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Using Circuitscape to identify potential landscape corridors for the lesser horseshoe bat in Ireland

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1 Executive summary

- The Irish lesser horseshoe bat population consists of three or possibly four sub-populations and this report presents the results of a modelling study funded by National Parks and Wildlife Service during 2020 to produce a baseline map of potential ecological corridors to connect these.
- The modelling was conducted using Circuitscape, which is predictive software that uses electrical circuit theory to represent the landscape as a resistance surface through which a species can move according to resistance values posed by landscape features.
- The following datasets were used: roost data from all six counties in which the lesser horseshoe bat occurs; GIS information for land cover, distance to roads, distance to rivers, density of linear features; and density of street lights.
- Four different model scenarios were created:
  Scenario One examined the interaction between all roosts in all regions at landscape scale;
  Scenario Two examined the interaction between roosts in the northern and central regions;
  Scenario Three examined the interaction between the central and southern regions; and
  Scenario Four examined the interaction between roosts in east Kerry and south Limerick at a local scale.
- Model outputs identified pathways of potential connectivity within the landscape and areas of restricted movement (pinch points).
- There are high levels of local connectivity between roosts within each of the three regions but limited connectivity between the regions (Scenario One).
- There is good connectivity within and between the northern and central regions (Scenario Two).
- There is less scope for connectivity between the central and southern regions (Scenario Three).
- There are potential pathways to connect roosts in Limerick with those in east Kerry (Scenario Four) but field visits and detector studies are necessary to verify these.
- The high level of artificial illumination identified for the cities of Galway and Limerick may be acting as a barrier to movement; County Limerick has the highest density of street lights per m^2, while County Mayo has the lowest.
- Addressing the findings of this study will require a co-ordinated approach by a range of stakeholders at a landscape scale, ideally working to an Action Plan for the species.

2 Introduction

The lesser horseshoe bat (*Rhinolophus hipposideros*) is restricted to six western counties from Cork to Mayo in the Republic of Ireland and is the only Annex II bat species in the country. It is a highly sedentary species that relies heavily on linear landscape features (hedges, stonewalls, treelines, rivers and woodland edges) along which to navigate and avoids flying across open areas (Schofield, 2008). This species is also extremely photophobic and has strong positive associations with broadleaf woodland and riparian vegetation (Bontadina *et al.*, 2002; Boughey *et al.*, 2011; Motte and Libois, 2002; Reiter *et al.*, 2013). These characteristics make it particularly susceptible to changes in agricultural practices and the expansion of urbanisation.

Although the most recent population estimate for this species reflects an increase and is considered to be approximately 13,000 animals, other features of its conservation status are now inadequate, including range and habitat (National Parks and Wildlife Service, 2019). Using Species Distribution Modelling, Lundy *et al.*, (2011) identified a gap in the species' distribution, which is likely to have continued to expand in the intervening years. Two regions populated by the lesser horseshoe bat, one in Clare/Galway and one in west Cork/Kerry, are divided by a gap of marginally favourable habitat in Limerick and north Kerry. Although the land is currently marginally favourable for the species, its continued occurrence in this area could have important conservation implications for preventing further fragmentation of the meta-populations. However, the latest genetic research has highlighted that the lesser horseshoe bat population in the Republic of Ireland is no longer homogenous (Dool *et al.*, 2016; Harrington, 2018) and there is now a possibility that it consists of four isolated meta-populations in counties Cork and Kerry, Limerick, Clare and south Galway, and north Galway and Mayo. Unless steps are taken to reverse or halt this isolation, this places the species at risk of population decline and greater vulnerability to extinction (Rossiter *et al.*, 2000).

One method to identify functional connectivity within a landscape, by which these meta-populations could be linked, is to use predictive software, eg, Circuitscape (McRae *et al.*, 2008). Functional connectivity can be defined as the degree to which the landscape facilitates or impedes movement of individuals between resource patches (Taylor *et al.*, 1993). Circuitscape is a method of identifying and visualising functional connectivity within a landscape using electrical circuit theory. The landscape becomes a resistance surface through which a species can move according to the resistance scores of the various landscape features within it. Resistance scores are based on the permeability of that feature to the movement of the focal species. The model outputs allow us to examine connectivity within the landscape and identify important pinch points. Pinch points represent areas where movement would be funnelled or bottle-necked and thus may be particularly important to keep intact. Even a small loss of area in these pinch points could disproportionately compromise connectivity (Castilho *et al.*, 2015).

The aim of this modelling exercise is to identify the potential pathways and barriers to movement of lesser horseshoe bats across their known range in the Republic of Ireland. The management practices needed to conserve this species are known, and have proven to be successful, but these now need to be implemented at strategic locations to link meta-populations, rather than as previously undertaken to benefit individual colonies. Knowledge of these pathways is the first step in developing a targeted approach to conserving this species at a landscape scale, which could be implemented by landowners under future funding streams, eg, LIFE programme or the next Common Agricultural Policy (CAP 2020).

3 Methods

3.1 Roost data

The locations and latest roost counts of 261 lesser horseshoe bat roosts in the Republic of Ireland recorded by the National Parks and Wildlife Service (NPWS) Article 17 Report and within Bat Conservation Ireland's (BCIreland) national database were used to create the first three modelling scenarios (please see Section 3.4 for further information). In this modelling exercise, summer and winter roosts were not considered independently. Although there are over 800 roost records for the lesser horseshoe bat in the NPWS database, many of these are multiple records and there is also some duplication of records. Eight additional roost records for counties Kerry and Limerick known to Vincent Wildlife Trust (VWT) were used to create the fourth modelling scenario (please see Section 3.4 for further information). These were not represented in the 261 roost records held by NPWS or BCIreland, but had been reported to Vincent Wildlife Trust (VWT) at various times since 1997. Some were of bats visible within roosts, but others were of droppings only or detector records.

3.2 Map extent

The study area for this project was created by adding a 15km buffer to the current known range (National Parks and Wildlife Service, 2019) of the lesser horseshoe bat. In addition to this, the area around counties Limerick, Cork and Kerry were extended to increase the geographical coverage of the model. This was done to identify potential new routes of functional connectivity between these areas (Figure 3.2.1).

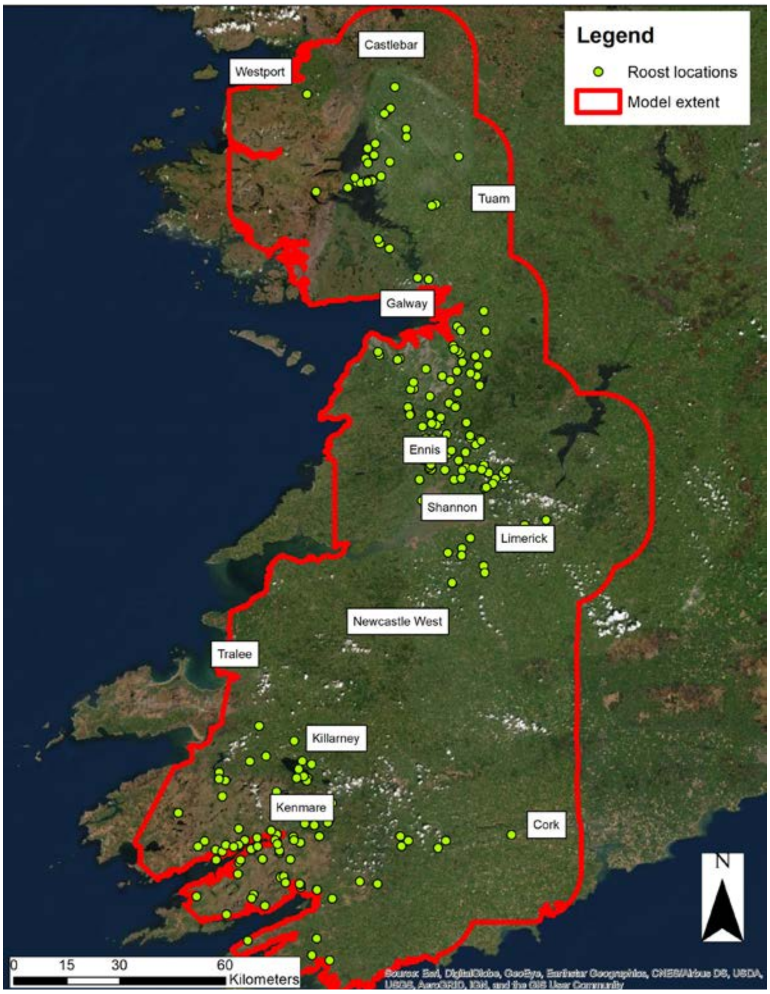

Figure 3.2.1 Extent of the study area for the purpose of modelling functional connectivity for the lesser horseshoe bat along the west coast of the Republic of Ireland.

3.3 Environmental variables/GIS data

Based on the current literature, expert opinion and previous studies on the movement and dispersal ability of the lesser horseshoe bat (Glover *et al.*, 2018; Schofield, 2008; Schofield, 1996), 18 landscape features were selected and ranked based on how resistant they are to the movement of this species. Fifty-metre resolution Geographical Information System (GIS) data for each feature were obtained to create five different environmental variable datasets (see Table 3.3.1). When creating the 'distance to roads' variable, the most current annual average daily traffic volumes (AADT) were obtained and ranked based on the number of vehicles using the roads (Fu *et al.*, 2017). Density environmental variables were based on either the total count (streetlights) or the total length (linear features) of the features within the 50m GIS raster cell. Linear features within the landscape feature 'urban' were also clipped and excluded from the layer. This was done to try and reduce those linear features that consisted of domestic boundaries surrounding properties, rather than actual linear features, eg, hedgerows and stone walls.

Table 3.3.1 Environmental variables and landscape features used in the Circuitscape model. AADT = average annual daily traffic.

Environmental Variable	Feature	Grouped Layers	Rank	Source
Land cover	Broadleaved forest	Broadleaved forest	1	Environmental Protection Agency (2012)
	Scrub	Transitional woodland-shrub	2	Environmental Protection Agency (2012)
	Mixed forest	Mixed forest	3	Environmental Protection Agency (2012)
	Grassland	Natural grasslands, Pastures, Land principally occupied by agriculture, with significant areas of natural vegetation	4	Environmental Protection Agency (2012)
	Green urban areas	Green urban areas	5	Environmental Protection Agency (2012)
	Coniferous forest	Coniferous forest	6	Environmental Protection Agency (2012)
	Lakes	Lakes	7	Environmental Protection Agency (2012)
	Mosaic of habitat	Moors and heathland, Inland marshes, Peat bogs, Sparsely vegetated areas, Bare rocks	8	Environmental Protection Agency (2012)
	Arable	Complex cultivation patterns, Non-irrigated arable land	9	Environmental Protection Agency (2012)
	Estuaries and coastal	Coastal lagoons, Beaches, Dunes, Sands, Estuaries, Intertidal flats, Salt marshes	10	Environmental Protection Agency (2012)
	Urban	Airports, Continuous urban fabric, Discontinuous urban fabric, Dump sites, Industrial or commercial units, Mineral extraction sites, Port areas, Sport and leisure facilities, Construction sites	11	Environmental Protection Agency (2012)
Distance to roads	National Primary Routes (Motorway, National Primary)	Main road	AADT 19,506	Ordnance Survey Ireland (2018)
	A roads (National secondary roads)	First Class	AADT 6,906	Ordnance Survey Ireland (2018)
	B roads	Second to Fourth Class	AADT 4,403	Ordnance Survey Ireland (2018)
	Minor roads (Rural private avenue, Minor roads, Tracks, Footpath)	Fifth to Eighth Class	AADT 1,089	Ordnance Survey Ireland (2018)
Distance to rivers	Rivers	Rivers and streams	N/A	Ordnance Survey Ireland (2018)
Density of linear features	Linear features	N/A	N/A	Ordnance Survey Ireland (2018)
Density of streetlights	Streetlights	N/A	N/A	County Councils (as of May 2020)

3.4 Modelling approach

The movement of the lesser horseshoe bat within a landscape is influenced by the heterogeneity of environmental variables within it and the association of the species with these different variable types. Following a similar modelling framework designed by Shirk *et al*., (2010) and later utilised by Finch *et al*., (2020) and Glover *et al*., (2018), environmental variables were used to create functional connectivity models for the species. Once the raster resistance layers were created for each environmental variable, following the details described later in Section 3.5, they were then combined to create a single multivariate resistance GIS raster. This was then inputted into Circuitscape (Version 4.0.5) to create the functional connectivity models.

In total, four different model scenarios were created. Scenario One examined the interaction between all roosts across the entire range of the lesser horseshoe bat in the Republic of Ireland. Each of the 261 roosts were weighted according to the number of lesser horseshoe bats recorded in them (ie, roost size) and the model was set such that each roost was trying to connect with every other roost in the model extent (one to all). The roosts were then split into different regions based on their geographical locations. The northern region consisted of all roosts in counties Galway and Mayo (n = 39); the central region consisted of those roosts in counties Clare and Limerick (n = 120); and finally, the southern region consisted of all roosts within counties Cork and Kerry (n = 102).

Scenario Two represents the northern and central regions and, in this model, the combined roosts in the central region were set to connect with those combined roosts in the northern region. A similar approach was taken for Scenario Three, which represents the central and southern regions, where all the combined roosts in the central region were set to try and connect with those combined roosts in the southern region. Scenario Four was created by using the additional eight roost records for the east Kerry and the south Limerick areas, a Euclidean distance of approximately 45km. This was done to focus the model outputs to try and further identify zones of high functional connectivity at a more local level.

3.5 Mathematical functions

When examining an ecological system, there is rarely a linear response curve between a species and an environmental variable that reflects an increase in weight assigned to that variable and an increase in the resistance cost of the variable (Etherington, 2016). To account for this, we rescaled the function for our raster data to have a range of response curves based on previous functional connectivity modelling work for the lesser horseshoe bat in Wales (Table 2.5.1; Glover *et al*., 2018).

Table 3.5.1 Slope and maximum resistance values for each of the five environmental variables used to create the multivariate resistance layer.

Environmental layer	Slope values for the multivariate model	Resistance values for the multivariate model
Land cover	5	100
Distance to roads	5	10^8
Distance to rivers	4	2,000
Density of linear features	3	22,000
Density of streetlights	1	10

3.5.1 Land cover

Our 11 discrete land cover features were ranked based on expert opinion in an order of least resistance to highest resistance to the movement of lesser horseshoe bats in the landscapes (Table 3.3.1). A resistance surface for 'land cover' was created using the following equation:

R = (Rank/Vmax)x*Rmax

Where R is the resistance for each raster pixel and Vmax is a constant that represents the highest number of resistance ranks in the model. As stated by Shirk et al., (2010), this means that as the expert opinion ranking moves nearer the highest resistance rank (Vmax), the overall resistance increases towards Rmax at a rate controlled by the response curve (x).

3.5.2 Distance variables

Each of the two continuous distance variable functions were classified in different ways. Euclidean 'distance to rivers' were calculated using the following function:

R = (Det/Vdmax)x*Rmax

Where Det is the distance from the variable, in this case rivers, and Vdmax is a constant that is defined by the maximum distance for that variable. Landscape resistance scores for road raster data were classified using four levels or ranks (19,506, 6,906, 4,403, and 1,089) based on average annual daily traffic (AADT) on each road type. Both distance to and rank of each variable were multiplied by 0.5 so they carried equal weight within the function. As the 'distance to roads' variables were ecological inverse to 'distance to rivers' we used the following function:

R = ((1- (Det/Vdmax))*0.5 + 0.5*(Rank/Vrmax))x*Rmax

Vrmax is a constant that represents the highest number of resistance ranks for 'roads', in this case it is set to the highest AADT (19506). A maximum distance (Vdmax) of 500m for 'rivers' and 2000m for 'roads' were chosen as suitable cut off distances, based on the increased pixel size of the current study and the results from (Glover et al., 2018).

3.5.3. Density variables

A resistance surface for both density of 'linear features' and 'streetlights' were created using the following equation:

R = (Density/Dmax)x*Rmax

Where 'Density' is the density of the raster pixel and Dmax is the maximum density of the layer.

4 Results

The four maps or scenarios produced by the modelling process show varying degrees of functional connectivity for the lesser horseshoe bat throughout its Irish distribution range.
Scenario One represents the total range of the species along the west coast as three main populations; Scenario Two shows the northern and central populations; Scenario Three shows the central and southern populations and Scenario Four shows the Limerick/north Kerry area in greater detail.

Scenario One (Figure 4.1) revealed that while there are high levels of local connectivity between roosts within each of the three regions, there are limited pathways of connectivity between the regions at a landscape scale.

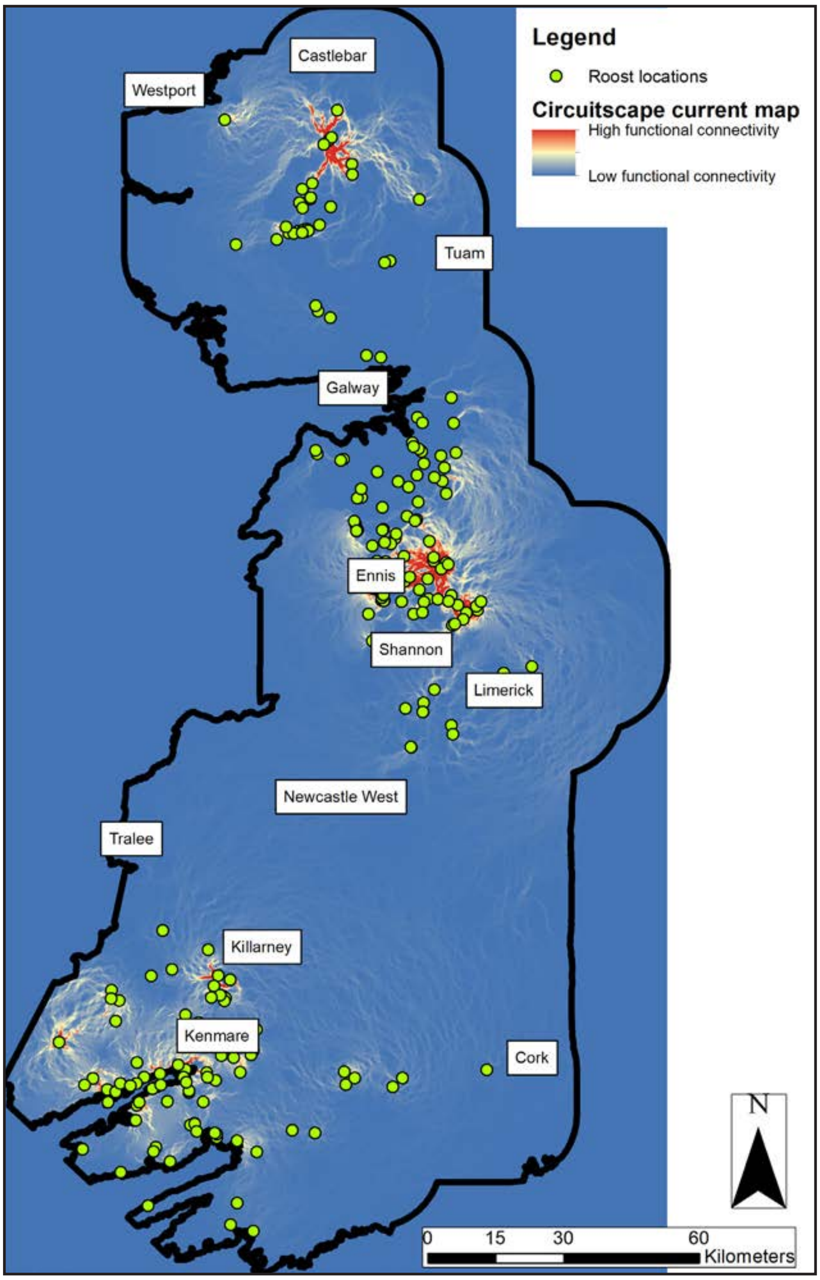

Figure 4.1 Scenario One Illustrating areas of high and low functional connectivity for the lesser horseshoe bat across its entire range in the Republic of Ireland.

Scenario Two (Figure 4.2, indicates that there is a good level of functional connectivity within and between the northern and central areas. However, it also clearly highlights that the area surrounding Galway City is acting as a critical pinch point in the landscape for the species.

Lower levels of functional connectivity can be observed in Figures 4.1 and 4.2, which includes the Burren, despite relatively high levels of bat roosts in this area. There are several reasons for this. Firstly, the extent of the maps were primarily designed to identify areas of functional connectivity between the central and northern regions, rather than within the central region. Secondly, the modelling approach used here, which is based on river systems and woodlands (that are heavily utilised as commuting corridors by bats) is not the most suitable for an area like the Burren, which lacks above ground river systems and large areas of woodland.

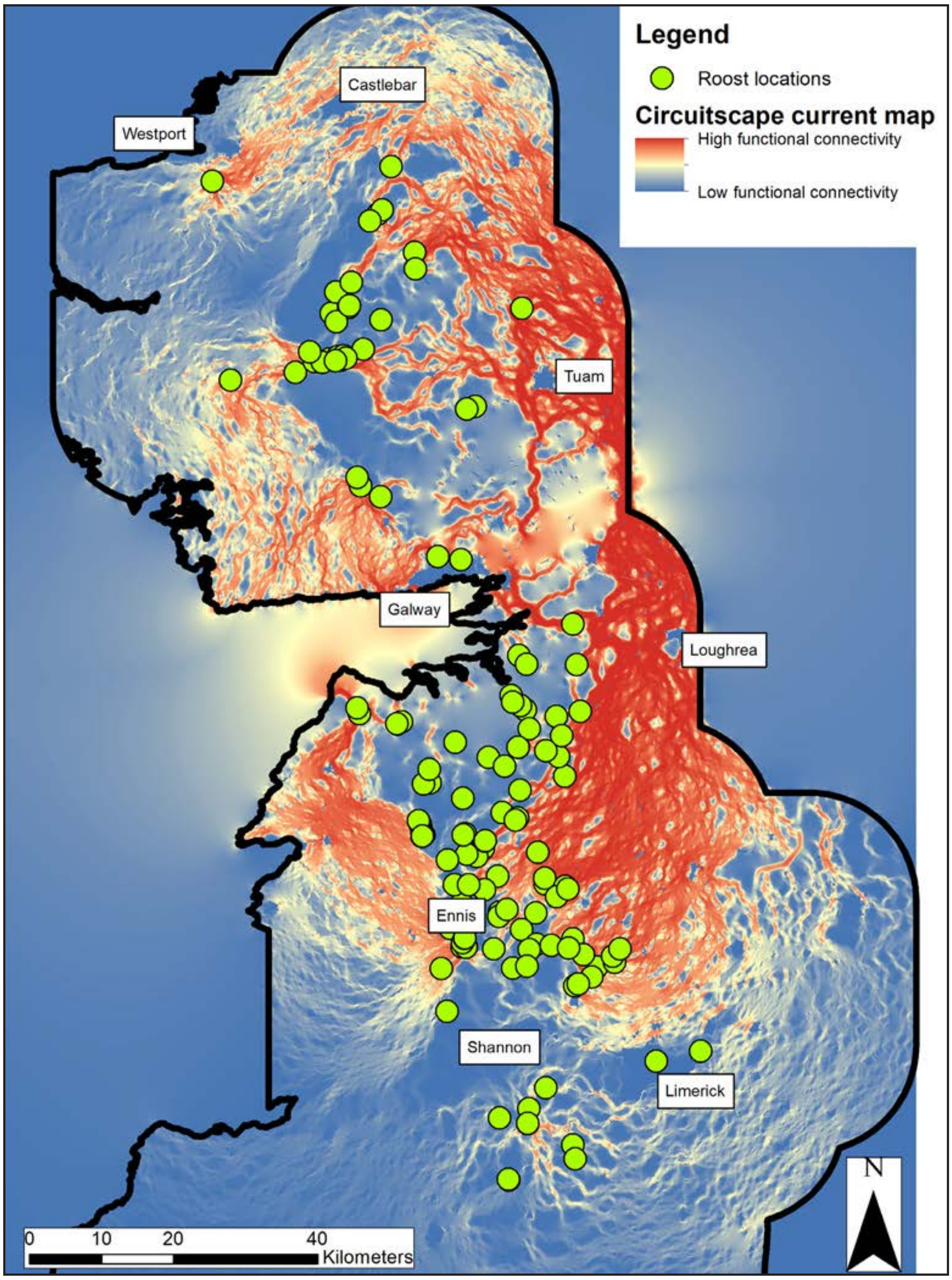

Figure 4.2 Scenario Two Illustrating areas of high and low functional connectivity for the lesser horseshoe bat across the northern and central extent of its range. *The dense area of high functional connectivity, however, along the eastern border of the map, opposite Galway City, should be treated with caution as it is likely to be a product of the model extent selected rather than a true representation of high functional connectivity for the species.*

Scenario Three (Figure 4.3) illustrates that there are numerous, smaller, more dispersed, pathways of connectivity between the central and southern region, although there is less scope for connectivity in this region, compared to that seen in Scenario Two.

Figure 4.3 also shows a lack of high functional connectivity within the west Kerry area. Once again, this is because the map extent was primarily designed to identify areas of functional connectivity between the central and southern regions, rather than within the southern region itself.

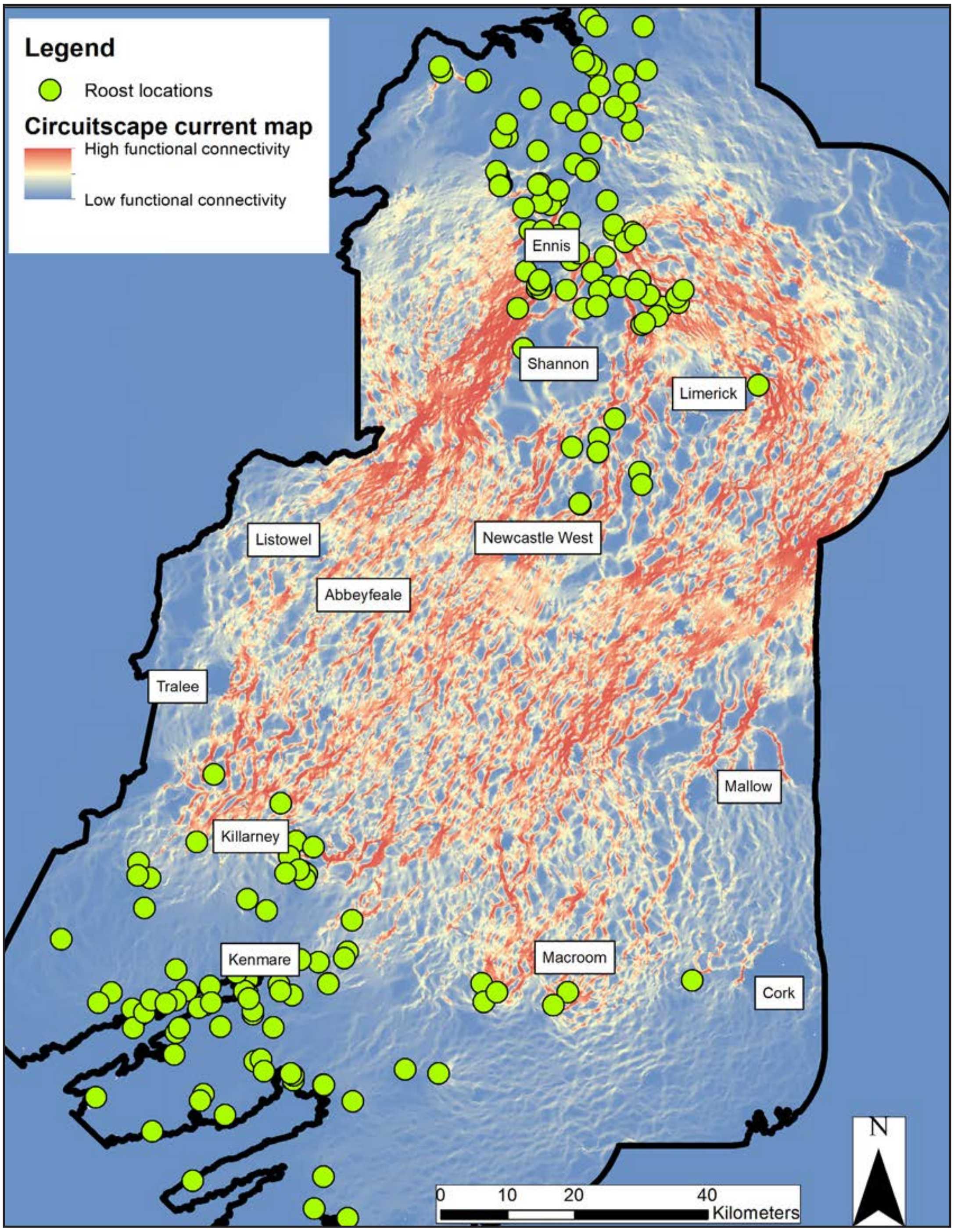

Figure 4.3 Scenario Three Illustrating areas of high and low functional connectivity for the lesser horseshoe bat across the central and southern extent of its range.

Scenario Four (Figure 4.4) shows that there are potential pathways between Rathkeale in County Limerick and Castleisland in north Kerry, but also barriers to connectivity.

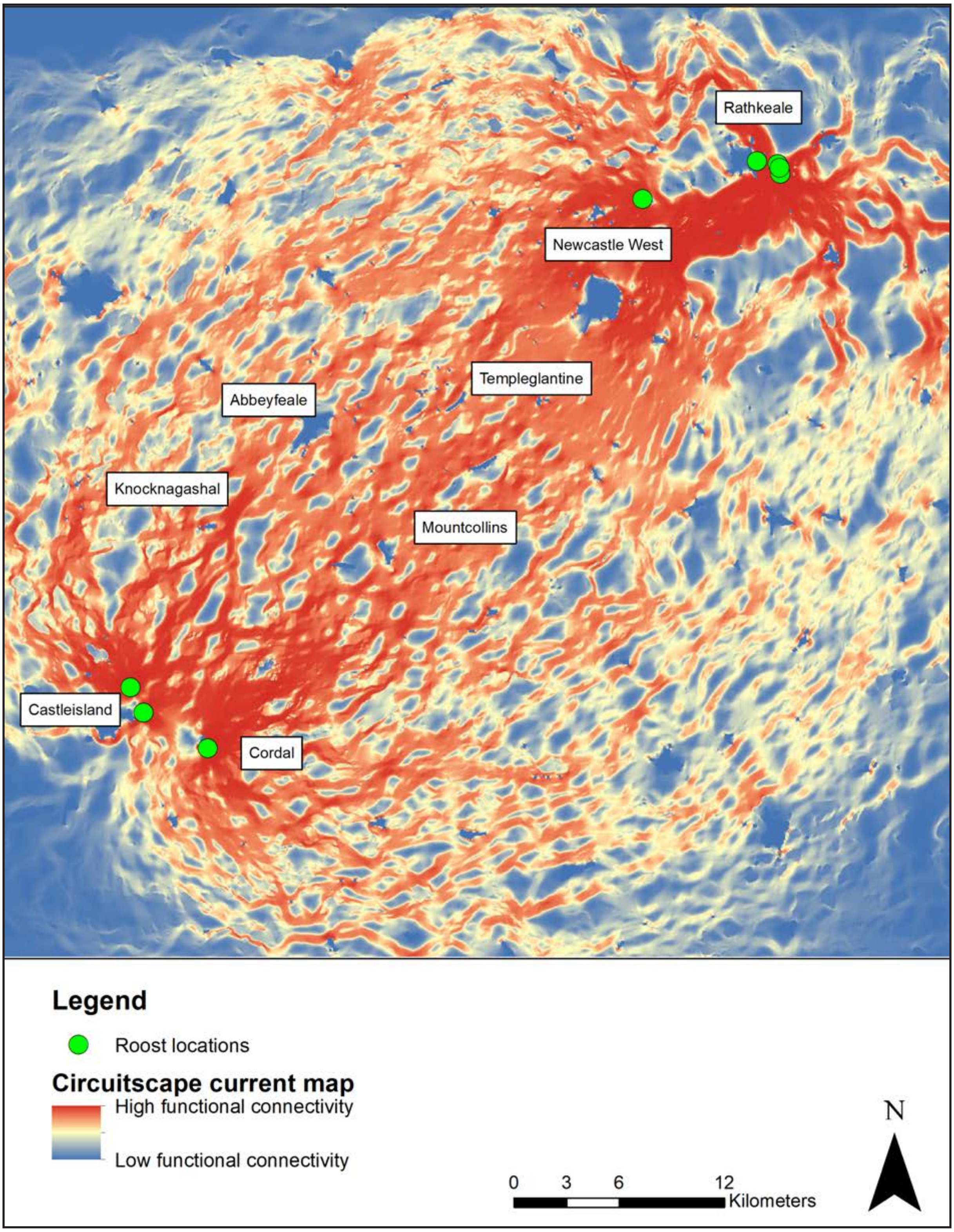

Figure 4.4 Scenario Four Illustrating areas of high and low functional connectivity for the lesser horseshoe bat at a local scale between counties Kerry and Limerick.

Finally, when the eight additional roost records used to create Scenario Four were overlaid with the model output from Scenario Three, they all occurred along the areas of predicted high functional connectivity generated by this model. Figure 4.5 shows the locations of these additional roosts.

Incorporating the lighting data obtained from each county council revealed that there are high densities of lighting surrounding Galway and Limerick Cities, which could be acting as a barrier to the movement of lesser horseshoe bats (Figure 4.5). Table 4.1 shows that County Limerick has the highest density of streetlights per metre-squared, while County Mayo has the least.

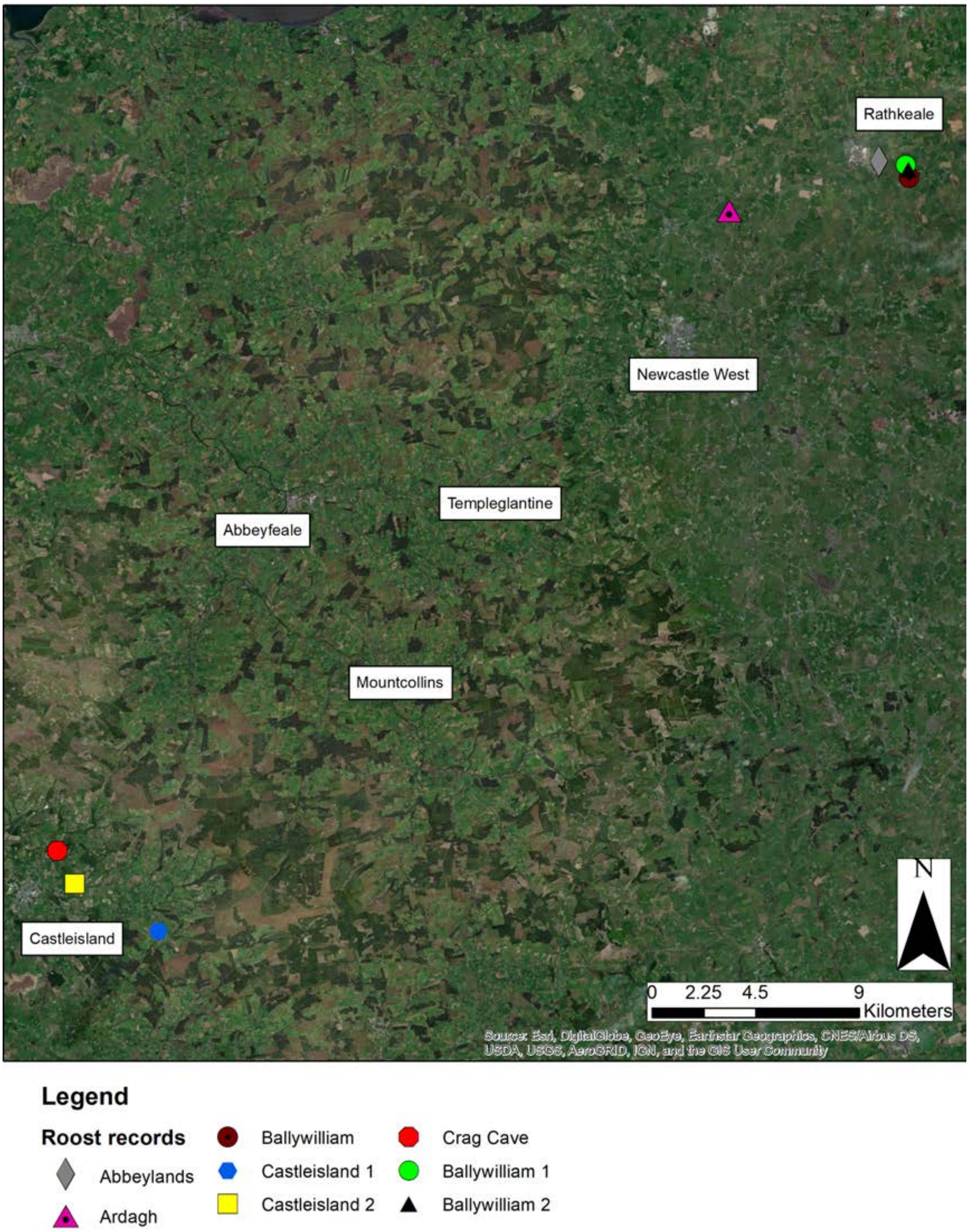

Figure 4.5 The locations of the eight additional roosts in the counties of Kerry and Limerick.

Table 4.1 Slope and maximum resistance values for each of the five environmental variables used to create the multivariate resistance layer.

County	Streetlight density (m^2)
Limerick	$8.19e^{-06}$
Cork	$7.19e^{-06}$
Galway	$4.10e^{-06}$
Clare	$4.18e^{-06}$
Tipperary	$3.96e^{-06}$
Kerry	$3.62e^{-06}$
Mayo	$3.34e^{-06}$

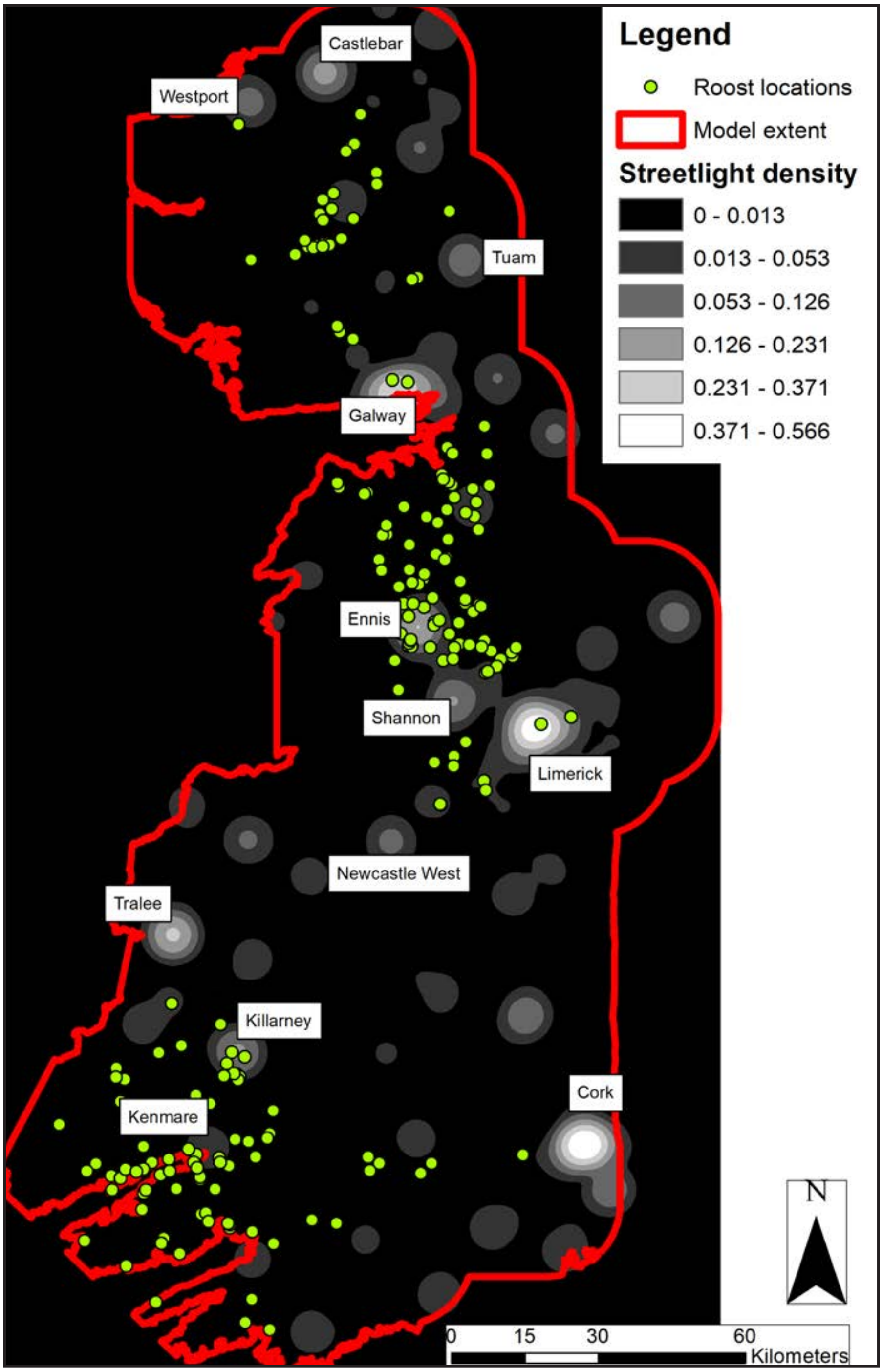

Figure 4.6 Map illustrating streetlight density across the model extent.

5 Discussion

This is the third desktop study undertaken by VWT to investigate the gaps in the distribution of the lesser horseshoe bat in Ireland, but the first to consider these over its entire range and to incorporate data on artificial lighting. The use of Circuitscape in this project indicates there is scope to maintain or create connectivity for the three meta-populations now identified for this species, but further work is necessary to test the outputs of the modelling before any extensive conservation actions are undertaken.

The modelling predicts there are areas of relatively high functional connectivity between roosts in each of the three regions, but there is limited connectivity between the regions at a landscape scale. This may be due to the level of urbanisation associated with the cities of Galway and Limerick, because this study shows that these two cities are responsible for the highest streetlight density in the model, so are acting as barriers to the movement of this photophobic species between the different regions and are therefore major pinch points. In addition, County Limerick (as a whole) has the highest overall streetlight density per metre-squared, compared to any of the other counties within the model. This fact is believed to be a major contributory factor, along with changes to land-use, to the formation and expansion of the population gap between County Limerick and north Kerry/west Cork. The two previous desktop studies undertaken by the Trust between the years 2014-2016 focused on Limerick and north Kerry because knowledge about the lesser horseshoe bat population in these areas was considered critical if further fragmentation of the national population is to be prevented. Lyons (2014) concluded that the lack of natural hibernation sites due to the underlying geology and the uplands of The Stacks, Mount Eagle, Mullagharirk, Cnoc an Iompaithe and Knockanore were limiting the distribution of the species, but that favourable habitat may exist in the extensive system of rivers and streams, especially if these had associated vegetation. This report also highlighted the existence of the former Great Southern Trail railway line as a potential inter-county pathway for bats. Lenihan *et al*. (2020, in prep) used a species connectivity and corridor identification tool (Universal Corridor Network Simulator) to identify areas of potential connectivity in the Limerick and north Kerry area. The results of that study pointed to potential pathways within low lying agricultural land, bordered with hedgerows and adjacent to broadleaved woodland and mixed forestry, and avoiding the upland areas.

The local scale modelling undertaken in this study (Scenario Four) refines these general proposals and predicts there are corridors of connectivity the species could utilise, specifically to bridge the gap between Rathkeale and Castleisland in two sections along part of The Great Southern Trail between Rathkeale and Abbeyfeale, and a second corridor between Abbeyfeale and Castleisland. Rathkeale is within 11km of Limerick's largest maternity and hibernation colony at Curraghchase while small numbers of lesser horseshoe bats hibernate in caves in the Castleisland area, within 18km of the nearest Kerry maternity colonies at Milltown and Ballyhar. Information on the density, quality and structure of the habitat along these pathways would provide the basis for targeting a range of conservation actions in these areas to maintain, enhance or create foraging, commuting and roosting habitats for the species.

Information on the possible presence of lesser horseshoe bat along these pathways could be gained by using static detectors in a way similar to how the species was detected during the Environmental Impact Assessment conducted along the route of the proposed Foynes to Limerick Road, a distance of approximately 17km (EIAR, 2019). The species was detected at 12 out of 19 units placed on trees adjacent to treelines, small blocks of woodland, next to rivers, streams and along an un-used railway track.

6 Conclusion

The outputs from this modelling exercise clearly demonstrate the lack of functional connectivity for lesser horseshoe bats between the three regions that comprise the core populations for the species. It has highlighted the areas where practical conservation measures to increase functional connectivity in the landscape are possible, but also those areas that are acting as a barrier for the species.

The problem that needs to be addressed is the isolation of populations of lesser horseshoe bat and the long-term consequences that this has for the species in Ireland. Any future conservation initiatives must be taken and co-ordinated at a landscape scale rather than focused on individual sites, which has been the approach to conserving the species to date. A landscape approach, however, will involve liaison with a range of stakeholders and ideally should only be undertaken after a species action plan has been produced. Clearly the goal of such an action plan would be to prevent further fragmentation and to create links between the three regions.

NPWS has been undertaking practical conservation measures at lesser horseshoe bat roosts since the late 1980s, when hibernation sites in counties Kerry and Clare were grilled (O'Sullivan, 1994). Since 1994, VWT has undertaken a range of actions to help conserve the species: conducted regional surveys; bought and leased important maternity roosts; carried out desktop studies; advised third parties on roost enhancement; and helped NPWS develop a pilot Farm Plan for the species.

There is a wealth of information and experience about the species within Ireland that could now be incorporated into an action plan, which would list key stakeholders, identify sources of funding, clarify locations for appropriate actions, assign specific tasks to parties to achieve these and set milestones for their completion. The following are examples of some of the actions that could be included in such a plan.

- Undertake a static detector study along the potential pathway highlighted between Rathkeale and Castleisland, with the help of landowners, community groups, local authorities, Local Authority Waters Programme (LAWPRO), etc.
- Commence a NPWS Lesser Horseshoe Bat Farm Plan Scheme targeted at the areas highlighted as potential corridors.
- Include actions for the lesser horseshoe bat in all relevant future landscape Agri-Environmental Schemes.
- Produce a briefing note on the impact of artificial lighting on the lesser horseshoe bat for the six local authorities.

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