



BAT CONSERVATION
IRELAND

The Lesser Horseshoe Bat

**Mapping Landscape Connectivity to Facilitate
Species Recovery and Expansion in Ireland**



Citation

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About this Project

Modelling for this project was carried out by Patrick Wright and Colin Guilfoyle with input from Bat Conservation Ireland, Vincent Wildlife Trust, Atlantic Technological University and the Native Woodland Trust.

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Executive Summary

This report presents the results of a new study on landscape permeability for the lesser horseshoe bat throughout its range by identifying pathways that link known roosts with areas that may contribute towards the recovery and range expansion of the species.

For connectivity modelling, we need to use a resistance surface that represents the ability of the study organism to move through the landscape, along with a list of sites that we want to connect. The models were conducted at a national scale and then refined at four strategic locations.

The national scale modelling was conducted by using known locations of lesser horseshoe bat roosts and high nature value (HNV) woodlands; with habitat suitability maps (Fialas and Roche, 2025) as a resistance surface (100 m resolution). The results highlighted three main, well-connected roost clusters and the possibility for range expansion to high nature value (HNV, Ruas *et al.* 2024) woodland further north and east of the species' range (Figure 1).

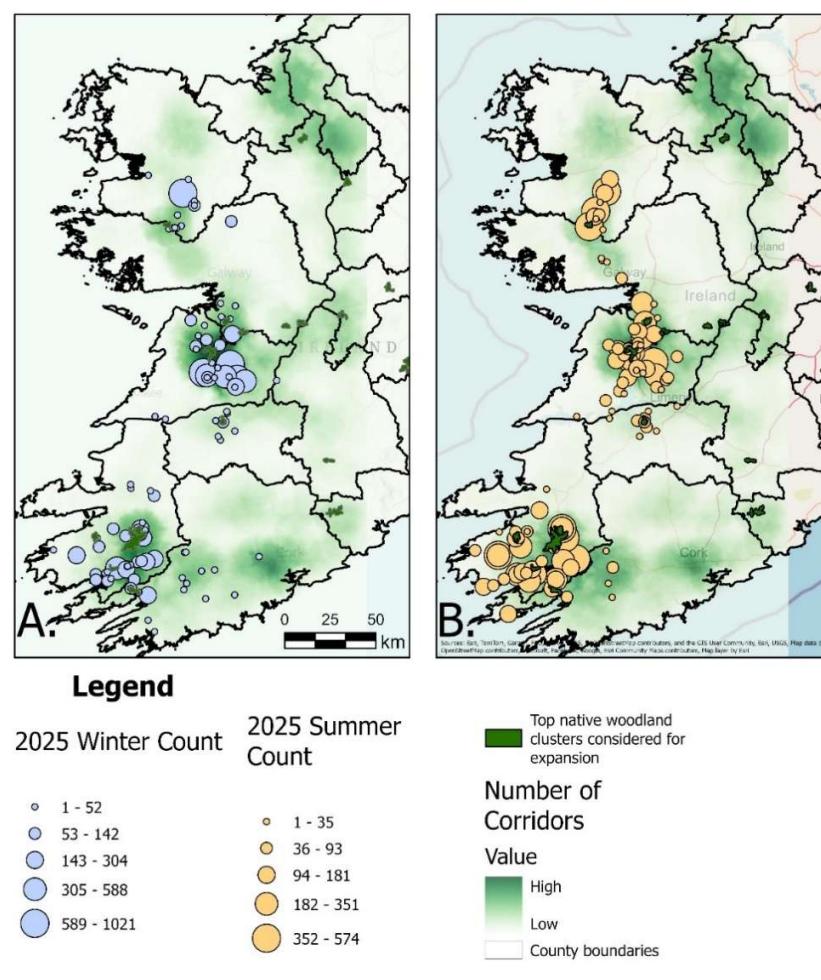


Figure 1 Number of bats counted at each site in 2025, and location of top native woodland clusters considered for expansion (Kelly and Duarte Campos, 2026).

Refined models were then performed at a higher resolution of 25m using the national land cover map and adjusted resistance values based on previous research (Lenihan *et al.*, 2021) to identify corridors and potential barriers. These models were performed in two areas (central-north Galway and Kerry-Cork-Limerick) to assess connectivity between populations; and then two extra areas where we anticipated potential range expansion (south-central Mayo and east Clare/south Galway/north Tipperary).

Results from these models provide details on the connectivity of lesser horseshoe bat habitat in the four areas. Corridors between bat roosts and suitable habitat were numerous and movement relatively unimpeded in certain regions. However, the corridors connecting populations in central-north Galway and Kerry-Cork-Limerick were typically either limited in number or long in distance, indicating constraints to movement between these populations. In terms of population expansion, connectivity currently appears favourable for bats to expand both northwards in Mayo and for expansion east from Clare and Galway, provided suitable roosts exist, although additional measures which improve habitat quality along identified corridors could increase this likelihood (Figure 2).

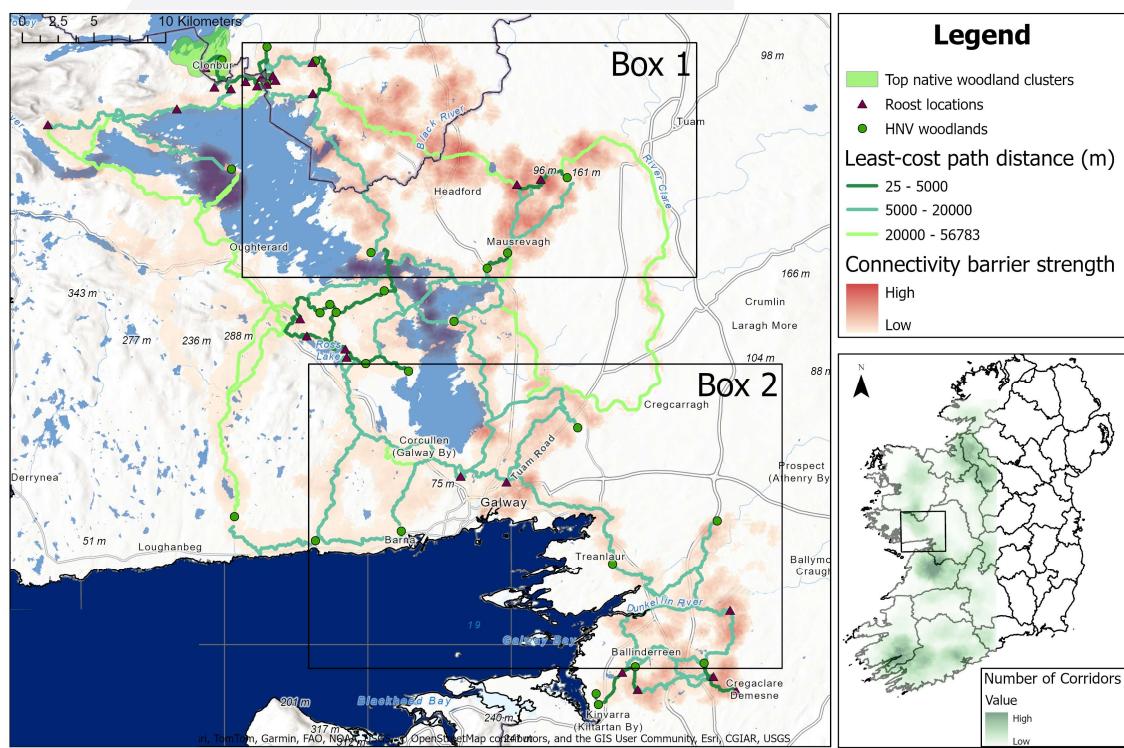


Figure 2 Example of the focus area in Central-north Galway, showing least-cost paths (LCPs) between roosts and HNV woodland and the strength of movement barriers.

The pathways identified are facilitated primarily by well-developed hedgerows and semi-natural woodlands and these must be retained, and in many cases expanded, to ensure future connectivity. Conversely, limited connectivity and restricted movement were largely driven by landscapes characterised by sparse semi-natural woodland cover or highly fragmented woodland patches embedded within land covers that are relatively impermeable to bat movement. These landscapes were typically dominated by improved grassland used for

livestock grazing, while large lakes, lowland and upland bogs, and urban areas further functioned as significant movement barriers.

Overall, the results of this study provide a robust spatial framework to support targeted conservation actions for the lesser horseshoe bat. By identifying pathways between roosts and suitable habitat, the findings can be used to prioritise locations for focused field surveys to confirm species presence and assess population status. The analysis also highlights landscapes where habitat enhancement and the reduction of movement barriers would most effectively improve connectivity, while identifying areas where existing habitat may be insufficient. In addition, evaluating roost availability within these priority areas will be essential to ensure long-term population recovery. Together, these insights offer practical guidance for conserving the species in an increasingly fragmented and changing landscape.

Introduction

The lesser horseshoe bat is restricted to six western counties from Mayo to Cork in the Republic of Ireland (Figure 3) and is the only Irish bat included under Annex II of the Habitats Directive. It is a highly sedentary species that relies heavily on linear landscape features for navigation (hedges, stonewalls, treelines, rivers and woodland edges) and it avoids flying across open areas (Schofield, 2025). This species is also extremely photophobic, in other words it avoids lit spaces, and it has strong positive associations with broadleaf woodland and riparian vegetation (Bontadina *et al.* 2002, Boughey *et al.* 2011). These characteristics make it particularly susceptible to changes in agricultural practices and the expansion of urbanisation and infrastructure. The lesser horseshoe bat has a highly specialised echolocation system and short broad wings. This echolocation system allows it to detect the wing beats of flying insects while its wing shape makes it highly manoeuvrable. These characteristics are believed to be an adaptation for foraging in cluttered environments, such as broadleaved woodland.

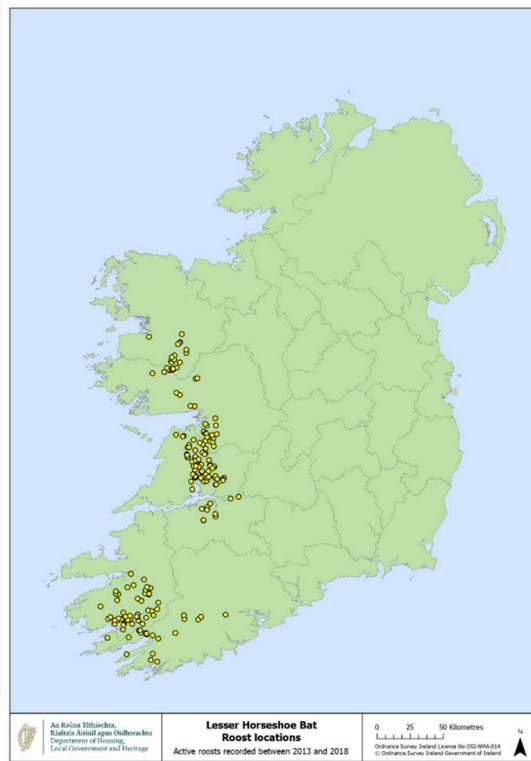


Figure 3 Lesser horseshoe bat distribution in Ireland. (source: NPWS database, 2021)

Although the most recent population estimate for this species reflects an increase and is approximately 15,000 individuals (Fialas and Roche, 2025), other features of its conservation status are now inadequate, including range and habitat (National Parks and Wildlife Service, 2019). 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 that it now consists of four isolated meta-populations: north Galway and Mayo; Clare and south Galway; Limerick; and Cork and Kerry (Figure 4). Unless steps are taken to reverse or halt this

isolation, fragmentation of the small population places this species at risk of population decline and greater vulnerability to extinction.

As this species is closely associated with High Nature Value (HNV) habitats such as woodland and requires good habitat connectivity, its conservation and management can be used as 'umbrella conservation' for all species reliant on these habitats. Nature connectivity in Ireland has been shown to be lower in Ireland compared to other European countries and there are real opportunities for increasing ecological integrity with landscape level works (Segar *et al.* 2021).

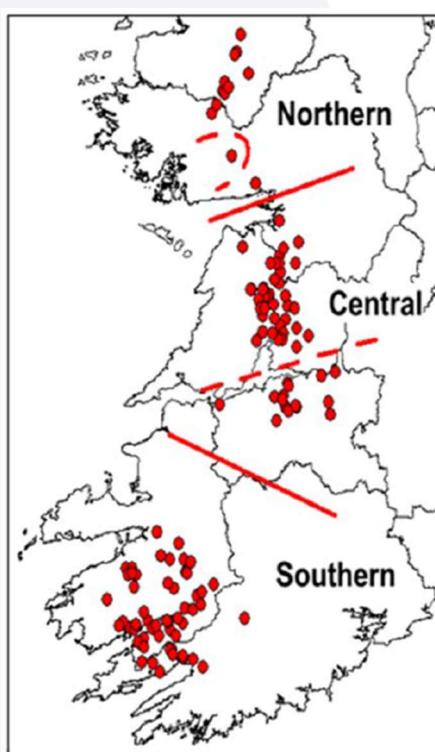


Figure 4 Genetic breaks between populations of lesser horseshoe bats by Harrington (2018).

The aims of this project are to

- Assess landscape connectivity for the lesser horseshoe bat across Ireland by modelling least-cost paths (LCPs) that link known roosts with areas of suitable habitat and
- Identify areas where there are high conservation value native woodlands that could be expanded onto adjacent public lands, to promote the recovery of the species.

This project contributes to the implementation of Article 4(7) of the Nature Restoration Law, which requires Member States to establish restoration measures for terrestrial, coastal, and freshwater habitats of the species listed in Annex II. These measures aim to improve the quality and quantity of such habitats, including through their re-establishment, and to enhance ecological connectivity, until habitats of sufficient quality and extent are achieved. In

addition, Art 4(10): “The restoration measures referred to in paragraphs 1 and 4 shall consider the need for improved connectivity between the habitat types listed in Annex I and take into account the ecological requirements of the species referred to in paragraph 7 that occur in those habitat types.”

Fialas and Roche (2025) determined the extent of suitable habitat in Ireland for the lesser horseshoe bat using Habitat Suitability Modelling (HSM, Figure 5). This new modelling study focuses on identifying key corridors (LCPs) at a higher spatial resolution using detailed land cover maps that could, within the framework of the Nature Restoration Plan, provide a way to reconnect isolated sub-populations of this Annex II species. It will also identify where tree cover could be increased to benefit not just the lesser horseshoe bat but all species that rely on woodland habitat, while also achieving targets for woodland expansion. Clusters identified in the IEN Native Woodland Cluster report/mapping (2025) will also be interrogated.

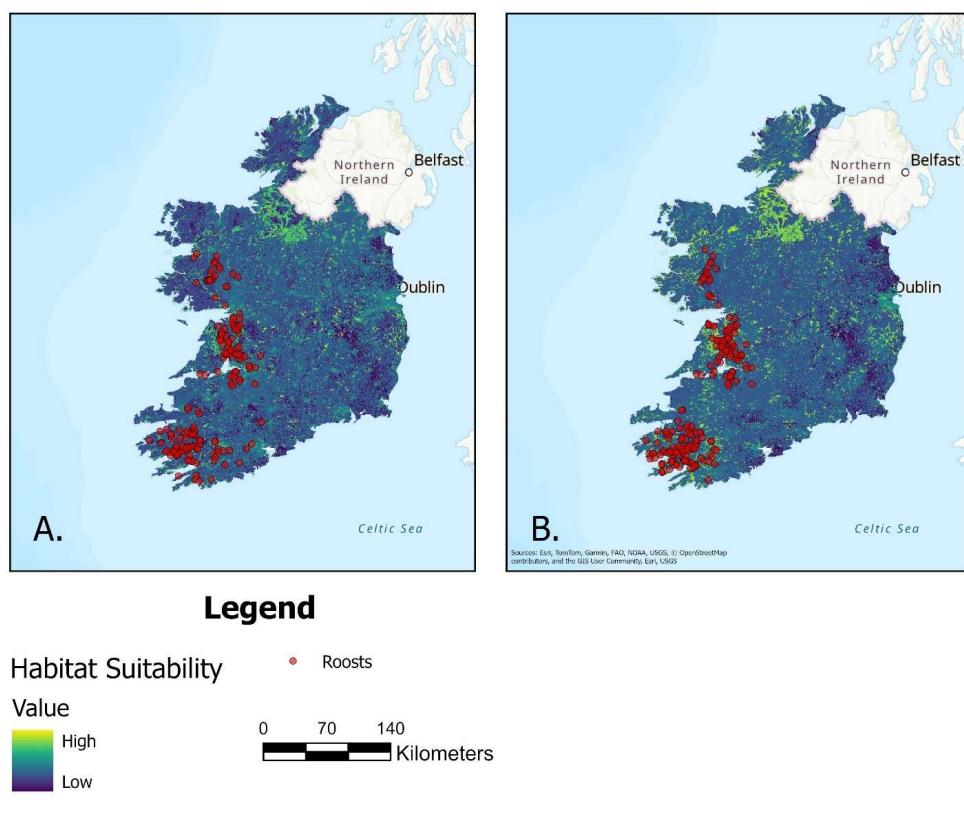


Figure 5 Predicted winter (A.) and summer (B.) roost suitability for the lesser horseshoe bat across the Republic of Ireland, based on ensemble species distribution modelling based on Fialas and Roche (2025).

Results

National models

When assessing functional connectivity for a species, we typically need to create a resistance surface. A resistance surface is a spatial layer whose values represent the ability of the study organism to move through each grid cell. High resistance values represent areas that are difficult for the species to move through.

We first ran models at a national scale to identify broad patterns in connectivity between suitable habitat and the location of roosts. Here, to create a resistance surface representing the ability of the species to move through the landscape, we performed a linear conversion of habitat suitability model outputs where the highest suitability was given a resistance score of 1. Then, we analysed how well-connected roosts are in the landscape by calculating least-cost paths between summer and winter roosts.

The outputs from the analysis of the models including roosts only (no HNV woodland) are shown in Figure 6. Winter and summer roosts had a high overlap due to the similarities between habitat and point locations. We identified three main clusters of connected roosts. The first cluster in southern Ireland was the largest and extended over County Kerry and County Cork. The second cluster was located in County Clare and County Limerick. Finally, the third cluster comprised roosts located in County Galway and Mayo. This cluster occupied a smaller area and, despite the short distances between roosts, did not show such good connectivity. In some cases, this cluster showed slight connectivity with the second cluster between Galway City and County Clare.

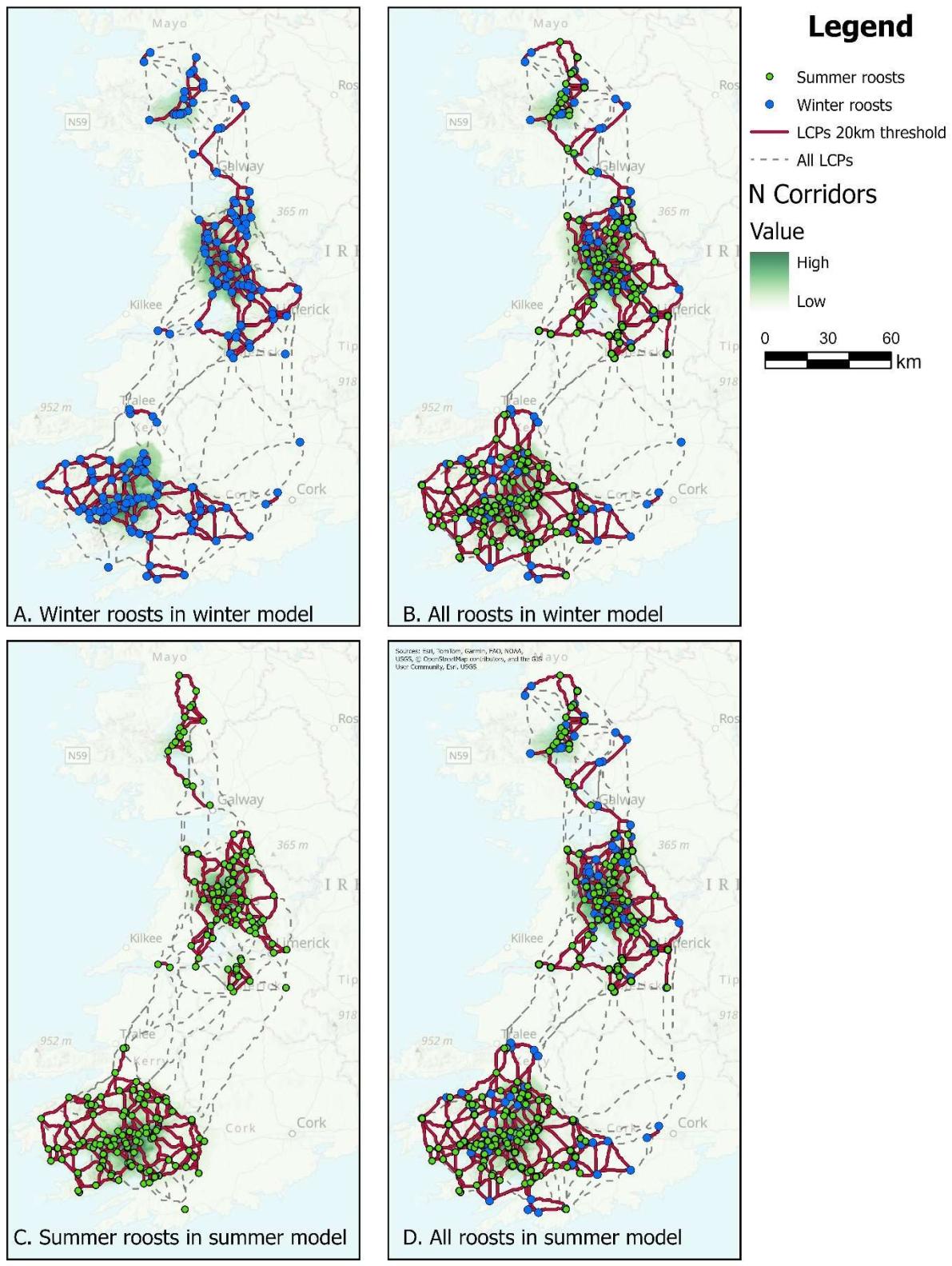


Figure 6 Least-cost path outputs for all roost models.

The winter and summer models which included HNV woodland and all roosts as nodes were both very similar. In Figure 7, we present the results from the summer models only to

summarise all results. Within the species range, we observed very strong similarities in clustering patterns whether HNV woodland were included in the models or not. Therefore, lesser horseshoe bat roosts are found in areas with high cover of HNV woodland. Consequently, well connected areas of HNV woodland adjacent to lesser horseshoe bat range are likely to be optimal for potential range expansion of the species.

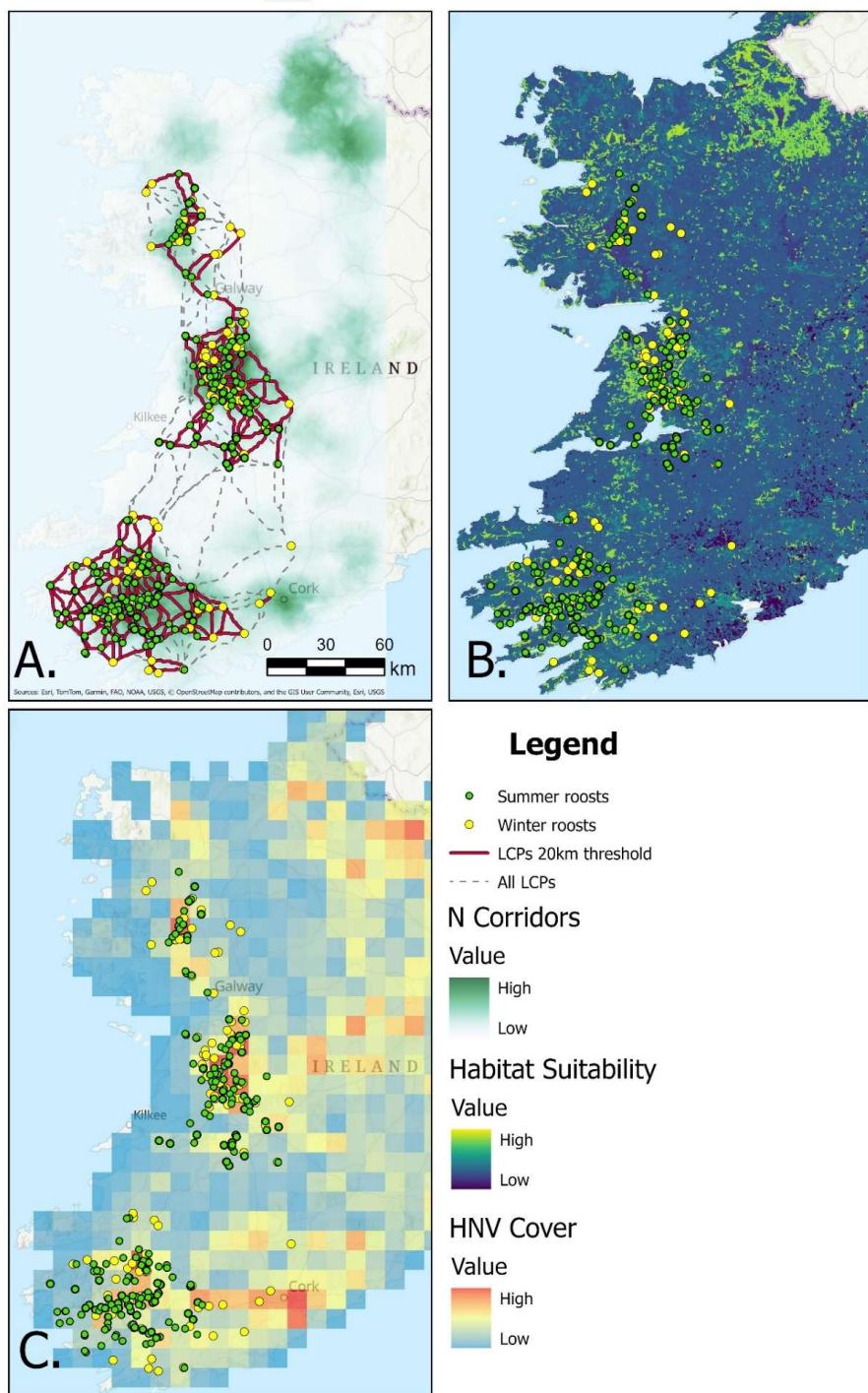


Figure 7 A. Number of corridors connecting lesser horseshoe bat roosts and HNV woodland and least-cost paths connecting roosts only. B. Predicted summer roost suitability and C. amount of HNV woodland cover at a 10 km resolution.

In Figure 8, we focused on two areas within the species' range where habitat improvement could result in improved connectivity between populations:

- **central-north Galway** – Connectivity in this area is key as movement appears to be restricted to a main corridor with few summer roosts and Galway city as a main barrier.
- **Kerry-Cork-Limerick** - previously addressed by Lenihan *et al.* (2021), where potential paths through Limerick and north Kerry were identified, which could then enable bats to move between the other counties that comprise its Irish distribution.

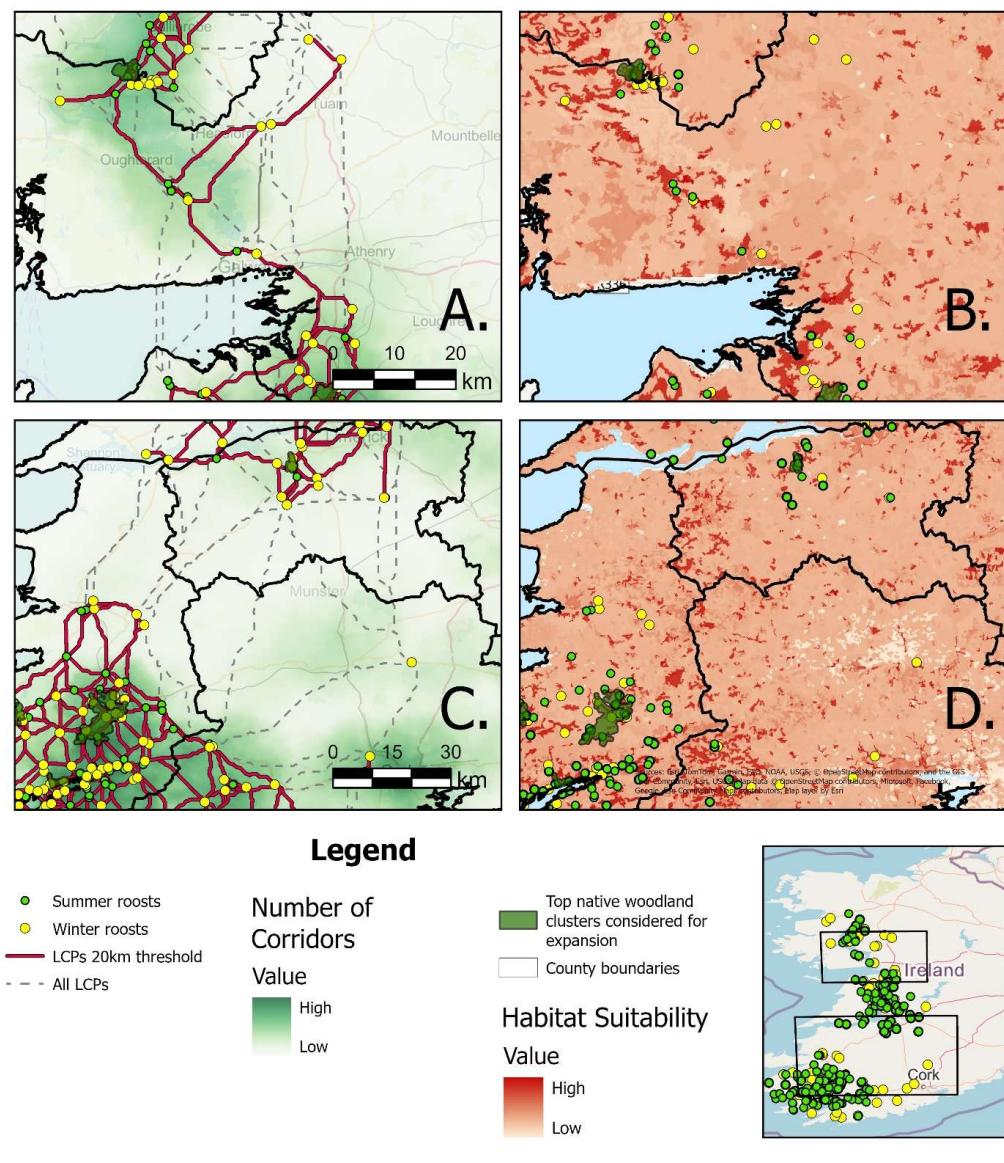


Figure 8 Focus on two areas (A & B) central-north Galway and (C & D) Kerry-Cork-Limerick where habitat improvement could benefit lesser horseshoe bat population linkage.

In Figure 9, we focused on two additional areas within the species' range where habitat improvement could result in range expansion.

- **south-central Mayo** - At the northern edge of the species' range, there is a high level of HNV woodland connectivity and suitable habitat. Efforts to facilitate movement should be made here. Then, connectivity between County Mayo and County Leitrim across County Sligo could be improved as it offers a large area of well-connected habitat.
- **east Clare/south Galway/north Tipperary** – The central lesser horseshoe bat cluster has the potential to expand east into County Offaly and Tipperary, where a relatively high cover of HNV woodland also currently exists.

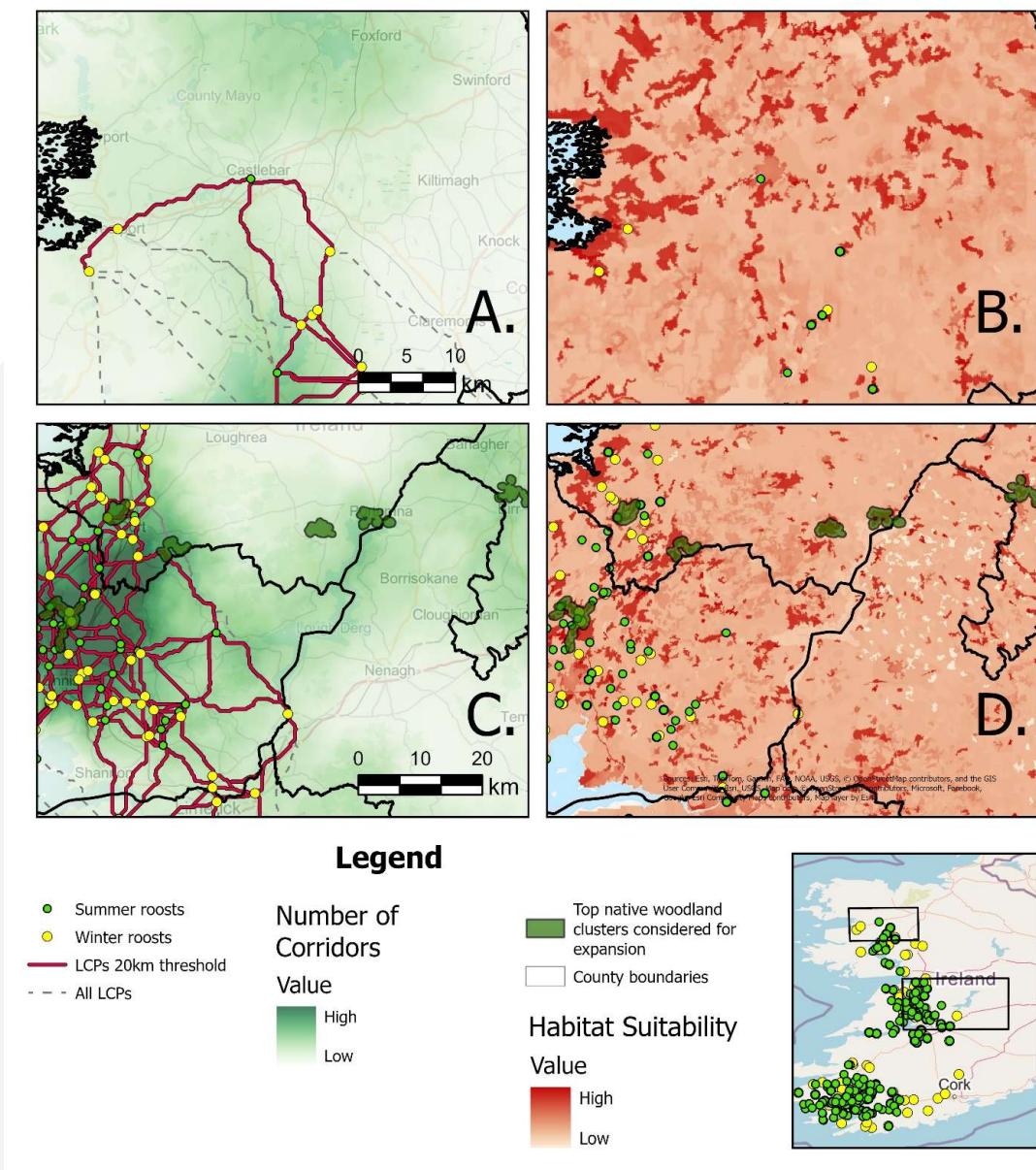


Figure 9 Focus on two areas (A & B) east Clare/south Galway/north Tipperary and (C & D) south-central Mayo where habitat improvement could result in range expansion.

The population size of most roosts is large within the core of the roost clusters. However, low numbers of bats are often recorded at winter sites on the edge of the species range, while very few summer roosts are recorded within these same areas. This is specifically visible in east County Cork (Figure 10). Of the 30 high conservation value native woodland clusters that

can be expanded onto public land identified by the IEN (2025), eight are within lesser horseshoe bat range and another eight are within the possible range expansion area (Figure 10). Measures to improve habitat connectivity could be targeted in possible range expansion areas.

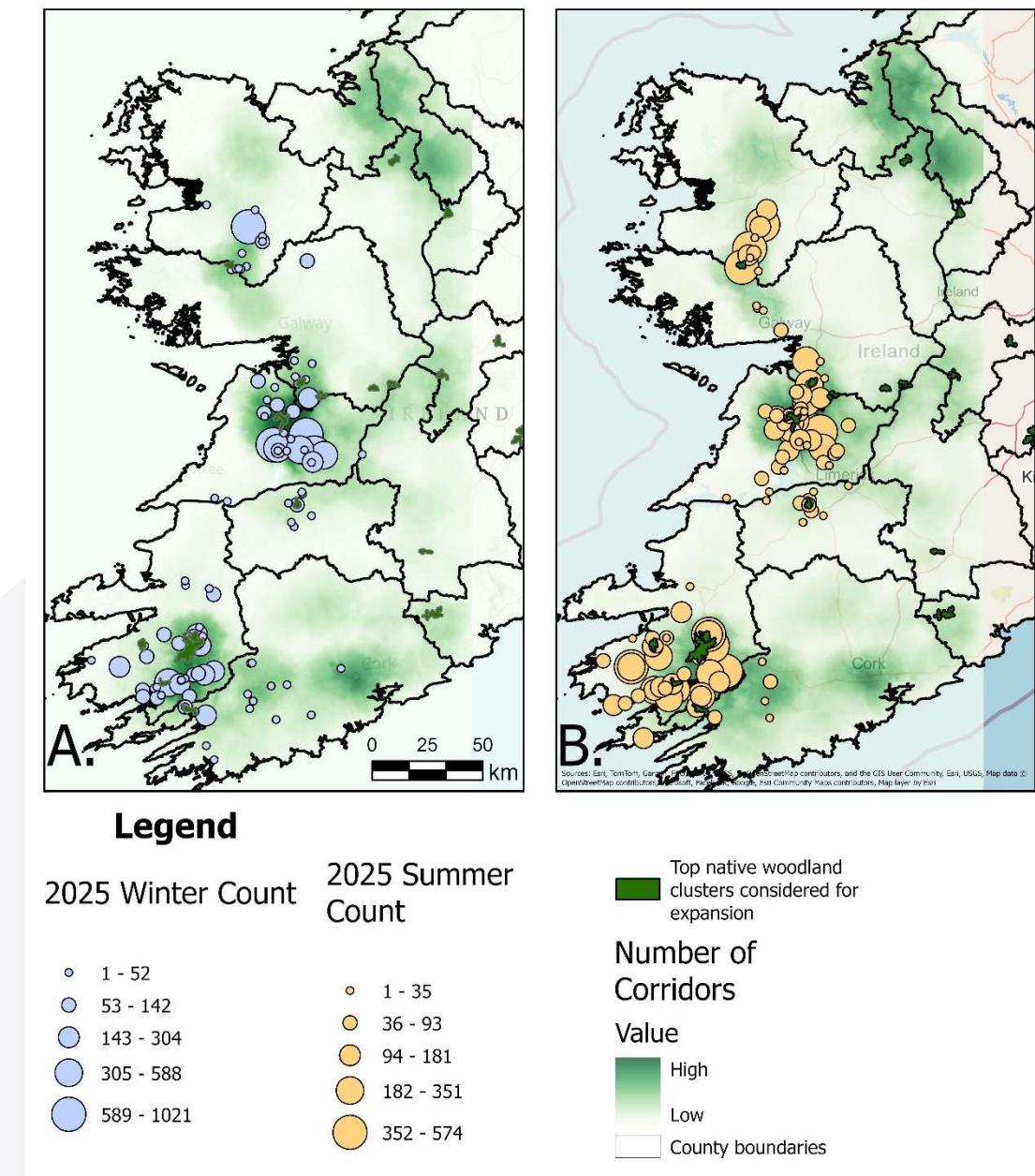


Figure 10 Number of bats counted at each site in 2025 and location of top native woodland clusters considered for expansion (IEN, 2025).

Focused Models

The models undertaken at a national scale provided 'big picture' insight into landscape connectivity for the lesser horseshoe bat. The next step consisted of running new models using a slightly different approach. Here, we did not use outputs from the habitat suitability models to create a resistance surface, but the latest high-resolution national land cover data (NLC 2018; Lydon and Smith, 2023). The analysis undertaken here provides information on potential corridors between roosts and HNV woodlands, but also the identification of barriers in the landscape where high connectivity barrier strength impacts negatively on the movement of bats. These models allow for targeted measures by policymakers and interested parties to facilitate landscape actions in highlighted areas, showing the localised barriers and improvements that can be made.

Central-north Galway - Figure 11

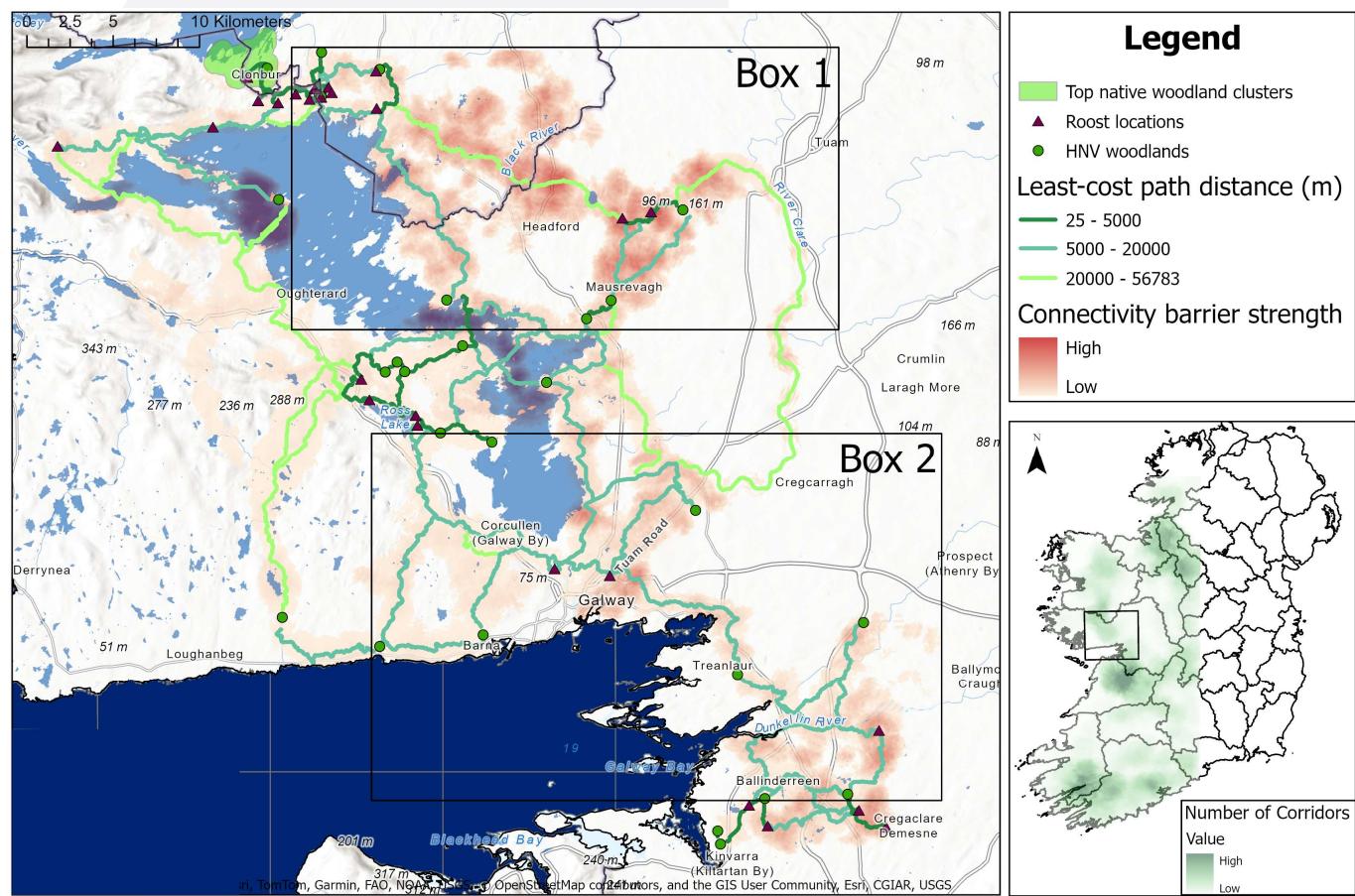


Figure 11 Barrier mapper output showing barrier strength for central-north Galway focus area along with least-cost paths between existing roosts and HNV woodlands and top native woodland clusters considered for expansion (IEN, 2025). Rectangles show areas of interest for targeted measures to improve the overall viability of the network. Inset map includes the number of corridors identified from the previous national models (Figure 7A).

The outputs were consistent with the national mapping undertaken in the previous section, highlighting a single corridor between roosts south and north of Galway city. Galway city is a significant barrier for the species due to the high levels of urbanisation and artificial lighting. This specific area benefitted from high resolution mapping using extra precise datasets, such as the National Tree Map and streetlight coordinates, with the software Circuitscape (Wright, 2021; Appendix 2). In similar situations, such modelling techniques using Circuitscape may provide better information on landscape connectivity and identify refined barriers in the landscape. The land adjacent to Lough Corrib, within which semi-natural woodland is locally common, is of high importance to bat movement and persistence in this region, given that movement either west or east is impeded by extensive blanket peatlands and agricultural landscapes with low woodland cover, respectively. Priorities for this region are improving connectivity between roosts in the Cong/Clonbur area and those in the lower Corrib catchment (Box 1) and increasing viable linkages between roosts north and south of Galway city (Box 2).

Box 1 – This area has the highest cover of strong barriers to movement in the region but represents a key area for the connection of existing roosts in Cong/Clonbur Headford and from there, further south to Galway City. In the first instance, linear landscape features along the least-cost paths, such as hedgerows, tree lines, stonewalls etc., should be retained. Those working on the ground in ACRES, conservation agencies, forest companies and local authorities etc. can focus their efforts on the mapped least-cost paths to identify locations where native woodland pockets, hedgerow reinstatement or widening, agroforestry and riparian woodlands can be developed or supplemented thus boosting connectivity around the shores of Lough Corrib and between Headford and Cong. Other measures in the area such as refitting of farmyard lighting under ACRES, investigations of suitable structures to see if LHB roosts are already present, and addition of artificial structures in the landscape to boost roosting resources can also be carried out along the length of the least-cost paths identified. This area needs a very strong focus on connectivity, with additional measures to boost habitat and roosting potential wherever possible. The pathway running close to the shore of Lough Corrib appears more favourable in terms of distance than that running between Cong and Headford, and therefore could be prioritised for habitat improvement works.

Box 2 – Similar to Box 1 above. in the first instance, linear landscape features along the least-cost paths, such as hedgerows, tree lines, stonewalls etc., should be retained. Those working on the ground in ACRES, conservation agencies, forest companies, local authorities etc. can focus their efforts on the mapped least-cost paths to boost connectivity – for example identify locations where native woodland pockets, hedgerow reinstatement or widening, agroforestry and riparian woodlands can be developed or supplemented thus boosting connectivity around the shores of Lough Corrib. Investigations of suitable structures may identify new roost sites or where none are present there is scope for provision of artificial sites. There may be potential to provide a specialised scheme within the Native Woodland Scheme that targets increased woodland cover while targeting conservation measures for the lesser horseshoe

bat. Other possibilities include infrastructure works to include underpasses for bats in roads. Increasing the number of viable linkages between roosts south and north of Galway City would be highly beneficial also. This could involve a number of measures which increase tree cover east of the city between Athenry, Oranmore and Claregalway, including natural regeneration, applied nucleation, afforestation with broadleaved native species, hedgerow planting, riparian woodland creation and agroforestry. The local authority could implement measures to minimise light trespass into connectivity corridors, while ACRES consultants could encourage clients to retrofit existing farmyard lighting with biodiversity-friendly fittings.

Galway City and County would benefit from the development of a local working group to understand how to improve connectivity within current agricultural and rural activities.

Kerry-Cork-Limerick - Figure 12

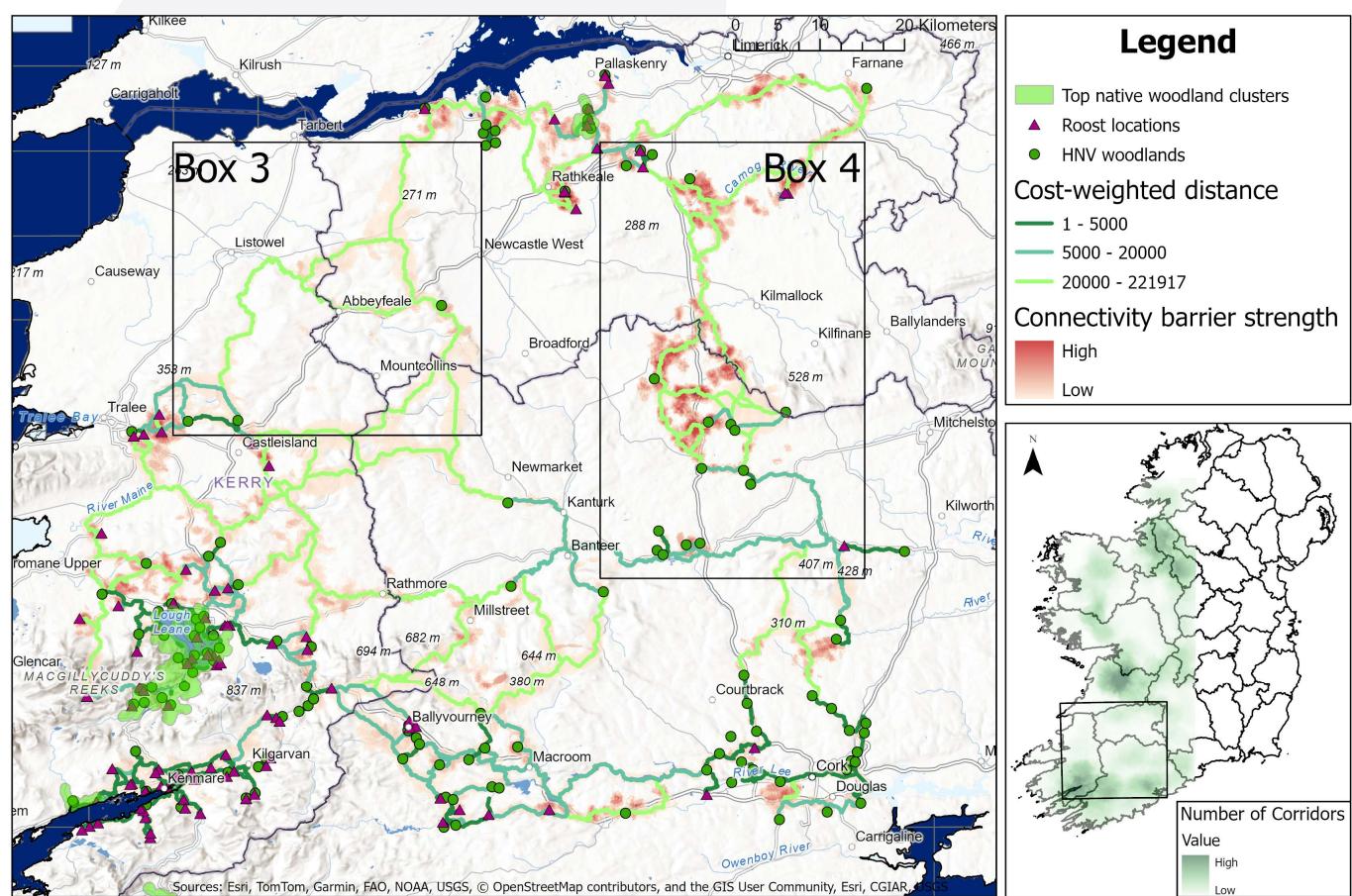


Figure 12 Barrier mapper output showing barrier strength for Kerry-Cork-Limerick focus area along with least-cost paths between existing roosts and HNV woodlands and top native woodland clusters considered for expansion (IEN, 2025). Rectangles show areas of interest for targeted measures to improve the overall viability of the network. Inset map includes the number of corridors identified from the previous national models (Figure 7A).

This region has been an area of interest in Ireland for lesser horseshoe bat conservation in recent years, as there is a known gap in the distribution of the species between the populations in Cork/Kerry and those in Limerick (Harrington, 2018; Lenihan, 2021), which was reaffirmed by the national models in the previous section. The priority areas in this region are the western pathway between north Kerry and Limerick (Box 3) which has been previously analysed as a movement corridor for lesser horseshoe bats (Linehan, 2021) and the eastern pathway between north Cork and Limerick (Box 4) which we identified as a potential alternative linkage between these populations based on the national models and cover of HNV woodland in this region. The analysis also highlighted a potential gap between populations in west Cork and those around Cork City. Creation of habitat and roosting sites along the River Lee between Macroom and Cork City would appear to be the most straightforward approach to ameliorate this linkage issue.

Box 3 – The results support the findings of Lenihan *et al.* (2021) with corridors running along the west of the Stacks Mountains and east towards the Mullaghareirk Mountains, with relatively low barrier strength along both corridors. This would indicate that habitat is relatively suitable for bats in this region, and indeed Fialas and Roche (2025) indicated suitable habitat exists in the west Limerick area. The main issue, therefore, is the distance between existing roosts and HNV woodlands being too far apart to support maintained functional connectivity. Stepping-stone populations through roost creation and increasing woodland cover along these pathways could circumvent this and reconnect these sub-populations. In the first instance, linear landscape features along the least-cost paths, such as hedgerows, tree lines, stonewalls etc., should be retained. Similar to boxes above, those working on the ground could focus their efforts on the mapped paths to boost connectivity – for example identify locations where native woodland pockets, hedgerow reinstatement or widening, agroforestry and riparian woodlands can be developed or supplemented thus boosting connectivity. The development of larger areas of native woodland should be prioritised along LCPs here in order to support viable population connectivity.

Box 4 – This region has a high cover of HNV woodland and is potentially limited by the lack of available roosts, which could be further explored. Connecting this area with the populations in Limerick, along with further work to link roosts and suitable habitat further south in Cork City and the Blackwater Valley would create a second potential route for connection of the sub-populations in Cork/Kerry and Limerick. This may conflict with the proposed development of the M20 motorway, depending on the final selected route, or may be facilitated by it, if planting or scrub natural regeneration is permitted along its length. Barriers in this region are currently large areas of improved grasslands with low cover of hedgerows or other woodland features, along with large roads in some cases. In the first instance, linear landscape features along the least-cost paths, such as hedgerows, tree lines, stonewalls etc., should be retained and subsequent efforts should be focused on boosting these linkages.

South-central Mayo - Figure 13

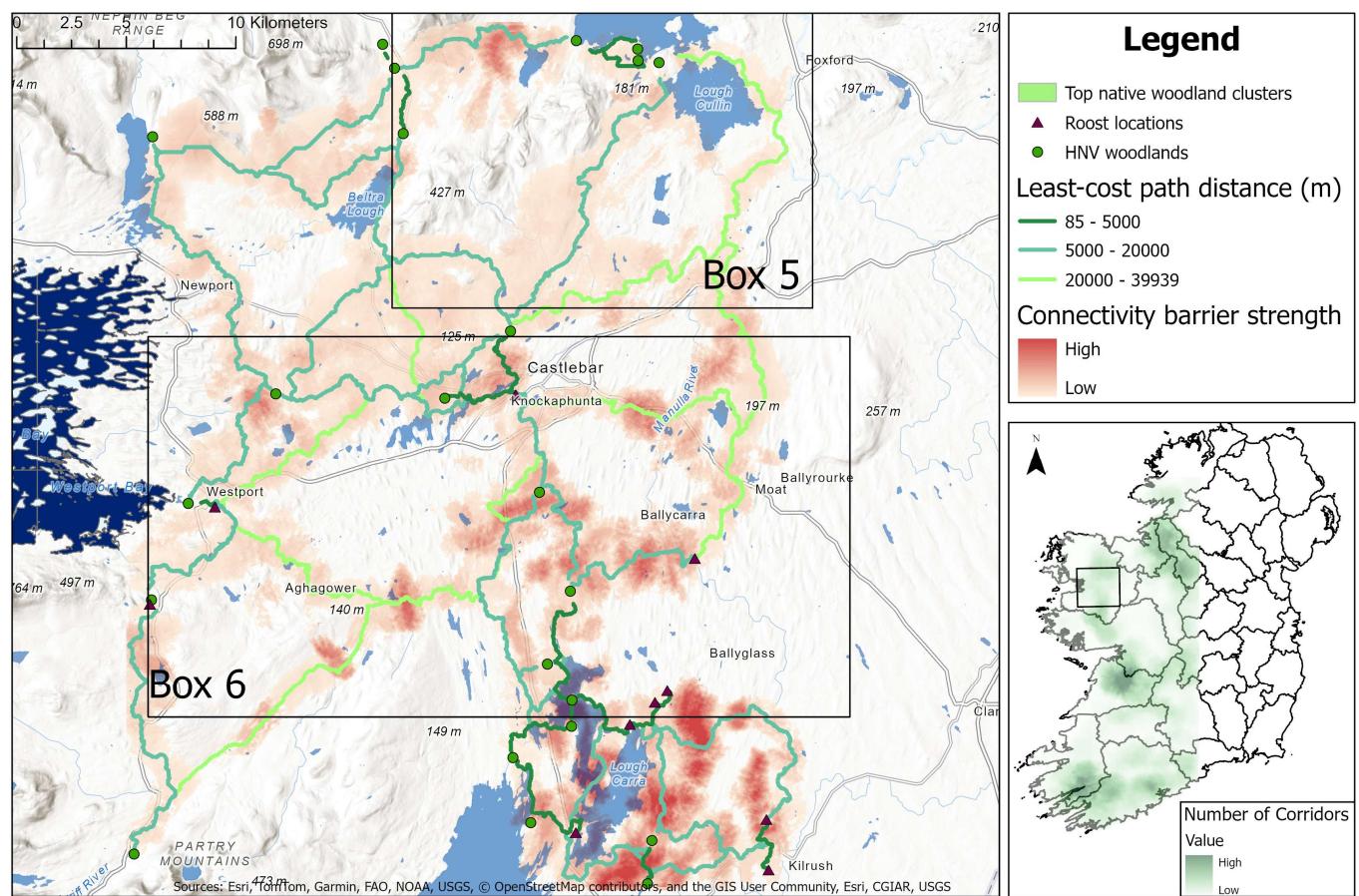


Figure 13 Barrier mapper output showing barrier strength for south-central Mayo focus area along with least-cost paths between existing roosts and HNV woodlands. Rectangles show areas of interest for targeted measures to improve the overall viability of the network. Inset map includes the number of corridors identified from the previous national models (Figure 7A).

National models, along with previous HSM (Fialas and Roche, 2025) identified a high cover of HNV woodland, and therefore potentially suitable lesser horseshoe bat habitat, in the region around Lough Conn and Pontoon in Mayo, and also further northwest into Sligo and Leitrim. These counties are currently north of the species range limit in Ireland but there is potential for range expansion into these regions if connectivity between existing roosts and habitat further north is favourable. Two priority areas were identified in this region. The first is directly northwest of current roosts in the Lough Carra and Lough Mask area (Box 5). It is currently characterised by a mosaic of woodland, grassland, heath and bog, which lie between the urban centres of Westport and Castlebar. This location is crucial to enable the expansion of the species further north. The second priority area is southwest of Loughs Conn and Cullin. This area already holds suitable woodland habitat, but the presence of roost sites is not known and should be investigated.

Box 5 - This represents the most feasible area for range expansion north and towards suitable habitat in Leitrim/Sligo. Croaghmoyle Mountain NHA and Cunnagher More Bog NHA split the potential corridors which link this area to existing roosts and other HNV woodlands. The most

favourable route is likely the central corridor which runs from Castlebar northwards, straddling upland habitat before reaching Pontoon, through a mosaic of marginal agricultural land and conifer plantations. Abandonment of grazing land appears common in this corridor, which is promoting scrubland expansion. Measures which support such woodland expansion through natural regeneration could be used to avoid tree removal for future land improvement, along with increased native woodland cover following replanting of current conifer plantations after clearfell. Promotion of a riparian corridor further east along the Manulla River, using woodland at Breaffy as a stepping stone, also represents an opportunity for improving connectivity.

Box 6 – Prioritising increased tree cover in this region will be highly important to overcoming barriers which are potentially hindering expansion north to favourable habitat in Box 5. Emergent birch woodland on cutover bogs is potentially facilitating some movement of bats north and west to Castlebar and Westport currently, but roosts sites in these areas may be absent. These could be added artificially if on-the-ground investigation confirms that existing roosts are absent. Current barriers are mainly areas of agricultural land with low woodland or hedgerows cover, which could be circumvented through agri-environmental measures which promote an increase in tree cover. It would be important to engage with Mayo County Council to promote woodland corridors from Lough Lannagh north through or around Castlebar town. Further surveys should be undertaken to understand the distribution of bats around Westport and Brackloon and whether these populations are connected to those at Lough Carra via the corridor through Aughagower.

East Clare/south Galway/north Tipperary - Figure 14

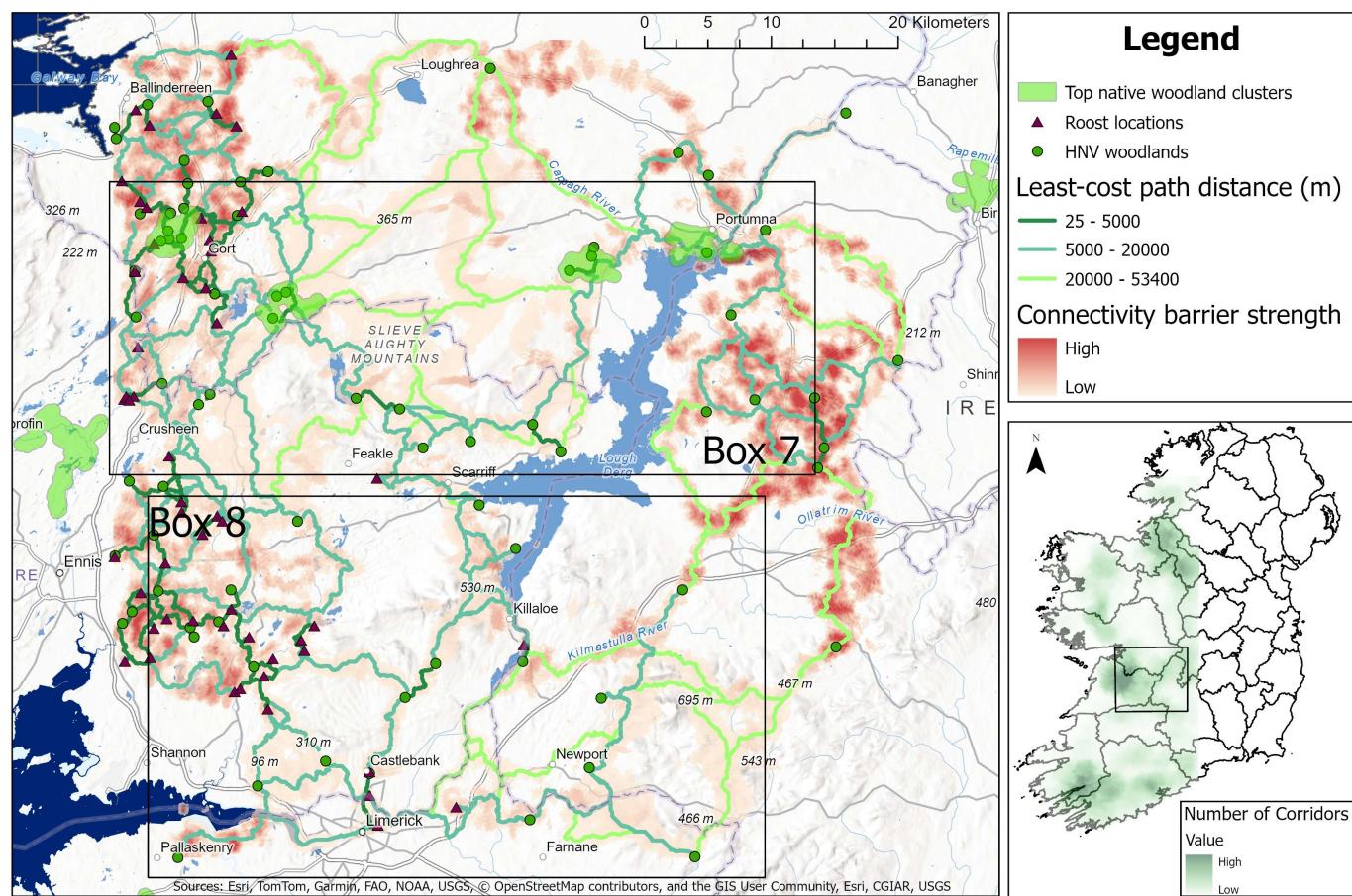


Figure 14 Barrier mapper output showing barrier strength for east Clare/south Galway/north Tipperary focus area along with least-cost paths between existing roosts and HNV woodlands and top native woodland clusters considered for expansion (IEN, 2025). Rectangles show areas of interest for targeted measures to improve the overall viability of the network. Inset map includes the number of corridors identified from the previous national models (Figure 7A).

The final focus area assessed the potential for eastward expansion of the population from the numerous existing roosts and HNV woodlands in east Clare and south Galway across the River Shannon and Lough Derg into north Tipperary, where there is a relatively high cover of HNV woodland. Further expansion into Offaly from here is also possible. Priority areas analysed further were the northern pathway from Gort including the Slieve Aughties and northern section of Lough Derg (Box 7) and the southern pathway from east of Ennis across the Shannon to west of Killaloe (Box 8).

Box 7 – There appears to exist a viable corridor for potential range expansion from existing roosts around Gort, along the southern edge of the Slieve Aughties to Feakle and Scarriff. From here, a corridor north exists to woodlands around Woodford and Portumna, which have already been suggested for expansion. If further efforts are made to increase both the availability of roosts and woodland cover along the east and west shorelines of Lough Derg, bats may also be able to disperse directly across the lake. Although a number of HNV woodlands exist in close proximity to one another east of Lough Derg, the surrounding

landscape is highly intensified and promotion of measures which improve the suitability of habitat for foraging and dispersal would be critical to enable this range expansion. Surveys of roost availability in general in this area would be useful to (a) prevent removal of existing roosts and (b) identify where artificial roosts could be created.

Box 8 – This area highlights a potential alternative route around Limerick City north to Killaloe and east to Newport. Direct measures which increase habitat and roost availability north of Killaloe towards the cluster of HNV woodlands in Box 7 is needed, however, before population expansion via this route becomes viable as current least-cost paths are unlikely to be viable based on their length. This area overall represents very good habitat potential for the lesser horseshoe bat and could be an ideal area to run an EIP for improving connectivity and roost provisions.

Discussion

The lesser horseshoe bat is the only Irish bat species with a dedicated Species Action Plan (NPWS 2022). The rationale for this Species Action Plan was based on several facts, including concerns about the effects of habitat loss and landscape connectivity on its distribution and range within the six counties in which it occurs. In the most recent Article 17 Report to the EU Commission, its conservation status was deemed ‘Unfavourable Inadequate’ (NPWS 2025). The plan lists 29 actions deemed necessary to restore this species to a favourable conservation status (three of these address connectivity) and states that actions to address connectivity need to be targeted and based on additional modelling.

Following the study undertaken by Finch & McAney (2020), the models performed in this report provide a more practical approach as we focused specifically on key sites to identify barriers at different scales and resolutions that must be addressed to ensure the long-term resiliency of the lesser horseshoe bat population. Our results suggest the presence of three main roost clusters (Kerry-Cork, Clare-Limerick, Galway-Mayo), although some of our models also suggest the potential presence of a fourth cluster separating Counties Clare and Limerick. This is equivalent to the genetic cluster identified by Harrington (2018).

Connectivity between clusters was particularly constrained with few paths identified and limited habitat available. The national models suggested that more habitat was available further east and north of the species’ range, than between clusters. Therefore, it may be better to ensure range expansion further east and north, than between clusters. The focused models, however, depict a slightly more nuanced picture, especially between Kerry/Cork and Limerick where other corridors were identified.

In terms of population expansion eastwards from known roosts in Clare and south Galway, there appears to be viable linkages between the most eastern of existing roosts at Killaloe and Feakle to HNV woodland sites at the north end of Lough Derg, which are also suggested for expansion (IEN, 2025). These sites are then also within dispersal distance of a number of HNV woodlands on the east side of Lough Derg. High barrier strength between these woodlands indicates habitat that is less permeable to bat movement, however. In this case there is a high cover of improved grassland and roads, with a lack of hedgerows or small woodland patches. A similar situation is present in central Mayo, where higher barrier strength is seen in the region between existing roosts at Lough Carra and those at Castlebar, for the same reason. These barriers could be circumvented through the creation of woodland cover and improved hedgerow management, potentially in combination with wildlife overpasses where locally applicable (See Figure 15 for an example of how these features contribute to improved connectivity). Although bogs are common in both regions, they do not appear to be major barriers to bat movement in these examples. Additionally, the lesser horseshoe bat may benefit from the predicted increase in temperatures, which could enable it to expand its range

further north, as persistently low winter temperatures have likely prevented the species from occupying otherwise suitable habitat..

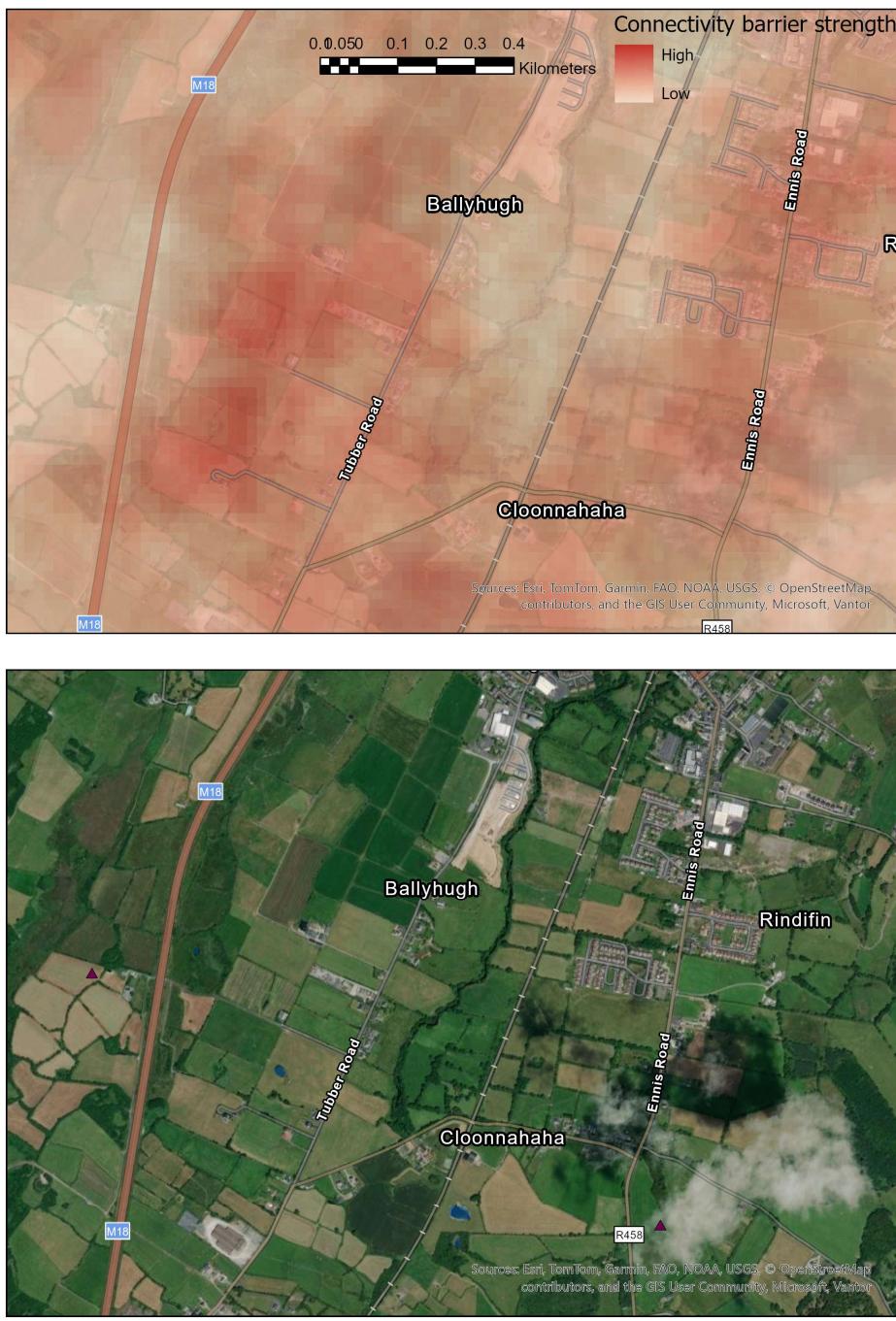


Figure 15 Example from Co. Galway showing contrasting barrier strengths with higher values around main roads and fields with small/no hedgerows and lower values along woodland corridors and good hedgerows.

While the focused models helped identify sections of corridors that could benefit from some improvements (e.g. increased tree cover, hedgerow planting...), these alone may not be sufficient. Roost availability is also a critical factor for lesser horseshoe bats, with roosts acting

as stepping stones in connecting populations. This approach was used for the Mulkear lesser horseshoe bat Project (Vincent Wildlife Trust, 2023) in Limerick where permanent new bat roosts were constructed on farms to ensure connectivity between bats that occur in west Cork and Kerry and those farther north, in counties Clare, Galway and Mayo.

Further modelling may still be possible at a higher resolution around barriers where urbanised habitat has been identified. Indeed, Wright & McAney (2023ab,2024) have already undertaken some modelling using the software Circuitscape (McRae & Beier, 2007). These refined models (2-15m resolution) based on work by Finch *et al.* (2020) have the benefit of including artificial lights at night (ALAN), a critical barrier for the species which could not be incorporated due to the scale and timeline of this study, and provide a more nuanced look around transport infrastructure (See Appendix 2).

In summary, this study provides a robust spatial framework to guide targeted conservation of the lesser horseshoe bat. By identifying pathways between roosts and suitable habitat, we can anticipate where the species range may expand and how well populations are linked. The results will directly help prioritise field surveys, habitat enhancement, and barrier reduction to improve connectivity, key actions that will be needed to implement the Nature Restoration Law. The analysis also highlights areas with insufficient habitat and underscores the importance of assessing roost availability to support the long-term population recovery of the species.

Recommendations

The results presented in this report provide information to help create a strategy to link known roosts with areas of suitable habitat to promote the recovery and/or expansion of the lesser horseshoe bat. The key recommendations arising from this study are:

1. First Do No Harm

- Retain hedgerow, woodland, tree lines, scrub, stone walls and other linear landscape features that are situated within approximately 100m of the least-cost pathways identified in this study.
- Ensure any planned new artificial light at night or infrastructure does not create new barriers along existing least-cost paths identified in this study.

2. Ground Truthing & Surveys

- Increase survey effort within ‘edge of range’ corridors, e.g. north Mayo, or between clusters, e.g. west Limerick, to determine the presence or absence of the species.
- Ground-truth key areas to assess habitat and roost availability.

3. Proactive Conservation

- Use the least-cost path models to target interventions such as allowing natural regeneration, hedgerow reinstatement, pocket native woodlands, agroforestry and dark sky friendly retrofitting of farmyard and other lighting.
- Develop local targeted schemes to facilitate dual goals of woodland expansion and lesser horseshoe bat conservation where potential exists to connect clusters or expand current range.
- Develop local action groups of key interested parties in areas identified by the refined models to facilitate planning and conservation works for lesser horseshoe bat.
- Where no roosts are present, particularly along long least-cost paths, look into potential for adding roost structures for summer or winter, or adapting existing buildings to make them suitable for the species.
- Develop best practice guidance for infrastructure works in areas that show habitat connectivity. Facilitate inclusion of wildlife friendly measures such as underpasses, wildlife bridges, or reduced artificial lighting.

4. Track Progress

- Share new roost record and location data with the National Parks and Wildlife Service so that changes in the species’ distribution and range can be mapped and recorded.
- Keep track of conservation actions and share a record of these with members of the Species Action Plan Steering Group/National Parks and Wildlife Service.

5. Future Study

- Refine models in areas where ALAN is likely to be a major barrier.

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Appendix

App 1. Methods

Graphab

We used the software graphab (Foltête *et al.*, 2021) which is dedicated to the modelling of landscape networks to quantify habitat connectivity. We used both winter and summer habitat suitability outputs as a basis for the landscape connectivity models.

A resistance surface is a spatial layer whose values represent the ability of the study organism to move through each grid cell. High resistance values represent areas that are difficult for the species to move through. Here, to create a resistance surface representing the ability of the species to move through the landscape, we performed a linear conversion of the habitat suitability outputs where the highest suitability was given a resistance score of 1.

Then, for the selection of nodes, which are the points or areas in the landscape that we aim to connect, we performed a suite of models at a national scale. First, we used a combination of winter and summer habitat suitability outputs against winter and summer roost locations. Then, we included High Nature Value (HNV) woodlands as nodes to better understand movement of the species throughout this specific habitat, and from its current range into other areas which are likely to be suitable (Table 1).

Table 1: Summary of models with nodes (top row) and each habitat output (column)

	Winter roosts	Summer roosts	All roosts	All roosts + HNV	HNV
Winter HSM	X	-	X	X	X
Summer HSM	-	X	X	X	X

In Graphab, we first calculated least-cost paths (LCPs) between all nodes. Then, we recalculated LCPs by including a dispersal threshold equivalent to 20 km which is more representative of the species' ability to disperse. We also created a corridor output which summarises the number of pathways between nodes and helps better visualise areas which are well connected in the landscape.

Linkage Mapper

We used the Linkage Mapper toolkit (McRae and Kavanagh 2011), an open-source GIS toolbox for wildlife habitat connectivity analysis, in combination with the National Land Cover Map (Lydon and Smith, 2023) to further investigate four areas of interest for lesser horseshoe bat populations in terms of connectivity and population expansion. The four areas selected for fine scale analysis were (A) Kerry-Cork-Limerick (population linkage), (B) central-north Galway (population linkage), (C) south-central Mayo (potential expansion) and (D) east Clare/south Galway/north Tipperary (population expansion).

Similarly to the Graphab analysis, Linkage Mapper relies on the use of a resistance surface and nodes, or core areas. For this analysis, the National Land Cover Map (Lydon and Smith, 2023) was used to develop the resistance surface, since it enabled high resolution land cover data to be incorporated into the connectivity analysis. Land cover classes were reclassified into resistance values based on previous research on lesser horseshoe bat (Lenihan *et al.*, 2021) with some adjustments made based on expert opinion (see Table 2). Resistance surfaces were developed at a resolution of 25m. Finer resolution was not carried out due to computing constraints.

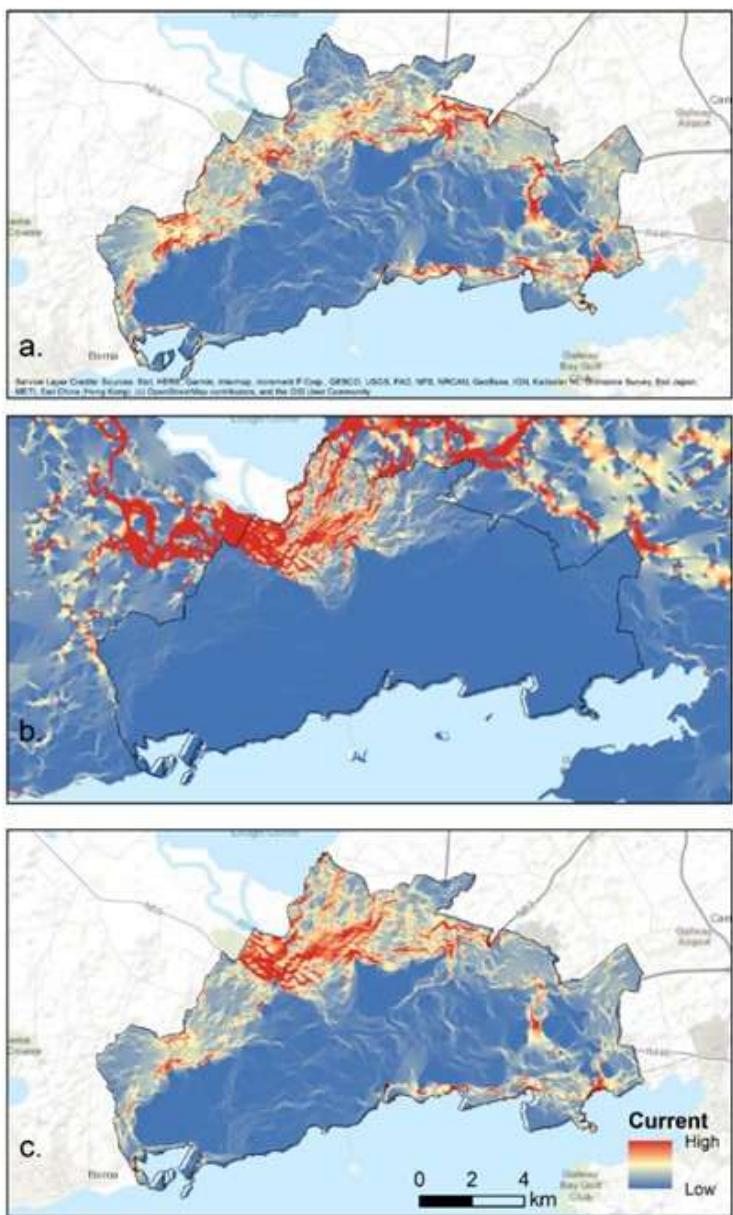
Nodes used were a combination of winter and summer roost sites, along with HNV woodland areas. Since roost sites existed as a point dataset, a 100m buffer was applied to each roost to form roost polygons. HNV woodlands below 10 ha were removed to reduce the number of nodes to maintain computational feasibility.

Firstly, the Build Network and Map Linkages tool was utilised to map linkages between nodes as least cost corridors for each area. We did not include a Euclidean or cost-weighted threshold for corridors in this case as the analysis was somewhat exploratory in order to identify potential corridors which could be prioritised for improvement and also to identify major landscape barriers.

Barrier Mapper (McRae *et al.*, 2012) was then used to identify areas along least-cost corridors which could be targeted for restoration measures to improve connectivity between core areas. Barriers were mapped using a 500m detection radius. Outputs were normalised between 0-1 so that values were comparable across the four areas. We also include the top native woodland clusters selected for expansion (citation) in output maps where relevant, alongside urban areas and lakes.

Table 2: Resistance values used for each land cover type from the National Land Cover Map.

Land cover	Resistance
Hedgerows	1
Broadleaved Forest and Woodland	1
Treelines	1
Mixed Forest	10
Rivers and Streams	10
Transitional Forest	25
Scrub	25
Coniferous Forest	50
Wet Grassland	100
Dry Grassland	100
Swamp	100
Sand Dunes	100
Fens	100
Bracken	100
Cultivated Land	700
Improved Grassland	800
Amenity Grassland	800
Exposed Rock and Sediments	1000
Bare Peat	1000
Other Artificial Surfaces	1000
Lakes and Ponds	1000
Wet Heath	1000
Dry Heath	1000
Blanket Bog	1000
Ways	1000
Buildings	1000
Bare Soil and Disturbed Ground	1000
Artificial Waterbodies	1000
Cutover Bog	1000
Raised Bog	1000
Saltmarsh	1000
Mudflats	1000
Coastal Sediments	1000
Marine Water	1000
Transitional Waterbodies	1000
Burnt Areas	1000

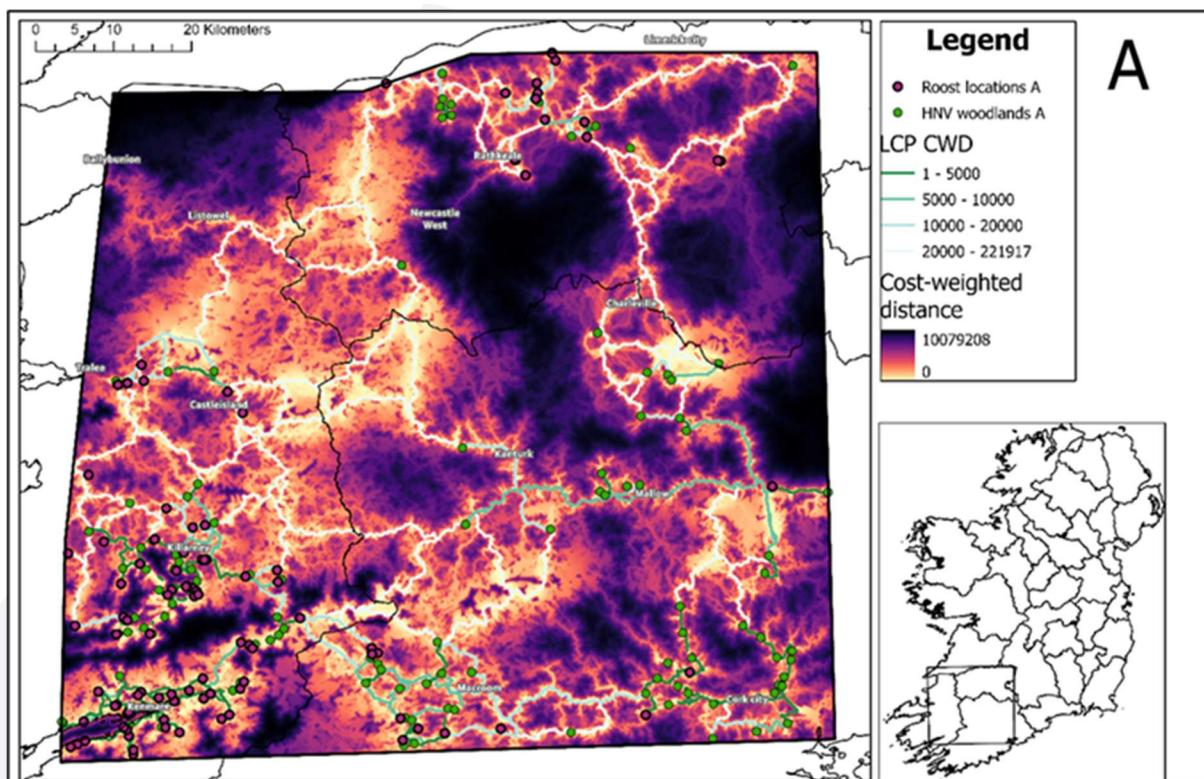


App 2. Circuitscape outputs from Galway city modelling report (Wright, 2021)

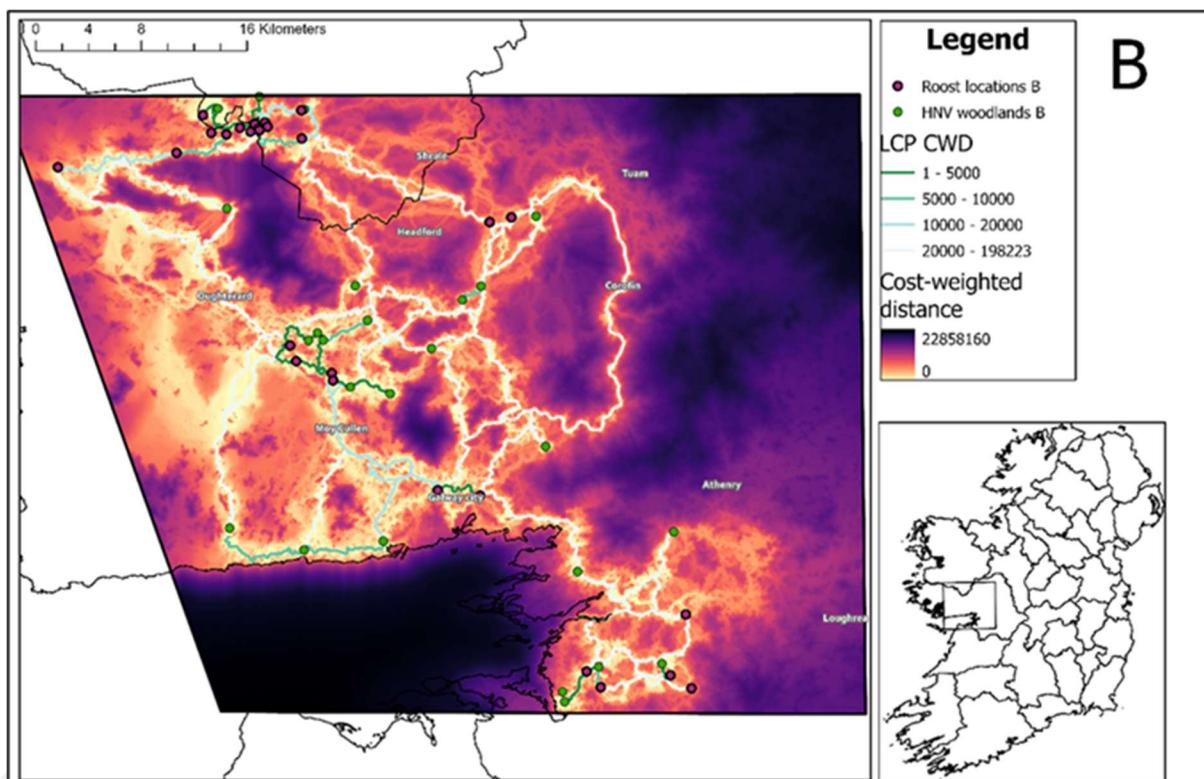
App 3. Other model outputs

Build Networks and Map Linkages tool outputs for four focused areas with LCPs displayed as cost-weighted distance.

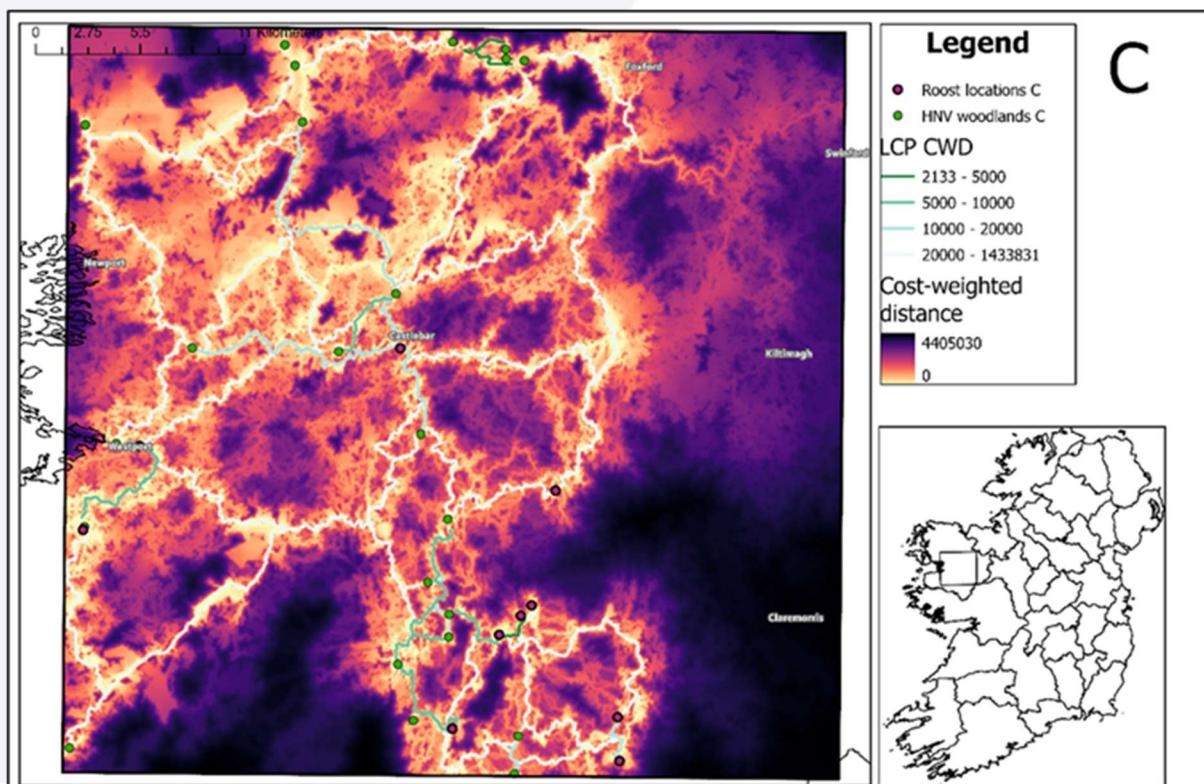
(A) Kerry-Cork-Limerick



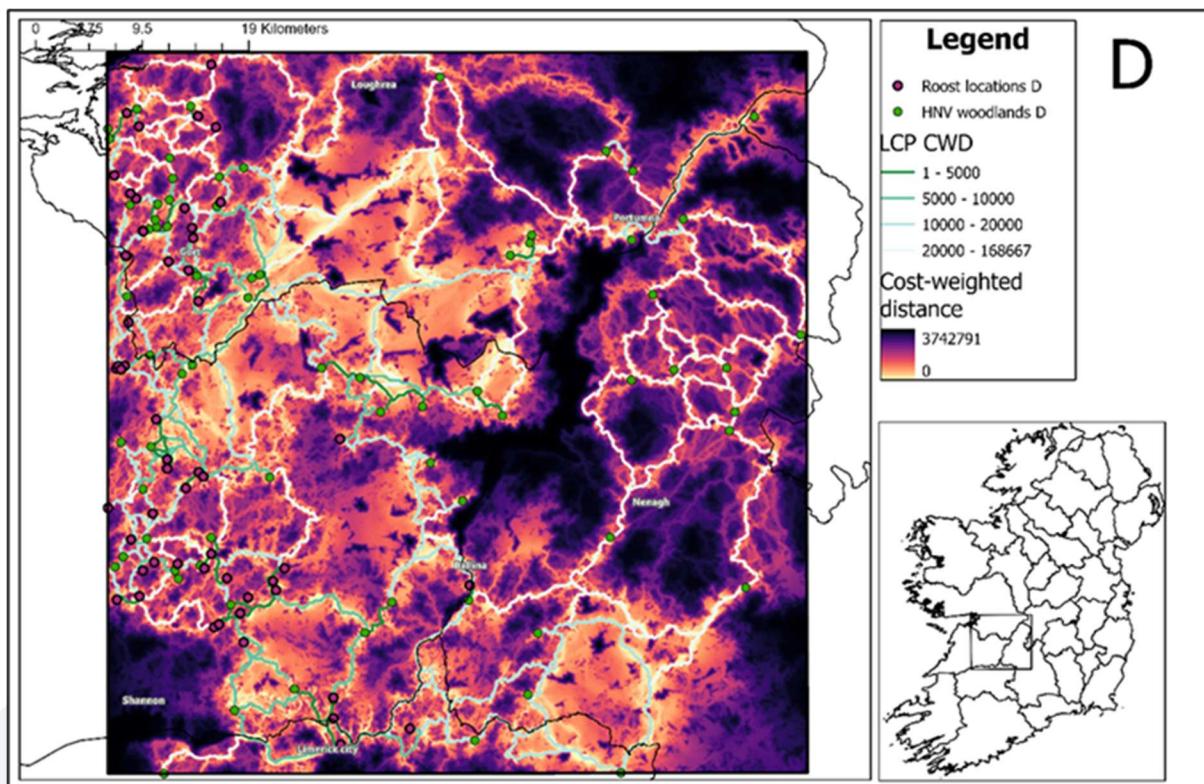
(B) Central-north Galway



(C) south-central Mayo



(D) East Clare/south Galway/north Tipperary





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