Modelling functional connectivity pathways for bats in urban landscapes

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Summary: With the extent and density of urbanised land-use set to increase, implications arise for the quality of semi-natural and ecological processes. This paper incorporates empirical evidence from a study of gap crossing within a least-cost path methodology to develop a model of functional habitat connectivity for *P. pipistrellus* within the City of Birmingham. The model takes into particular consideration lighting and distance from trees, which are known to influence routes chosen by this species. The landcover types responsible for delivering function connectivity were then analysed, with initial results suggesting greater importance than would be expected for some landcover types such as gardens.

KEYWORDS: bats; least-cost; networks; connectivity; urban ecology

1. Introduction

Movement between resource patches is an important process in the life history of many species. The role of landscape structure in facilitating movement is of particular interest to landscape ecologists (Belisle 2002). However, structurally connected habitats do not necessarily equate to functionally connected habitats. Additional characteristics of the landscape may also influence the degree to which movement between patches is impeded such as the nature of land-cover and land-use types. Translating species specific responses to movement barriers into travel costs may be a particularly effective approach to estimating functional connectivity (Belisle 2005).

The extent of urbanised land-use is set to increase, characterized by an increase in sealed land-cover density (McKinney 2002) and fragmentation of land-use patches (Luck and Wu J 2002; Zhang et al 2004). Green networks and corridors have been influential in guiding city planning in many areas of the world (Fleury and Brown 1997; Turner T 2006). However, there are very few studies that focus on their role in delivering functional connectivity within urban areas and how this varies with the density and composition of the built form. Some bat (Chiroptera) species are sensitive to structural connectivity as well as land-cover types and land-uses, so are ideal model organisms for analyses of this nature.

This paper seeks to analyse functional connectivity for *Pipistrellus pipistrellus* (Schreber 1774), a nocturnal species of insectivorous bat commonly present in urban areas in the UK. Least-cost analysis is a method widely used to analyse habitat connectivity and animal movement (Ganskopp et al. 2000, Halpin and Bunn 2000, Gonzales and Gergel 2007) but often lacks empirical data to inform cost values (Rayfield et al 2010). This paper demonstrates the incorporation of empirical evidence within a least-cost path methodology to develop a model of functional habitat connectivity for *P. pipistrellus* . This species is known to move preferentially along tree lines (Verboom 1997), and is responsive to artificial lighting (Arelttaz 2000). Estimates of distance and lighting thresholds for gap crossing were therefore derived from field surveys, to inform the modelling of a cost surface. The implications for functional connectivity of an urban landscape were subsequently explored through least cost path modelling.

2. Methodology

2.1 Data Inputs

A high-resolution nighttime photographic survey (2008) was secured for the City of Birmingham (UK), resampled to 1m pixel resolution, ground-truthed and reclassified to represent ground incident lux (lx). Vegetation cover was estimated using aerial near-infrared photography (2007) at 2m pixel resolution and was combined with photogrammetric data (2007) to generate a GIS layer representing trees greater than 4m in height. The lighting and tree cover datasets were used to identify gaps in tree lines suitable for bat surveys. 24 survey sites were selected, stratified between three median distance classes (20-40m, 40-60m and 60-80m) and three median lux classes (0lx, 0-20 and 20+). The flight path of each crossing bat were recorded using thermal and infra red cameras and mapped in a GIS (Fig 1). The crossing distance and maximum lux for each flight path were calculated. Bat activity was recorded at each site, but where no crossing events were recorded, the distance and lux for the darkest possible flight path were calculated. Data from the most common bat species *P. pipistrellus* was then used to inform the creation of a cost surface for the study area.

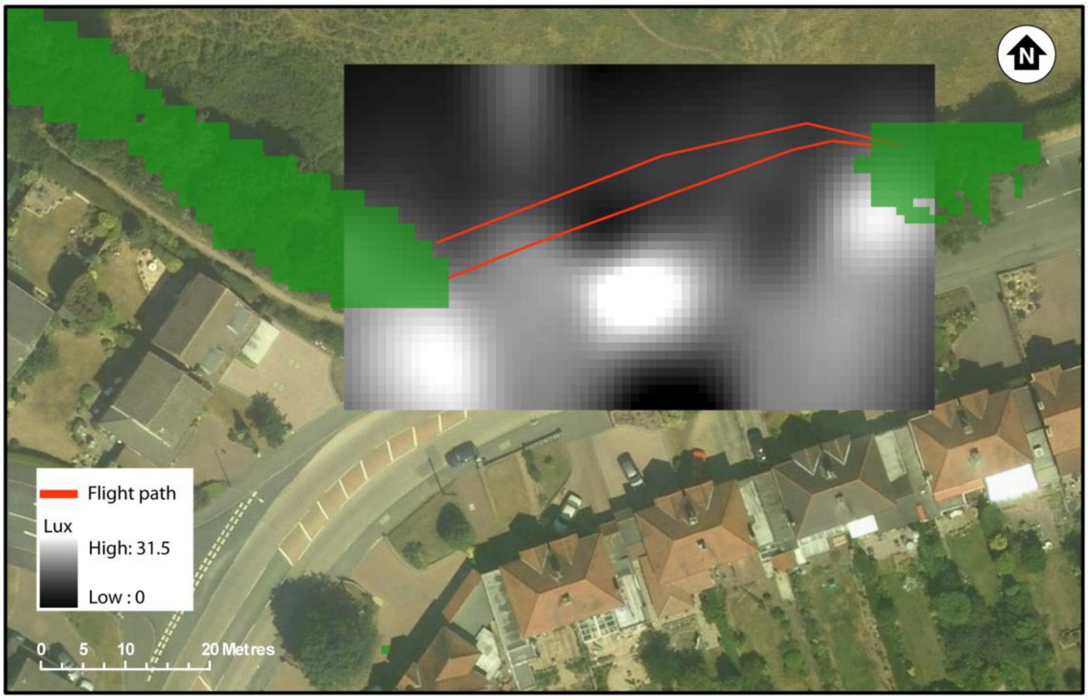

Figure 1: An example of a lit gap in a tree line, overlain with two bat flight paths.

2.2 Creating a cost surface

Using data from the field studies of flight paths, binomial models for gap crossing were developed for both distance from trees (metres) and artificial light (lux). The modelled probabilities of crossing were in turn translated into look-up tables from which distance from trees and light were reclassified into surfaces representing the probability that a bat would move through a given a location. These surfaces were then inverted to convert the probabilities into cost surfaces, then multiplied together to reflect the interaction between distance from trees and light. The final cost surface represents the impedance on bat movement through the landscape.

2.3 Calculating least-cost paths

In order to simulate the movement of our target bat species through the landscape, a series of least-cost paths were developed representing the routes of lowest accumulated cost which bats would in theory be most likely to use. Least-cost surfaces were generated for each of eleven origins, representing a selection of ponds throughout the study area, chosen for similar size and characteristics. Ponds were chosen, given their value as feeding sites for *P pipistrellus* and therefore the importance of their accessibility. A grid of sample points evenly placed at 50m intervals were then specified as the destinations to which least-cost paths would be generated. Only sample points falling within a 500m radius of the associated pond where used as inputs for this stage of the analysis, as this was the maximum spatial scale found to be relevant to explaining *P. pipistrellus* activity on urban ponds (Hale et al. in press).

The least-cost paths were made into a network data set, then using an Origin Destination (OD) cost matrix the length of routes along the least-cost paths to each destination was calculated using ArcGIS Network Analyst. The number of sample points whose least-cost path to the pond was less than 500m was used as an indicator of functional connectivity. This was intended to reflect the proportion of landscape that theoretically has access to each pond, facilitating comparison between different parts of the landscape.

By buffering the least-cost paths from each pond by 10m and extracting the underlying landcover as represented by the Ordnance Survey MasterMap topography layer, an indication of the land cover types responsible for delivering least-cost paths at each site was derived. In addition, for each pond the proportion of land cover within 10m of the paths was compared to the overall landcover within 500m of the pond. This provided an indication of land cover types that were disproportionately responsible for delivering connectivity.

All data processing and analysis was computed using python script with ArcGIS10.

3. Results

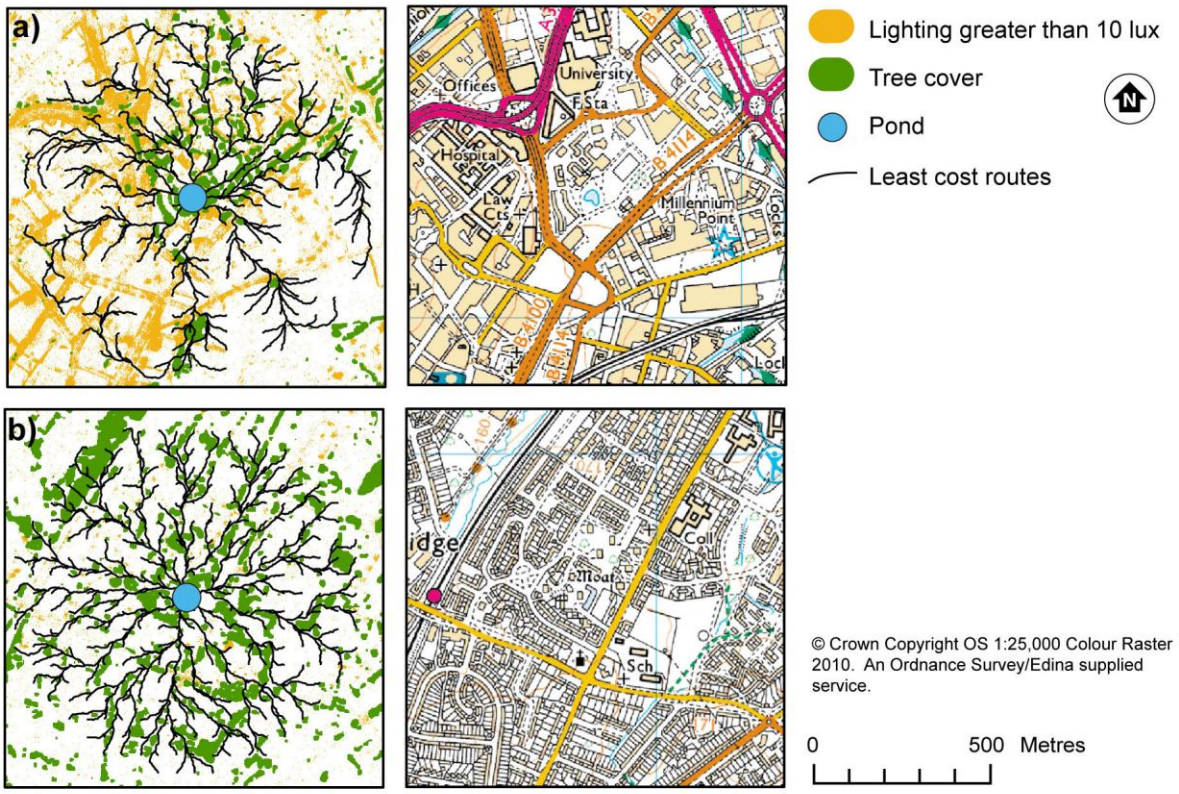

Figure 2: Contrasting least -cost path networks surrounding a) a city centre pond and b) a pond located in a residential suburb

The landscape across the study area varies both in the density of built landcover as well as associated tree cover and lighting levels. These in turn influence the functional capability of the landscape. For example, figure 2 shows the least-cost paths for two of the ponds studied. Pond A is situated in a city centre location with the density of built landcover within 500m at 81%, with a proportion of sample points with least-cost paths to the pond of less than 500m of 58%. Meanwhile Pond B is situated in a residential suburb with a built density of only 39% and with 69% of points reached within 500m. In general, there is a pattern of decreasing landscape connectivity with increasing built density. 40% of least cost routes pass through the built form (man-made surfaces), while of the remaining landcover types, gardens account for 31% of routes and semi-natural green spaces account for 24%. These figures, however, fail to account for the proportions of overall landcover available. The next step was, therefore, to take into consideration the difference between the proportion of land cover responsible for delivering the least-cost paths and the overall proportion of that land cover type available. Figure 3 shows that gardens appear to deliver a greater proportion of least-cost paths than would be expected if all landcover was favoured equally. Meanwhile roads and other built surfaces are less favoured. The variation between sites appears to be due to the surrounding built density, with gardens delivering a disproportionately high level of connectivity in low density areas.

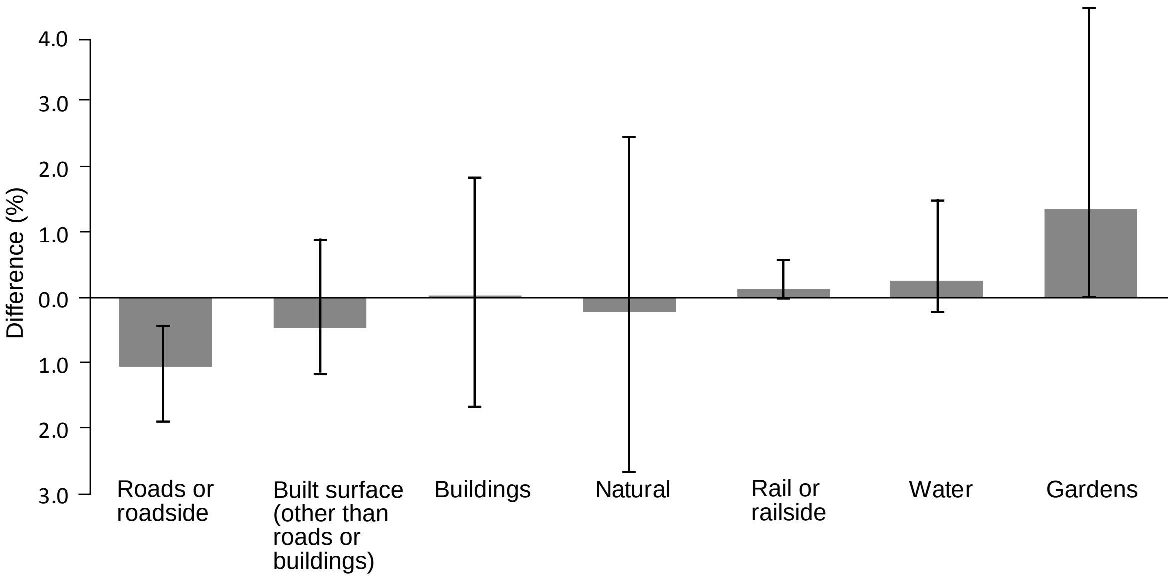

Figure 3: Difference between landcover delivering least-cost paths and entire landcover available within 500m of ponds

4. Discussion

The initial results presented suggest greater importance for some landcover types such as gardens than would be expected, in delivering connectivity. That modelled functional landscape connectivity for *P. pipistrellus* appears to reduce with built density has implications for housing density targets and urban biodiversity policy. The results are potentially sensitive to the way in which the empirical evidence is interpreted and input into the model and further work is, therefore, also required to test the sensitivity of the model to these inputs. In addition, the spectral quality of the lighting and composition of the tree lines may also be significant and should be explored further.

One limitation is that the model assumes all individuals within a population have the same ability and motivation to disperse and that they incur the same movement costs. This may not be the case (Belisle 2005) and models may be further refined to reflect this. A second limitation is that our model assumes individuals are dispersed evenly over the landscape and are all trying to move towards a central point (pond). In reality, roosts will not be spread evenly and bats may move between several ponds and other feeding areas. Therefore, future work might also consider modelling connectivity between potential roost locations and multiple feeding destinations and comparing bat activity of routes with differing modelled costs.

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7. Biography

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