies habitat resources that are actively selected or avoided by animals, enabling management of these resources to minimize impact on the health of wildlife populations (McGreer et al., 2015; Northrup, Anderson, & Wittemyer, 2015; Roever, Boyce, & Stenhouse, 2010). In this regard resource management has a similar goal to evidence-based urban planning. In an urban environment, a focus for planning may be to promote increased selection, or efficient use, of resources by people, often to promote public health outcomes (Agudelo-Vera, Mels, Keesman, & Rijnaarts, 2011).

Resource selections functions (RSFs) are a popular analysis tool used by ecologists to quantify habitat selection (Ciuti et al., 2012; Morrison, Boyce, Nielsen, & Bacon, 2014; Nielsen, Stenhouse, & Boyce, 2006; Whittington et al., 2011), and the model structure is generally applicable to any dataset containing information on locations that were used, but lacking information on those that were available but unused. GPS data meet these conditions (Johnson, Nielsen, Merrill, McDonald & Boyce, 2006).

RSFs contrast locations and associated resources of interest ($x_1 \ldots x_n$) used by the individual with resources found at a set of randomly selected locations contained in an area deemed available to the individual, where the resources have the potential to be encountered. This area is known as the *domain of availability* (Manly, McDonald, Thomas, McDonald, & Erickson, 2002). The advantage this setup has over just summing the number of locations that overlap a specific resource (probability of use), is that, by accounting for the availability of the resource on the landscape, we can infer a behaviour: either selection or avoidance. The difference between the two becomes clear when considering a resource that is rare on the landscape. A sum of the number of GPS points (or proportion of all points) that fall on or near a given resource might indicate its use and these could be compared to other resources. However, such an approach does not control for how common or rare that resource is overall; or, in other worlds, how available the resource may be for use. Critically, RSFs enable an assessment of whether an individual disproportionally uses a resource relative to its availability. Thus, researchers in ecology have gravitated towards the term ‘selection’, and they use the term ‘avoidance’ to describe the reversed (Lele, Merrill, Keim, & Boyce, 2013). In describing our approach, we also adopt this terminology.

In wildlife management, different methods of determining the domain of availability, i.e. the scale of the analysis, are used to answer alternate questions that can result in different estimates of habitat resource selection (Johnson, 1980; Meyer & Thuiller, 2006; Northrup, Hooten, Anderson, & Wittemyer, 2013). First-order selection involves delineating the domain of availability as the entire landscape. This scale of analysis is usually applied to answer questions relating to population distribution relative to large-scale landscape variables. Another common method used when there is interest in how an individual selects its environment at a seasonal or annual scale, is to delineate the “core home range” of each individual, i.e. an area representing where they spent most or all of their time, then select available points within this range (Johnson, 1980). This is known as second-order selection.

Another approach used in many ecological applications, is the masking of habitat to remove areas of a landscape that are not available to an individual and, if falsely determined as available to an individual, could lead to biased estimates of selection (Alldredge, Thomas, & McDonald, 1998). For example, wildlife in mountainous areas are restricted by elevation, with higher-elevation habitat being inaccessible to the animal due to ice and rock. Misinterpreting these areas as available would therefore be incorrect, and would produce incorrect estimates (Northrup et al., 2013).

1.2. Case study: walking behaviour in university students

RSF’s have been commonly used in the field of ecology, wildlife management and conservation biology for nearly 20 years, primarily due to the widespread collection of traditional radiotelemetry as well as GPS radiotelemetry data from animals (Cagnacci, Boitani, Powell, & Boyce, 2010). Spatially-explicit volunteered geographic information (VGI; Haklay, 2013; Lindquist & Galpern, 2016) is a similar data type increasingly used in studies relating to human mobility, specifically in urban environments (Ratti, Frenchman, Pulselli, & Williams, 2006; Semanjski, Bellens, Gautama, & Witlox, 2016; van der Spek, van Schaick, de Bois, & de Haan, 2009). It represents an alternative to self-reported survey-based participation that can reduce bias and cost as well as achieve large sample sizes. In the era of smartphone technology, this data collection method has the exciting potential to open new avenues of research and become the standard (Birenboim & Shoval, 2016). Following the widespread adoption of smartphones in many parts of the world, there are increasingly individuals within urban populations that carry a device with a GPS sensor. Smartphones record locations that far surpasses the typical frequency of data analyzed in wildlife tracking. Critically, the high temporal resolution of these data overcomes analytical problems associated with low fix intervals (Frair et al., 2004) and offers researchers new opportunities to directly observe how individuals navigate, use and select their environment (Gonzalez et al., 2008).

By characterizing movement patterns, these data can be applied to investigate movement related to physical activity. For example, it could be used to support urban design that promotes walking behaviour and healthy lifestyles (Glazier et al., 2014; Sandalack et al., 2013), which may also impact on city air quality, and reduced carbon emissions (Delmelle & Delmelle, 2012). Previous evidence suggests a number of environment factors influence the ‘walkability’ of an area (Christian et al., 2011; de Vries, Hopman-Rock, Bakker, Hirasing, & van Mechelen, 2010; Oakes, Forsyth, & Schmitz, 2007). Urban green space and trail networks are correlated with higher walkability metrics (Toftager et al., 2011), and therefore are linked with improved physical and mental outcomes (Tzoulas et al., 2007). However, the exploitation of city green spaces is dependent on a number of factors, such as general accessibility and weather (Clark, Scott, & Yiannakoulias, 2014; Wright Wendel, Zarger, & Mihelcic, 2012,), and understanding these relationships can inform urban planning efforts aimed at promoting year-round outdoor recreation opportunities.

We present an application of RSF’s within an urban-human context (“urban RSFs”) using a VGI source obtained from university students. We use data collected from GPS-enabled smartphones to identify where students select to walk within the city. Specifically, we investigated how participants’ selection of urban green spaces and associated features such recreational trails and water bodies changes temporally