A feasibility study for the recovery of pine martens in south Cumbria

June 2022

Authors

1. Mic Mayhew, BVM&S, MRCVS, MSc
2. Andy Jennings, PhD, MSc, BSc
3. Ellie Kent, MSc, BA
4. Chris Brookes, PhD, MSc, BSc

1 and 3. Institute of Science, Natural Resources & Outdoor Studies, University of Cumbria, Rydal Rd, Ambleside, LA22 9BB.
2. Small Carnivore Specialist, Knox Drive, Harrogate, North Yorkshire, HG1 3JJ.
4. Willow Drive, Kendal, LA9 6AY.

Acknowledgements

Our sincere thanks go to Jon Beardsley, Tom Dearnley and Andrew Stringer from Forestry England, Colin Barr, Rick Emslie and Edward Mills from Rusland Horizons Trust and Bart Donato and colleagues from Natural England for their advice and support with field work, and community engagement. We are also grateful to Jenny MacPherson, Steve Carter and Patrick Wright from Vincent Wildlife Trust for help with modelling and to Bob Cartwright and the members of the Westmorland Red Squirrel Group for their understanding and ongoing efforts to restore red squirrel populations. We are indebted to Ed Sandys and his family at Graythwaite Estate and John Hodgson and colleagues from the Restoring Hardknott Forest project for their support with ecological surveys and for their inspiring efforts to recover native species through largescale landscape restoration. A final huge vote of thanks goes to Jo Sayers, the Back On Our Map (BOOM) Project Manager, for her oversight, Deborah Brady who supported the early stages of this study and all our dedicated students and volunteers including Anne and Chris Brookes, Samantha Haddock, Joseph Taylor, Naomi MacGregor, Jono Green, Tasmin Fletcher, Craig Holden and Jenny Williams.
Cover photo: Mic Mayhew

Suggested citation: Mayhew, M., Jennings, A., Kent, E., Brookes, C. (2022) A feasibility study for the recovery of pine martens in south Cumbria. Back on our Map (BOOM) Project Report, University of Cumbria.

Contents

List of Figures

List of Tables

Table 19. Reasons for and against pine marten population recovery in south Cumbria (Farmer n = 36, Public n = 90).

Table 20. Percentage use of various pest control measures on a temporary or permanent basis by farmers and landowners.

Table 21. The names or enterprises and organisations engaged during the feasibility study, categorised by sector.

Executive Summary

The European pine marten (*Martes martes*) is a medium-sized, semi-arboreal mustelid that is found in Western Eurasia, and is primarily associated with forested habitat. As an opportunistic omnivore, pine martens consume a broad range of seasonally abundant food resources, with a preference for small mammals.

During the Mesolithic, the pine marten was possibly the second most abundant carnivore in Britain, and until the end of the 19th century, the species was still widespread in Cumbria. However, woodland clearance, trapping of pine martens for their fur, and predator control activities, resulted in a prolonged population decline to a distributional nadir in 1915, with one remaining stronghold in northwest Scotland and small, scattered populations in northern England and Wales. During the 20th Century, reduced levels of persecution, increases in woodland cover and full legal protection enabled pine martens to recolonise most of their former range in Scotland and spread into Northumberland and north-east Cumbria. However, this expansion has been very slow and the pine marten is still critically endangered in England; the last confirmed record in south Cumbria was from Satterthwaite in July 2010.

Analyses have shown that natural recovery across most of England and Wales is unlikely without some intervention. The use of reintroductions in contemporary pine marten recovery projects in mid-Wales and the Forest of Dean has demonstrated the effectiveness of this approach to establish new population foci and expand existing metapopulations. A recent UK-wide analysis of pine marten habitat identified the forests of south Cumbria as one of two priority areas for reintroduction over the next decade, as part of a long-term strategic recovery plan for the species.

This feasibility study was initiated in September 2019 by the Back On Our Map (BOOM) project, administered through the University of Cumbria, and in partnership with Forestry England, Natural England, Cumbria Wildlife Trust and Morecambe Bay Partnership, with support from Vincent Wildlife Trust and Rusland Horizons Trust. The aim of the study was to determine if reintroduction is the best approach to recover the species across south Cumbria, and to examine the biological and social factors that would influence the establishment of a viable breeding population, in accordance with the IUCN and national translocation guidelines.

Our analyses showed that recolonising martens from north-east Cumbria could take many decades to reach south Cumbria, and would be unlikely to establish a viable population in the south. However, natural recolonisation augmented by a reintroduction in the south would generate a larger total population, which would take considerably less time to spread across Cumbria and establish a stable metapopulation. This indicates that the translocation of animals to a suitable area in south Cumbria would be a better option for recovering pine marten populations across this region.

Ecological niche modelling and other GIS analyses were carried out to determine the potential distribution of the pine marten across Cumbria and to help identify a potential recovery region (PRR) in south Cumbria with core habitat in the Rusland Valley woodlands and Grizedale Forest. The mean ecological carrying capacity of the PRR was 83 individuals (range = 24-159). The population viability analyses indicated that a translocation of around 40-50 animals would be the optimal cohort release size, and this cohort size was tested under various scenarios. An isolated founder population in the PRR would initially increase in abundance, before declining towards extinction; however, limited immigration of pine martens from north-east Cumbria would reverse this decline and result in population growth and stability in the long-term.

The potential for a pine marten population in the PRR to function as part of a resilient metapopulation was assessed by modelling dispersal pathways and connectivity with the nearest existing population in the north-east of Cumbria. The results suggested that dispersal between populations will occur, despite the presence of high resistance landscape features, such as the Cumbrian fells and major road networks. GIS analyses and camera trapping to record traffic volumes, revealed that the south Cumbria PRR has a road mortality risk that is lower than the Forest of Dean, with average daily traffic volumes on the minor road network of approximately one third of the regional average for the north-west of England.

Field studies in the PRR were conducted to ground-truth the habitat models and maps, establish the prey base of small mammals, and record the detection frequency and distribution of native and non-native wildlife. The understorey layer was characterised by having abundant, seasonal dietary resources, such as bilberry and blackberry, and tussock grass and woody debris, which provide habitats for small mammals. Oak, birch and Sitka spruce were the most abundant species across the PRR, but many stands were young and even aged, which suggests that the availability of tree cavities for rest and den sites is likely to be low. Overall, the forest microhabitat features compared favourably with the Forest of Dean, and pine marten den boxes can be installed to mitigate any relative lack of arboreal cavities.

Small mammal surveys revealed a robust prey base for pine martens, with a four-fold higher relative abundance compared to the Forest of Dean. Wood mice accounted for 80% of all captures, with smaller proportions of bank voles and field voles. A network of camera traps was used across the Rusland Valley and Grizedale Forest. No pine martens were detected, which suggests that there is currently not a viable breeding population in the PRR. Red squirrels had a restricted distribution towards the northern end of the study area, whereas grey squirrels were very widely distributed.

The reintroduction of a native, small predator, such as a pine marten, is likely to support ecosystem function through impacts on trophic cascades. Native prey species in the PRR have co-evolved adaptations to avoid pine marten predation over millennia. However, contemporary British landscapes have changed over time and it remains important to conduct ecological risk assessments to assess the costs and benefits from a recovering pine marten population to native and non-native species in the PRR. The risk of pine marten predation on threatened adult woodland birds is considered to be low, although nestlings and eggs would be at greater risk, and site appropriate mitigation measures may be needed to avoid nest predation in bird boxes. Our assessments revealed low risks and potential benefits for threatened mammalian species; as pine marten populations grow, asymmetric predation of grey squirrels will increase the red squirrel population. However, for bat species, it will be important to assess the vulnerability of known colonies in the PRR before any pine marten releases are made, and mitigation measures may be necessary at maternity roosts in underground structures and in buildings. The predation risk of pine martens on reptile and amphibian species is considered to be low.

A reintroduction project should engage comprehensively with the general public and stakeholder groups in the recovery area and should only proceed with widespread support from local communities. Within the PPR, we targeted specific audiences, using face-to-face meetings, videoconferencing tools, broadcast and social media, and questionnaires administered door to door. The consultation focused on representatives from the general public, the farming and field sports community, the forestry and statutory sectors, conservation NGOs, academia, and local business. There is broad cross-sector support for the recovery of pine martens in south Cumbria: 81% of the public, and 69% of the farming and field sports community. Furthermore, 74% of the public and 56% of the farming and field sports community agreed that reintroduction should be used as a method to re-establish viable pine marten populations in their area. The most frequent reason given in favour of a reintroduction was the potential for pine martens to support the recovery of red squirrels, and the most common reason against was related to the impacts of pine marten predation on native songbirds.

This feasibility study has demonstrated that there is suitable habitat, widespread public support and relatively low risks for a pine marten reintroduction in south Cumbria. As such, it provides a robust evidence base that the reintroduction of pine martens is likely to be successful and is the appropriate approach to expand the regional metapopulation and support the recovery of this mustelid in the North-West of England. We recommend that a translocation project should be developed, in partnership and without delay, that will strengthen networks with local stakeholder groups, explore ecotourism opportunities, and establish mitigation strategies, a release methodology, and a post-release monitoring programme. The translocation of pine martens from Scotland should follow best practice protocols to minimise risks to donor populations, and founder animals should be sourced from areas with robust pine marten populations that have not been trapped for translocation purposes within the last five years.

1. Project goals and justification

1.1 Background

The European pine marten (*Martes martes*) is a medium-sized mustelid that is found in western Eurasia and is predominately associated with forested habitat (Lariviere and Jennings, 2009). Fossil evidence suggests that this species evolved during the late Pleistocene and appeared in Europe 0.4 million years ago (Hughes, 2012). At the height of the last Ice Age, around 18,000 years ago, conditions in Britain and Ireland were too severe for pine martens, and they refuged in the warmer, ice-free parts of Europe (Birks, 2020). As the climate began to warm again, and the ice sheets retreated, pine martens recolonised Britain and Ireland before the flooding of the English Channel, around 10,000 years ago, separated Britain from the rest of continental Europe.

Post-glacial tree cover in Britain was at its maximum in the Mesolithic, before humans started clearing woodlands for agriculture around 6,000 years ago (Birks, 2020). During the Mesolithic, the pine marten was perhaps the second most abundant carnivore species in Britain, with an estimated population size of 147,474 (Maroo and Yalden, 2000). From the Neolithic onwards, humans caused a prolonged decline in pine marten abundance and distribution through progressive woodland clearance, trapping of martens for fur, and intensive predator control to protect game birds and poultry (Birks, 2020). By the early 1800s, the pine marten was rare in many counties in England, Scotland, and Wales; it went extinct in most of these counties during 1850 to 1915 (Langley and Yalden, 1977). By the beginning of the 20th Century, this once widespread carnivore species had contracted to a single population in northwest Scotland and small, scattered pockets in northern England and North Wales (Langley and Yalden, 1977). The pine marten was now the second rarest native carnivore in Britain, and numbers had fallen to around 2,000 – a decline of over 98% since Mesolithic times (Birks, 2020).

After the pine marten had reached its distributional nadir around 1915, conditions improved for this species during the remainder of the 20th century, with woodland cover increasing (Bright and Smithson, 1997; Watts, 2006) and levels of persecution declining (Tapper, 1992). By the mid 1970s, the Scottish population had spread eastwards into the Grampians (Langley and Yalden, 1977), and by 2013, pine martens had expanded back into much of their former range across the Scottish region (Croose et al., 2013; Croose et al., 2014). Recent evidence in Northumberland and Cumbria indicates that pine martens are expanding south through the Scottish Borders and recolonising some parts of northern England (Sainsbury et al., 2019; Croose, 2021).

The expansion of pine marten populations in Scotland has been slow, possibly due to low reproductive rates, low population densities, and legal culling which continued until 1988, when the pine marten was granted full legal protection in Britain (Birks, 2020; Appendix 1). Pine marten populations in England and Wales had failed to recover from their historical decline, and the species remains very rare south of the Scottish border (Birks and Messenger, 2010). The Welsh population has not yet expanded, and English records are mainly limited to the Cheviot Hills, Lake District, North York Moors and the Peak District, with occasional evidence in places such as Hampshire, which are potentially the result of covert releases (Langley and Yalden 1977; Sainsbury et al., 2019; Birks, 2020; Fig. 1). It is not known precisely why pine martens in England and Wales have failed to recover, but the effects of environmental and demographic stochasticity may have prevented their expansion (MacPherson et al., 2014). There is now a general consensus that southern pine marten populations are so small that they are highly vulnerable to environmental, demographic and genetic factors, which can interact in a downward spiral or extinction vortex (Gilpin and Soulé, 1986; MacPherson et al., 2014), and that natural recovery across most of England and Wales is unlikely without intervention (Jordan, 2011; MacPherson and Wright, 2021).

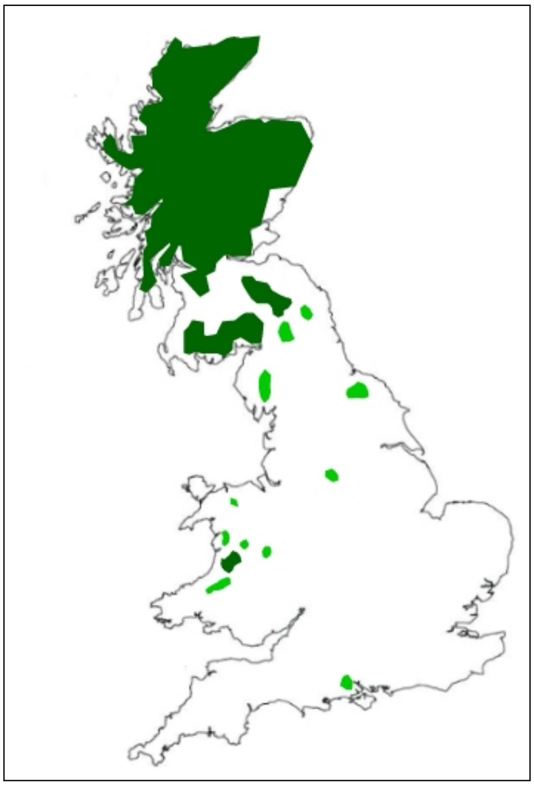

Figure 1. Current pine marten distribution in Britain (up to 2016). The dark green areas show established populations, and the light green patches are areas with occasional records (reproduced from Sainsbury et al., 2019).

Under international treaties, such as the Bern Convention (1979) and the Rio Convention (1992), the UK is obliged to restore populations of its native species (Hetherington, 2006). Consequently, the pine marten is identified as a candidate species for reintroduction in the government's 25 Year Environment Plan (DEFRA, 2018). Reintroduction programmes have been increasingly employed to re-establish absent species, or reinforce endangered populations, in order to create self-sustaining populations that are resilient to stochastic events (Lewis et al., 2012). In the 1980s, field surveys were conducted throughout Britain (Velander, 1983; Strachan et al., 1996), and several feasibility studies for recovering pine marten populations in England and Wales were published during the 1990s (Bright and Harris, 1994; Bright and Smithson, 1997; Bright and Halliwell, 1999). A pine marten reintroduction took place in Galloway Forest, southwest Scotland, between 1980 and 1981, as it was thought that the northern Scottish population was too remote to recolonise southern Scotland, (Shaw and Livingstone, 1994; Sainsbury et al., 2019). Since 2007, the Scottish Society for the Prevention of Cruelty to Animals has released rehabilitated abandoned/orphaned kits from the Highlands into Upper Tweeddale, in the eastern Borders region of Scotland (Croose et al., 2014).

The establishment of stable populations outside Scotland will enable the pine marten to reclaim much of its former range across England and Wales, and will greatly improve its conservation status, as it is still the second rarest carnivore in Britain, with a current total population estimate of 3,700 (Mathews et al., 2018). In 2014, the Vincent Wildlife Trust assessed the feasibility of translocating pine martens from Scotland to England and Wales (MacPherson *et al.,* 2014), and this was followed by the introduction of 51 individuals into central Wales between 2015 and 2017; released animals were fitted with radio-collars, and the follow-on monitoring programme has documented high survival rates and successful breeding (VWT, 2020).

After completion of the pine marten translocations to Wales in 2017, the Gloucestershire Wildlife Trust (with several partners) determined that the establishment of another major population in the Forest of Dean and lower Wye Valley would help avoid inbreeding depression and increase metapopulation stability in the Wales/West England region. A feasibility study was completed in 2018 (Stringer et al., 2018), and a total of 35 pine martens were translocated from Scotland to the Forest of Dean in 2019 and 2021. At least five breeding events have been documented, and the estimated pine marten population in spring 2022 was 40 individuals (Gloucestershire Wildlife Trust, 2022).

The Forest of Dean pine martens now contribute to a metapopulation in the Wales/West England area, which will greatly increase the likelihood that they will persist in this region (Stringer et al., 2018). A metapopulation helps to maintain gene flow, which allows a species to evolve and adapt to future threats, such as climate change and disease outbreaks, and reduces the likelihood of inbreeding depression, which impacts on individual and population fitness (Hanski, 1998).

Although pine martens in Scotland and Wales will expand their range, they are unlikely to be able to reinforce most of the remaining English pine marten populations due to habitat constraints in the interjacent regions (MacPherson et al., 2014; Stringer et al., 2018; MacPherson and Wright, 2021).

1.2 The history of the pine marten in Cumbria

Evidence from place names, hunting records and the literature, suggests that the pine marten frequently occurred across most of Cumbria until the end of the 19th Century, with a stronghold in the central Lake District (Webster, 2001; CBDC, 2020; Fig. 2). The pine marten was referred to as the 'sweetmart' or 'mart', which was incorporated into at least a dozen Cumbrian place names, such as Mart Crag, near Coniston, and Mart Knott, in Ennerdale. MacPherson (1892) believed that the pine marten could be found through the high mountains of Central and Western Lakeland, including

Kentmere, Longsleddale, Haweswater, Mardale, Martindale, Patterdale, Grasmere, Kirkstone Pass, Borrowdale, Eskdale, Ennerdale and Wastdale; although the species was hunted in all of these districts. By 1915, however, the pine marten had been extirpated from many counties in England as a result of persecution and the loss and fragmentation of woodland, although Langley and Yalden (1977) claim that this species has never been extinct in Cumberland and Westmorland.

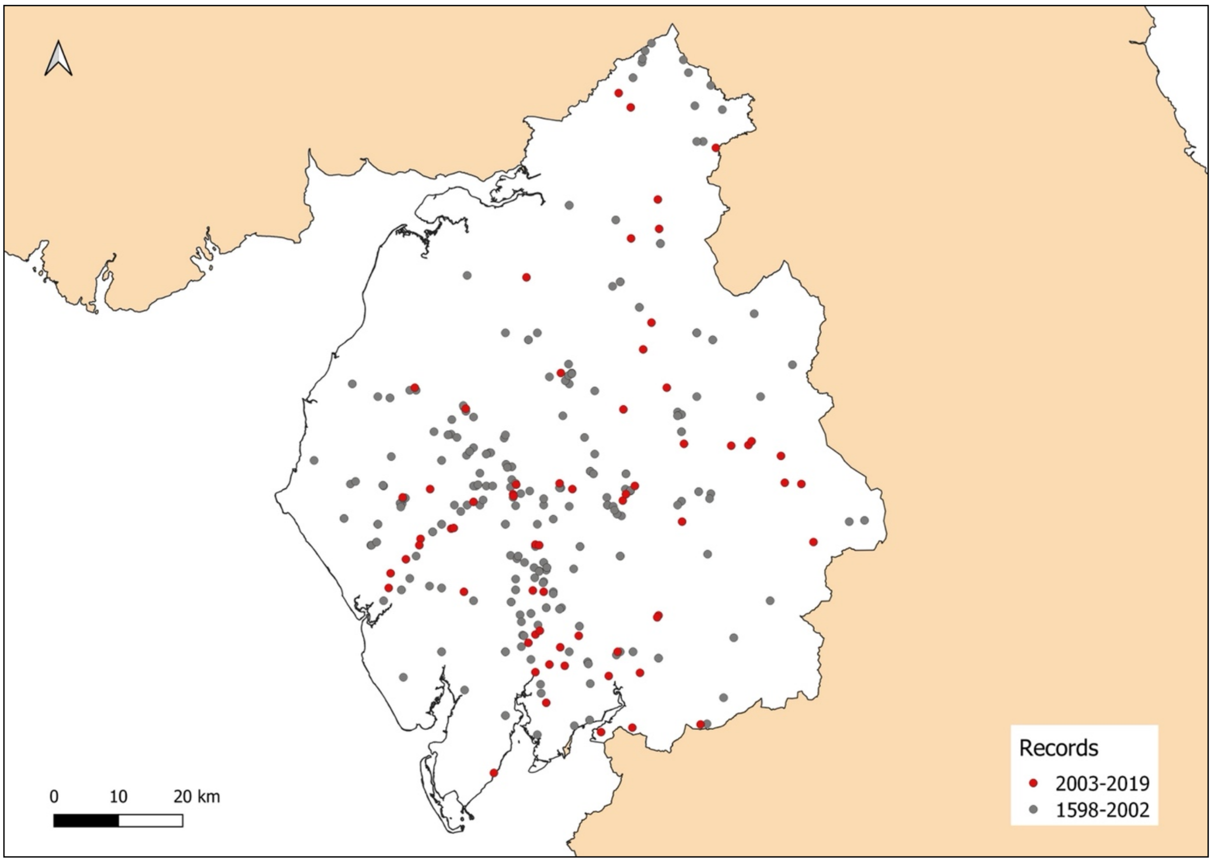

Figure 2. Pine marten occurrences in Cumbria from 1598 to 2019 (CBDC, 2020).

Pine marten records from individual sightings and organised surveys suggest a steep decline in Cumbrian pine marten populations from the 1970s onwards (Bright and Harris, 1994; Strachan et al., 1996; Croose, 2021). Strachan et al. (1996) found that pine martens were still present across Cumberland and Westmorland between 1977-88, with a few records from the slopes of the Pennines in north Cumbria. A 1993 survey conducted in northern England, using camera traps and scat transects, concluded that there were no longer any viable populations in Cumbria, and that any remaining individuals were likely to be long-term survivors of historic populations, or translocations from elsewhere (Bright and Harris, 1994).

Since the year 2000, 109 pine marten records have been submitted to the Cumbria Biodiversity Data Centre, although it is considered that many are misidentified as polecats (*Mustela putorius*) and other species (CBDC, 2020). Until recently, the last confirmed pine marten record was a scat from Satterthwaite, which was subjected to DNA analysis in July 2010 (CBDC, 2020). Between 2017 and 2020, the Vincent Wildlife Trust conducted field surveys for pine martens near the Scottish Borders, in Northumberland and Cumbria (Croose, 2021); they obtained a few camera trap records in northeast

Cumbria, which suggests that pine martens are currently recolonising the northern part of Cumbria from populations in Scotland.

1.3 Why translocate pine martens to south Cumbria?

The pine marten is an elusive species, and where populations are sparse it is difficult to find evidence of pine martens without intensive surveys (Birks and Messenger, 2010). This makes it challenging to accurately assess their population status in Cumbria, and it is impossible to prove their absence from an area. However, given the recent efforts by the BOOM (Back On Our Map) project, from September 2019 onwards, to detect pine martens in south Cumbria through field surveys (camera traps, scat transects) and comprehensive community engagement activities, the lack of any confirmed records suggests that if individuals do remain, there is certainly no viable breeding population of pine martens in the south of the county.

Field studies have suggested that the pine marten is a philopatric species, with new recruits to the population settling close to occupied areas (Bright and Smithson, 1997). Consequently, the recolonisation of formerly occupied regions by pine martens has been very slow. Under these circumstances, translocations of animals can be a viable conservation strategy and a very effective method of establishing or reinforcing population foci, and increasing rates of spread (Bright and Smithson, 1997; MacPherson and Wright, 2021).

Given the complexity, risks and cost of translocation projects, however, it is important to consider all options in the context of species restoration, including natural recolonisation through the improvement and expansion of suitable habitat to enable dispersal. MacPherson and Wright (2021) generated HexSim spatially explicit population models to determine where in Britain natural recolonisation is likely to occur in the next 25 years. Their model, which incorporates the recent translocations into central Wales and the Forest of Dean, predicts with a low probability that pine martens will have penetrated far into English counties during this time period (Fig. 3). Our analyses (see Sections 2.3.5 and 2.3.6) also show that recolonising martens from north-east Cumbria could take many decades to reach south Cumbria, and that natural recolonisation alone is unlikely to establish a viable population in the south. Furthermore, a reintroduction in the south, augmented by natural colonisation, will together generate a larger total population, and it will take considerably less time for these two populations to spread across Cumbria and establish a stable metapopulation. This indicates that the translocation of animals to a suitable site in south Cumbria would be a better option for recovering pine marten populations across this region.

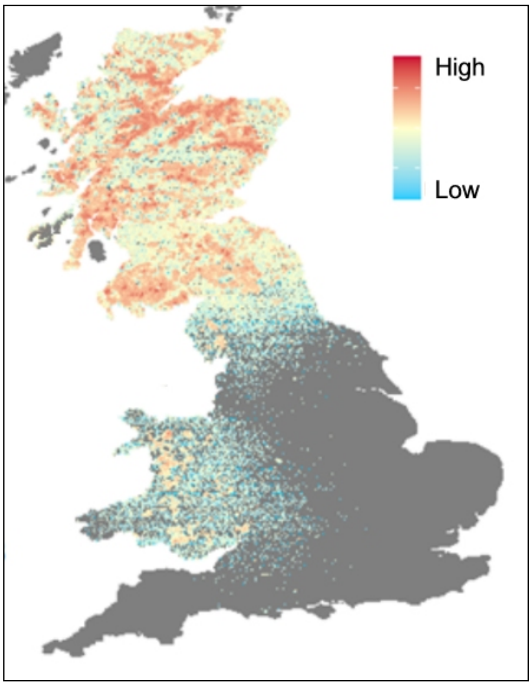

Figure 3. HexSim predictions of pine marten occupancy after the next 25 years; reproduced from MacPherson & Wright (2021).

The habitat suitability and connectivity modelling of MacPherson and Wright (2021) shows a large amount of suitable habitat for pine martens in the Lake District, particularly around Grizedale, and there is good connectivity across central and southern parts of Cumbria (Fig. 4). Their HexSim simulations indicates that a population of pine martens reintroduced to south Cumbria would be viable and highly likely to establish. More detailed habitat suitability, connectivity and population viability analyses for Cumbria are presented in Section 2.

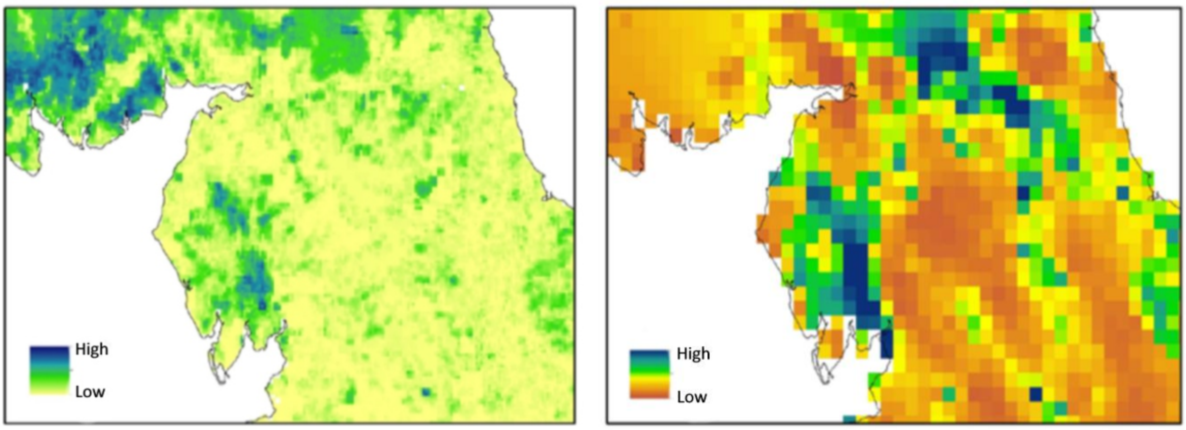

Figure 4. Habitat suitability (left) and connectivity (right) for Cumbria; reproduced from MacPherson & Wright 2021.

A project to recover the pine marten population in south Cumbria would improve its conservation status in Britain and would also represent a major step towards restoring the pine marten to its former range across northern England. This is very important when one considers that a species can very quickly be lost from public consciousness when it is rare, or absent for prolonged periods, and that consecutive generations perceive the state of the environment they are raised in as normal (Baum and Myers, 2004). Re-establishing pine martens in this region would also form a crucial stepping stone between the Scottish and Welsh populations to which links could be established or enhanced through woodland creation initiatives, as well as the construction of green bridges and wildlife underpasses to enable dispersal across main roads.

The modelling and field work outputs outlined in Section 2 suggest that a translocation of pine martens to south Cumbria would result in the establishment of a viable breeding population. The justification for a contemporary release of pine martens in this region is also strengthened by the commitments of many local landowners, private estates and statutory bodies to increase regional forest cover and connectivity through woodland creation schemes. Graythwaite Estate in the Rusland Valley is embarking on an ambitious landscape restoration project across 400 hectares (Edward Sandys, pers. comm.); the Lake District National Park authority has pledged to create over 200 hectares of woodland per annum, and The England Trees Action Plan 2021-24 describes a target of 30,000 hectares of new woodland planting before the end of the current parliament through woodland creation grants for landowners (DEFRA, 2021; Lake District National Park, 2022). An increase in both woodland cover and pine marten abundance would benefit other wildlife species, such as red squirrels (*Sciurus vulgaris*; see Section 3).

The restoration of the pine marten in Cumbria would also bring regional economic benefits to rural communities through ecotourism. In Scotland, there has been a surge in interest from visitors wanting to see pine martens, and this is contributing to the estimated £276 million generated by wildlife tourism through visitor centres, local hotels, B&Bs, and holiday cottages, as well as through wildlife tours and holidays that offer pine marten viewing opportunities and experiences (pinemarten.ie, 2022). This topic is further explored in Section 4.

1.4 Aims and objectives

The aim of this feasibility study was to examine the biological and social factors that would influence the establishment of a viable breeding population of pine martens in a potential recovery region (PRR) of south Cumbria, which can connect to existing populations in the north, and bring wide ranging benefits for both wildlife and people.

A recovery project will be considered biologically feasible if the overall risk of mortality is low and suitable foraging, denning and resting habitat exist in a forested landscape of sufficient quality and spatial configuration to support a self-sustaining pine marten population. Social feasibility will be determined by the level of public and stakeholder support for a pine marten reintroduction in the PRR and by the results of a community engagement programme to determine that the historic causes of extinction have been overcome.

The main objectives of this feasibility study were to:

- Identify a potential recovery region (PRR) within a network of suitable habitat in south Cumbria and quantify mortality risks within the PRR.
- Evaluate the connectivity between a reintroduced pine marten population in the PRR and existing populations further north and analyse the likelihood of population viability under different scenarios.
- Conduct field surveys to characterise woodland microhabitat features, quantify the prey base of small mammals, and describe the abundance and distribution of native and non-native wildlife within the PRR.
- Carry out ecological risk assessments to determine the impacts of recovering pine martens on sympatric species of native and non-native wildlife in the PRR.
- Implement a comprehensive public and stakeholder consultation to collate opinions, share knowledge, establish the level of community support, and determine the extent of anthropogenic risk to a founder pine marten population.

1.5 National and international translocation guidelines

This feasibility study has been designed and implemented in accordance with the International Union for Conservation of Nature Guidelines for Conservation Translocations (IUCN, 2013), as well as the Scottish and English Codes for Conservation Translocations (NSRF, 2014; DEFRA 2021).

Biological feasibility

The IUCN guidelines for reintroduction (IUCN, 2013) state that the selection of suitable recovery sites is of paramount importance, as it has been shown that releasing animals into unsuitable habitat is a major cause of failure in translocations (Wolf et al., 1998). Releases into areas with low chances of success are counter-productive, and raise animal welfare issues (Harrington et al., 2013). The recovery region should have a large enough carrying capacity to accommodate an increase in population size and to sustain a viable population in the long-term. This feasibility study uses GIS, modelling and ecological surveys to assess the suitability of habitats in Cumbria and to identify a potential recovery region (see Section 2).

The provenance and availability of founder pine martens from populations in Scotland should also be carefully considered to ensure the selection of healthy animals of the appropriate age and genetic provenance, and ecological risk assessments should be carried out to quantify and mitigate risks to the founder population and from a translocated pine marten population to sympatric, native species at the release site (see Sections 2.1 and 3)

The guidelines also caution against a reintroduction if the historic causes of extinction remain, or if novel contemporary threats are likely to constrain the establishment of a viable breeding population.

Intensive predator control to protect game shooting interests and the loss and fragmentation of woodland habitat were the main causes of pine marten extirpation (Langley and Yalden, 1977; Birks, 2020). There has been a significant reduction in game keeping since the early 1900s (Tapper, 1992), and in 1988, pine martens were given full legal protection under the Wildlife and Countryside Act 1981 (Appendix 1). It is now illegal for gamekeepers to trap pine martens, and gamekeeping practices have changed considerably over the last century, with lethal control now closely focused on a small number of pest species in order to avoid the accidental killing of non-target animals. However, although current levels of illegal wildlife persecution are much reduced compared to historic times, it remains important to quantify contemporary risks to a translocated pine marten population from legal pest control measures such as shooting, tunnel traps, and second- generation anticoagulant rodenticides (SGARs; see Section 4).

There has been significant afforestation of Britain since the 1950s (Bright & Smithson 1997), and forest cover is currently back to a similar level as in the 11th century (Watts, 2006), so that woodland availability for pine martens is at its highest for many years. Even though much of this increase is due to the creation of large conifer plantations on sheep pasture in nutrient-poor uplands, which is suboptimal habitat for pine martens, these forests still have good strategic value to pine marten re-establishment.

Novel threats have arisen as a result of large changes in the landscape since pine martens were widespread and common, including the expansion of urban areas and increases in roads and vehicle traffic, particularly in the more densely populated parts of Britain. These and other relevant factors will be assessed and discussed in Section 2.

Social feasibility

A recovery project should engage comprehensively with the general public and stakeholder groups in the recovery area to collate opinions, mitigate concerns, discuss potential costs and benefits, and to provide a platform for effective dialogue. The decision to use translocations as an approach to recover a species should be conditional upon widespread support for the initiative from the local communities. If the scale and scope of community consultation is inadequate and does not address the legitimate concerns of rural stakeholders, the level of opposition to the translocation and associated risk to the founder pine martens will remain high. Section 4 describes the range of community groups that were included in the consultation, the methods and tools that were used in the engagement process, and the results of questionnaire-based surveys.

2. The biological feasibility of recovering pine marten in Cumbria

2.1 Source/donor populations for translocations

An important aspect of a recovery programme is the identification of donor populations that show genetic, morphological, physiological and behavioural characteristics that are appropriate to the reintroduction sites, from which animals can be removed without detrimental effects (MacPherson & Wright, 2021). Animals sourced from areas with similar prey species, competitors, predators and habitats often show higher rates of post-release survival and reproduction (Aber et al., 2013).

Pine marten populations can be overharvested, which may cause a genetic bottleneck that leads to inbreeding, loss of genetic diversity and population decline; therefore, the size and genetic diversity of potential donor populations are central points to consider when assessing the impacts of removing animals for translocation projects (IUCN, 2013). Jordan et al. (2012) compared the haplotype composition of historical and current pine marten populations in England, Scotland and Wales, and found no differences between the main haplotype of contemporary populations across the UK. Bright and Halliwell (1999) examined the effects of removal on hypothetical source populations of 20 and 50 pine martens and showed that two years after 15% of adults (or adults and sub-adult) animals were removed, there was more than an 80% probability that populations would have returned to their initial size. These two studies support the view that the Scottish population is an appropriate source for translocations and that animals can be removed without detrimental effects (MacPherson and Wright, 2021). However, the total number of animals that can be translocated from each donor site will be carefully determined (based on survey data), especially considering that some Scottish populations have been harvested recently for the pine marten recovery programmes in Wales and Gloucestershire.

MacPherson and Wright (2021) have provided guidelines for minimizing the impact of harvesting source populations, and the following recommendations will be followed. Regions that contain suitable pine marten donor populations for translocations will be identified on the basis of woodland cover, altitude, and known length of occupancy by pine martens. From each large forest block, between two and four individuals will be removed in autumn (at the end of the breeding season) to minimise the impact on the viability of the source population, as the removed individuals will quickly be replaced by dispersing juveniles, or non-territory holding adults. The actual number of pine martens to be taken from each source site will be based on scat and hair surveys carried out in the preceding March, and on conservative estimates of the number of adult pine martens present, derived from correlates of pine marten density and woodland area, and the analyses of genetic data. As pine martens are territorial, untrapped 'refugia' (at least twice the size of a mean pine marten home range) will also be incorporated into the trapping plan.

To allow source populations sufficient time to return to their initial size, sites from which animals have previously been removed for translocations will not be re-trapped until at least five years have elapsed since they were last trapped. In addition to site surveys and habitat assessments at each proposed donor site, informal consultations will be carried out with local stakeholders and residents to ascertain if there were any concerns about a small number of animals being removed from the area, or if any other projects, research studies, or businesses (e.g., commercial hides or tourism enterprises) might be impacted.

Donor sites used so far have been north of Speyside and along the Great Glen (MacPherson and Wright, 2021). Other suitable areas that have not previously been used as harvesting sites include some private estates in Moray, east of Inverness. More northerly forest blocks, such as those around Loch Shin, could be potential areas; however, these would be logistically more challenging because of their remoteness, and they would also necessitate a longer journey by road for those animals that were trapped and translocated to Cumbria, with implications for animal welfare. Although there are potential donor sites further south, some of these are an important source of dispersers to the largely un-colonised area south of the Central Belt, and this region is where the recovering pine marten population is thought to be having a negative impact on the grey squirrel (*Sciurus carolinensis*) population (and consequently benefiting native red squirrels). Hence, there will be a presumption against removing pine martens from central or southern Scotland where recolonisation has only occurred relatively recently (MacPherson and Wright, 2021).

Monitoring the course of a recovery programme is essential, and an integral part of this is the collection of baseline ecological information on any potential release area before translocations take place. Without this, it will be impossible to determine if any observed changes after releases relate to the impacts of the released animals. Ecological surveys have been conducted in the PRR (see Section 2.4) and are ongoing and survey effort has focused on the species and ecological processes that may be affected by translocations. Radio-telemetry will be used for post-release monitoring of translocated animals to determine population trajectory, habitat use, reproduction, recruitment, and home range sizes in the release areas. All this information will be used for an adaptive management programme that will inform future translocations, thus ensuing the highest probability of survival and site fidelity for released individuals.

2.2 The biology, habitat requirements, and diet of the pine marten

The following information is summarised from Stringer et al. (2018) and Lariviere and Jennings (2009), with references therein.

Pine martens are solitary and sexually dimorphic, with males (1360–1587g, 69-71cm nose to tail) larger than females (960-1116g, 62-64cm nose to tail). Mating takes place in July and August, and between 1-5 kits are born in March or April after a gestation of 8-9 months, which includes a period of delayed egg implantation. Natal dens are used for between 45 to 70 days, after which the kits stay with the adult female until late winter; the kits are fully-grown after 6-8 months. The dispersal of juvenile pine martens is highly variable and half of them do not disperse, instead staying local to the mother's home range. Displacement distances may differ between males and females, and vary from 2.3km to 214km. Pine martens have a maximum lifespan of 10–15 years.

Pine martens are a generalist omnivore, eating a wide range of seasonally abundant foods, including mammals, birds, plant materials, invertebrates, and to a lesser extent amphibians, reptiles, and fish. The dietary niche breadth and proportion of these different food groups in the diet varies between seasons and across the pine marten's range, with the most abundant and available species more likely to be eaten. Small mammals are the most important component of the diet and are hunted throughout the year. Field voles (*Microtus agrestis*), bank voles (*Myodes glareolus*), and wood mice (*Apodemus sylvaticus*) are abundant and widely distributed in south Cumbria (see Section 2.4.2), but studies in Scotland have demonstrated a preference for field voles, which often use grassland habitats beyond the woodland edge. Bird eggs and chicks are often hunted in the spring and summer months, including common woodland species, such as wood pigeon (*Columba palumbus*), wren (*Troglodytes troglodytes*), and thrushes (*Turdus* spp.). Fruit from shrubs and trees are eaten in the autumn, and pine martens show a preference for rowan (*Sorbus aucuparia*) and bilberry (*Vaccinium myrtillus*), as well as cherries (*Prunus* spp.), blackberries (*Rubus fruticosus*), and ivy berries (*Hedera helix*). The most commonly eaten invertebrates are often beetles (Coleoptera). Despite this broad diet, pine martens tend to specialise on certain common species; for instance, nearly half of the yearly diet in Scotland was made up of field voles, rowan berries, and bilberry.

Pine martens maintain territorial home ranges, and do not tolerate overlaps with individuals from the same sex. Males have a larger home range size than females, with mean ranges varying between <1 to 33km^2. The density of a population also varies widely, from 0.12 to 2.6 pine martens per km^2 (with mean values ranging between 0.1 and 0.87 per km^2). In continental Europe, it has been shown that pine marten population density can be predicted by mean monthly winter temperature (November to March) and seasonality, which means that there is the potential for high-density populations in the UK due to warm winter temperatures; however, the high abundance of foxes in the UK and the relatively high density of roads may limit population densities in this region. Other known predictors of pine marten density include the abundance of voles (especially in winter), and the availability of carrion.

Pine martens are highly adaptable and may utilise a range of habitats, however, their survival is dependent on the presence of woodland (coniferous, deciduous, or mixed), as trees are thought to be essential for pine marten predator escape, although three-dimensional landscapes, such as rocky outcrops and cliffs, may be suitable alternatives. For pine marten survival in Scotland, it is suggested that at least 20% of a landscape needs to be woodland, with >0.25 km^2 woodland patches. Pine martens will forage along the forest edge and into open habitats, particularly for voles in scrub, grassland and hedgerows, but only within a certain distance from woodland (average: males ~ 75m, females ~ 30m). Pine martens do avoid some habitat types, in particular open ground, such as agricultural land and heathland, as well as urban areas. Roads and wetlands may impede dispersal but are not a strict barrier to movement. Riparian woodlands are thought to be important habitat corridors for pine martens.

Pine martens need shelter for resting, breeding and thermoregulation, and will use a variety of structures, including squirrel dreys, bird nests, log piles, cavities in trees, root plates, burrows, rocky outcrops, and buildings. Pine martens actively seek out tree cavities as natal den sites, as they provide protection against predators and enhanced thermal insulation. In continental Europe, cavities made by black woodpeckers (*Dryocopus martius*) are often used to rear kits, at an elevation of between 3 to 12 metres above the ground. As the black woodpecker is not present as a breeding bird in Britain, pine martens will use the nesting chambers of smaller resident species, such as the great spotted woodpecker (*Dendrocopos major*) and green woodpecker (*Picus viridis*), if the entrance hole and associated cavity have enlarged as a result of decay. As old-growth deciduous forest is rare in Scotland, tree cavities are used infrequently; instead, dens are often found in rocky outcrops, snagged branches of wind-thrown trees, and within man-made structures.

2.3 Habitat mapping and modelling

2.3.1 Ecological niche modelling

Introduction

Knowledge of geographical distributions and habitat preferences are central to the conservation of threatened species and are of paramount importance when assessing their conservation status and evaluating levels of threats and protection (Jennings et al., 2013; Jennings and Veron, 2015). Ecological niche modelling is a valuable tool for predicting the distributions of poorly known species in remote and inaccessible regions, and uses the environmental characteristics of known occurrences to assess the suitability of regions where current records of a species are absent (Elith et al., 2006; Jennings and Veron, 2011). Outputs of ecological niche modelling may highlight unknown populations and, can be used to identify key areas for fieldwork and conservation initiatives. In addition, predictive distribution models may improve our understanding of a species' ecology, and can be used to maximise the effectiveness of ecosystem restoration and species reintroduction programmes (Jennings et al*.,* 2013; MacPherson et al., 2014).

This modelling process is based on the realised niche, relying on the assumption that location data used in the model are representative of a species' true requirements and that appropriate predictor variables are used to identify areas that meet its ecological requirements. However, some regions of a potential distribution may not be inhabited due to the presence of a competitor, geographical barriers, or because the species has been extirpated from an area for some reason.

Maxent (Phillips, et al., 2006) uses a machine-learning algorithm to characterise probability distributions from presence-only data. It is widely used to model suitable habitat for various species (Jennings and Veron, 2011; Jennings et al., 2013; Jennings and Veron, 2015) and has been shown to perform better than other presence-only modelling techniques (Elith et al., 2006; Hernandez et al., 2006). Maxent requires relatively few (<30) presence locations to construct useful models, which is advantageous for rare or difficult to detect species when the amount of occurrence data is often limited (Wisz et al., 2008). The advantage of this method is that it requires only presence data to develop the model; true absence data for elusive species with low detection probabilities, such as the pine marten, are almost impossible to verify.

The aim of this modelling was to predict the potential distribution of pine martens within Cumbria. Cumbrian Pine marten occurrence records were combined with two environmental layers, land cover and elevation, to predict possible areas of occupancy. Various classes of land cover have been shown to be important variables for modelling the potential distribution of pine martens (MacPherson et al., 2014), and even though the pine marten does not appear to be constrained by elevation (Lariviere and Jennings, 2009; MacPherson et al., 2014), altitude may provide a useful surrogate for other variables, such as prey density, tree cover and productivity, which may impact its distribution (Bright and Smithson, 1997; MacPherson et al., 2014). Altitude may also have a link with mortality risks; for instance, heavy predator control is associated with grouse moors that are on higher ground.

Methodology

Pine marten presence locations were extracted from a report published by the Cumbria Biodiversity Data Centre (CBDC, 2020), and from the NBA Atlas (nbnatlas.org); each record had both location information and a UK National Grid reference. The most recent records from 2003 to 2019 were selected for the ecological niche modelling (Fig. 2). Records with the same coordinates were removed from this data set in order to minimise autocorrelation effects.

A 2012 Corine land cover map for Cumbria was downloaded from <www.eea.europa.eu/data-and-maps/data/corine-land-cover-accounting-layers/>; this layer was chosen as it has a close time correspondence to the modelling records (i.e., no record was dated more than nine years from the habitat data layer). An elevation layer was obtained from the SRTM 90m DEM Digital Elevation Database (srtm.csi.cgiar.org/srtmdata/). Both layers were imported into QGIS 3.16 (qgis.org/en/site/) and clipped to the county of Cumbria.

Maxent 3.4.4 (biodiversityinformatics.amnh.org/open_source/maxent/) was used for the ecological niche modelling. The random seed setting was chosen, with 75% of the records used for training and 25% for testing. The 10th percentile was used as the threshold value; this is the value above which the model correctly classifies 90% of the training locations and is commonly used in species distribution modelling (Razgour et al., 2011; MacPherson et al., 2014). All other settings were left at default, and the model was run for 20 replications. Model fit was assessed using Receiver Operator Characteristic curve analysis, using the Area Under the Curve (AUC) values across all replicated runs; AUC values greater than 0.90 are classed as very good, with 0.70-0.90 being good, and an AUC of less than 0.70 classed as uninformative (Swets, 1988).

Model performance was also evaluated using the True Skill Statistic (TSS; Allouche et al., 2006), which ranges from −1 to +1, with values <0 to 0.20 indicating no or slight agreement, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement. The significance of each environmental variable in explaining the variance in the presence location data was evaluated from jacknife plots. The QGIS plugin 'Molusce' was used to test for correlation between the environmental layers using Cramer's V coefficient, by converting the elevation layer to categorical variables.

Results

A total of 64 presence locations were used in the Maxent modelling. Figure 5 shows the predicted distribution map for the pine marten in Cumbria, based on the best performing model from 20 replicates. The final model that included both environmental layers (land cover and elevation) had good performance scores by the evaluation criteria: AUC_{train} = 0.82, AUC_{test} = 0.85; TSS = 0.62. This combined model also performed better than those that only included land cover (mean AUC_{train} = 0.55, mean AUC_{test} = 0.45), and only elevation (mean AUC_{train} = 0.22, mean AUC_{test} = 0.19).

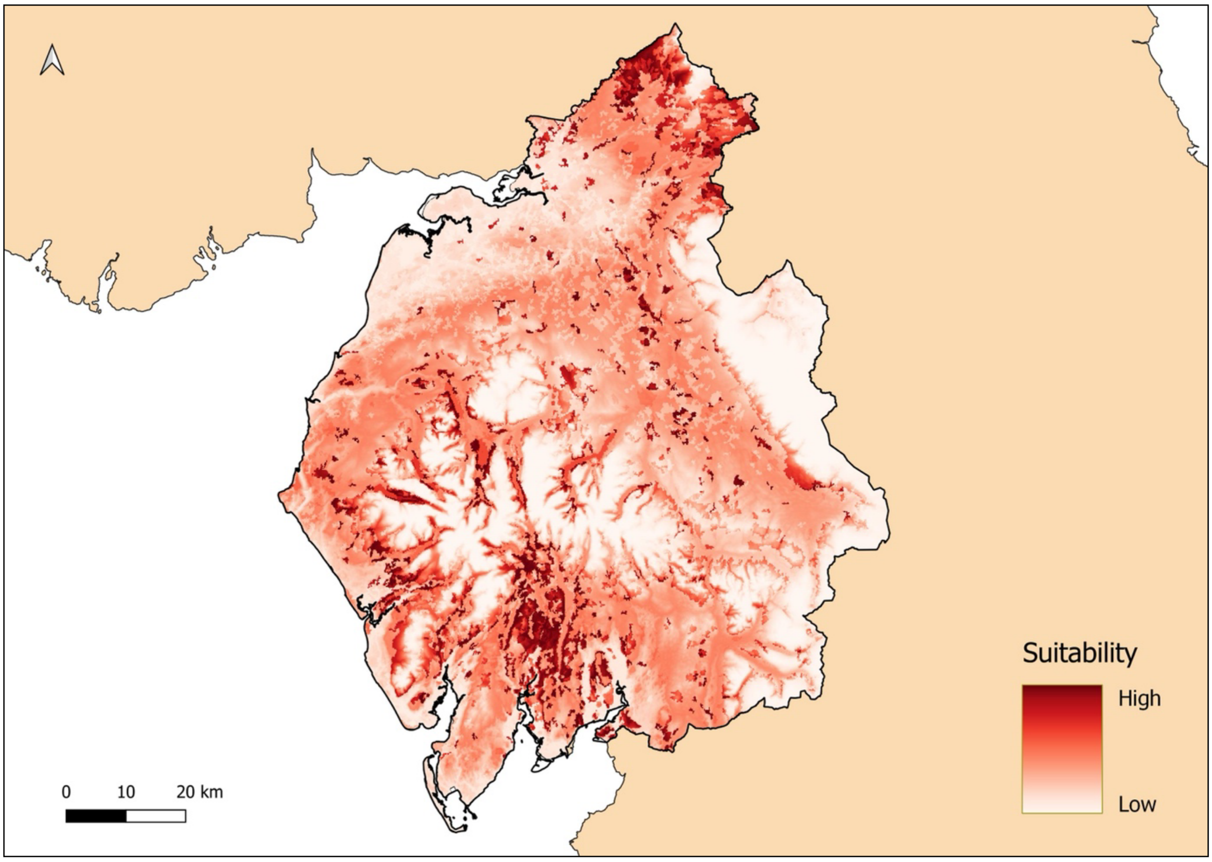

Figure 5. Predicted distribution map for the pine marten in Cumbria, based on maxent ecological niche modelling using both land cover and elevation. The darker shades of red indicate areas of higher suitability for pine martens (or higher probability of occurrence).

The contribution of each environmental layer to the final model was 67.6% for land cover, and 32.4% for elevation. The jacknife tests on training gain, test gain and AUC showed that land cover had the highest impact on training gain, and also decreased the gain the most when omitted. The response curves show that pine martens responded highest to wooded land classes: broadleaved, conifer, mixed woodland, and woodland shrub, and that the responses of pine martens to elevation increased from sea level to 100m, and then declined at higher altitudes.

Discussion

Our ecological niche modelling produced a well-supported distribution map that shows the potential areas that are most suitable for pine martens in Cumbria (particularly wooded areas), although model extrapolation should be treated with some caution when making predictions for areas that are beyond the range of the data used to construct the model.

The strong association with wooded land that was found in the final model concurs with pine marten field studies, which show that this species is associated primarily with well-structured, mature forests (Pulliainen, 1981; Brainerd, 1990; Storch et al., 1990; Brainerd et al., 1994; Brainerd and Rolstad, 2002). MacPherson et al. (2014) found that almost 70% of their habitat suitability model performance was from wooded land classes (broadleaf, conifer, mixed woodland, and transitional woodland scrub). Although mature forest is the most preferred habitat of pine martens, some field studies have shown that pine martens can also persist in scrubland, coppices, and patchily wooded areas (De Marinis and Massetti, 1993; Pereboom et al., 2008; Manzo et al., 2012). In Scotland, Caryl, et al. (2012) found that scrub and tussock grassland is consistently selected by pine martens, which is supported by our modelling results: pine martens had a fairly high response to natural grassland areas. This suggests that scrub/grassland habitats may provide resources, such as high densities of field voles, that are not widely available in commercially-managed forest plantations (Caryl et al., 2012). However, field studies have also shown that pine martens avoid some open habitats, such as agricultural land, moors and heathland (Pulliainen, 1981; Storch et al., 1990; Bright and Smithson, 1997; Pereboom, 2008; Balestrieri et al., 2014), which is consistent with the negative association with moor and heath that MacPherson et al. (2014) found in their habitat suitability model.

Model performance was improved by including elevation as an environmental variable, whereas the final habitat suitability model of MacPherson et al. (2014) for Britain performed better when elevation was removed. Their modelling technique differed from this study, which may account for this discrepancy: they plotted each environmental variable onto a 10 x 10km square grid, and used the mean altitude per 10km square as an elevation layer. Although pine marten distribution does not appear to be constrained by elevation within its range, occurring up to 2000m above sea level (Balestrieri et al., 2010), the modelling outputs suggest that pine martens may be more prevalent at altitudes around 100m. It is unclear what factors are associated with this result, whether there are changes in habitat quality, prey availability, or mortality risks, with altitude, and this therefore warrants further investigations. In Scotland, Bright and Smithson (1997) found that the population density of pine martens was low in spruce-dominated forest on higher ground, most likely due to lower food availability. As the pine marten is primarily a woodland species, the distribution of forested patches may be a causal factor: most lowland woodland in Britain has been cleared for arable farming and urban development, and high elevation land is mainly covered by open moorland; MacPherson et al. (2014) found that pine martens had a negative association with moor and heath.

The assumption that recent occurrence records are representative of a species' fundamental niche may not be true for a declining species that has been forced into refuges of sub-optimal habitat that do not provide the environmental conditions needed to support a viable population (Pulliam, 2000). This may have happened during the pine marten's distributional nadir in Britain at the beginning of the 20th Century, when they might have been restricted to areas with lower levels of persecution rather than suitable habitat features. However, this suggestion has been disputed by some pine marten experts (Birks, 2020), and we found that pine marten occurrences recorded during the past 100 years span the whole of Cumbria despite high levels of persecution in many areas up to fairly recent times, which suggests that this species selects primarily for habitat features rather than levels of persecution.

It also could be argued that the records used in the modelling are biased to those areas where more time has been spent searching for pine martens in Cumbria and that this has distorted the model outputs. However, the modelling that MacPherson et al. (2021) conducted for the whole of Great Britain, using a larger number of presence locations from a wider geographical area, also showed similar predictions to those produced from this study for the county of Cumbria.

Conclusions

The aim of this ecological niche modelling study was to determine the potential distribution of the pine marten across Cumbria, under contemporary land cover conditions and across a wide range of elevations. The final model performed well, which indicates that this method is useful for identifying the most suitable areas for pine martens in Cumbria.

2.3.2 Identification of a potential recovery region in south Cumbria

In addition to our ecological niche modelling, we also performed other GIS analyses for identifying the most optimal potential recovery region in south Cumbria. Bright & Harris (1994) and MacPherson et al. (2014) suggested that each 10x10km UK National Grid square of a potential recovery region should contain at least 500ha of contiguous or non-contiguous woodland. We calculated the amount of woodland within all 10km square blocks across Cumbria, using the NFI data set and QGIS (see Section 2.4), and assigned these to different categories of woodland cover (ha) (Fig. 6).

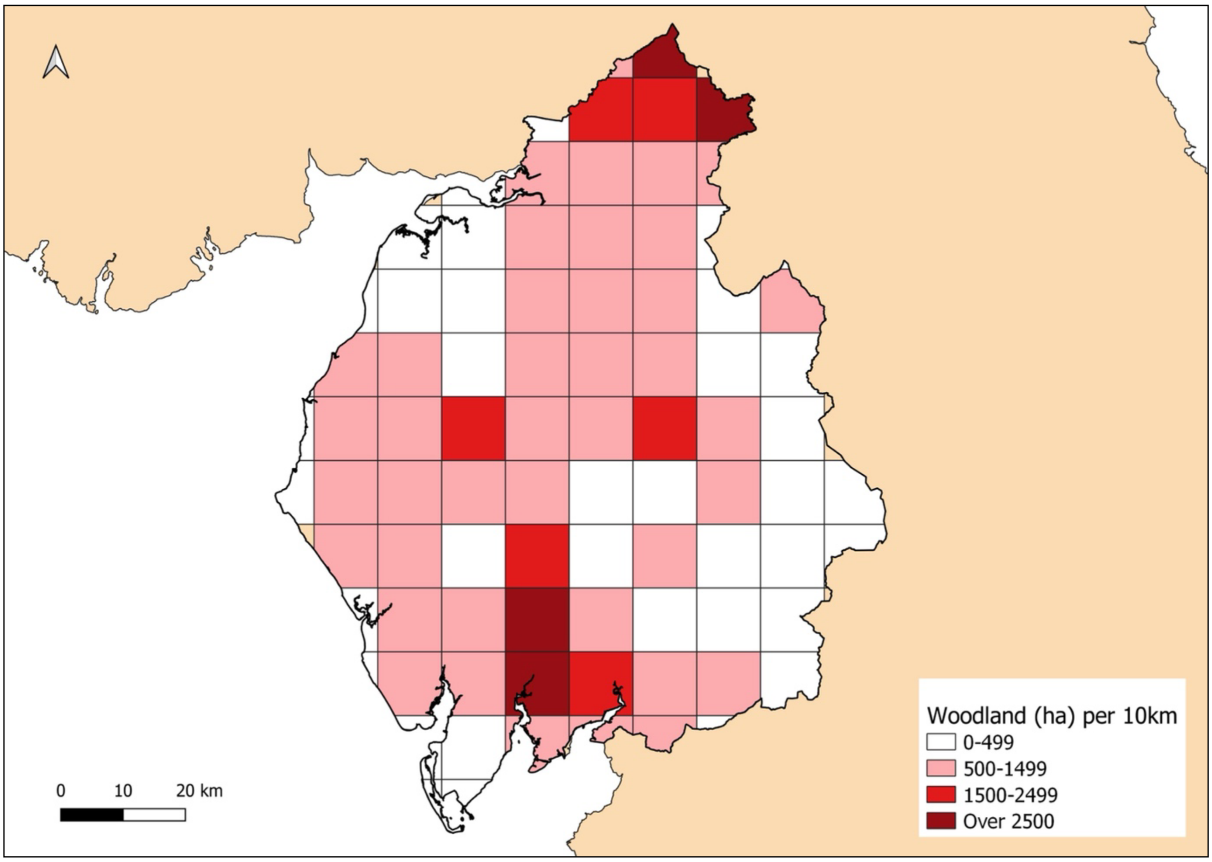

Figure 6. The amount of woodland (ha) per 10x10km UK National Grid square in Cumbria; a minimum of 500ha of forested area per 10km square is considered to be suitable for pine martens (MacPherson et al., 2014).

The modelling of Moll et al. (2016) suggested that pine martens will occupy habitat near human development or agricultural land, provided the broader area contains a baseline level of wooded habitat comprising 0.25km patches with a minimum of 20% wooded cover. We calculated the percentage of existing woodland within 10km square blocks across Cumbria, using the NFI data set and QGIS (see Section 2.4), and assigned these to different categories of woodland cover (Fig. 7).

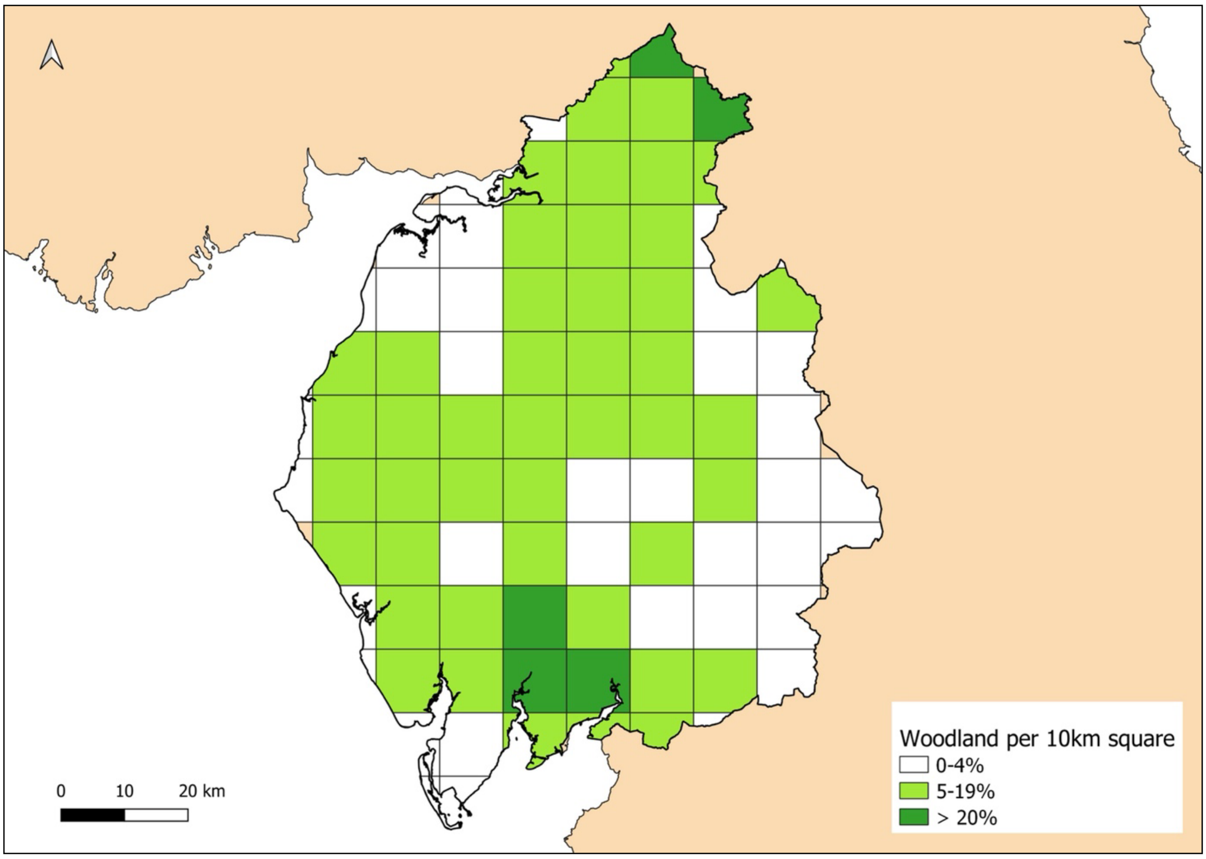

Figure 7. The percentage of woodland within 10x10km UK National Grid squares.

Using the predicted distribution map for the pine marten in Cumbria (Fig. 5, Section 2.2), and the additional GIS analyses in this section (Figs. 6 and 7), we delineated a potential recovery region in south Cumbria, which is shown in Figures 8 and 9.

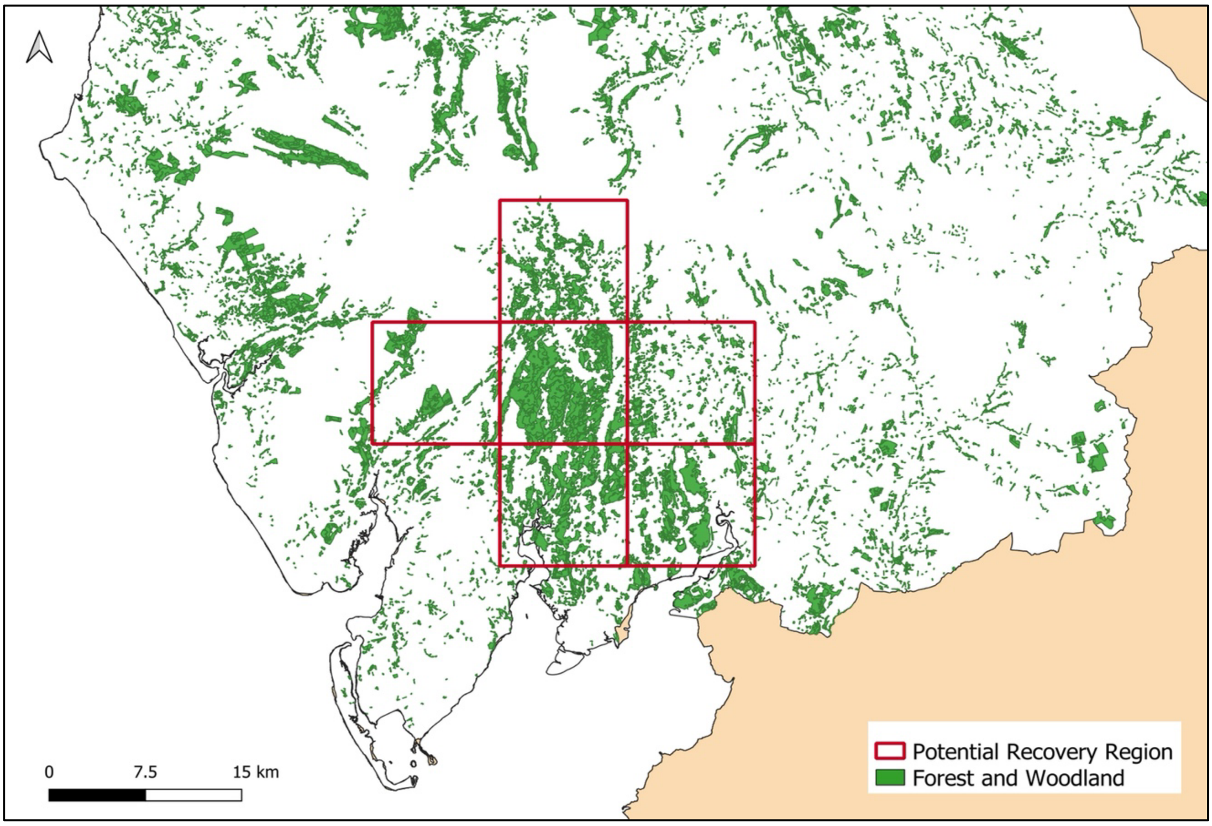

Figure 8. The location of a potential recovery region in south Cumbria.

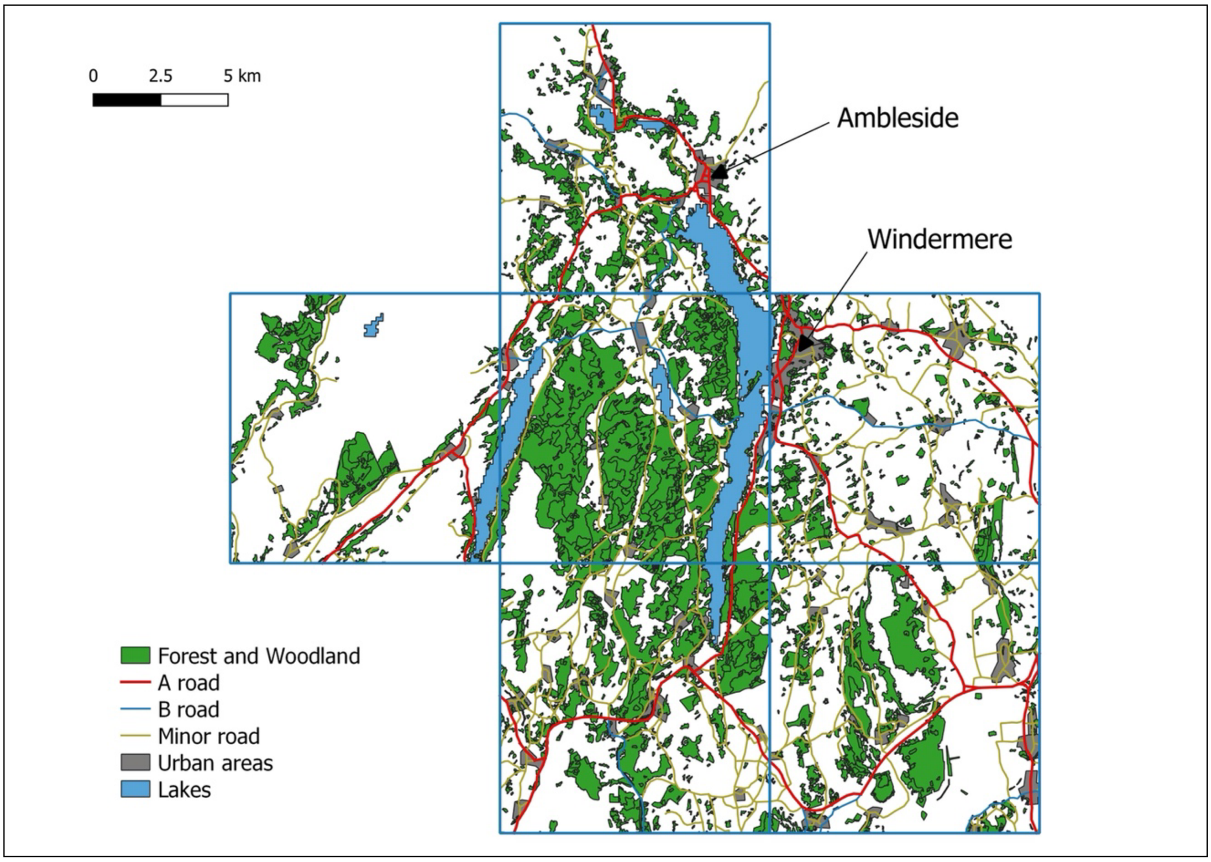

Figure 9. The potential recovery region in south Cumbria showing all woodland areas, roads, and urban regions.

However, other factors, such as mortality risks, may also impact the suitability of any potential recovery region. These additional factors are assessed in the following section and will also be carefully considered before a final decision is made as to whether any translocations go ahead.

2.3.3 Suitability assessment of the potential recovery region

Introduction

Reintroductions have two phases, establishment and spread, during which different factors limit populations (Bright and Smithson, 2001). During establishment, when a population is very small, factors operating in a stochastic manner (especially on mortality risks and sex ratios) are likely to determine success (Bright and Smithson, 2001). Spread occurs when a population grows and increases in distribution, escaping stochastic extinction vortices (Soulé, 1987). Stochastic mortality is an over-riding constraint during establishment of reintroduced populations, and factors affecting birth rates, especially food availability, are likely to have a dominant influence on the probability that a reintroduced population will spread (Bright and Smithson, 2001). Hence, suitability assessments of recovery regions need to consider two different sets of factors: those promoting establishment and those promoting spread (Bright and Smithson, 1997).

The IUCN guidelines for species reintroductions highlight that matching habitat suitability and availability to the needs of a candidate species is central to the feasibility and design of a successful recovery project (IUCN, 2013). They also state that the structure of available habitats should be taken into account in determining whether an area is suitable for releasing translocated animals, and that habitat suitability should also include an assurance that the release of animals (and their subsequent movements) is compatible with permitted land uses in the affected area, such as agriculture and game shooting.

Previous conservation translocations that have reported a low rate of success have frequently cited low habitat suitability in the release area as one of the reasons for failure (Wolf et al., 1996; Armstrong et al., 2002; Cook et al., 2010). Reintroductions of American martens, (*Martes americana*) have demonstrated that translocations into high quality habitats have a disproportionately high success rate (Slough, 1994). Hence, a large effort should be put into quantifying and characterising the habitats of suitable release regions before considering any translocations (MacPherson et al., 2014; Stringer et al., 2018). Several landscape scale (or macro-habitat) features, such as the percentage of woodland cover, have proven to be useful predictors of the habitat suitability of an area for pine martens, and it has been hypothesised that pine martens select habitat on the basis of three factors: food availability, the availability of suitable denning and resting sites, and the risks of mortality (MacPherson et al., 2014; Stringer et al., 2018;).

Causes and rates of mortality are important considerations when evaluating the suitability of habitats for pine martens, as they may increase the chance of population extirpation despite other factors indicating high-quality habitat (Stringer et al., 2018). Pine martens breed only once per year, and have a slower reproductive rate than smaller mustelids (Lariviere and Jennings, 2009), which makes them particularly vulnerable to increases in mortality, with adult survival a key predictor of population persistence. Bright and Harris (1994) formulated a model of pine marten population viability that predicted that even low rates of additional mortality will result in a large reduction in population growth and increase in extinction probability. Hence, post-release mortality during the establishment phase of an introduction has a crucial influence on the success of a recovery project, and predicting potential rates of mortality is essential for estimating the risk of population extinction (Stringer et al., 2018).

The aim of this section was to assess the macro-habitat characteristics and anthropomorphic levels of mortality for the potential recovery region (PRR) in south Cumbria. Available GIS data were used to determine the habitat characteristics, potential mortality risks from traffic on major roads, and the possible impact of game hunting interests. Given the increasing volume of tourist traffic in the Lake District National Park, it was also considered important to quantify traffic flow along the network of minor roads in the pine marten feasibility study area. Furthermore, the merits of the PRR in south Cumbria were compared with the pine marten release sites in the Forest of Dean and lower Wye Valley (Gloucestershire) and North Ceredigion (Wales).

Habitat suitability

Pine martens are primarily associated with deciduous and coniferous forests (Lariviere and Jennings, 2009; Birks, 2020). Although some field studies have revealed that they will also use less-forested areas and young forest stands (Brainerd et al., 1994; Pereboom et al., 2008; Balestrieri et al., 2010), dense forest cover is still essential, and pine martens do not venture far into open habitats (Storch, Lindstrom and De Jounge, 1990; Brainerd and Rolstad, 2002; Caryl et al., 2012). Hence, the availability, size and connectivity of forested areas in a release region will greatly affect the survival and persistence of pine martens.

The population modelling of Bright and Harris (1994) found that extinction risk was greatly reduced when the number of animals released was increased above 30. This concurs with a study of American marten reintroductions (Slough, 1994), which found that they succeeded in all cases where at least 30 animals had been released. Based on these findings, MacPherson et al. (2014) recommend that potential recovery regions should have sufficient woodland cover for at least 30 pine marten home ranges. Since the minimum home range for a male marten is 200ha (Zalewski and Jędrzejewski, 2006; Balestrieri et al., 2010), this recommendation translates to minimum of 6,000ha of woodland, although MacPherson et al. (2014) state that this could be across a number of well-connected woodland blocks within a release region.

Food availability, which affects breeding success, has a large impact on how a population increases and expands its distribution. Optimal pine marten recovery sites should have high quality habitat that supports sufficient food resources, and this was assessed by conducting field studies (see Section 2.4).

For protection from predators and adverse weather conditions, pine martens need suitable den sites for both resting and raising young (Brainerd et al., 1995; Birks et al., 2005), and these are an essential requirement in any potential release region. Across continental Europe, pine marten breeding dens are usually located several metres above ground in tree cavities, (Lariviere and Jennings, 2009; Birks, 2020), but tree cavities are scarce in Britain (Birks et al., 2005), particularly in commercially-managed forests, which have relatively short felling rotations. However, the lack of tree den sites can be mitigated by erecting nest boxes, and various designs have been developed and tested in the field (e.g., www.pinemartendenboxes.co.uk/). The availability of den sites is a crucial factor that will need to be investigated during field surveys.

Mortality risks

Persecution

The trapping, shooting and poisoning of pine martens, predominantly by gamekeepers, was one of the main causes of pine marten extirpation from much of Britain (Birks, 2020). The pine marten was given full legal protection in 1988, so that it is now illegal to kill or harm them. Gamekeepers must take reasonable precautions to prevent the capture of protected species, but pine martens are still sometimes accidentally killed by lawful predator and pest control activities, which are particularly practised around pheasant (*Phaisanus colchicus*), and poultry pens.

In Cumbria, there is a risk of mortality associated with grouse shoots, which dominate some large upland areas in this county, particularly in the eastern regions. Red grouse (*Lagopus lagopus scotica*) are shot on driven grouse moors, which depend entirely on wild birds, unlike many pheasant or partridge shoots that rely on rearing and releasing. Heather moorland comprises 25% of the British uplands and around half of it is managed by private landowners for red grouse shooting (Fletcher et al., 2013). The numbers of red grouse available for shooting are maximised through employing gamekeepers to manage heather by rotational strip burning and by controlling predators and parasites of grouse (Fletcher et al., 2013).

GIS modelling has revealed that pine martens tend to avoid moorland (MacPherson et al., 2014), and field studies have shown that they only venture into open habitats within a certain distance of woodland: female pine martens will travel on average 30.4m from woodland into open habitats, up to a mean maximum distance of 93.7m, while males will on average travel 75.1m, up to a mean maximum distance of 199.6m (Caryl et al., 2012). However, pine martens may be vulnerable to persecution where woodland borders keepered grouse moors, as there is a risk that they are accidentally, or illegally, killed by measures that are employed on grouse moors to control mammalian predators and raptors, which have caused the deaths of pine martens (Raptor Persecution UK, 2017). To assess this mortality risk, the extent of keepered grouse moors across Cumbria and the potential release region was measured.

Foxes

Intra-guild predation by foxes has been identified as a potential limiter of pine marten population size (Birks, 2020). In Sweden, there was direct evidence of red fox (*Vulpes vulpes*) predation on pine martens, and a disease outbreak caused a severe reduction in red fox numbers that resulted in a concurrent increase in pine marten numbers, perhaps due to a reduction in predation rather than competitive release (Lindström et al., 1995). However, a study in Finland found no evidence of red fox influencing pine marten population density at a landscape scale (Kurki et al., 1998), and the killing of fox cubs by a pine marten has been recorded (Brzeziński et al., 2014), which indicates that the interactions between pine martens and red foxes are not straightforward. It has been hypothesised that red foxes are more likely to predate pine martens at higher latitudes and in areas with colder winter temperatures, because pine martens are more likely to den in underground burrows during colder months, potentially leaving them more exposed to ground-dwelling predators during these times. In Britain, pine martens may be at greater risk of predation by red foxes due to the pine marten's preference for field voles, which results in pine martens being more likely to use non-forest habitats and coming into contact with foxes (Storch et al., 1990; Baltrunaite, 2010). In addition, it is thought that red fox populations in the UK may currently be over four times more numerous than in historical times, due to mesopredator release (Maroo and Yalden, 2000). However, the availability of arboreal den sites supplemented with den boxes, as safe havens for pine martens to rest and breed, is more likely a critical factor that will greatly compensate for any mortality risks from foxes.

Roads

Pine martens are vulnerable to mortality from vehicle collisions, especially released animals exploring an unfamiliar landscape as they establish new home ranges (Velander, 1983; McPherson et al., 2014; Stringer et al., 2018), and dispersing juveniles, particularly males, are the most likely to be killed on roads (Stringer et al., 2018). In one French study, 30% of all pine marten fatalities were attributed to collisions with vehicles (Ruette et al., 2015). Excessive levels of road mortality may increase the chance of population extinction, or preclude the establishment of a reintroduced population (Stringer et al., 2018).

There are three key predictors of road mortality: roadside vegetation, traffic volume, and road bends/road sinuosity (Aaris-Sorensen, 1995; Taylor and Goldingay, 2010; Grilo et al., 2011; Barthelmess, 2014). Roadside vegetation is a key factor when suitable habitat borders on the roads, and roads that pass through woodland will likely pose the greatest risk to pine martens (MacPherson et al., 2014). Animals are more likely to be killed at bends in roads rather than straight sections, as they cannot see approaching traffic, and drivers may see an animal too late to avoid a collision (Grilo et al., 2011; Barthelmess, 2014).

Road kills are thought to be most common where traffic is at intermediate intensities (2,500–10,000 Annual Average Daily Flows), because roads with very high intensities of traffic may act as a complete barrier to animal movement, and the chance of encountering cars is much lower on roads with low traffic volumes (Seiler, 2003). Stringer et al. (2018) found that pine marten road mortality was more likely on motorways and primary roads; secondary roads had a medium level of risk, and tertiary and unclassified road types the lowest.

Methodology

Habitat characteristics

Woodland GIS data from the 2018 National Forest Inventory (NFI) for England (data-forestry.opendata.arcgis.com) were used to calculate the total area of habitat features within the Cumbria PRR. The NFI covers all forests and woodlands over 0.5 ha and 20m wide, with a minimum of 20% canopy cover. To assess the degree of forest fragmentation within the Cumbria PRR, the plugin 'Fragstats' was used in QGIS 3.16 to calculate the characteristics of woodland patches. All GIS analyses were done in QGIS 3.16.

Mortality risks – major roads

The total length of all road types was calculated for the PRR, using Ordnance Survey vector data (www.ordnancesurvey.co.uk/opendatadownload). Traffic flow was derived from the 2019 traffic data from the UK Department for Transport (www.dft.gov.uk/traffic-counts/download.php), which records the amount of traffic on each link of the major road network (A roads and motorways). Annual Average Daily Flow (AADF) is the number of vehicles estimated to pass a given Count Point (CP) on the road, in a 24-hour period, on an average day in the year. AADF figures are available for each junction-to-junction link on the major road network, and are converted into traffic volume using equations (1) and (2):

$$(1)\ \text{Traffic}_{CP} = \text{AADF}_{CP} \text{ x length of link road (km) x } 365$$

$$(2)\ \text{Total traffic} = \Sigma\text{Traffic}_{CP}$$

These figures were summed for all CPs within the Cumbria PRR to obtain the total annual volume of traffic within this region. The proportion of roads in this region that intersect woodland was calculated and used as a multiplier for the annual volume of traffic per kilometre of road to provide a relative index of traffic mortality risk for pine martens (MacPherson et al., 2014).

The density of motorways and primary roads was calculated for each 10km national grid square within Cumbria. These road types were converted to raster squares measuring 10m by 10m, and the number of these road squares within a 10km by 10km square gave a road density value for that square. A Road Density Percentage (RDP) was then calculated as the percentage of 10m by 10m squares identified as a motorway or primary road within a 10km by 10km square, and an average RDP value was calculated for the Cumbria PPR. The RDP was compared with the Forest of Dean recovery region and with the Netherlands, where pine marten populations live alongside high road densities (Stringer et al. 2018).

Mortality risks – minor roads

A search carried out through the Department of Transport website revealed that there are no active traffic volume counting points across the minor road network in the PRR, necessitating the collection of primary data. The 2018 National Forest Inventory and Openroads layer from the Ordnance Survey Data Hub (https://osdatahub.os.uk/downloads/open/OpenRoads) were manipulated in QGIS 3.4.3 to identify sections of the minor road network where woodland cover extended to one or both sides of the road edge. A network of five camera traps was deployed for up to 9 months at high-risk crossing points in the Rusland Valley and Grizedale Forest, where landowner access had been granted (Fig 12). High-risk locations included any sections of the minor road network where woodland cover extends to both sides of the road edge and bends in the road reduced visibility. Locations were widely dispersed across the study area and were selected to include busy and quiet sections of the minor roads network.

Cameras were installed once a month, from sunrise on Sunday to sunrise on Tuesday, to enable temporal comparisons in traffic volume between daytime and nightime, weekdays and weekends, and across the months. The original aim was to conduct the study for a calendar year, but ongoing issues with vandalism of the cameras resulted in a decision to stop collecting data from Camera 1 and 2 after 6 months, and 3, 4 and 5, after 9 months. To comply with General Data Protection Regulations (GDPR), all images on the SD card were deleted as soon as the data had been processed.

Mortality risks of gaming interests

A search on the website 'GunsOnPegs' (gunsonpegs.com/shooting/search/shoots) was carried out to locate places in the potential recovery region that hold commercial shoots, and to identify which game species are hunted. Data on the extent of keepered grouse moors across Cumbria was obtained from the 'Who owns England?' website (Who owns England, 2016). The number of pheasant rearing premises per postcode district was downloaded from the 'Who owns England?' website (Who owns England 2018); UK postcode shapefiles were downloaded from <www.opendoorlogistics.com/downloads/>. All GIS analyses were done in QGIS 3.16.

Results

Habitat characteristics

The habitat characteristics of the PRR in south Cumbria are given in Table 1, together with the corresponding data for the pine marten release sites in the Forest of Dean and lower Wye Valley (Gloucestershire) and North Ceredigion (Wales) (data extracted from MacPherson et al., 2014). The potential recovery region in south Cumbria contains more than 6,000ha of woodland, which is the minimum amount that could support 30 pine martens (MacPherson et al., 2014).

Table 1. Habitat characteristics of each recovery region in south Cumbria, Forest of Dean (Gloucestershire), and North Ceredigion (Wales).

Characteristics	**South Cumbria**	**Forest of Dean**	**Ceredigion**
No. 10km squares with >500ha woodland cover	6	6	7
NFI Category (ha):			
Broadleaved	8,564	9,800	1,928
Conifer	3,362	6,953	9,402
Mixed-broadleaved	464	354	115
Mixed-conifer	396	529	160
Assumed woodland	237	115	227
Open area	218	243	262
Felled	1,734	350	3,360
Ground prepared for planting	35	99	188
Low density	24	8	116
Shrubland	68	50	10
Young trees	856	904	2,034
Total woodland >0.5ha	**15,758**	**19,420**	**17,803**
Mean woodland cover (ha) / 10km square	2,626	3,237	2,543
Mean % woodland cover / 10km square	25	39	36
No. 1km squares with >25% woodland cover	242	340	357
Woodland fragmentation statistics:			
Edge length (km)	2,520	2,323	1,807
Edge density (m/ha)	0.02	0.01	0.01
Total number of patches	1,093	779	602
Mean number of patches per 10km square	182	130	86
Greatest patch area (ha)	5,122	7,107	2,787
Mean patch area (ha)	14	24	28

[1]*Data for Forest of Dean and North Ceredigion taken from MacPherson* et al. *(2014).*

The percentage of broadleaved, conifer, mixed woodland and open areas within each pine marten recovery area are shown in Figure 10.

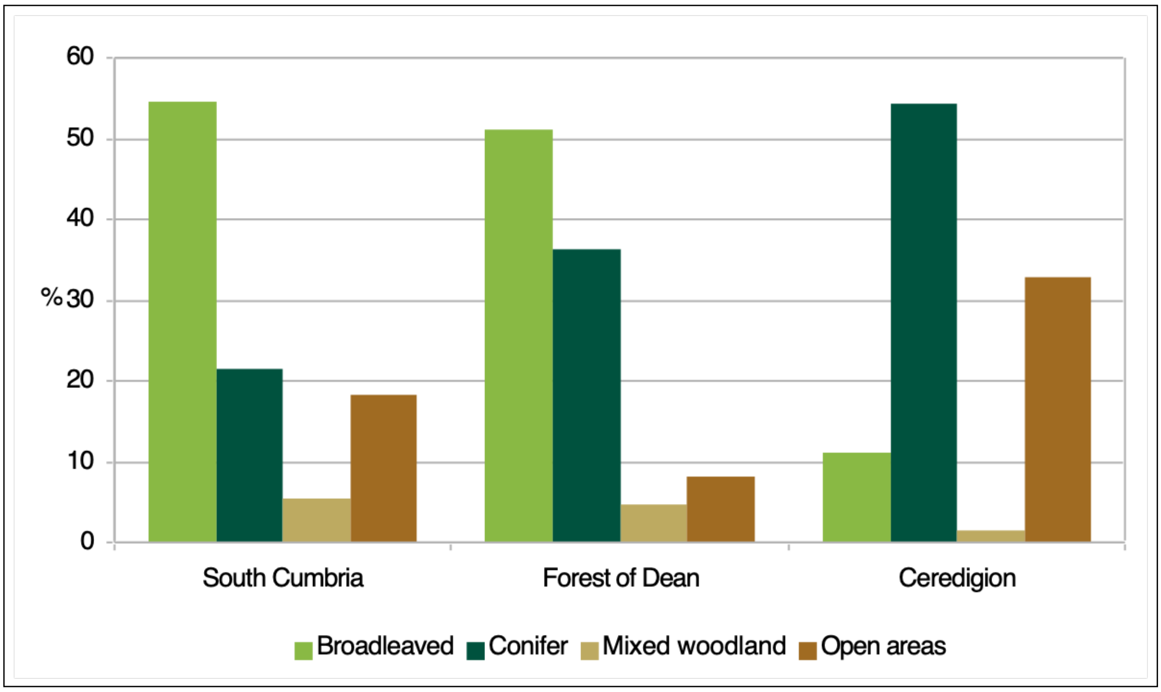

Figure 10. The percentage of broadleaved, conifer, mixed woodland and open areas (felled, ground prepared for planting, shrubland, and young trees) within each recovery region in south Cumbria, Forest of Dean (Gloucestershire), and North Ceredigion (Wales).

Mortality risks

Major Roads

Table 2 summarises the road and traffic information for each recovery region and Figure 11 shows the road density per 10km square for south Cumbria; road density percentage (RDP) is shown in respect to the mean road density that pine marten populations live alongside in the Netherlands, where the mean RDP for motorways and primary roads was 0.42% (Stringer et al. 2018).

Table 2. Road lengths, traffic flow, road density percentage and index of road mortality risk within each recovery region in south Cumbria, Forest of Dean (Gloucestershire), and North Ceredigion (Wales).

Characteristics	**South Cumbria**	**Forest of Dean**	**Ceredigion**
Road Lengths (km):			
Motorways	0	9	0
A Roads (including primary A roads)	130	126	60
B Roads	49	117	43
Minor Roads	457	926	356
Km of all roads/10-km square	106	196	66
2019 Traffic Volume per year on major roads (1000 vehicle kilometres)	363,223	507,619	40,148
% of major roads within woodland	20	20	28
Mean road density percentage of major roads	0.19	0.26	-
Index of road mortality risk	547	753	185

Major roads = motorways + Primary A roads + all other A roads
Data for Forest of Dean and North Ceredigion from MacPherson et al. *(2014)*

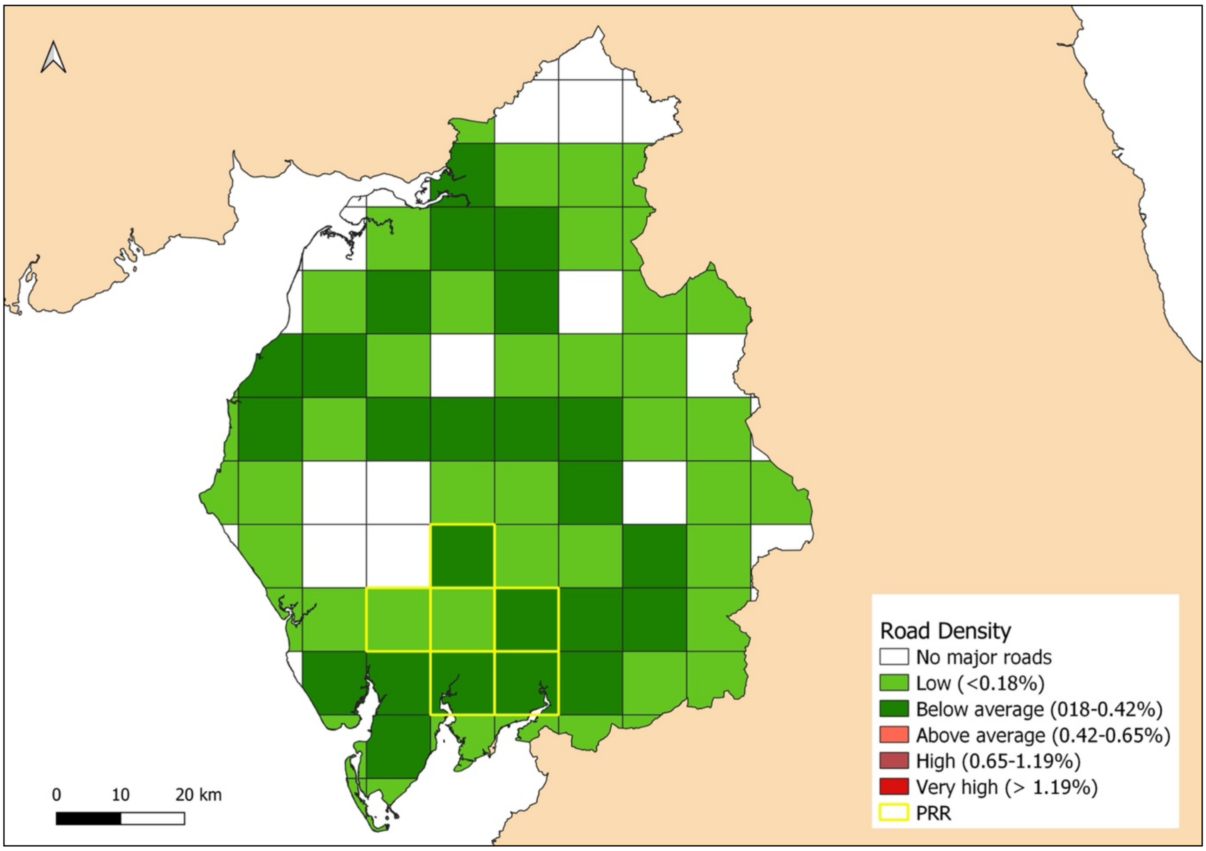

Figure 11. Road density per 10km square. The road density percentage is shown in respect to the road density that pine marten populations live alongside in the Netherlands (mean = 0.42%).

Minor roads

Average daily traffic (ADT) volumes for Cameras 3 and 4 across 9 months revealed peak traffic flows in August (326), declining to a nadir in November (117), and building again through the spring months (Figure 13.). Weekends were consistently busier than weekdays, with an average increase in ADT volumes of 20% across 8 months. October was the only month with higher weekday than weekend traffic volumes. A comparison between average traffic volumes during the daytime and night-time revealed dramatic declines during the hours of darkness, with average night-time traffic volumes just 7.4% of daytime volumes (range 4%-10%; Figure 14.). As expected, the busiest road was between Newby Bridge and Hawkshead on the east side of the Rusland Valley, with approximately a threefold increase in daytime traffic volumes, and a fourfold increase in night-time volumes, compared to the next busiest traffic counting point at C1.

These results demonstrate higher average daily traffic volumes during the summer and early autumn, which is consistent with holiday periods, and could present a collision risk to young pine martens dispersing in September and October. The decrease in the volume of traffic at night may reduce the risk of collision, as this species is primarily nocturnal; although, one study in Białowieża Forest revealed that 31% of pine marten activity through the year was during daylight hours (Zalewski, 2001).

However, in a regional context, the ADT volumes across the Rusland Valley and Grizedale area are substantially lower than those across the North-West of England, with a mean ADT volume of 342 compared to 900 for the equivalent minor road class category in the North West. Overall, the relative risk of pine marten mortality from vehicular collisions is deemed to be low.

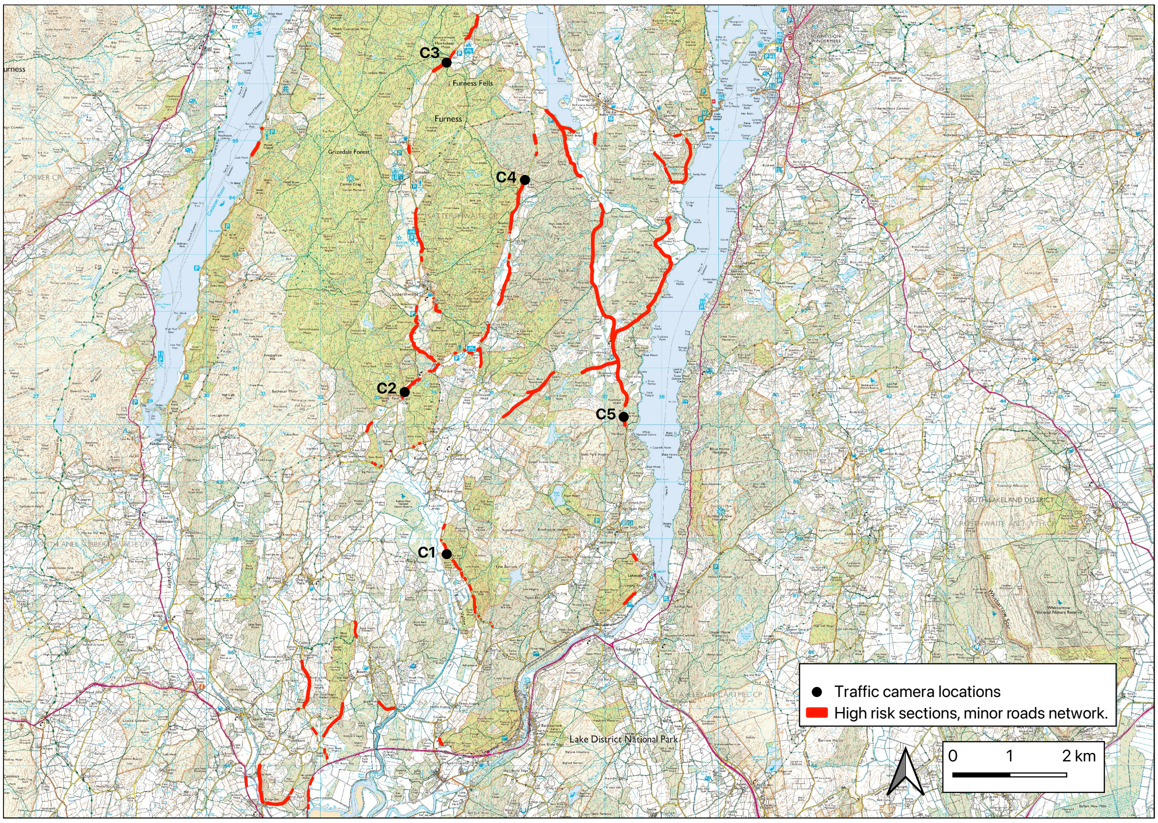

Figure 12. High risk sections of the minor road network across accessible landholdings in the Rusland Valley and Grizedale area with the locations of traffic counting cameras.

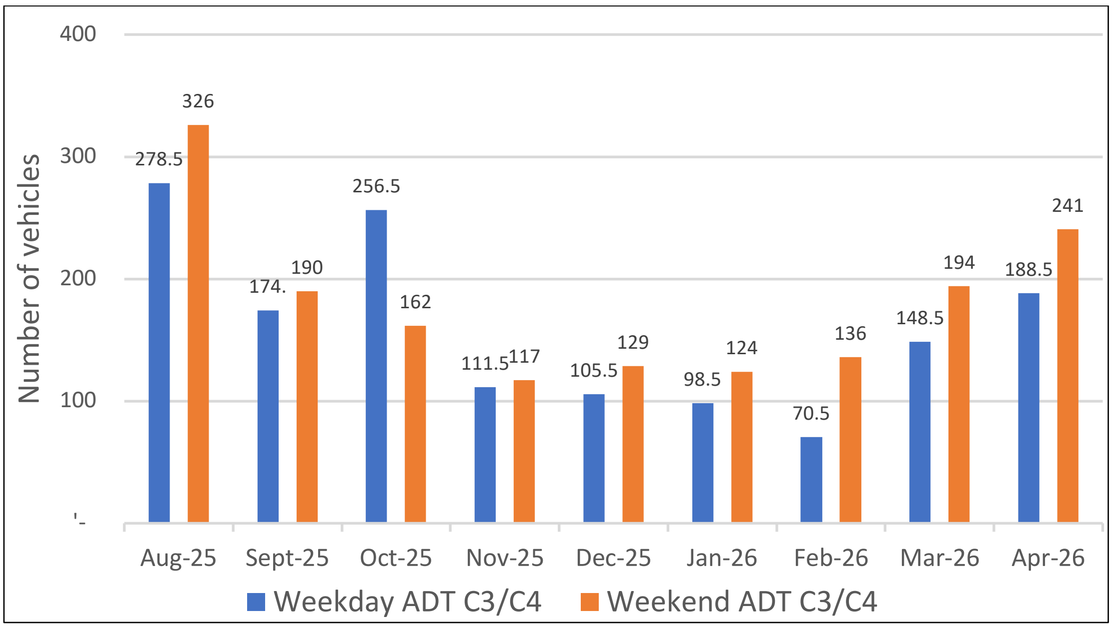

Figure 13. Average daily traffic (ADT) volumes during the week and the weekend between August 2021 and April 2022 for cameras 3 and 4.

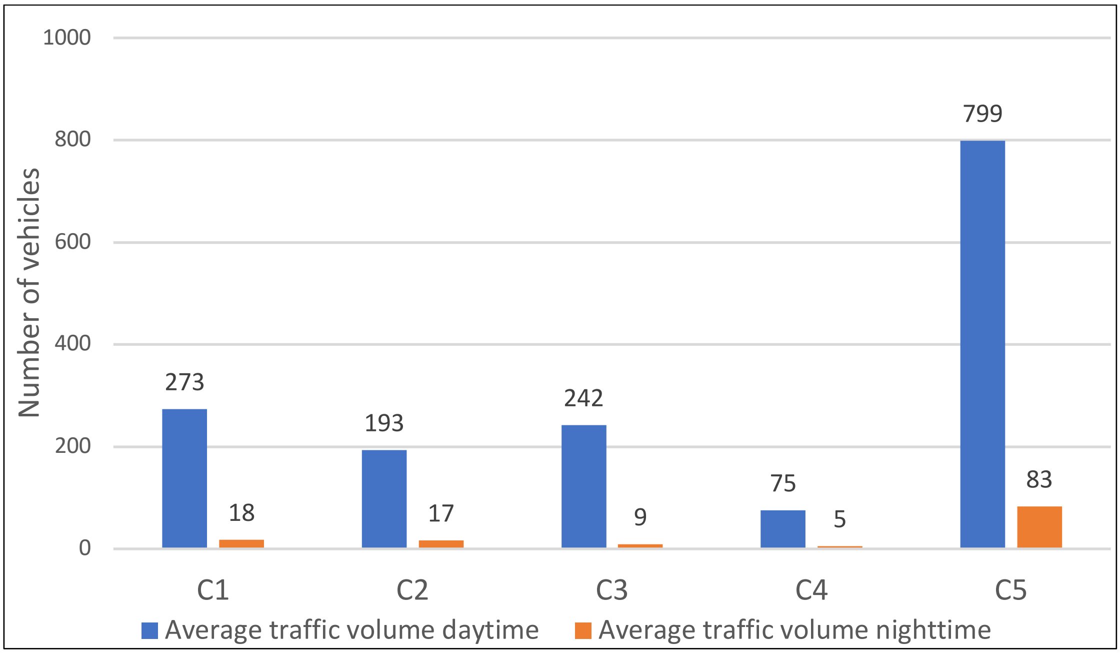

Figure 14. Average traffic volumes during the daytime and nightime between July and December 2021 for cameras 1,2 and between August 2021 and April 2022 for cameras 3,4 and 5.

Game shooting

Only two pheasant shoots were located within the south Cumbria PRR. Figure 15 shows the extent of keepered grouse moors across Cumbria, and Figure 16 shows the number of pheasant rearing premises per postcode district.

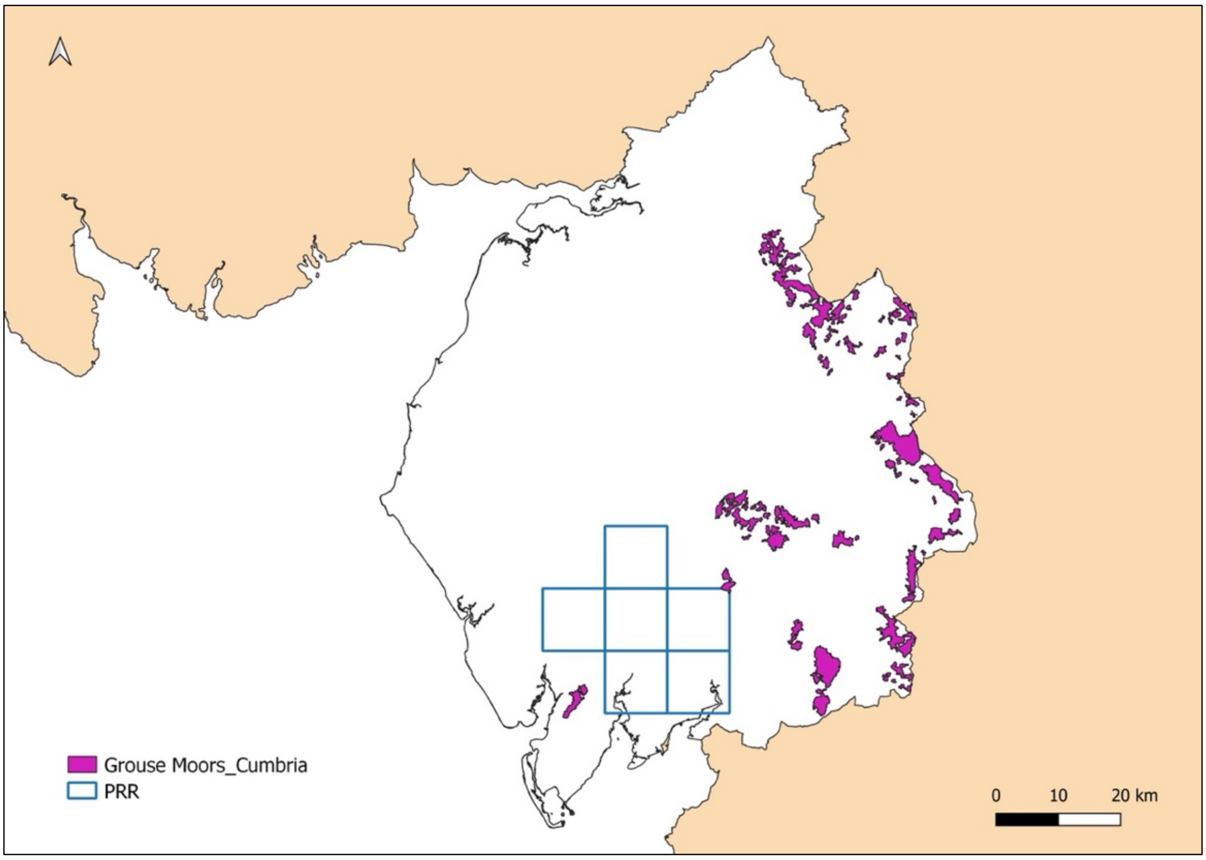

Figure 15. The extent of keepered grouse moors across Cumbria.

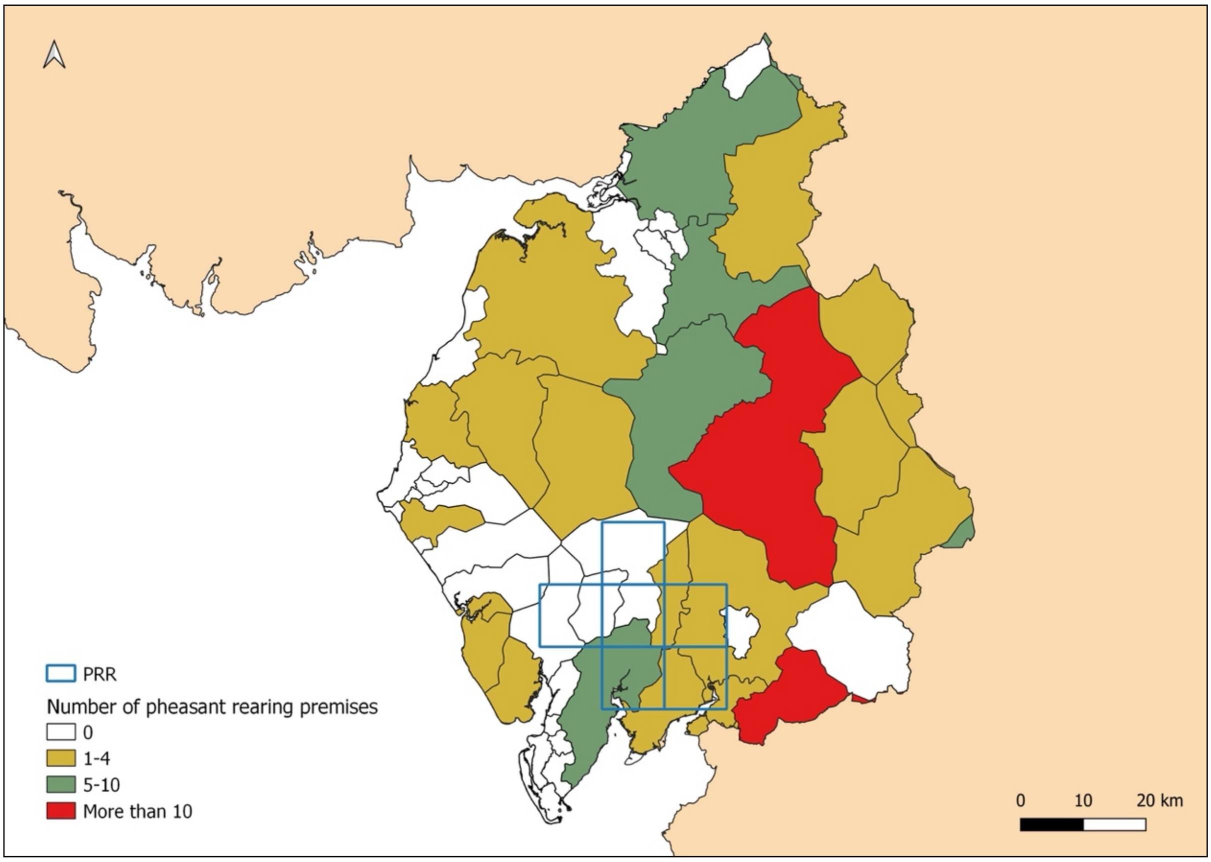

Figure 16. The number of pheasant rearing premises per postcode district.

Discussion

This section has provided important information regarding the characteristics of forested areas within the south Cumbria PRR. However, the GIS data that were used have limitations. For instance, it was not possible to evaluate the age and vertical and horizontal structural diversity of woodlands, which provide the necessary elements that pine martens require for foraging, denning, and breeding. These are factors and studies of food availability are assessed in Section 2.4.

Although the south Cumbria PRR has a higher road mortality risk than the pine marten release region in North Ceredigion, it is lower than the Forest of Dean release area. The Road Density Percentage for the Forest of Dean PRR (0.26%) was found to be below the RDP for pine marten populations living in the Netherlands (0.42%), which has the 3rd highest road density in Europe (3.3%), and higher than the UK (1.8%; Stringer et al., 2018). This suggests that some pine marten populations are capable of withstanding high levels of road mortality risk, and on this basis, Stringer et al. (2018) predicted that road density in the Forest of Dean PRR would not preclude population establishment of translocated pine martens.

Reducing road risk could improve the likelihood of recovery success and various mitigation measures can implemented to reduce levels of road mortality, including providing arboreal crossings, posting warning signage, improving existing culverts, and creating dedicated wildlife underpasses and crossings (‘green’ bridges; Grilo et al., 2008).

Although predator control measures relating to game shooting could have a significant impact on pine martens in some areas, no grouse moors were found within the potential release region in south Cumbria. Although the number of pheasant pens, commercial shoots and high-risk areas on grouse moors were quantified, there is wide variation among game estates and pheasant rearers in the level and type of pest control that is carried out, and it is difficult to quantify the actual mortality risks to pine martens, since these predator control activities are often covert, and sometimes illegal. The main purpose of this exercise was to flag this issue as a potential conflict, and to highlight an important stakeholder group with which to engage.

2.3.4 Ecological Carrying Capacity and Population Viability Analyses

Introduction

The ecological carrying capacity (ECC) of a species in an area is the size of the maximum stable population that can live there (Sayre, 2008). Estimating the ECC of potential recovery regions is important for predicting whether a stable population can be established. Many factors can influence the EEC of an area, including habitat quality, food availability, population density, and home range sizes (Sayre, 2008).

Population Viability Analyses (PVA) uses the ECC of an area and species life history traits to assess the risk of a population going extinct. It is essential for a recovery project to predict the likelihood of a population success, and different scenarios can be tested to see how the uncertainty of ECC estimates affects the chance of success. A number of approaches to population modelling have been applied to *Martes* populations (Bright and Halliwell, 1999; Buskirk et al., 2012; Powell et al., 2012; Stringer et al., 2018), and all life history parameters for these models have been thoroughly sourced from the literature (Stringer et al., 2018).

Road mortality has been identified as a potential risk for pine martens (see Section 2.4), and its impact on the likelihood of a translocation success was tested here. We also created a simple metapopulation scenario that reflects the consequences of a translocation in south Cumbria, whereby an expanding population from the north of Cumbria will eventually reach and link-up with the translocated population.

Methodology

Ecological carrying capacity

Density: the density estimates values of Stringer et al. (2018) for pine martens in a variety of woodland habitats were used: 0.5-1 per km^2 for deciduous, and 0.1-0.5 per km^2 for coniferous. The amount of deciduous and coniferous woodland in each PRR was calculated in Section 2.4. This method predicts the ECC for both adults and juveniles, since both are incorporated in the density estimates.

Home range size: the values of Stringer et al. (2018) were used: for minimum ECC, maximum home range = $10km^2$; and for maximum ECC, minimum home range = $1.5km^2$. The amount of deciduous and coniferous woodland in each PRR was determined in Section 2.4. The number of female home ranges a quantity of habitat would support was calculated (pine marten territories do not overlap significantly for individuals of the same sex), and a 50:50 sex ratio was assumed to calculate potential population size and hence ECC. This method predicts only the adult ECC.

Population Viability Analyses (PVA)

Vortex is computer software (Lacy and Pollak, 2018; scti.tools/vortex/) commonly used for PVA that has been previously used on pine martens (Powell et al., 2012; Stringer et al., 2018), and here, the modelling methodology of Stringer et al. (2018) was followed. For the analyses, the worst-case scenario that currently no pine martens exist in the south Cumbria PRR was assumed (i.e., the initial population size is zero), and when testing the impact of ECC on the likelihood of recovery success, the release cohort size was kept at 40 individuals to reflect a potential translocation of individuals. A stable age distribution was used but modified to ensure that all animals were ≥2 years old, as juveniles would not be translocated. A total of 1000 iterations were run, over a 50-year period.

Road mortality is a key concern for pine marten recovery projects (see Section 2.4), and most likely affects males more than females (Stringer et al., 2018). For adult females, ‘High’ and ‘Very High’ mortality rates were tested, with mortality increased by 2.5% and 7.5%, respectively. For adult males, ‘High’ and ‘Very high’ mortality rates were tested, with mortality increased by 5% and 15%, respectively. Since road mortality most likely impacts dispersing sub-adults the greatest, the influence of varying the mortality rate within individuals aged 1-2 and adults was tested separately.

Using the *Supplementation* option in Vortex, we simulated what would happen if 2 males and 2 females enter the translocated population each year, from Year 20 onwards; we repeated this for 3 males and 3 females. The following Vortex parameters were used: max age of reproduction = 8; sex ratio = 50%; density dependent reproduction: A = 1; B = 16; mortality rates as in Powell et al., 2012; ECC = 100; initial population Size = 40 (all animals ≥2 years old); first year of supplement = 20 years.

Results

Ecological carrying capacity

Table 3 shows the ECC estimates for the PRR using the two methods. The overall mean ECC of the PRR was 83 individuals (range = 24-159), and 310 for the whole of Cumbria (range = 94-630).

Table 3. Ecological carrying capacity in each of the release regions in south Cumbria, Forest of Dean and North Ceredigion, and for the county of Cumbria, as estimated by the abundance of suitable habitat, density, and home range.

Region	Type of woodland	Area of Woodland (km^2)	Density estimate (per km^2)	Estimated Ecological Carrying Capacity					
				Using density			Using home range		
				Min	Max	Mean	Min 10km^2	Max 1.5km^2	Mean
South Cumbria	Deciduous	85.64	0.5-1	43	86		17	114	
	Coniferous	33.62	0.1-0.5	3	17		7	45	
	Total	**119.26**		**46**	**102**	**74**	**24**	**159**	**91**
Forest of Dean*	Deciduous	98.00	0.5-1	49	98		20	131	
	Coniferous	69.53	0.1-0.5	7	35		14	93	
	Total	**167.53**		**56**	**133**	**94**	**34**	**223**	**128**
Forest of Dean, Wye Valley, and Wentworth**	**Total**	**277.20**		**113**	**245**	**179**	**55**	**370**	**213**
Ceredigion*	Deciduous	19.28	0.5-1	10	19		4	26	
	Coniferous	94.02	0.1-0.5	9	47		19	125	
	Total	**113.30**		**19**	**66**	**43**	**23**	**151**	**87**
Cumbria	Deciduous	256.42	0.5-1	128	256		51	342	
	Coniferous	215.90	0.1-0.5	22	108		43	288	
	Total	**472.32**		**150**	**364**	**257**	**94**	**630**	**362**

* *Data from MacPherson* et al. *(2014)*
** *Data from Stringer* et al. *(2018)*

Population Viability Analyses

The probability of extinction decreases rapidly as ecological carrying capacity increases, until the ECC reaches around 74 individuals, after which, further declines in extinction risk are minimal (Fig. 17). Increases in adult mortality rates raised the probability of extinction, with female mortality having the largest impact (Fig. 18). Sub-adult mortality had a much smaller effect on the probability of extinction risk than adult mortality (Fig. 19). As release cohort size increased, the probability of extinction decreased steadily, but began to level off at around 40-50 individuals (Fig. 20).

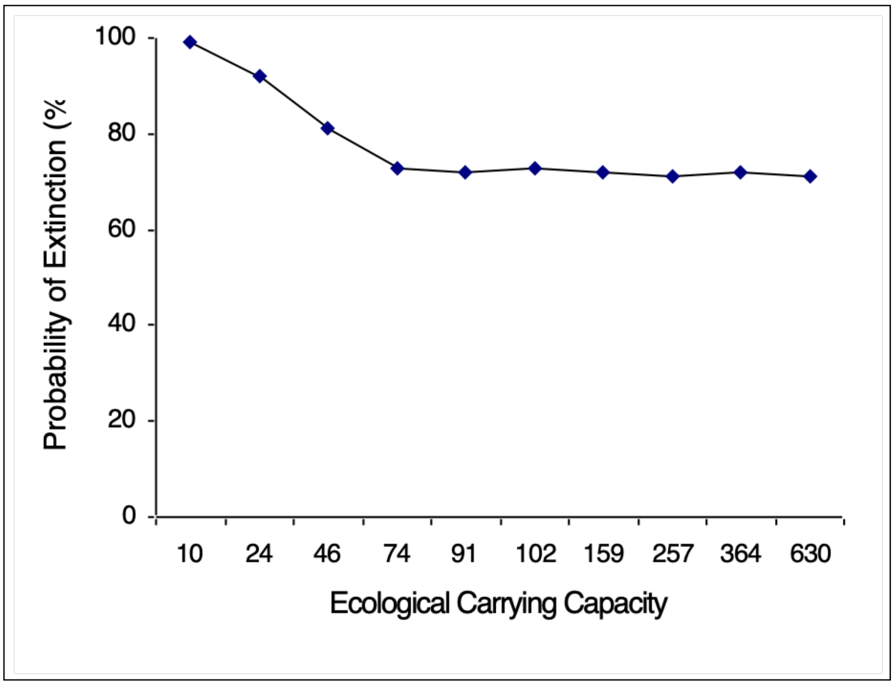

Figure 17. The effect of ecological carrying capacity on probability of extinction.

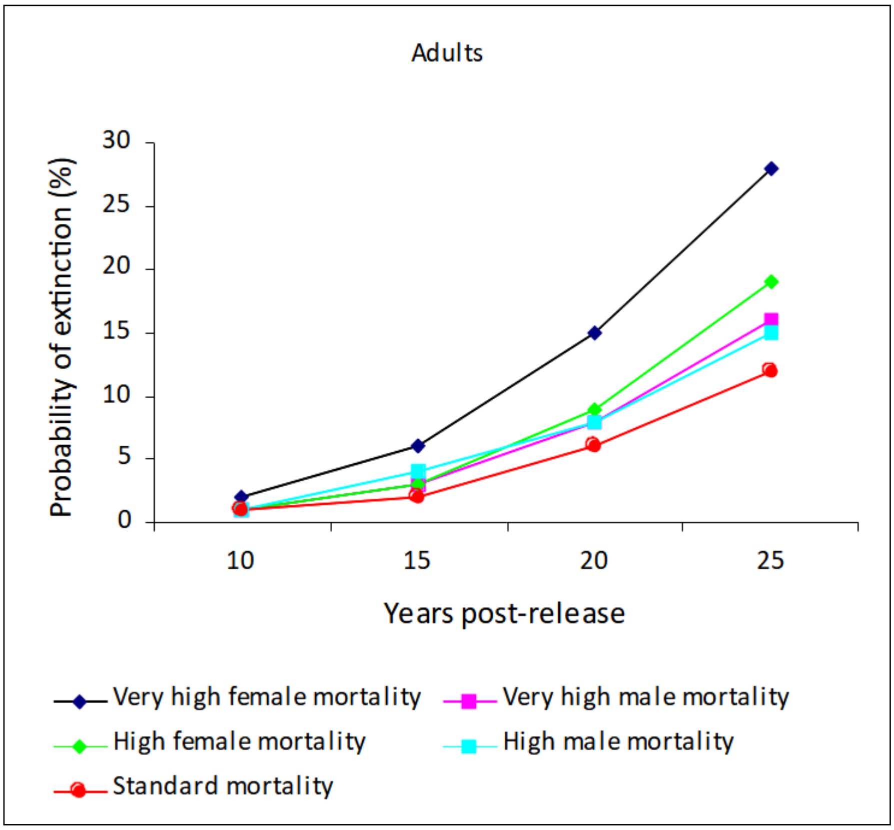

Figure 18. The effect of increases in adult mortality rates on probability of extinction.

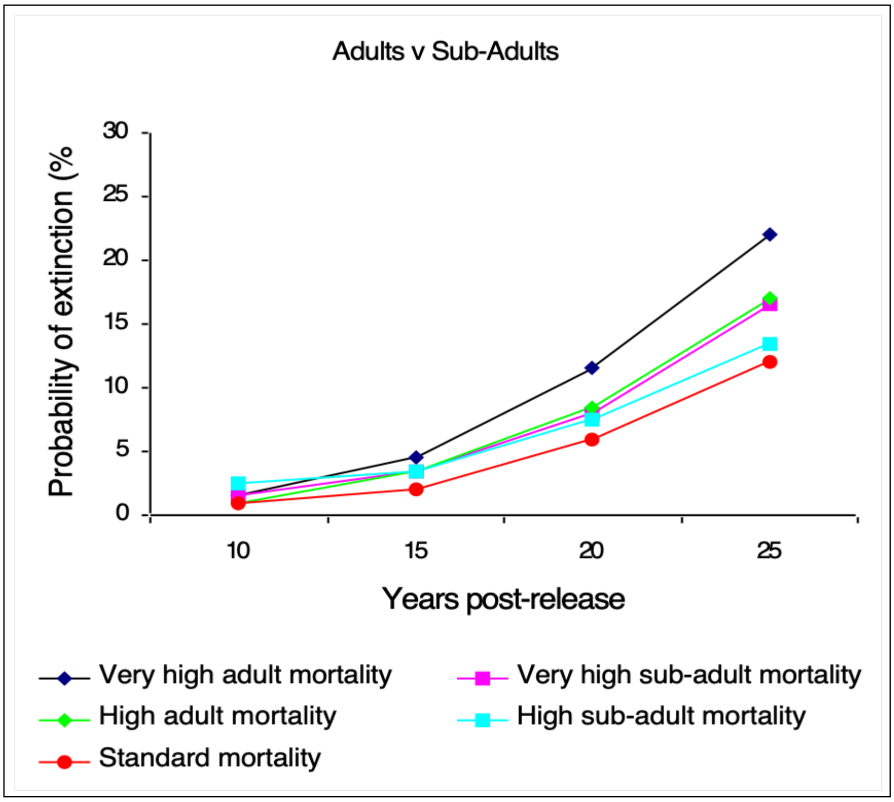

Figure 19. The effect of increases in adult and sub-adult mortality rates on probability of extinction.

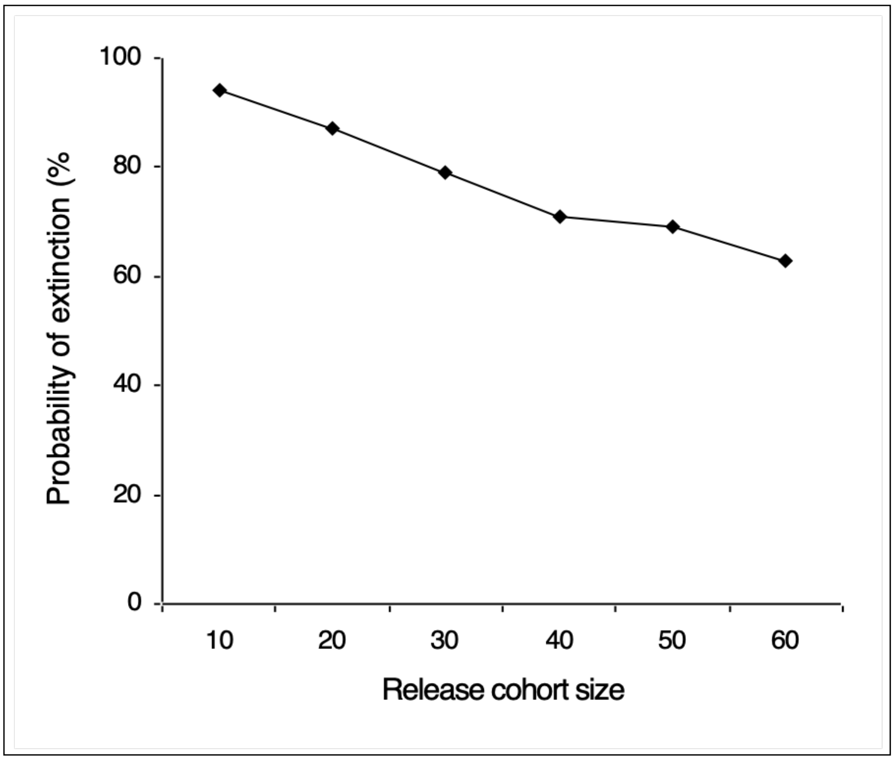

Figure 20. The effect of release cohort size on probability of extinction.

Figure 21 shows the scenario in which 2 males and 2 females enter the translocated population each year, from Year 20 onwards. After an initial small increase, the population then declines towards zero, but when individuals from an external source start dispersing into this population from year 20 onwards, the translocated population immediately stops declining and then rapidly expands to a population size of around 50-55 individuals, which then remains stable over a long period of time. A similar output was produced if 3 males and 3 females disperse into the translocated population, although this time the population size stabilised at around 60-65 individuals.

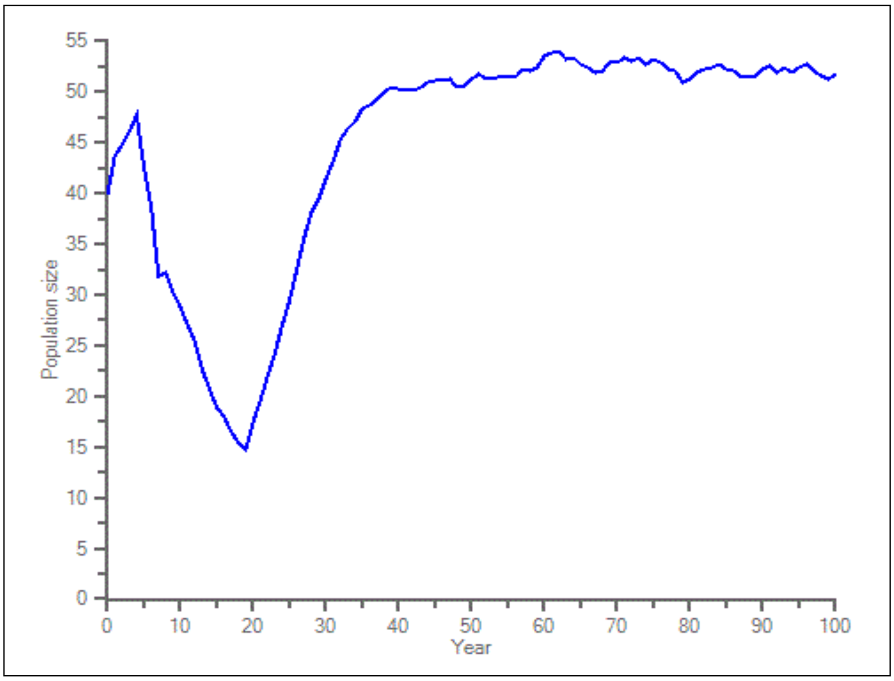

Figure 21. Predicted changes in population size for a translocated population in south Cumbria, and a potential scenario in which 2 males and 2 females from an external source enter this population each year, from Year 20 onwards.

Discussion

Here, a range of estimates of the ECC for the south Cumbria PRR have been produced. Although estimates are useful for determining whether a viable population can be established in a release region, the actual ECC for a recovery area strongly depends on local conditions (habitat quality, food availability, etc.), and therefore comparisons between sites are difficult to make without precise data. Two different methods for calculating ECCs were used due to potential errors that are associated with each one; for instance, the estimate using home ranges did not consider the likely scenario that there would be gaps between individual home ranges (Stringer et al., 2018). Although the different estimates broadly agreed, caution should be used when interpreting these results. The lowest carrying capacity estimates, and scenarios with high adult mortality, carried high extinction risks. If the recovery programme goes ahead, long-term monitoring of the population will be essential, and density estimates from this monitoring will give actual ECC values.

Powell et al. (2012) showed that the two key predictors of pine marten reintroduction success were increasing the size of the release cohort and the number of release sites. The population modelling of Bright and Harris (1994) showed that extinction risk was greatly reduced when more than 30 pine martens were released, which concurs with a study of American marten reintroductions that found they succeeded in all cases where released cohorts exceeded 30 animals (Slough, 1994). Our results indicate that a translocation of around 40-50 animals would be the optimal cohort release size.

Our Vortex modelling analyses have indicated that a translocated population of 40 pine martens may go extinct if it remains isolated. This is not surprising, as the history of the pine marten in Britain has shown that once populations are fragmented and become isolated, they can disappear quite rapidly from a region. However, our findings indicate that it takes only a few dispersing individuals from an external source for a local population to remain stable, and avoid extinction, which suggests that this species depends strongly on a stable metapopulation structure within a region for its continued existence. Since pine martens are expanding into Cumbria from the north, there is a strong likelihood that they would link up with a translocated population in the south within the next few decades (see the HexSim simulations in Section 2.2.5).

2.3.5 Dispersal and population growth

Introduction

It is important to predict how a successfully recovered population may expand its geographic range and link with other populations. This can also help identify areas in which pine martens may have an ecological impact, and where socio-economic costs and benefits may be realised. The dispersal of juvenile pine martens is highly variable, and approximately half of them do not disperse, instead staying local to the mother's home range (Larroque et al., 2015). Displacement distance may differ between males and females, and ranges from 2.3km to 214km (Broekhuizen and Muskens, 2000; Larroque et al., 2015). It is thought that an open landscape does not limit dispersal (De Groot, 2016), although it is possible that males are more willing to cross open landscapes than females (Caryl et al., 2012). Large tidal rivers may be an impediment to pine marten movements, but pine martens have previously used large road bridges with high volumes of traffic. They can also cross standing water to at least a distance of 150m (Brown, 2010).

Landscape resistance

A landscape resistance map replicating a methodology used by Ruiz-Gonzalez et al. (2014) in northern Spain and by Stringer et al. (2018) in the Forest of Dean was developed for Cumbria (Fig. 22). Resistance maps are used to identify how difficult a landscape may be to traverse for a dispersing individual, and provide a useful comparison to landscape connectivity maps (see below). Here, we attributed resistance values to the different land cover classes of a 2018 Corine land cover map (downloaded from www.eea.europa.eu/data-and-maps/data/corine-land-cover-accounting-layers – the higher the value, the more 'resistant' is the habitat to pine martens (Fig. 22).

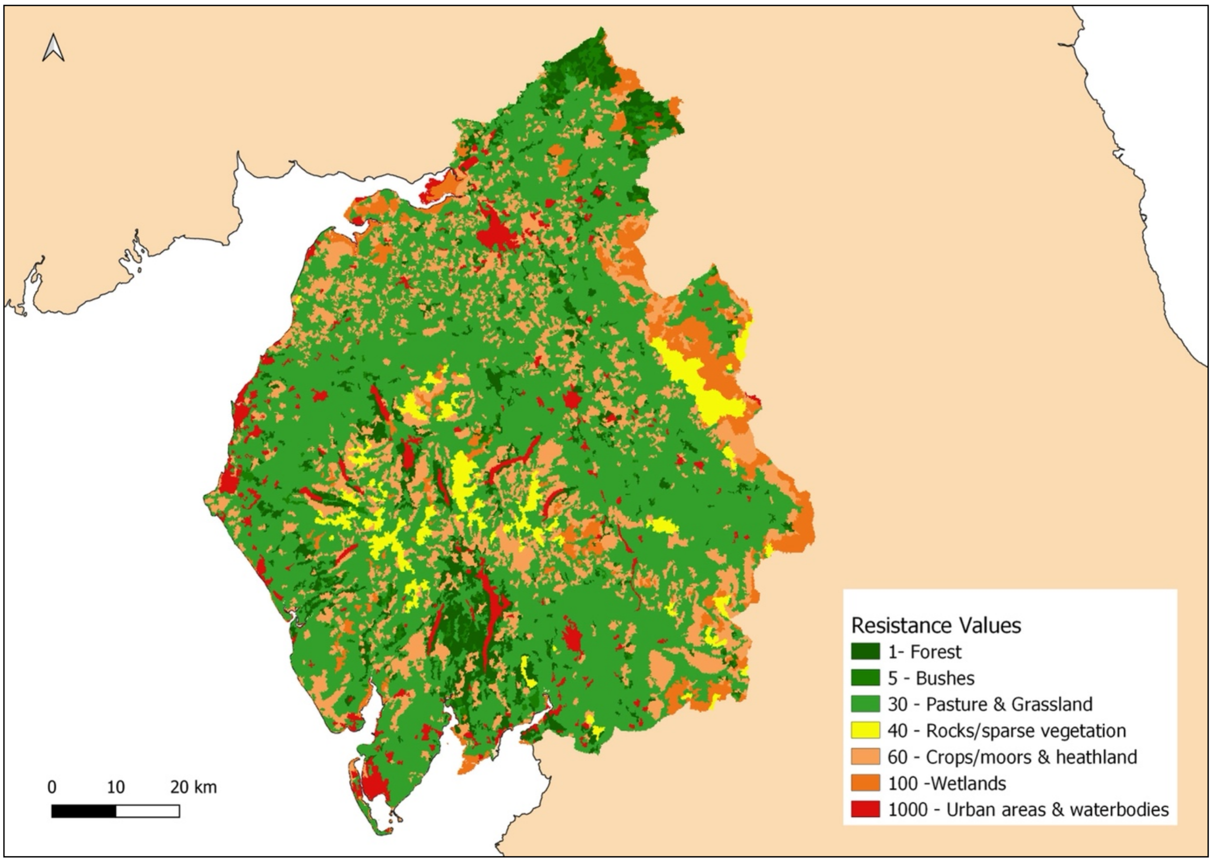

Figure 22. Landscape resistance map showing the difficulty pine martens may have in traversing different types of land cover; the higher the value, the more 'resistant' is the habitat to pine martens.

Landscape connectivity

To conduct connectivity analyses across Cumbria, we used Circuitscape (circuitscape.org), which calculates all the possible pathways between specific points through a landscape (using either resistance or conductance surfaces) and produces a 'current' map that identifies areas of high connectivity. We created a simple model with just two focal nodes: a recolonising population in the northeast of Cumbria and a translocated population in the south (centred on Grizedale Forest). To create 'current' maps, we used the Resistance Map (Fig. 22) for resistance surfaces and the Ecological Niche Modelling Map (Fig. 5) as a conductance map (i.e., the reciprocal of resistance – darker shades of red indicate greater ease of movement). Finally, we used the QGIS plugin 'Least Cost Path' to determine which of the different connection pathways between the two hypothetical populations has the least cost (or lowest resistance); we plotted this pathway in Figures 23 and 24.

The two outputs from the Circuitscape modelling were broadly similar, and Figure 23 is the one using the ENM map. Warmer colours (red) indicate areas with higher current density; yellow areas are 'pinch points,' or areas where connectivity is tenuous, and blue areas signify low conductivity. Both outputs show 'current flow' between the two populations, although there are several 'pinch' points where habitat enhancements would improve the connectivity between them.

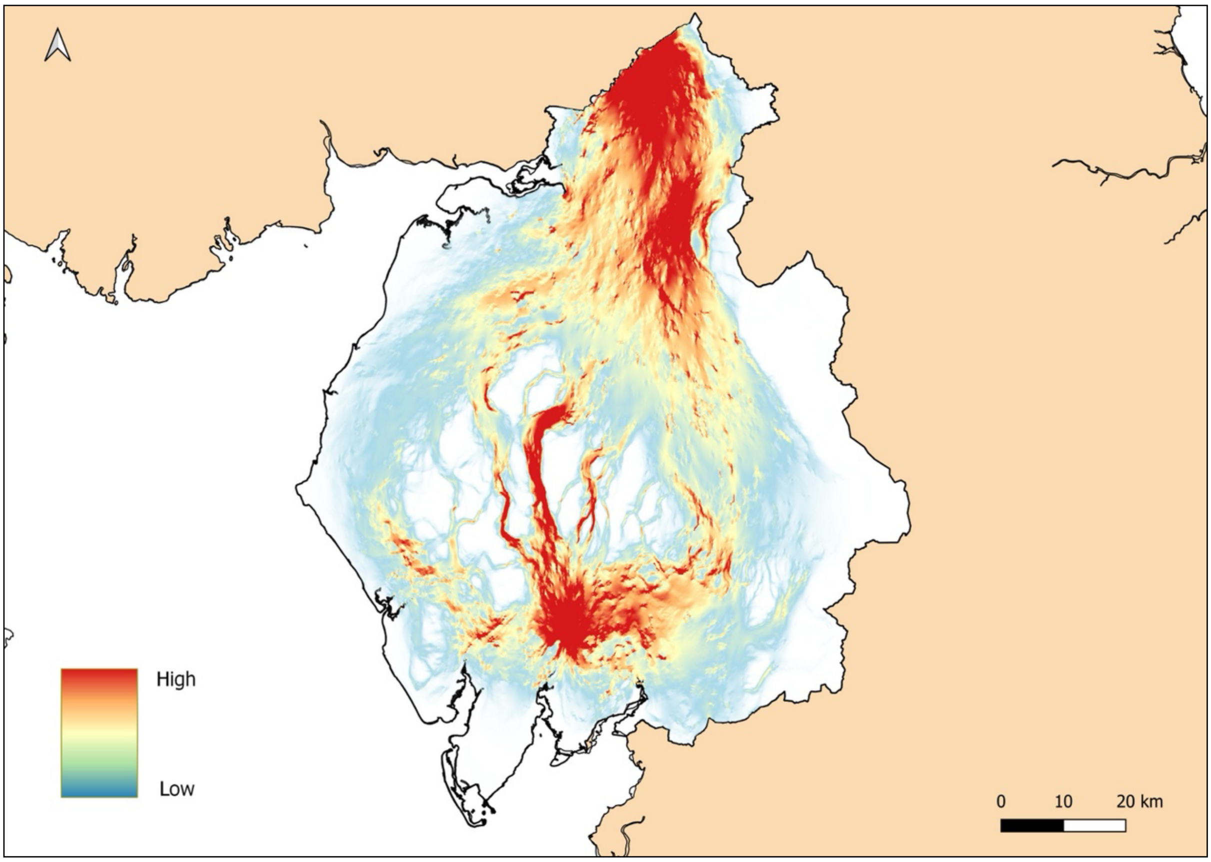

Figure 23. Landscape connectivity map using conductance surfaces. Warmer colours (red) indicate areas with higher connectivity; yellow areas are 'pinch points,' or areas where connectivity is tenuous, and blue areas signify low conductivity.

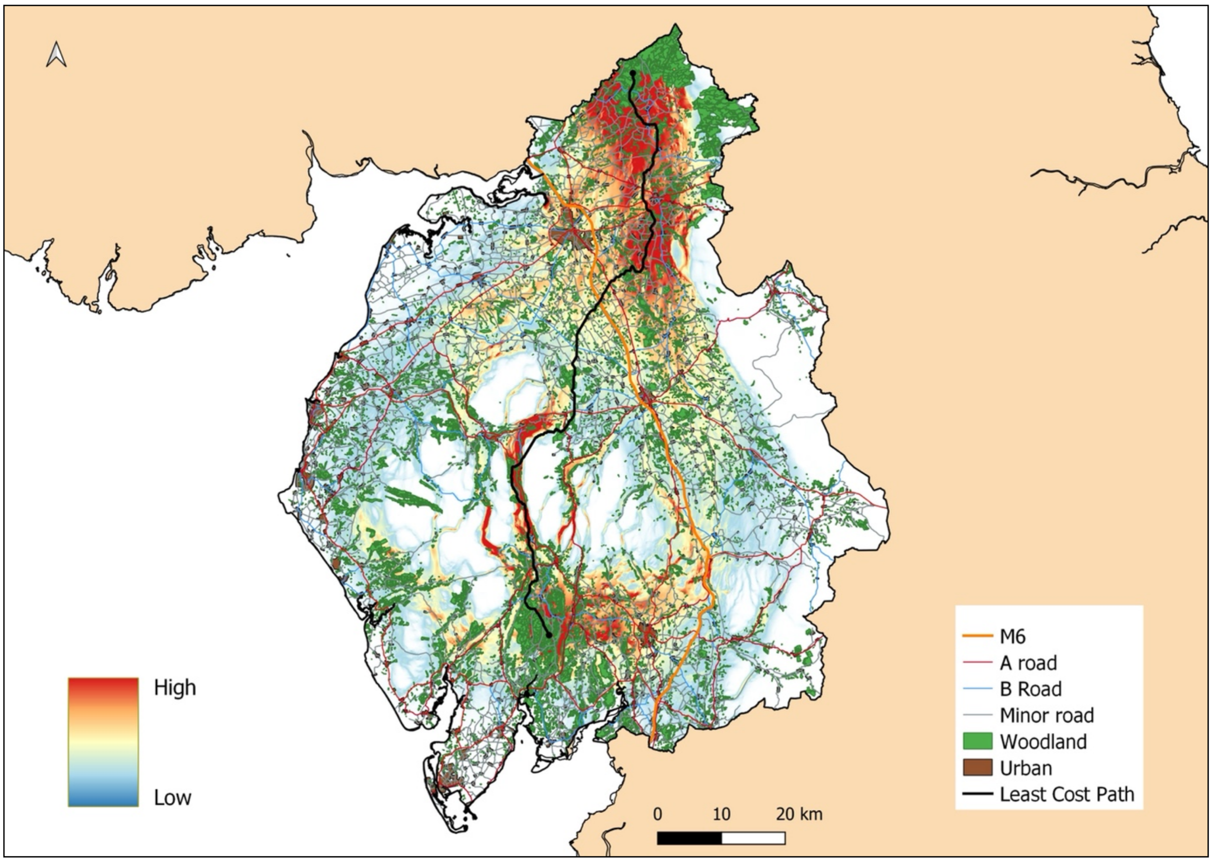

Figure 24. Landscape connectivity map (using conductance surfaces) overlaid with the least cost path, roads, woodlands, and urban areas. Warmer colours (red) indicate areas with higher connectivity; yellow areas are 'pinch points,' or areas where connectivity is tenuous; and blue areas signify low conductivity.

It is thought that at least 20% of a landscape needs to be forested to support a pine marten territory (Moll et al., 2016), although pine martens have been found in landscapes with as little as 5% woodland cover (see Section 2.4). The percentage of existing woodland (derived from the NFI data set, see Section 2.4) within all 1km square blocks across Cumbria was calculated using QGIS, and squares were allocated to one of two woodland categories: >20% and 5 to 19%. We then produced a habitat map that looks at the connectivity of woodland habitats across Cumbria based on the percentage of woodland and overlaid the least cost path. (Fig. 25).

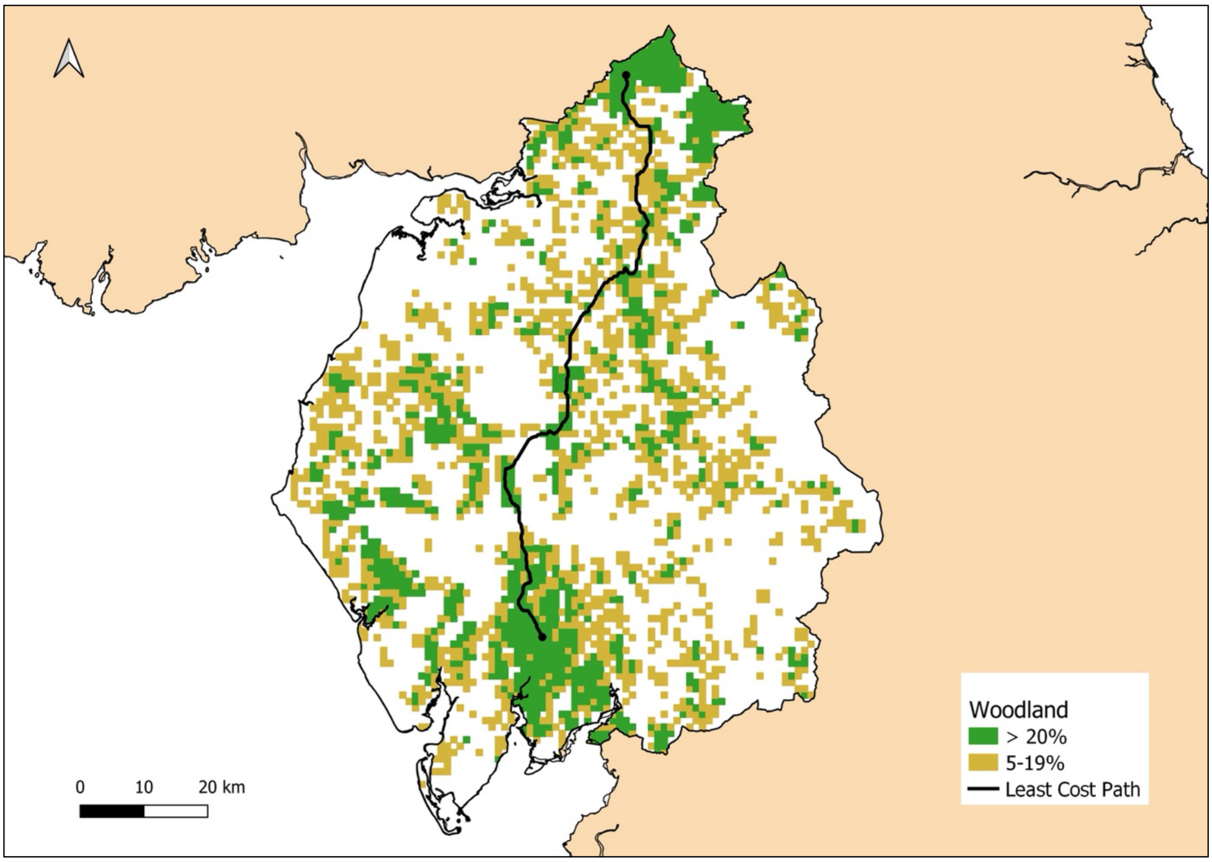

Figure 25. The percentage of existing woodland within all 1km square blocks across Cumbria, and the least cost path.

Discussion

The landscape connectivity map and connectivity analyses show a good network of forested land throughout Cumbria, which would facilitate the movement of individuals from one area to another. The restoration and creation of woodland patches and habitat corridors would further enhance the ability of pine marten populations in Cumbria to expand across this region and into neighbouring counties.

Neither of our connectivity outputs considered the impact of roads on the movements of pine martens across the Cumbrian landscape. However, Červinka et al. (2015) have shown that pine martens are more likely to cross roads at points where their most favourable habitat (i.e., woodland cover) is found alongside each side of the road. To cross a major road that has multiple lanes, such as the M6, pine martens might also use cattle bridges and road underpasses (and perhaps those that are closest to woodland cover) – American martens have been recorded using culverts (Clevenger et al., 2001). Additionally, there are mitigation measures – pine martens have been documented crossing major roads using green bridges or ecoducts (Natural England, 2015).

This connectivity exercise could be taken further by using these outputs to identify where specific habitat corridors could be enhanced/created for the benefit of pine martens (and other woodland animals and plants). Although this is beyond the scope of this feasibility study, it would be an important future project thorough collaborations with other organisations, such as Cumbria Wildlife Trust and the Woodland Trust.

The distance of the least cost pathway is 114km. Sainsbury et al. (2019) estimated that the Scottish pine marten population expanded at a rate of 1.7km per year between 1975 and 2015 (95% confidence interval: 0.8-2.7km). Using this expansion rate (and the least cost pathway), a recolonising population in northeast Cumbria would take around 67 years (range = 42-142 years) to reach the Grizedale area, whereas it would take around 33 years (range = 21-71 years) for the recolonising and translocated populations to meet up in central Cumbria. Of course, this is a simplistic scenario/calculation, and as our HexSim modelling shows (see Section 2.3.6), establishing an actual scenario/timeframe for the recovery of the pine marten across the whole of Cumbria could be quite complex. However, this estimation indicates that a translocated population in south Cumbria would significantly speed up the recovery of the pine marten in Cumbria, as well as helping to establish a stable metapopulation structure in this region.

2.3.6 HexSim population viability and connectivity modelling

Hexsim (hexsim.net) simulates a population of individual animals and their interactions with each other and with the landscape (as represented by a habitat suitability map). To model a reintroduction, animals are introduced at a specified location, and from there individuals move through the landscape and occupy new areas. Hexsim records population counts for each year and maps the locations occupied by individual animals.

We used Hexsim to address two questions. First, would a reintroduction in south Cumbria establish a viable population? Second, how likely is it that pine martens would naturally recolonise south Cumbria from the existing population in Kielder Forest (without the need for a reintroduction in the south)? To answer these questions, we ran three different scenarios: Scenario 1 – recolonisation in northeast Cumbria; Scenario 2 – reintroduction in south Cumbria; Scenario 3 – reintroduction in south Cumbria with recolonisation in the northeast. In Scenario 1, 4 animals were added each year within a specified area in northeast Cumbria to simulate continuous colonisation from Kielder Forest. In Scenario 2, 20 animals were added in year 1, and 20 in year 2, to a designated area in south Cumbria. Scenario 3 added 20 animals in both years 1 and 2 in the south and added 4 animals per year in the northeast, using the same areas as in Scenario 1 and Scenario 2. We used the same parameters as MacPherson & Wright (2021) for all HexSim modelling. Each scenario ran for 50 years and was replicated 50 times, representing 2,500 years. There were no extinctions.

Table 4 shows summary population totals across all replicates and all years. The first 10 years are excluded from the summary to allow the population to stabilise and to remove the effect of low initial population size, especially in Scenario 1. All models showed large fluctuations in population size from year to year and between replicates. In Scenario 3, the average population size was roughly equal to the sum of Scenarios 1 and 2, which suggests that martens were exploiting more territory, and formed a more robust population.

Table 4. The population totals for three different HexSim scenarios, each summarised across all replicates and all years.

Scenario	Minimum	Maximum	Average
1: Re-colonisation in northeast Cumbria	17	72	47
2: Re-introduction in south Cumbria	18	94	45
3: Combination of 1 & 2	49	142	94

Hexsim can generate maps of pine marten territories for each year of the simulation, and by overlaying these maps we can determine the number of years that an area is part of a marten territory. Figure 26 shows the length of time of territory occupancy and the level of connectivity between each territory for Scenario 3, over the next 50 years.

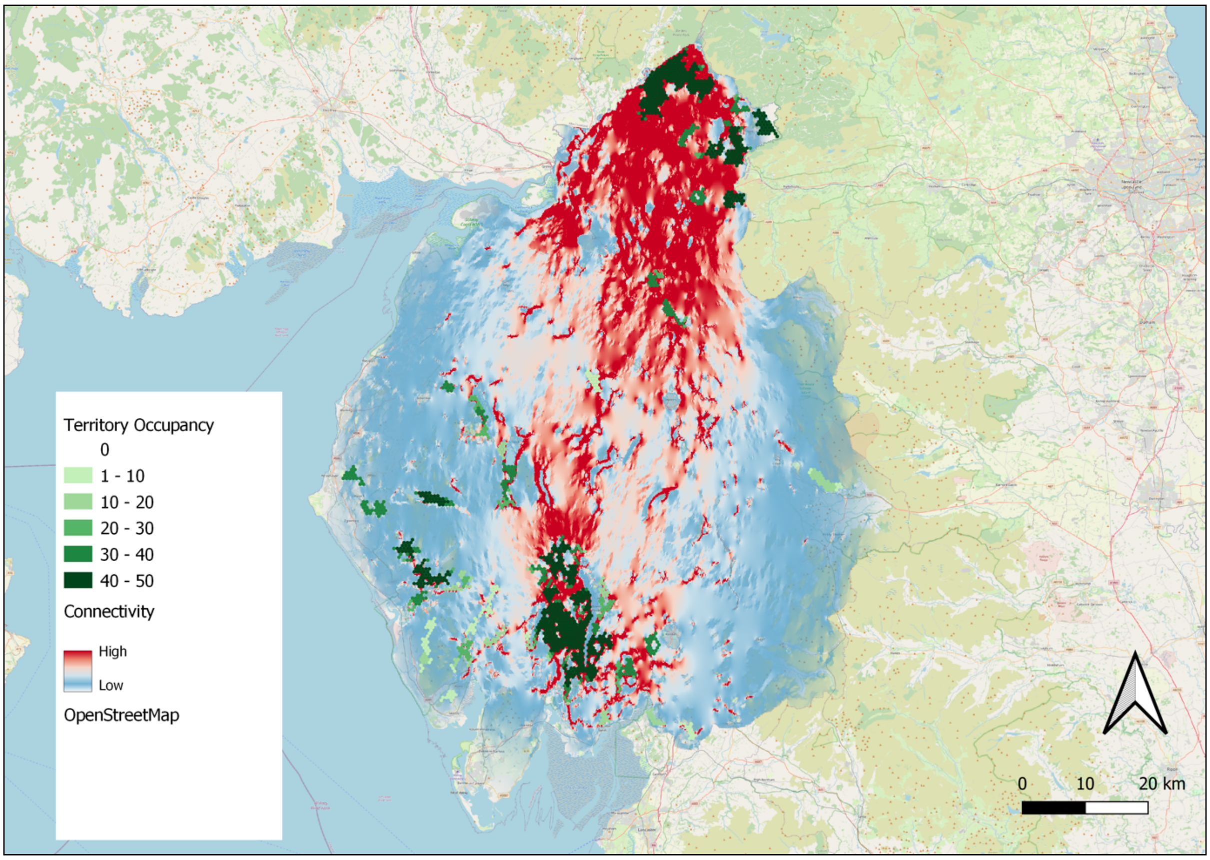

Figure 26. The predicted output for Scenario 3 (a reintroduction in the south and recolonisation in the northeast) showing the location and length of time of territory occupancy (in years), and the level of connectivity between each territory (max time span = 50 years).

To estimate the likelihood of martens from northeast Cumbria colonising the south within 50 years, Scenario 1 was run again, this time mapping the year of arrival in each map cell and counting the number of years each cell was occupied. The model was run for 50 years with 20 replicates. Figure 27 shows the minimum number of years taken for recolonising martens to reach the south, and the duration of marten presence in south Cumbria. Out of 20 simulations, pine martens reached the south within 6 years only once and failed to reach the south at all in two simulations. Only once did recolonising martens establish a population in the south that persisted into year 50 (i.e., with a 5% probability).

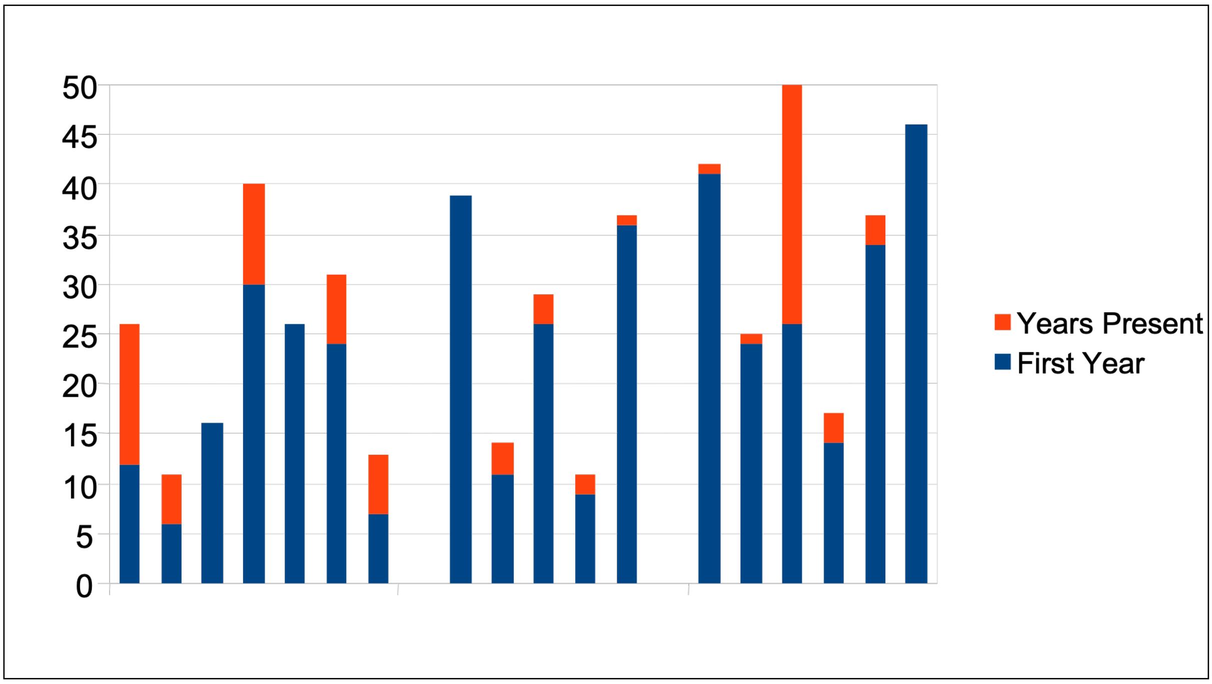

Figure 27. Results of twenty HexSim simulations predicting the minimum number of years taken for recolonising martens in northeast Cumbria to reach the south, and their duration in south Cumbria (maximum time span = 50 years).

Conclusions

Our Hexsim modelling indicated that a reintroduction in south Cumbria would be viable, that natural recolonisation alone is unlikely to establish a viable population in the south, and that a reintroduction augmented by natural colonisation would generate a larger population than a reintroduction alone.

2.4 Habitat Surveys

2.4.1 Woodland plots

Introduction

The suitability of woodland micro-habitat for pine martens is determined by the extent of vertical and horizontal structural features, which provide shelter and safe, elevated denning opportunities, as well as the presence of specific plant species that produce seasonal food resources (Caryl, 2008; Caryl et al., 2012).

Ancient semi-natural deciduous woodland with standing dead wood and distinct structural layers is optimal pine marten habitat (Caryl, 2008). The canopy provides thermally-insulated arboreal den sites and contributes to the accumulation of course woody debris on the forest floor, which provides cover and habitat for small mammals (Birks et al., 2005). The shrub layer supports prey species, such as nesting songbirds in the spring, and a source of berries in the autumn from trees and shrubs, such as rowan and hawthorn (*Crataegus monogyna*; Zalewski, 2005; Caryl, 2008; Caryl et al., 2012; Twining et al., 2019). A rich field layer can provide bramble, bilberry and other seasonal fruits as well as tussocky grassland habitat for small mammals (Zalewski, 2005; Caryl, 2008; Caryl et al., 2012; Twining et al., 2019). Woodland edge habitats such as un-grazed rough grassland often support dense populations of field voles which constitute the most important prey item for pine martens across the seasons on the British mainland (Caryl, 2008). Male martens will travel further than females across grassland habitats, but on average do not disperse more than 100 metres from the safety of the woodland edge (Caryl, 2008; Pereboom et al., 2008).

By contrast, un-thinned conifer plantations are less frequently used by pine martens, as they lack structural complexity, contain very few suitable arboreal cavities, and cast dense shade, which prevents the development of a field layer (Caryl, 2008). Due to the absence of tree cavities in conifer plantations, pine martens will often resort to using terrestrial den sites, such as root plates and rocky outcrops, where the kits are more exposed to predation by red foxes and are less well insulated (Birks et al., 2005).

The aim of this assessment was to survey habitat quality across distinct woodland strata in the Rusland Valley and Grizedale Forest, within the PRR, by recording and quantifying habitat features that contribute to the survival of pine martens.

Methodology

Landcover categories were sourced from Corine 2018 Landcover maps and manipulated in QGIS 3.4.3 to stratify available woodland into the following four habitat types:

- Broadleaf
- Conifer
- Mixed (broadleaf and conifer)
- Grassland (including clear-fell, scrub and young trees)

A stratified non-random sampling design was used to survey a network of 69 equidistant plots and the number of plots surveyed within each habitat type was proportional to the total area of the habitat type. All plots were surveyed once during the growing season between July 6 and 31 August 2021, using small groups of volunteers. Each survey plot consisted of an inner circle of 5.6 metres radius

(0.01 hectare), within a larger circle of 9.7 metres radius (0.03 hectares). Vegetation variables relating to the field and ground layers were surveyed within the inner circle, and those relating to the canopy layer were recorded in the larger outer circle.

Canopy layer:

Woodland type

- We ground-truthed the habitat type against the stratified Corine 2018 Landcover category.

Diameter at breast height (DBH)

- We identified the species and measured the DBH of all trees with a diameter greater than 7cms.

Canopy cover

- We estimated the percentage canopy cover using a densiometer and determined whether the canopy was single or multi layered.

Fruiting trees and shrubs

- We counted the number of fruit and nut bearing trees. These included mature trees and saplings over 2 metres in height, such as rowan, crabapple (*Malus sylvestris*), wild cherry (*Prunus avium*), yew (*Taxus baccata*), and blackthorn (*Prunus spinosa*).

Woody debris

Scored presence across the plot as follows:

- 0 = no debris
- 1 = only fine debris/branches (<7cm diameter)
- 2 = only coarse woody debris (>7cm diameter)
- 3 = both fine and coarse woody debris present

Root plates and rocky outcrops

- We recorded the presence and number of root plates.
- We recorded the presence of rocky outcrops with cavities of sufficient diameter (>5cm) and size to provide shelter or terrestrial denning sites for a pine marten.

Field and ground layers:

Percentage cover

- We estimated the percentage ground cover of vegetation, soil, and bare rock.

Vegetation height

- We estimated the mean height (cm) of the field layer vegetation, based on 10 height measurements, taken at intervals of 3 paces around the circumference of the smaller survey plot, using a measuring stick and disc.

Results

Forest Type

Of the 69 woodland plots, almost equal proportions were classified as broadleaf (22%), conifer (20%) and grassland habitats (20%) but the main species composition was mixed woodland which accounted for 38% of all plots. A number of plots which were classified as conifer woodlands on Corine 2018 landcover maps were re-classified as mixed plots due to the presence of broadleaf trees.

DBH

The mean density of trees across all habitat strata (>7cm DBH) was 563 per hectare, with the highest density in conifer habitats, and lowest in grassland habitats (1183 and 7, respectively) (Table 5). A total of 23 tree species were recorded, with Sitka spruce (*Picea sitchensis*), birch (*Betula spp*.) and oak (*Quercus* spp.) representing the three most abundant tree types (birch and oak were not identified to species level).

Table 5. The density of trees per hectare in each of four habitat strata, extrapolated from the survey results across 69 woodland plots.

	Broadleaf	Conifer	Mixed	Grassland	Total
Total trees (all species)	191	497	486	3	1165
Total area (ha)	0.45	0.42	0.78	0.42	2.07
Total trees/ha	424	1183	623	7	563

Table 6. Tree species diversity, abundance and mean DBH across 69 stratified woodland plots.

Species	Abundance	Mean DBH (cm)
Sitka spruce *(Picea sitchensis*)	519	18
birch (*Betula* spp.)	204	13
oak (*Quercus* spp.)	117	32
hazel (*Corylus avellana*)	64	13
larch (*Larix spp*.)	51	20
Scots pine (*Pinus sylvestris*)	48	16
willow (*Salix spp*.)	26	10
alder (*Alnus glutinosa*)	23	29
sycamore (*Acer pseudoplatanus*)	23	34
ash (*Fraxinus excelsior*)	21	23
western red cedar (*Thuja plicata*)	18	9
yew (*Taxus baccata*)	12	18
douglas fir (*Pseudotsuga menziesii*)	7	59
rhododendron (*Rhododendron ponticum*)	7	11
holly (*Ilex aquifolium*)	6	16
hemlock (*Tsuga heterophylla*)	4	10
Norway spruce (*Picea abies*)	4	70
rowan (*Sorbus aucuparia*)	4	9
cherry (*Prunus* spp.)	2	10
hawthorn (*Crataegus monogyna*)	2	23
beech (*Fagus sylvatica*)	1	73
sweet chestnut (*Castanea sativa*)	1	37
wych elm (*Ulmus glabra*)	1	63

The four trees with the highest mean DBH were beech, Norway spruce, wych elm and Douglas fir (73, 70, 63, 59, respectively) (Table 6). Oak is particularly important to pine martens, as trees above a DBH of 60cm have been shown to contain a disproportionately high number of cavities that females can use as denning and resting sites (Zalewski, 1997); 73% of oak trees across all woodland plots were in the lowest two DBH classes (0-20cm and 21-40cm), and only 9% of trees had a DBH greater than or equal to 60cm (Fig. 28).

The mean DBH of all species was highest in the broadleaf strata (24cm), and lowest in the grassland habitats (15cm) (Fig. 29). The mean DBH of all species across all strata was 19cm.

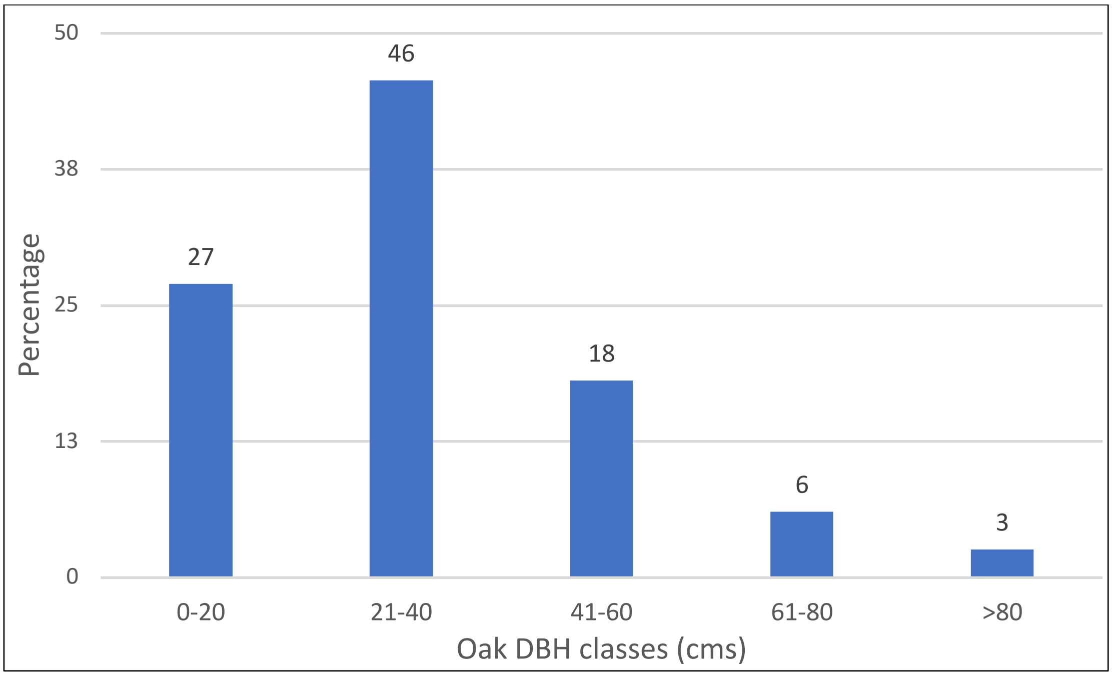

Figure 28. Percentage of oak trees in DBH classes across 69 stratified woodland plots.

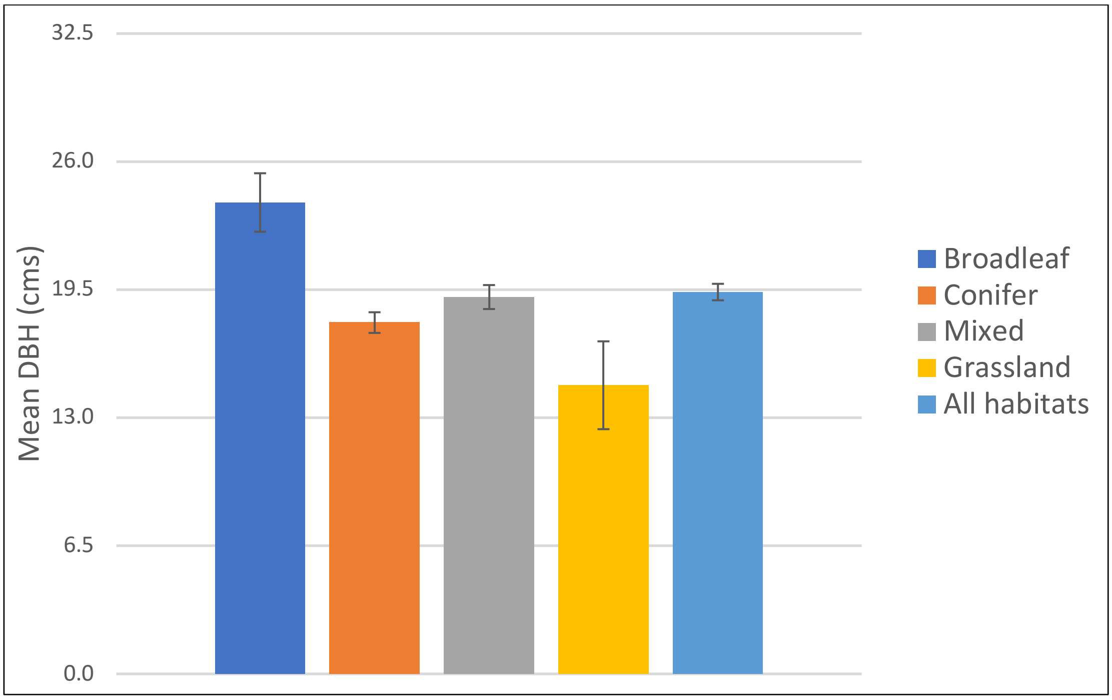

Figure 29. Mean DBH and standard error of all tree species across four habitat strata.

Ground cover

The dominant ground cover across all woodland plots was grass (27.5% of total area), followed by moss (14.7%), and bracken (*Pteridium aquilinum*) (13.6%). Bramble and bilberry, which constitute important food plants for pine martens in the autumn, covered 12.5% of the total survey area, with negligeable cover of raspberry, *Rubus idaeus* (0.2%; Fig. 30). The mean height of ground vegetation in all strata was 42cm, with the tallest vegetation across the three woodland strata in the broadleaf plots (mean 51.6cm) (Table 7).

Woody debris was present in 59 of the 69 survey plots, but only covered 8.2% of the total area. Thirty-five plots contained both fine and coarse woody debris, whereas 13 held only fine debris, and 11 only coarse woody debris.

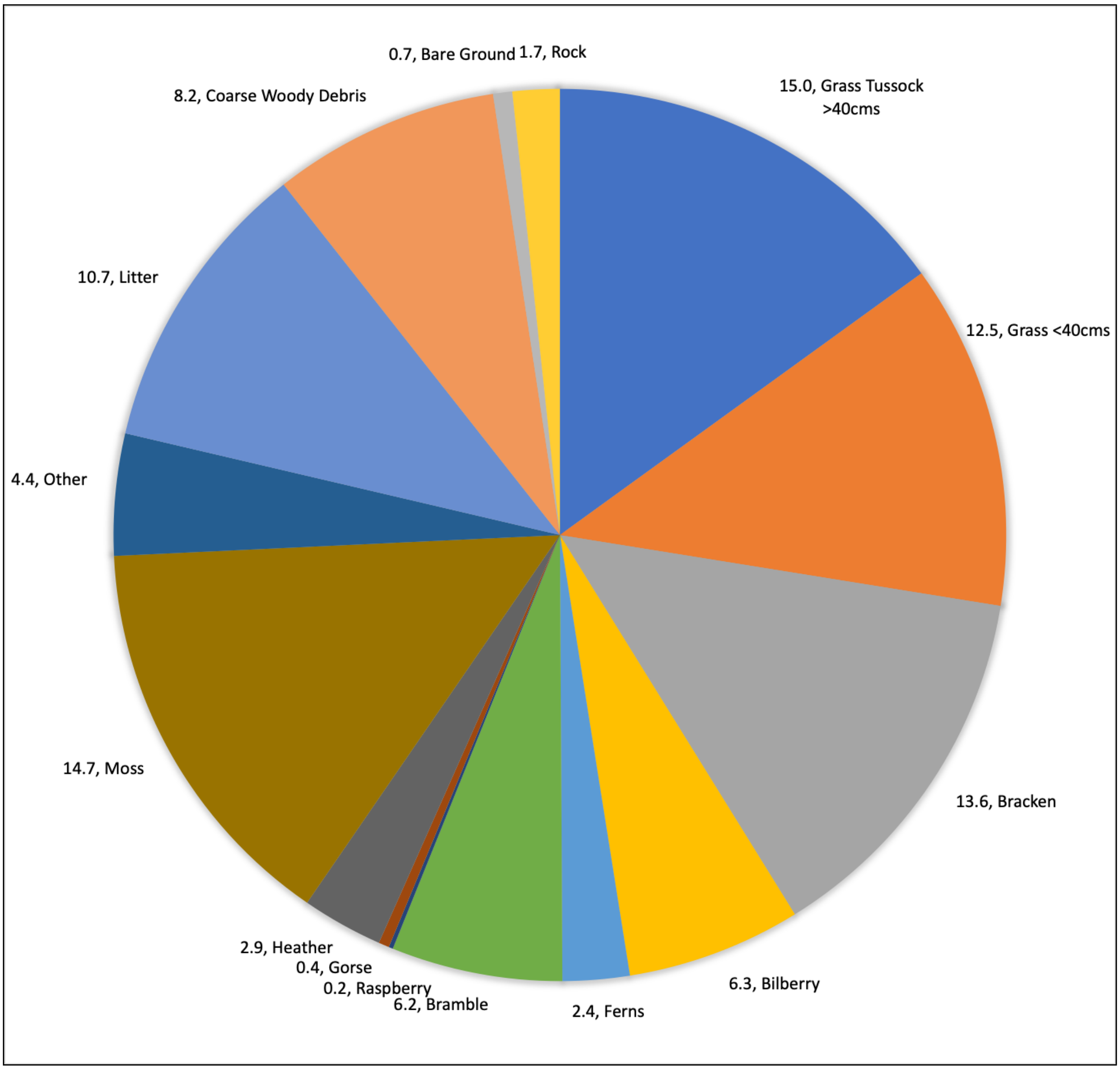

Figure 30. Percentage ground cover across all woodland plots.

Table 7. The vegetation height, number of fruit trees and root plates and presence of rocky outcrops across the 4 habitat types.

	Broadleaf	Conifer	Grassland	Mixed	Mean
Mean vegetation height (cm)	51.6	21.4	54	41.1	42.0
No. Fruit trees	5	12	0	73	22.5
No. fruit trees per hectare	11.1	28.6	0	93.6	33.3
No. root plates	3	5	6	8	5.5
No. root plates per hectare	6.7	11.9	14.3	10.3	10.8
Presence of rocky outcrops	3	3	3	12	5.25

Discussion

Studies have revealed that female pine martens show a strong preference for thermally insulated tree cavities as natal den sites, if they are available (Zalewski, 1997; Birks et al., 2005; Kleef and Tydeman, 2009). In the Polish old growth forest of Białowieża National Park, 67% of all nest cavities were located in oak and lime (*Tilia* spp.)., and in younger mixed forest areas (60 years old) in the Netherlands, a range of conifer and broadleaf species were used, including larch, beech, Scots pine and oak (Zalewski, 1997; Kleef and Tydeman, 2009).

The abundance of arboreal cavities increases with DBH in tree species where cavities are present. In Białowieża National Park, the mean DBH of trees with occupied cavities was 85.6cm (range 44-150) for oak, 58cm (range 44-75) for ash and 54cms (33-75) for (Zalewski, 1997). The most frequent arboreal cavities used as natal dens by pine martens in mainland Europe are disused black woodpecker nest sites (Zalewski, 1997; Kleef and Tydeman, 2009).

Within the PRR, small numbers of veteran broadleaf trees were recorded across the 69 woodland plots, but in contrast to Białowieża National Park, the forests of south Cumbria are typically young, even-aged stands, and the mean DBH of oak, ash and alder were only 32, 23, and 29cm, respectively. Furthermore, the absence of black woodpeckers in the UK is likely to reduce the availability of suitable natal dens in veteran broadleaf trees. Further studies are required to quantify tree cavities across the PRR and the availability of great-spotted woodpecker nest cavities, which would decay and enlarge over time to meet the spatial needs of a female marten with kits.

The lack of arboreal den sites can be compensated by using pine marten boxes. These have been successfully used in pine marten recovery areas in Galloway Forest, mid-Wales and the Forest of Dean, to provide insulated den sites where a scarcity of natural tree cavities limits the extent of population growth (Croose et al., 2016). Artificial den boxes could also be installed in the forests of south Cumbria according to the methodology of Croose et al. (2016) to support the reproductive needs of a reintroduced pine marten population .

Although terrestrial cavities provide suboptimal denning sites for pine martens, they are used to rest and shelter during periods of inactivity (Birks et al., 2005). Within the PRR, 30% of the woodland plots had rocky outcrops that were deemed suitable for pine martens to use (entrance diameter >5cm, with substantial cavity), and 51% of plots (compared to 30% in the Forest of Dean) had coarse woody debris, which provides cover and habitat for small mammals.

Comparisons between south Cumbria and the Forest of Dean in the composition of the field and canopy layers were challenging, as surveys were conducted during the summer in Cumbria, and between November and March in the Forest of Dean. Within the south Cumbria PRR, the understory layer provided many of the seasonal dietary resources for pine marten: 40% of plots had bilberry and 39% had blackberry, which are important components of the diet in the autumn, and 54% of all plots contained tussock grass (Forest of Dean: 32%), which provides habitat for small mammals, especially field voles. Fruiting trees were present in 28% of plots, with a mean of 4.7 trees in plots where they were found (Forest of Dean: 17% and 2 trees, respectively).

2.4.2 Small mammals

Introduction

Pine martens are omnivores and will feed on a wide range of seasonally abundant plant and animal-based foods; however, small mammals, particularly field voles, form an important part of their diet in the UK (Birks, 2020).

This study aimed to quantify the small mammal prey base for a reintroduced pine marten population in the south Cumbria PRR, which we compared with the Forest of Dean recovery area. Live traps were deployed across suitable habitat to catch small mammal species, taking precautions to minimise stress and ensure the highest standards of animal welfare. In particular, measures were taken to avoid the capture of shrews (*Sorex* spp.), which are protected by law, experience high rates of trap mortality, and are not important prey items for pine martens; only vegetable baits were used, and the responsible project officer carried the appropriate Natural England licence.

Methods

Longworth traps were used to catch small mammals using apple, carrot, and mixed grains as bait. The nest chambers were filled with timothy hay to prevent heat loss following capture. Traps were installed overnight (without pre-baiting) and checked after an interval of no more than 12 hours.

The surveys were undertaken on public and private landholdings in the Rusland Valley and Grizedale Forest. Corine Land Cover (2018) data were used to stratify the forest area into broadleaf woodland, conifer woodland, mixed woodland and grassland, to determine differences in the abundance and species composition of small mammals across these habitat types. The grassland stratum included areas of clear fell, young trees and scrub.

Trapping was undertaken at 4 distinct sites per strata, with no replicates, and a total of 16 trapping events were completed between 6 September and 28 October 2021; this time frame corresponds with peak abundance of small mammals at the end of the breeding season (Sibbald et al., 2006), and enabled quantitative comparisons with the Forest of Dean feasibility study (Stringer et al., 2018).

A series of 16 randomly chosen monads were mapped across the four habitat strata, and within each monad, the trapping site was selected by the field worker to ensure access and avoid high-risk areas (public footpaths/felling activity; Fig. 31). At each trapping site, a square grid of 25 Longworth traps was deployed, with each trap 10 metres apart, and covering an area of 50m x 50m. All captures were identified to species level, weighed and sexed, prior to release at the site where they were caught.

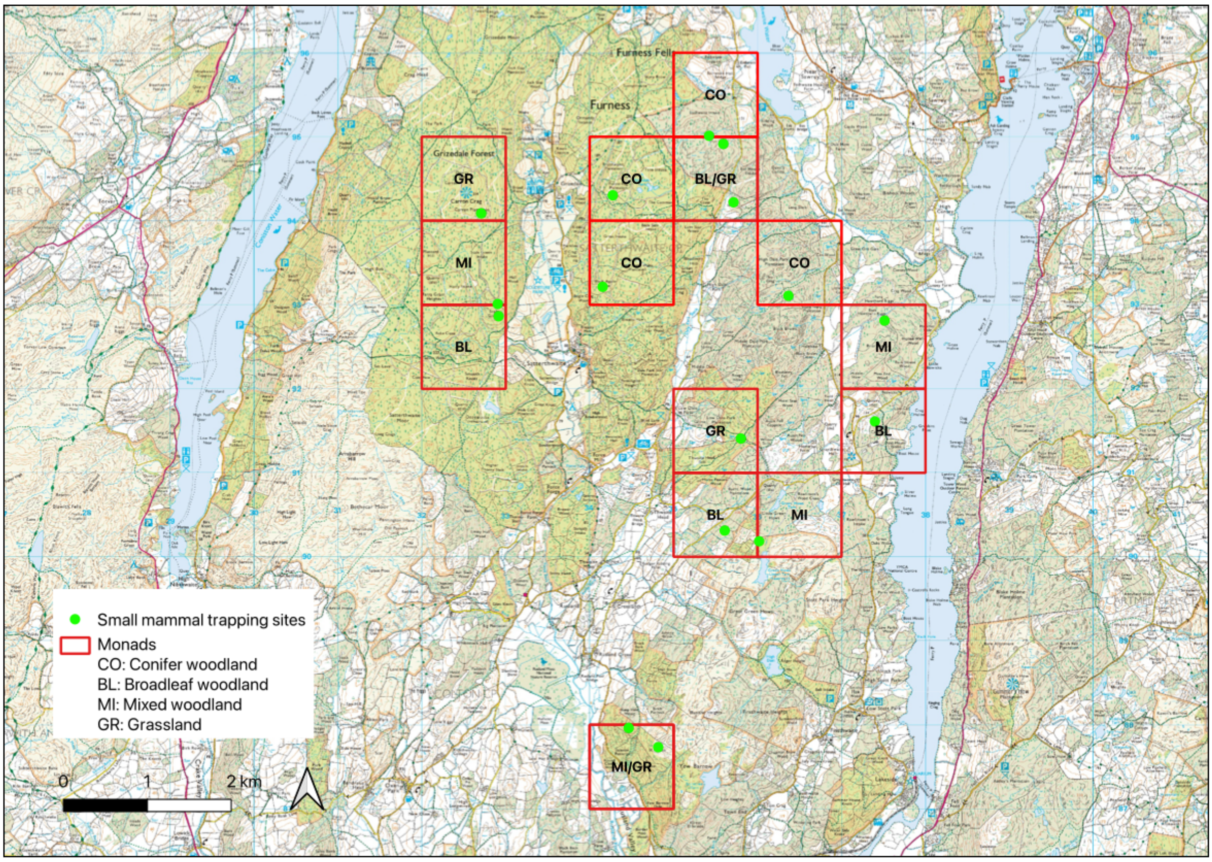

Figure 31. Habitat strata monads with location of small mammal trapping sites in Rusland Valley and Grizedale Forest.

Results

A total of 129 small mammals were trapped, of which 2 were found dead and 127 were released unharmed. Of the three species trapped, wood mice were most abundant across all habitat strata (103 captures), followed by bank voles (23 captures) and field voles (3 captures; Fig. 32). Field voles were only captured in grassland habitats, whereas bank voles and wood mice were trapped across all four habitat types.

Mean capture rates for bank voles were highest in broadleaf woodland (that had abundant areas of tussocky grassland), and lowest in conifer habitats, which were dominated by needle litter and less cover in the understorey (Fig. 33). By contrast, the mean capture rate for wood mice was highest in conifer woodlands, with a maximum trap rate of 56% at one plantation site dominated by Sitka spruce.

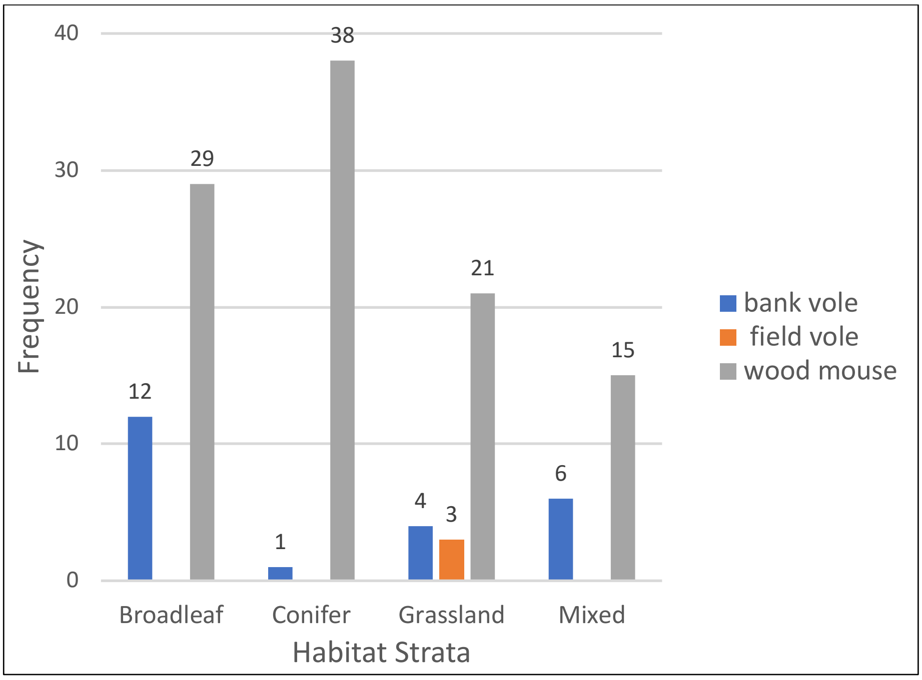

Figure 32. Abundance of small mammal species across four habitat strata.

Figure 33. Mean capture rate with standard error of small mammal species across four habitat types.

An index of abundance was calculated as the mean number of captures per 100 trap nights (xn/100TN) for all species across each habitat type (Table 8), and for individual species across all habitat types (Table 9). These results demonstrate a fourfold increase in xn/100TN across all species and strata in the Rusland/Grizedale area compared to the Forest of Dean (Stringer et al., 2018). This discrepancy relates to very high densities of wood mice in Rusland/Grizedale possibly related to a mast year in 2020 with a 25% capture rate across all traps deployed (Table 9).

Table 8. Mean captures per 100 trap nights of all species stratified by habitat in south Cumbria and the Forest of Dean.

	xn/100TN	
Habitat Strata	BOOM	Forest of Dean
Broadleaf	41.00	8.00
Conifer	39.00	11.43
Mixed	21.00	Unavailable
Grassland	28.00	6.86
All Strata	32.25	8.76

Table 9. Mean captures per 100 trap nights of individual species across all habitats in south Cumbria and the Forest of Dean.

	xn/100TN	
Species	BOOM	Forest of Dean
Wood mouse	25.75	5.33
Bank vole	5.75	0.00
Field vole	0.75	0.76
Yellow-necked mouse	0.00	2.67
All Species	32.25	8.76

Discussion

The relative abundance of small mammals across all habitat types within the PRR in south Cumbria suggests a robust prey base for pine martens. However, the results present a snapshot in time and do not account for seasonal fluctuations in wood mouse and bank vole populations, and the annual or multiannual cycles (three-to-four-year periodicity) in the population size of field voles (Flowerdew et al., 2004).

The disparity between small mammal abundance in south Cumbria and the Forest of Dean may reflect differences in environmental factors, such as habitat quality, climatic conditions, and improved overwinter survival due to high mast production in 2021 in south Cumbria. However, some methodological differences between the two study sites could have skewed the results. In the Forest of Dean, the exact trapping locations were randomised, whereas in south Cumbria, the field worker used non-random subjective methods within each monad to determine the trapping site.

Differences in the relative abundance of the three small mammal species relate to their habitat preferences and adaptability. The wood mouse is highly adaptable and is found in most habitats including woodland, rough grassland and urban green spaces (Marsh and Harris, 2000; Mathews et al., 2018). The bank vole can also occupy various habitats but shows a strong preference for mature broadleaved and mixed woodland (Flowerdew et al., 2004). By contrast, the field vole in uncommon in woodlands and restricted to open rough grassland habitats (Matthews et al., 2018).

The high relative abundance of wood mice (xn/100TN = 25.75) relates to the presence of the species across all strata with the highest trapping rate in conifer woodlands. The paucity of ground cover in conifer habitats resulted in the almost complete absence of vole species and the opportunity for more adaptable wood mice to occupy a vacant niche with no small mammal competitors. Field vole numbers were very low in the study as non-woodland habitats were underrepresented (4/16).

2.4.3 Camera traps

Introduction

Camera traps are widely used to detect rare and elusive wildlife species, including mustelids (Manzo et al., 2011). They are non-invasive, with minimal disturbance, and can measure species abundance and density (Manzo et al., 2012).

The aim of the camera trap survey was to record the detection frequency and distribution of native and non-native species across the study area, within the PRR. Although the focus was on the detection of pine marten presence, we also collected data on prey species, such as small mammals and red/grey squirrels, and predators of pine martens, such as red foxes; these data were used support the ecological risk assessments (see Section 3.4), by describing the woodland species assemblage that would interact with a reintroduced pine marten population.

Methodology

Between 1 July 2020 and 30 June 2021, 21 Browning Recon Force Advantage (Model BTC-7A) camera traps were installed in the Rusland Valley and Grizedale Forest, across a network of equidistant 1km^2 monads, in woodland habitat with more than 20% forest cover. Within each monad, a single camera trap was attached to a tree trunk (50-100cm above the ground), at least 200 metres from footpaths (to avoid detection by the public), and in areas with landscape characteristics that are favoured by pine martens (such as streams and fallen dead timber). The cameras were set to video mode, with a length of 20 seconds and a photo delay of 5 minutes. Each site was baited with sardines, jam and eggs, which were placed in the perforated horizontal cartridge of a T-sniffer (Fig. 34), to allow scents to be released slowly through a series of holes, thus creating a long-acting scent lure. The T-sniffers were positioned in the camera's field of view, and any pine marten accessing the elevated bait would reveal its bib pattern as a unique identifier. Monthly checks were carried out during the study period to replace camera batteries and SD cards, and to install fresh bait.

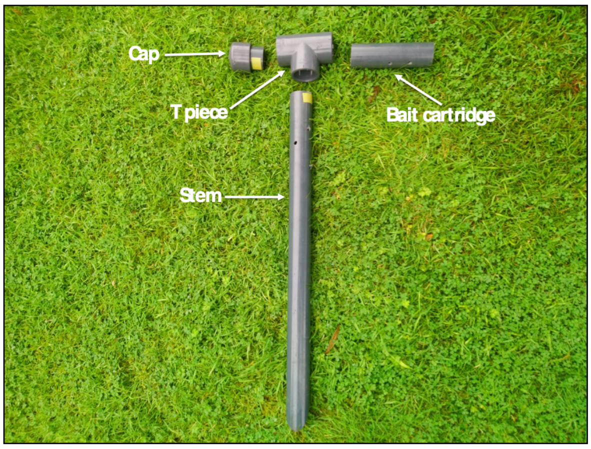

Figure 34. Components of a T sniffer (left) and a T sniffer and camera trap set up (right).

Results

A total of 7464 trap nights were completed during the study period, and 8184 individual animals of 43 species (mammals and birds) were recorded (Table 10). No pine martens were detected. Red squirrels accounted for a small percentage of the total number of detections (2.0%) and were distributed towards the northern end of the Rusland Valley and in parts of Grizedale Forest. Grey squirrels were very widely distributed across 90% of the camera trap locations, and were sympatric with red squirrels where they were detected; the ratio of grey to red squirrel detections was 13:1. Foxes were widely distributed across the study site; however, they are actively hunted, and unlike badgers (*Meles meles*), showed extreme vigilance when approaching the bait, which may account for the relatively low number of detections. Wood mice were ubiquitous across all camera trap sites and accounted for almost a third of all detections. The European polecat (*Mustela putorius*) was present in small numbers across central and northern areas of the Rusland Valley and in Grizedale Forest.

Table 10. The number of detections and occupancy (number of sites at which detected) for selected species (and all species) from 21 camera traps in the Rusland Valley and Grizedale Forest between 1 July 2020 and 30 June 2021.

Species	Number of detections	Percentage of total detections (all species)	Occupancy at 21 trap sites
Red squirrel	166	2	08/21
Grey squirrel	2191	27	20/21
Fox	240	3	19/21
Wood mouse	2440	30	21/21
European polecat	18	0.2	05/21
All species total	8184	100	

Discussion

The complete lack of pine marten detections must be interpreted with caution, as it is impossible to prove the absence of such an elusive mustelid. However, given our large surveying effort, the results suggest that either pine martens are not present within the potential recovery region, or their numbers are so low that the local population is unlikely to be viable. Further evidence was sought from community consultation work with 36 farmers landowners in the study area (see Section 4), who confirmed that pine martens have not been seen in the study area since the late 1990s. During 2020 and 2021, members of the public submitted about a dozen unconfirmed records of pine marten sightings, and a simple questionnaire-based scoring system was used to verify the accuracy of these sightings. Based on the behaviour and morphology of the animal, sighting distance and experience of the recorder, the majority of sightings were likely to be polecats, or other species misidentified as pine martens. The presence of polecats provides some confidence that the habitat is suitable for pine martens, as the dietary niche of polecats overlaps with pine martens (Jedrzejewski et al., 1989), and that current levels of persecution are low, since polecats are also vulnerable to legal and illegal pest control methods.

3. The ecological impacts of recovering the pine marten in Cumbria

3.1 Introduction

Predation is an important ecological process that can stabilise prey populations and improve ecosystem function and resilience (Ritchie et al., 2012). Predators influence trophic cascades by exerting top-down control to alter the behaviour and abundance of meso-predators and herbivores at lower trophic levels, with beneficial effects, such as an overall increase in species richness of native plants and animals. The reintroduction of the grey wolf (*Canis lupus*) to the Greater Yellowstone ecosystem in 1995 reduced the browsing pressure from elk (*Cervus canadensis*) on riparian plants, such as aspen (*Populus tremuloides*), which increased the abundance of beavers (*Castor canadensis*) and associated freshwater fish and invertebrates (Ripple et al., 2012; Boyce, 2018;). The predation of elk by wolves through the winter has also supported a suite of other predators, such as black (*Ursus americanus*) and brown (*U. arctos*) bears as they emerge from hibernation, and birds, such as ravens (*Corvus corax*), through the provision of carrion (Boyce, 2018).

Our camera trap surveys across the study area in the Rusland Valley and Grizedale Forest revealed abundant herbivores, such as red deer (*Cervus elaphus*), and meso-predators, such as foxes and badgers (see Section 2.3.3). Overgrazing by deer is associated with population declines in migrant bird species, such as the garden warbler (*Sylvia borin*), due to reductions in the density of understory foliage and available nesting and foraging sites (Gill and Fuller, 2007). Pine marten predation on grey squirrels would support the regeneration of broadleaved woodland habitats by reducing the level of ring barking and the breeding success of certain woodland bird species by reducing the incidence of nest predation by grey squirrels (Amar et al., 2006; Mayle et al., 2009; Newson et al., 2010; Sheehy and Lawton, 2014).

Compensatory predation replaces, or 'compensates' for, existing sources of mortality (i.e., the predated individual would have died of other causes) and does not affect overall prey survival in a population (Errington, 1946). Additive predation 'adds' to existing sources of mortality and decreases the survival of prey within a population (Errington, 1946). Predation by native predators is usually compensatory, whereas the mortality caused by non-native predators is more likely to be additive, often resulting in the decline or extinction of prey populations (Holt et al., 2008; Jennings & Veron 2019).

Introduced, non-native predators can have a devastating effect on naive prey populations, but this is less likely following the reintroduction of native species, such as the pine marten, to part of their former geographic range (Salo et al., 2007). When predators and prey co-exist over a long period of time, prey species evolve morphological or behavioural adaptations that can reduce the rate of encounters with predators or increase their prospects of escape if detected (Lima & Dill 1990). The pine marten is a native predator in Britain and has coevolved in an evolutionary arms race with many prey species across its range since it appeared in the fossil record 120,000 years ago (Birks, 2020). This evolutionary history has enabled avian and mammalian prey species to develop predator avoidance strategies including the selection of safe nesting and foraging sites.

The vulnerability of a species to predation by pine martens will depend on several factors, including the prey's habitat preferences, breeding biology, population density, anti-predator strategies, and the availability of alternative food resources for pine martens (MacPherson et al*.,* 2014). If pine martens hunt opportunistically, then prey vulnerability will also be related to the amount of time predator and prey spend in the same habitat, and there might be a particular risk for some rare species that occupy refuges in areas preferred by martens for foraging. Since pine martens are territorial, have relatively large home ranges and live at low population densities, their impact on rare and threatened wildlife is likely to be lower than more common predators, such as red foxes.

Even though many recovery projects have reported fears of negative ecological impacts resulting from the reintroduction of a native predator, very few examples of negative impacts have occurred, and these were mainly related to the transmission of disease forming pathogens (Stringer et al., 2018). However, despite the coevolution of pine martens with native prey species over thousands of years, modern landscapes have changed over time in size, structure and in terms of their assemblage of native and non-native species. Therefore, although the reintroduction of the pine marten to south Cumbria is likely to support ecosystem health, given the temporal changes to landscapes and wildlife populations, it remains important to assess the risk of potential additive mortality to protected or endangered species of birds, mammals and reptiles, which may have suffered recent population declines (IUCN, 2013).

3.2 Methodology

Birds

Data were extracted from the Birds of Conservation Concern 5 (Stanbury et al., 2021) and the Cumbria Bird Atlas 2007-11 (Cumbria Biodiversity Data Centre, 2015) to create a shortlist of Red and Amber listed breeding birds that are present in the PRR and which nest in areas that are most suitable for pine martens (woodland and woodland edge habitat). The relative importance of each listed species in the PRR was assessed in the context of the national population by Chris Hind, the Cumbria County Bird Recorder, and other colleagues with ornithological expertise, with reference to the most recent BTO 10-year population trends for the North-West of England. A literature search was then conducted on the short-listed species to establish the likelihood that a predation risk from pine martens will occur, and the potential impact if it does occur. Risks associated with all life stages were assessed (including predation of adults, chicks and eggs), and the relative risks of breeding in open nests and nests in tree cavities/bird boxes were also considered. Recommendations for mitigation measures and future monitoring are given.

Mammals

We used the IUCN – Compliant Red List for Britain's Terrestrial Mammals (Mathews and Harrower, 2020) and Cumbria Mammal Atlas 2017 (Cumbria Biodiversity Data Centre, 2017) to select native species for risk assessment if they are at risk of extinction (categorised as Data Deficient, Near Threatened, Vulnerable, Endangered, or Critically Endangered) and are distributed within the PRR in woodland or woodland edge habitats. A literature search was then conducted on the short-listed species to identify and quantify predation by pine martens.

Reptiles and Amphibians

Data from the Cumbria Biodiversity Data Centre (CBDC, 2010) were used to identify species for risk assessment that are distributed in the PRR in woodland or woodland edge (habitat suitable for pine martens). Distribution maps from the Amphibian and Reptile Groups (ARG) UK website (https://www.arguk.org) identified which of the BAP listed amphibian species were distributed within the PRR.

3.3 Results

Thirty-five Red listed and 51 Amber listed bird species were recorded as breeding (confirmed, possible, or probable) within the PRR. From this total of 86 avian species, 31 (13 Red, 18 Amber) nest in woodland and woodland edge habitats, and of these, 74% nest in open nests and 26% in tree cavities/bird boxes (Table 11).

Table 11. Red and Amber listed breeding birds recorded in the PRR.

Species	Scientific name	Red/Amber listed	Nesting habit	Importance in national context
cuckoo	*Cuculus canorus*	Red	open	low
greenfinch	*Chloris chloris*	Red	open	very low
hawfinch	*Coccothraustes coccothraustes*	Red	open	medium to low
house sparrow	*Passer domesticus*	Red	cavity/box	very low
marsh tit	*Poecile palustris*	Red	cavity/box	low
mistle thrush	*Turdus viscivorus*	Red	open	very low
redpoll	*Acanthis cabaret*	Red	open	very low
spotted flycatcher	*Muscicapa striata*	Red	cavity/box	low
starling	*Sturnus vulgaris*	Red	cavity/box	low
tree pipit	*Anthus trivialis*	Red	open	low
tree sparrow	*Passer montanus*	Red	cavity/box	very low
wood warbler	*Phylloscopus sibilatrix*	Red	open	medium to low

woodcock	*Scolopax rusticola*	Red	open	low
bullfinch	*Pyrrhula pyrrhula*	Amber	open	low
common redstart	*Phoenicurus phoenicurus*	Amber	cavity/box	low
common sandpiper	*Actitis hypoleucos*	Amber	open	very low
dipper	*Cinclus cinclus*	Amber	open	very low
dunnock	*Prunella modularis*	Amber	open	very low
kestrel	*Falco tinnunculus*	Amber	open	very low
nightjar	*Caprimulgus europaeus*	Amber	open	low
osprey	*Pandion haliaetus*	Amber	open	low
pied flycatcher	*Ficedula hypoleuca*	Amber	cavity/box	low
rook	*Corvus frugilegus*	Amber	open	low
songthrush	*Turdus philomelos*	Amber	open	low
sparrowhawk	*Accipiter nisus*	Amber	open	low
stock dove	*Columba oenas*	Amber	open	very low
tawny owl	*Strix aluco*	Amber	cavity/box	low
treecreeper	*Certhia familiaris*	Amber	open	low
willow warbler	*Phylloscopus trochilus*	Amber	open	low
woodpigeon	*Columba palumbus*	Amber	open	low
wren	*Troglodytes troglodytes*	Amber	open	low

Seven species of native mammals are found in the PRR that occupy habitat that is suitable for pine martens, including three species of rodents (water vole, *Arvicola amphibius*, red squirrel and hazel dormouse, *Muscardinus avellanarius*), 3 species of bats (Nathusius's pipistrelle, *Pipistrellus nathusii*, Brandt's myotis, *Myotis brandti*, and whiskered bat, *M. mystacinus*), and the European hedgehog, *Erinaceus europaeus* (Table 12).

Table 12. Red listed mammal species recorded in the potential release region.

Species	Scientific name	Red List Status
water vole	*Arvicola amphibius*	endangered
red squirrel	*Sciurus vulgaris*	endangered
hedgehog	*Erinaceus europaeus*	vulnerable
hazel dormouse	*Muscardinus avellanarius*	vulnerable
Nathusius's pipistrelle	*Pipistrellus nathusii*	near threatened
Brandt's bat	*Myotis brandti*	data deficient
whiskered bat	*Myotis mystacinus*	data deficient

Four reptile species are found within the PRR: common lizard (*Lacerta vivipara*), slow-worm (*Anguis fragilis*), grass snake (*Natrix helvetica*) and adder (Vipera berus; Table 13), and all are UK BAP Priority Species with protection under the Wildlife and Countryside Act 1981 (http://www.cbdc.org.uk/uploads/cbeb/statements/CBEB-Reptiles.pdf). Three amphibian species are found within the PPR: common toad (*Bufo bufo*), natterjack toad (*Epidalea calamita*), and great crested newt (*Triturus cristatus*; Table 13), and all are listed as BAP Priority Species (https://jncc.gov.uk/our-work/uk-bap-priority-species/).

Table 13. UK BAP Priority amphibian and reptile species recorded in the PRR.

Species	Scientific name
adder	*Vipera berus*
common lizard	*Lacerta vivipara*
grass snake	*Natrix helvetica*
slow-worm	*Anguis fragilis*
common toad	*Bufo bufo*
great crested newt	*Triturus cristatus*
natterjack toad	*Epidalea calamita*

3.4 Risk assessments and discussion

Birds

A literature search revealed 23 papers documenting dietary studies on pine martens across their range in Europe. All studies recorded birds as a variable component of the diet; 13 of the Red and Amber species listed in Table 1 were identified in scats from pine martens, but only at very low percentage occurrences, from 0.06% to 3.4% (Table 14)

Table 14. The number of published studies documenting predation of avian species listed in Table 1. with the percentage occurrence of species remains in pine marten scats.

Species	No of studies with evidence of predation	% Occurrence in scats
bullfinch *Pyrrhula pyrrhula*	1	0.1
dipper *Cinclus cinclus*	1	Not available
greenfinch *Chloris chloris*	1	Not available
hawfinch, *Coccothroustes coccothrausrtes*	1	0.06
osprey *Pandion haliaetus*	1	1.8
Rook *Corvus frugilegus*	1	0.1

Songthrush *Turdus philomelos*	2	0.34
spotted flycatcher *Muscicapa striata*	1	0.06
Starling *Sturnus vulgaris*	3	0.06/3.3
tawny owl *Strix aluco*	2	0.06
Treecreeper *Certhia familiaris*	1	0.7
Woodcock *Scolopax rusticula*	1	0.20
Wren *Troglodytes troglodytes*	4	1.6/0.2/0.1

Bright and Halliwell (1999) modelled the potential impact of pine marten predation on bird species. This suggested that even at a high pine marten population density, pine martens would be very unlikely to kill more than 0.8 individuals of a rare bird species per km^2 per year, which would probably not have a significant impact on rare bird populations. Furthermore, if pine marten predation is in direct proportion to bird abundance, then pine martens are much more likely to prey on common bird species, such as the blackbird (*Turdus merula*).

Eggs and nestlings are more vulnerable to predation than adult birds and pine martens are known to predate open-nesting, ground-nesting and cavity-nesting birds (Walankiewicz, 2002; Schaefer, 2004; Weidinger, 2009). European studies have revealed that pine martens can be responsible for 14-37% of predation events in open nests; however, eggs and nestlings may be more heavily predated by other species, such as jays (*Garrulus glandarius*) (29-60%), great spotted woodpeckers, and other mammalian predators (Walankiewicz, 2002; Schaefer, 2004; Weidinger, 2009).

The predation of osprey eggs and chicks by pine martens attracts a lot of media attention (Woodland Trust, 2019) and is a concern for residents in south Cumbria, where this charismatic raptor has recently recolonised suitable habitat. However, there is extensive range overlap between these two species, with little evidence of predation: Tishechkin (1991) documented the loss of only one brood of osprey nestlings, out of 57 active nests, to a pine marten in northern Belarus. To minimise any possible risk, land managers are advised to protect osprey nests by applying grease and cone baffles to the base of the tree trunk.

Ground-nesting birds are rare in woodland habitats, but some species, such as the Red listed woodcock, could be vulnerable to nest predation. Studies in Sweden and Finland have revealed that pine martens are only responsible for a small proportion of nest predation events (Angelstam 1986; Kurki et al., 1995); in the woodlands of south Cumbria, other generalist predators, such as corvids, badgers and foxes (which were frequently detected by our camera traps), are likely to remain the dominant predators of ground-nesting birds.

Birds that nest in natural tree cavities with entrance holes too small, or cavities too deep, for a pine marten to access the eggs, nestlings, or parent birds, are likely to experience the lowest predation risk. However, suitable nest cavities are usually associated with mature deciduous trees, which are uncommon in some of the young even-aged deciduous stands in south Cumbria, resulting in the use of nest boxes for priority woodland species, such as the pied flycatcher. Nest box holes are generally too small for pine martens to push their head through, but they can use their foreleg to reach eggs and nestlings up to a depth of 15cm inside the box (Balharry & Macdonald 1996; Olsen, 2013). Some studies have demonstrated that nests in boxes are exposed to higher predation rates than nests in tree cavities, as pine martens learn to associate the location and design of boxes with avian prey (Sorace et al., 2004; Czeszczewik, 2004). Measures to mitigate nest box predation include moving box locations each breeding season, or the use of cone/stovepipe baffles and entrance hole extenders (https://pinemarten.ie/the-pine-marten/pine-martens-and-bird-boxes/)

Predation on game bird species, such as the pheasant, is a particular concern for landowners with game shooting interests. However, an extensive study of pine marten diet in Scotland found that the number of free-flying pheasants taken by pine martens (2.9 per km^2) represented less than 1% of the birds released (Halliwell, 1997). Mammalian predators can cause considerable damage if they get into a pheasant rearing or release pen, but pine martens can be excluded by trimming overhanging branches, closing pop holes at dusk, and using a combination of line wire and overhanging electric fencing (Balharry, 1993).

Table 15. Avian risk assessment

Life stage and nesting habit	Likelihood of risk	Impact of risk
Adults	low	low
Open-nesting: eggs and nestlings	medium	low-medium
Tree cavities: eggs and nestlings	medium	low-medium
Ground-nesting: eggs and nestlings	low-medium	low-medium
Box-nesting: eggs and nestlings	medium	high

Mammals

Hedgehog

Hedgehogs are increasingly associated with urban areas and are often observed in gardens and amenity grasslands (Mathews et al., 2018); badgers are their main predator (Young et al., 2006), but pine martens may sometimes eat juveniles (Zalewski, 2007). Two studies from Białowieża National Park in Poland recorded low levels of European hedgehog predation by pine martens (Goszczynski, 1976; Jedrezjewsk et al., 1993). It is very unlikely that pine martens would have population-level impacts on hedgehogs in south Cumbria, and the complete absence of hedgehog detections from the camera trap network in the feasibility study area is likely to be related to the abundance and widespread distribution of badgers.

Bats (Chiroptera)

Bats are most vulnerable to predation when they are in their summer roost sites and winter hibernacula. Three bat species that are at risk of extinction are recorded in the PRR. Nathusius's pipistrelle is a migrant which is most often encountered in the autumn, but is known to breed in the UK at a small number of maternity roosts (Bat Conservation Trust, 2022). Crevices in trees, rocks and human dwellings are used as roost sites, which are frequently associated with large bodies of freshwater. Whiskered and Brandt's bats are morphologically very similar and share foraging and roosting sites. They hunt along woodland rides and prefer roosting in buildings, although trees and bat boxes are also used (Bat Conservation Trust, 2022).

Annual mortality rates of bat species in the British Isles varies between 20-33%, with avian predators accounting for 11% of bat mortality (Speakman, 2008). Many bird species have been recorded to hunt bats, with the highest rates of bat predation attributed to raptors, such as the tawny owl, barn owl (*Tyto alba*) and kestrel (Lesinki et al., 2009; Mikula et al., 2013). Domestic and feral cats (*Felis catus*) are also important predators of bats, particularly at summer maternity roosts in buildings (Ancillotto et al., 2013). Cats learn the location of entry and exit sites in roof cavities and target adult female bats as they emerge to feed at dusk (Mic Mayhew pers. obs.)

Studies have shown that pine martens very rarely hunt bats, which comprise less than 0.02% of the diet (Stringer et al., 2018). The entrances of bat boxes are usually too small for pine martens to gain access and bats have co-evolved with pine martens to select tree cavities that are too narrow and deep to enable predation by pine martens (Ruczyński & Bogdanowicz, 2005). Since bat box use is widespread, one would expect a greater amount of bat remains to occur in scats if pine martens were significantly preying upon bats in boxes (Stringer et al., 2018). However, pine martens are known to use attic spaces in houses as natal den sites, if alternative arboreal den sites are unavailable, which may bring them into greater contact with bats. However, it is unknown if this would have a significant impact on bat populations (Stringer et al., 2018). Pine martens have predated large colonies of bats in caves in Poland and Slovakia, but in both cases, predation was not thought to be impacting on the bat population (Obuch, 2012; Power, 2015).

Although the predation risk to bats from pine martens is generally considered to be very low, bat experts will be consulted to determine if any potentially vulnerable bat colonies exist within the potential release region. Mitigation measures to prevent martens entering underground sites with roosting and hibernating bats include the installation of predator-proof grills over cave and tunnel entrances. Bat maternity roosts in attic spaces can be protected by ensuring that all access routes to the roof space have a diameter less than 45mm.

Water vole

The water vole prefers habitats along slow-flowing rivers, streams and marshes with tall dense vegetation, and the American mink (*Neovison vison*) is its main predator (Mathews et al., 2018). Water voles can occupy riparian habitats within woodlands, but there is no evidence from dietary studies that they constitute an important part of the diet of pine martens, and population level impacts are extremely unlikely.

Hazel dormouse

Studies in Switzerland and Italy have shown that the hazel dormouse is opportunistically hunted by pine martens, but it is a minor component of their diet (Marchesi, 1989; Russell and Storch, 2004; Balestrieri et al., 2011). Even northern Italy, where hazel dormice are abundant and widely distributed, the frequency of occurrence in scats was only 3.7% (Balestrieri et al., 2011).

Hazel dormouse populations in Cumbria have experienced a steep decline in the last few decades and only one extant colony remains at Roudsea Wood and Mosses National Nature Reserve in the south of the county (Cumbria Biodiversity Data Centre, 2017). Given its scarcity, predation by pine martens is unlikely. Also, the network of boxes that has been installed at Roudsea (to support breeding efforts during the summer and autumn months) are designed with entrances facing the tree, which prevents access by pine martens.

Grey squirrels compete with hazel dormice for hazelnuts (Juskaitis, 2007). The control of grey squirrel populations by pine martens could therefore increase the availability of an important food item for hazel dormice, with associated reproductive and survival benefits.

Red squirrel

The decline of the red squirrel in Britain and Ireland is driven by grey squirrels through the transmission of squirrel pox virus (SQPV) and competition for resources (Sheehy et al., 2018). Recent evidence from the Irish Midlands and Scotland has revealed that where pine martens are sympatric with red and grey squirrels, the impact of predation is highly asymmetrical, with a dramatic decline in grey squirrel occupancy and an increase in red squirrel abundance (Sheehy et al., 2018; Twining et al., 2020). The mechanism is unclear, but may relate to the lack of predator avoidance behaviours in grey squirrels, which have not coevolved with pine martens (Sheehy et al., 2018; Twining et al., 2020). Therefore, even though red squirrels can sometimes constitute up to 5% of the diet of pine martens in Britain and Ireland (Twining et al., 2020), the return of pine martens to Cumbria is likely to benefit native red squirrel populations through their impact on grey squirrels. Furthermore, a decline in grey squirrels could support the recovery of some woodland bird species. Evidence suggests that grey squirrel populations are negatively correlated with populations of woodland birds, such as hawfinch and lesser-spotted woodpecker (*Dendrocopos minor*), either through direct predation of eggs and nestlings, or as a result structural changes to the woodland from ring barking of young deciduous trees (Amar et al., 2006; Newson et al., 2010).

Camera trap detections within the potential recovery region have revealed that red squirrels still occupy some woodlands in the north of the Rusland Valley and parts of Grizedale Forest, but grey squirrels were ubiquitous and widely distributed across the study area, including all red squirrel detection sites. In the event of a pine marten reintroduction, grey squirrel control (through methods such as culling) will still need to be maintained until the distribution and density of pine martens is sufficient to suppress grey squirrel populations through predation pressure. Also, pine martens have a strong aversion to entering urban and suburban areas, which could act as refugia for grey squirrels and enable them to recolonise adjacent woodlands (Twining et al., 2020). Therefore, grey squirrel control in Cumbrian towns and cities may need to be sustained in order to restore red squirrels.

Table 16. Mammalian risk assessment

Species	Likelihood of risk	Impact of risk
Non-bat species	low	low
Bats: building roost	medium	low-high
Bats: underground roost (cave/mine)	medium	low-high
Bats: natural cavities in trees	low	low
Bats: bat boxes	low	low

Reptiles and amphibians

Reptiles and amphibians are a minor component of pine marten diet, and form less than 10% of the animals consumed (Lynch & McCann 2007; Caryl, 2008; Birks, 2020). In Scotland, the common lizard and slow worm have been found in the scats of pine martens, and common toads were assumed to be amongst unidentified anuran remains (Caryl, 2008), but no evidence of the other UK BAP high priority herptile species have been documented in the diet of pine martens. The likelihood and impact of risk of pine marten predation on reptile and amphibian species is predicted to be low.

3.5 Conclusions

All bird and mammal species listed in Tables 11 and 12 co-exist with pine martens across substantial parts of their range in the Western Palaearctic and have co-evolved adaptations to avoid predation. As opportunists, pine martens are unlikely to encounter large numbers of rare woodland species and, therefore, predation pressure is only likely to result in local or regional population level declines for potential prey species that are nationally rare, but locally abundant, such as bat species.

The risk of pine marten predation on adult Red and Amber listed woodland birds is predicted to be very low, although nestlings and eggs are at greater risk, and site-appropriate mitigation measures may need to be taken to avoid nest predation in bird boxes (Table 15.). Some predation will occur on birds at all life-stages but are unlikely to contribute to national population declines as the importance of Cumbrian Red and Amber listed bird populations in Table 1 were assessed as medium-low to very low in national context.

The assessment of Red listed mammals revealed both risks and potential benefits from the presence of pine martens. Red squirrel numbers are likely to increase as pine marten populations grow, through a process of competitive release (Sheehy and Lawton, 2014; Sheehy et al. 2018), and some woodland bird species may also benefit. Overall, the predation risk to mammalian species in Table 12 is predicted to be low (Table 16.), but for Red listed bat species, it will be important to assess the vulnerability of known bat colonies in the PRR before any pine marten releases are made, and mitigation measures may be necessary at maternity roosts in underground structures and in buildings, in collaboration with statutory authorities, private landowners, and local bat groups.

With any risk assessment process, there is inherent uncertainly due to incomplete evidence, and a detailed monitoring and adaptive management strategy will still be needed to determine if risks have occurred and to decide what mitigation measures could be effective. An exit strategy should also be considered if unacceptable risks do occur, and mitigation measures prove unsuccessful.

4. The socio-economic feasibility of recovering the pine marten in Cumbria

4.1 Introduction

Community engagement is an integral part of any reintroduction project (Reading and Kellert, 1993; O'Rourke, 2014); particularly those involving carnivore species, as they have increased potential to raise contention (Linnell et al., 2010). To comply with the IUCN reintroduction guidelines, all factors contributing to previous extinction of the pine marten need to be excluded before any translocation can go ahead (IUCN, 2013), and meaningful community consultation is the best approach to assess and mitigate ongoing risks in the community, such as persecution, which resulted in historic pine marten population declines. Furthermore, comprehensive community engagement creates a platform for open dialogue on the potential costs and benefits of a recovering pine marten population, instigates foundations of trust, and facilitates informed ongoing discussion and decision-making.

The results from this study revealed broad cross-sector support for the recovery of pine martens in Cumbria: 81% of the public, 69% of farming, landowner and estate community. Reintroduction was also considered the favoured method of recovery as opposed to recolonisation. This support should be nurtured and developed as the foundation for a future pine marten translocation project and as part of a longer-term community engagement plan.

4.2 Methodolgy

The primary data collection methods used for the socio-economic feasibility study were door-to-door surveys with questionnaire and online surveys (using SurveyMonkey). The door-to-door surveys were conducted by staff and volunteers from the BOOM project, within the PRR, between the months of November 2021 and February 2022, with support from a local NGO, the Rusland Horizons Trust. A weblink to the online questionnaire was given or posted to those who were not home or unable to commit their time instantaneously.

Two questionnaires (see Appendices 2 and 3) were designed to differentiate between the main target groups, 'Farm, estate and landowners within the PRR' and 'Members of the general public within the PRR'. These will be referred to as 'Farm' and 'Public' questionnaires for the remainder of this section. The questionnaires differed slightly between the two groups to ensure that the themes in the questions were relevant to the target groups. Both questionnaires were designed with a mixture of open questions, multiple choice questions and questions that required a 5-point Likert scale response between 'Strongly agree' and 'Strongly disagree'. Both questionnaires can be found in the appendices.

The questionnaires were designed to cover a range of themes. The themes included attitudes towards a pine marten recovery in south Cumbria, and whether reintroduction should be used as the method for recovery. Furthermore, the questionnaires were designed to understand the potential risks to the founder population from the activities of the rural communities. Risks were evaluated by establishing the use of legal pest control, the type of livestock enterprise, the scale of game bird management, attitudes to pine marten control (Farm questionnaire) and perceived negative impacts to the respondent's business or livelihood (both questionnaires). The questionnaires were also used to solicit information on people's sightings of pine marten in the area, their attitudes towards biodiversity, and diversification into ecotourism.

Before administering the survey, all respondents were given an information sheet (see Appendix 4) containing facts about the pine marten and given an opportunity to ask questions. Respondents were advised regarding the purpose of the feasibility study and that questionnaire responses would be anonymous and used solely for research purposes at the University of Cumbria. Any objections or negative responses presented an opportunity to correct misinformation and discuss mitigation measures to protect livestock and/or game birds, if appropriate.

In addition to the door-to-door surveys, a variety of other engagement methods were selected during the term of the feasibility study to target the public and stakeholder groups. These included face-to-face focus groups, online presentations and workshops, press releases and stakeholder meetings. Weblinks to the 'Public' survey were often disseminated after such engagement activities which hold value as the primary method of relationship building and knowledge exchange between the project partners and the community.

4.3 Results

Response rate

Of the 43 farms that were mapped within the PRR, 90% (n = 39) of the landowners engaged with BOOM project staff and of those, 92% (n = 36) completed a 'Farm' questionnaire. A total of 90 'Public' questionnaires were completed including those returned through the post after receiving them at public forums (n = 29), weblink respondents on SurveyMonkey (n = 41) and door-to-door respondents in Satterthwaite and Finsthwaite (n = 20). Of these 90 people, 87 (97%) had prior knowledge of the pine marten and only 3 people (3%) had not heard of the species before.

Enterprise type

The respondents were asked how they best categorised their enterprise. Cattle and sheep were the most common form of livestock enterprise (sheep=78%, n=28 and cattle=64%, n=23). Two farms kept poultry for commercial use (6%) and 11% (n = 4) were estates with private or commercial shoots. Poultry farms and private/commercial shoots are considered 'high risk' enterprises given the potential for pine marten depredation but included just 17% (n = 6) of the landowners that completed the 'Farm' questionnaire. Of the four commercial/private shoots, one respondent declared releasing more than 10,000 birds a year; two released under 10,000 and the final shoot releases less than 1,000. Two commercial free-range poultry units had flock sizes of 200 and 50 birds respectively and nine remaining farms kept small flocks (<20) of 'back yard hens' (Table 17 and 18). Answers given for 'other' include land used for conservation, woodland and ecotourism activities.

Table 17. Summary of respondent's enterprise type from Farm door-to-door questionnaire survey.

Enterprise type	Number of farms	%
Cattle	23	63.9
Sheep	28	77.8
Pigs	1	2.8
Poultry inside	2	5.6
Poultry free range	2	5.6
Commercial shoot	2	5.6
Private shoot	2	5.6
Other	5	13.9

Table 18. A summary of total birds released annually from commercial/private shooting properties and flock size of indoor and free-range poultry farms.

Number of game birds released per annum, per enterprise	Number of enterprises	Flock size of indoor and free-range poultry	Number of farms
<1K	1	<20 (backyard hens)	9
1-10K	2	20- 50	1
>10K	1	200+	1

Attitudes to pine marten reintroduction

Of the 36 farms that responded to the questionnaire, 44.4% (n = 16) agreed with the statement 'I would like to see the recovery of the pine marten in south Cumbria', 25% (n = 9) strongly agreed and 2.8% (n = 1) strongly disagreed. In relation to this, 38.9% (n = 8) agreed that reintroduction should be used as the method to recover the pine marten population, 22.2% (n = 8) were unsure and 8.3% (n = 3) strongly disagreed (Fig 35).

Similarly, the public were asked about their attitudes to recovering pine martens in south Cumbria (Fig 36) and whether they thought reintroduction methods would be preferable to natural recolonisation. 81.1% (n = 73) of respondents either agreed or strongly agreed with the statement 'I would like to see the recovery of the pine marten in south Cumbria'. Only 2.2% (n = 2) strongly disagreed with this statement. Reintroduction was the favoured method of pine marten recovery with 74.5% (n = 67) of respondents either agreeing or strongly agreeing with this statement. There was more uncertainty regarding recolonisation with 27.8% (n = 25) of respondents describing uncertainty and 35.6% (n = 32) disagreeing.

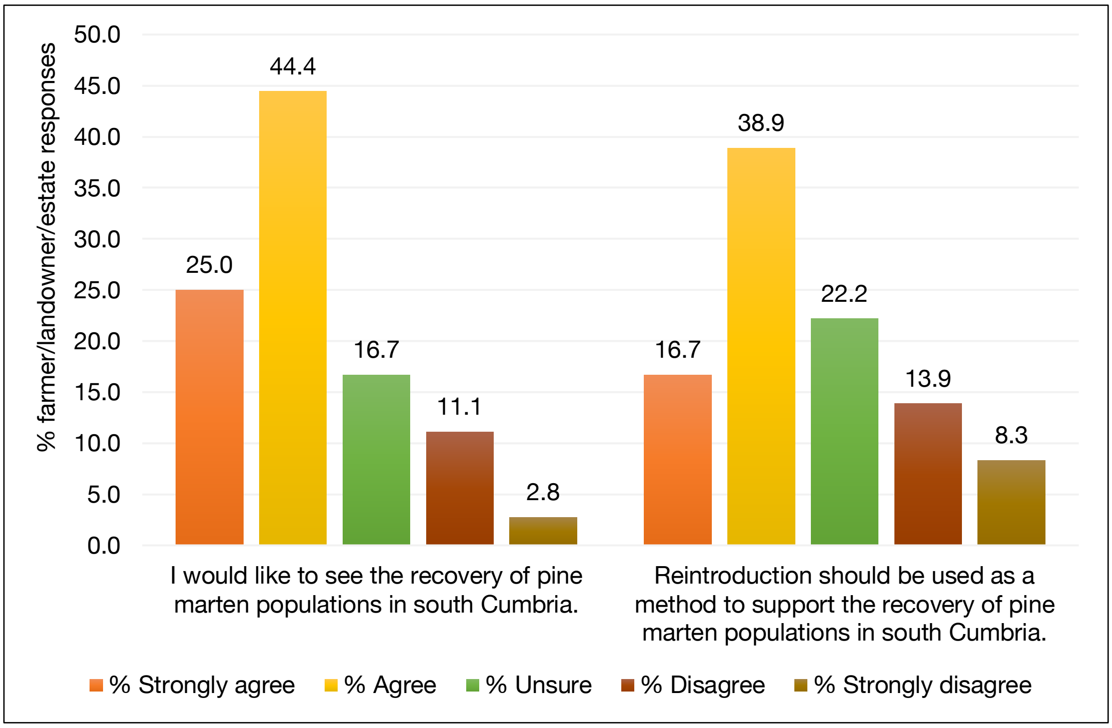

Figure 35. Responses from farmers and landowners to the statements, 'I would like to see the recovery of pine marten populations in south Cumbria' and 'Reintroduction should be used as a method to support the recovery of pine marten populations in south Cumbria.'

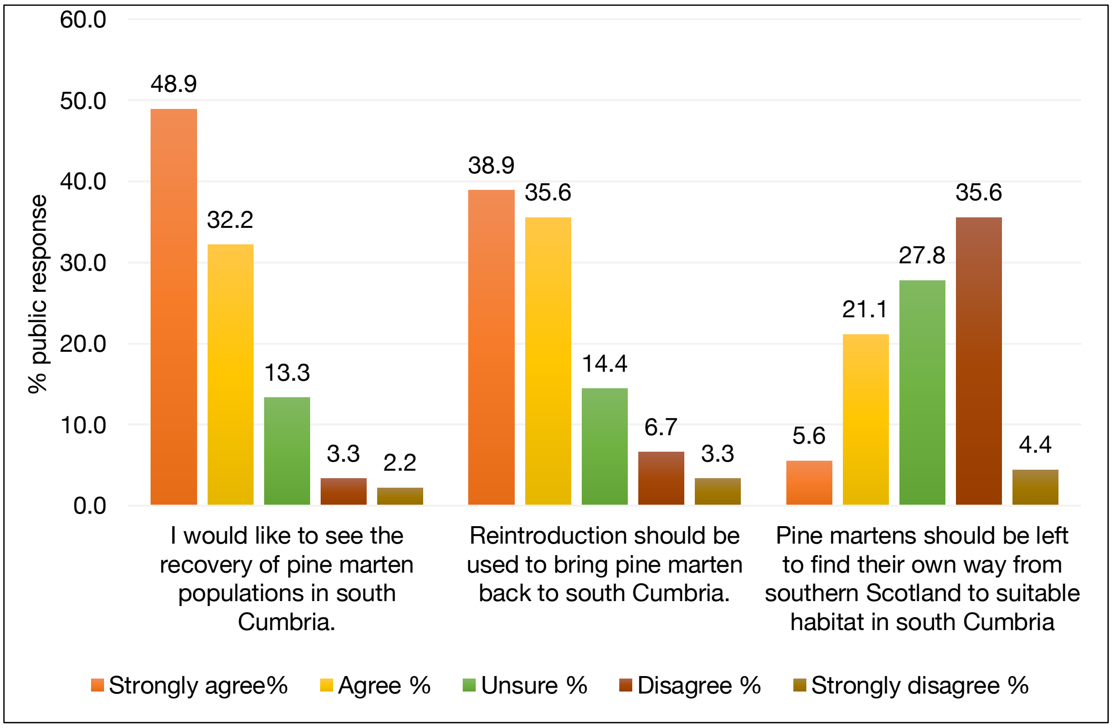

Figure 36. Responses from the public to the following statements, 'I would like to see the recovery of the pine marten populations in south Cumbria', 'Reintroduction should be used to bring pine marten back to south Cumbria' and 'Pine martens should be left to find their own way from southern Scotland to suitable habitat in south Cumbria'.

Respondents were then asked to elaborate why they were in favour or against a pine marten recovery in south Cumbria. Table 19 shows a summary of themes that were drawn from the responses and the percentage of people, from both the ‘Farm’ and ‘Public’ questionnaires, who responded in this way. The most common response from both groups in support of the recovery of pine martens was the perception that it would enhance the control of the grey squirrels (Farmers: 13.9%, n = 5; Public: 25.6% n = 23). Farm respondents also believed that pine martens would restore some balance to the ecosystem (8.3%, n = 3) and were in support of recovering the species because they generally liked to see wildlife (11.1%, n = 4). The public also focused on ecosystem balance (21.1%, n=19) but in addition they stated that the pine marten was a native species and therefore belonged in the landscape (18.9%, n = 17).

The most abundant reason for opposing the recovery of the pine marten was the impact on local wildlife (Farmers: 11.1%, n = 4; Public, 4.4%, n = 4) including the impact on young birds (Farmers: 5.6%, n = 2; Public: 6.7%, n = 6), red squirrels (Farmers: 2.8%, n = 1; Public: 2.2%, n = 2), bats (Farmers: 0%, n = 0; Public: 1.1%, n = 1) and other small mammals (Farmers: 0%, n = 0; Public: 2.2%, n = 2).

Table 19. Reasons for and against pine marten population recovery in south Cumbria (Farmer n = 36, Public n = 90).

Reason for opposition	Farm (%)	Public (%)
Impact on wildlife	11.1	4.4
Upset balance of nature	5.6	1.1
Unsuitable area	5.6	2.2
Impacts on young birds	5.6	6.7
Livestock impacts	2.8	0.0
Threaten red squirrels	2.8	2.2
Impact on bats	0.0	1.1
Foresee problems with shooting estates	0.0	1.1
Impact on other small mammals	0.0	2.2
Need more info	0.0	2.2
Traffic	0.0	1.1
Extra predator	0.0	2.2
Competition with owls	0.0	1.1
Not responded	25.0	5.6
Ambivalent	11.1	0.0

Reason for support	Farm (%)	Public (%)
Like to see wildlife	11.1	4.4
Grey squirrel control	13.9	25.6
Balance of ecosystem	8.3	21.1
Human responsibility	2.8	12.2
Native species	2.8	18.9
Pest control	2.8	1.1
There is good habitat	0	2.2

Perceived impacts and benefits on business or livelihood

Few farmers expected the pine marten recovery to have a negative impact on their business or enterprise with 5.6% (n = 2) agreeing or strongly agreeing and 86.1% (n = 31) either disagreeing or strongly disagreeing. In terms of the potential economic benefits from pine martens, respondents to the 'Farm' questionnaire agreed that the species could generate additional income for farmers and landowners as an ecotourism attraction, although this question did provoke a higher degree of uncertainty 16.7% (n = 6) with 44.5% (n = 16) agreeing or strongly agreeing and 38.9% (n = 14) disagreeing or strongly disagreeing (Fig 37.). Twelve (33.3%) respondents to the 'Farm' questionnaire stated that they had diversified into ecotourism.

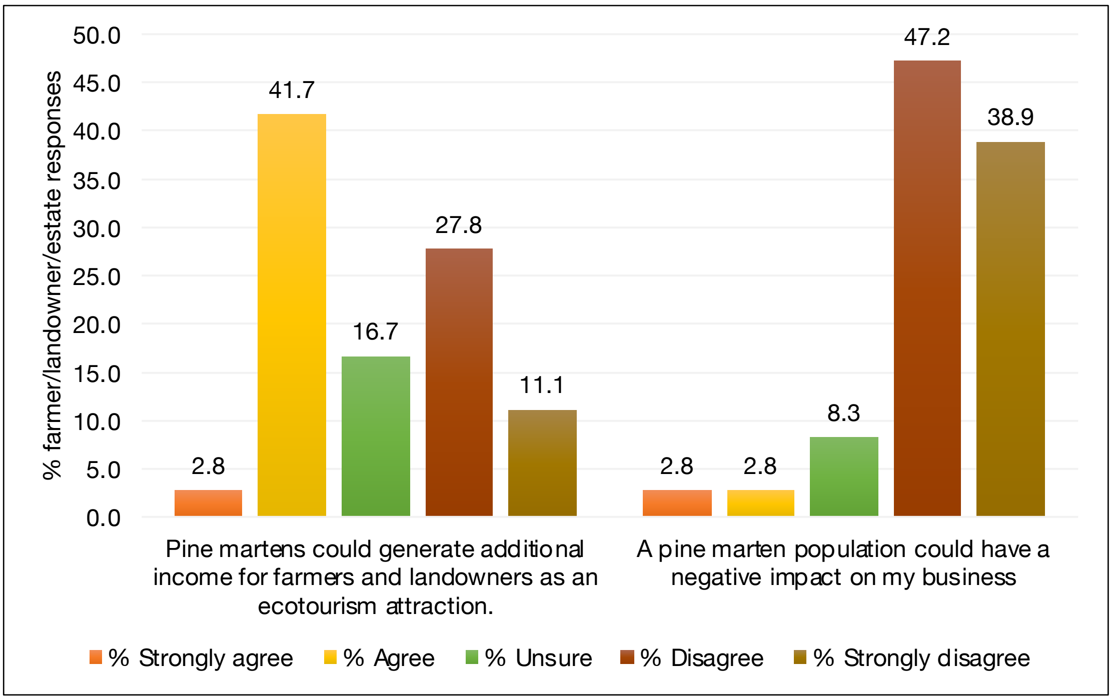

Figure 37. Responses from farmers and landowners to the statements, 'A pine marten could have a negative impact on my business' and 'Pine martens could generate additional income for farmers and landowners as an ecotourism attraction.'

Use of legal pest control measures

Farmers, landowners and estate managers were asked about their use of legal pest control measures as a means of quantifying risk to a founder pine marten population in the PRR. Of all respondents, 47.2% (n = 17) used SGARS (Second Generation Anticoagulant Rodenticides), but 94% of these people only used them on a temporary basis to control populations of rodents and other perceived pest species (Table 20). Of the 13.9% (n = 5) of respondents who used tunnel traps, all were deployed on a temporary basis but only 40% (n = 2) used tunnel trap excluders.

Table 20. Percentage use of various pest control measures on a temporary or permanent basis by farmers and landowners.

Type of pest control	Use overall (%)	Temporary use (%)	Permanent use (%)
Tunnel traps	13.9	100.0	0.0
SGARS (Second-Generation Anticoagulant Rodenticides)	47.2	94.0	6.0
Shooting	47.2		
None	22.2		
Other (mole traps/grey squirrel traps/cats	13.9		

Control of pine martens

Seventeen respondents (47.2%) either disagreed or strongly disagreed with the statement 'Farmers and gamekeepers should be free to control pine marten', 30.6% (n = 11) either agreed or strongly agreed and 22.2% (n = 8) were unsure (Fig 38).

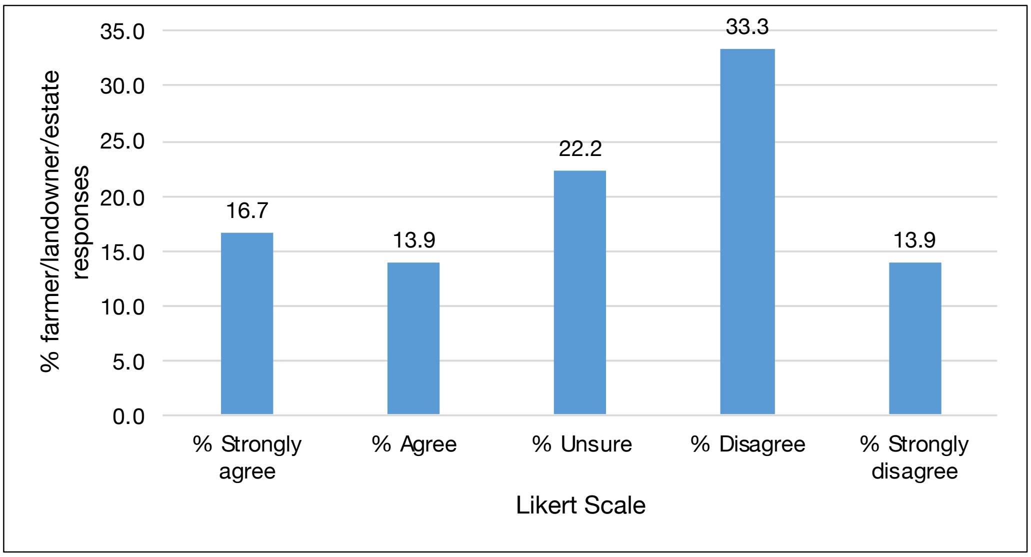

Figure 38. Response of farmers and landowners to the statement, 'Farmers and gamekeepers should be free to control pine marten.'

Focus groups, talks and meetings

Since February 2020, engagement events have been conducted with 24 local or regional organisations and enterprises using face to face and online methods (Table 21). It is important to note, however, that meetings with all key stakeholder groups from the farming and field sports community, the forestry and statutory sectors, conservation NGOs, academia, and local business are ongoing. SurveyMonkey links were shared during these public events and the results were included in 'Public questionnaire analysis.

Table 21. The names or enterprises and organisations engaged during the feasibility study, categorised by sector.

Name of Organisation/Enterprise	Sector
U3A Cockermouth	Academia
UoC Zoology BSc	Academia
Restoring Hardknott Forest Project	Academia/Statutory
Pine marten stakeholder meeting	All
Myotismart	Ecological consultancy
Brantwood Estate	Estate management
Dallam Tower Estate	Estate management
Graythwaite Estate	Estate management
Matson Ground Estate	Estate management
Penny Bridge Hall Estate	Estate management
RHT Farmers and Landowners Group	Farming/Landowning
Morecambe Bay Partnership	General Public
BBC Northwest	General Public
Cumbria Wildlife Trust	NGO
John Strutt Conservation Foundation	NGO
Rusland Horizons Trust	NGO
Vincent Wildlife Trust	NGO
Natural England	Statutory
Forestry England	Statutory
Lake District National Park	Statutory
HMP Haverigg	Statutory
Grange and District Natural History Society	Wildlife/Natural History
South Cumbria Squirrel Management Forum	Wildlife/Natural History
Westmorland Red Squirrel Group	Wildlife/Natural History

4.4 Discussion

The social feasibility study took a timely, measured approach, targeting specific groups of people. The farmers and landowners within the PRR are more likely to be directly impacted by a recovering pine marten population. As such they have a greater stake in any reintroduction project and represent a greater potential risk to the founder population than people living in areas beyond the PRR or those living in suburban/urban areas. Therefore, a consultation plan was drafted with a timeline that prioritised rural stakeholders inside the PRR prior to engagement with the general public within and beyond the PRR. The success of this approach is reflected in the very high response rate to the questionnaires (Farm=86%). Furthermore, by using door-to-door methods to administer questionnaires to farmers and landowners within the PRR, we limited the possibility of selection bias which can arise from disseminating weblinks via email to large groups of people such as members of wildlife NGOs who are sympathetic to conservation issues.

Although the targeted approach generated a good response rate, the sample size was small which could compromise the reliability of the results. The administration of the Farm questionnaire was constrained by Covid-19 restrictions, staff/volunteer capacity and the need to administer questionnaires during daylight hours when some farmers were busy on their land and unavailable. However, engagement activities with the rural community are ongoing and will help to develop the knowledge base and create a sense of ownership regarding the recovery of pine martens in south Cumbria.

Support for the recovery of the pine marten in south Cumbria is robust amongst farmers and landowners (69.4%) as well as the public (81.1%). The somewhat higher level of objection amongst farmers and landowners emphasises the importance of the targeted engagement approach, and presents opportunities for knowledge transfer, mitigation work and relationship-building with the rural communities. The support for pine marten population recovery is reflected in the results from other contemporary community-focused feasibility studies in England and Wales (Bright & Halliwell, 1999; Macpherson et al., 2014; Stringer et al., 2018).

The most common reason for support of a pine marten recovery project, across both groups, was the belief that a reintroduction would enhance the control of the invasive, non-native grey squirrel. Grey squirrels strip the bark from trees, reducing growth and causing tree death. This can lead to an estimated yield loss of 1-4 metric tons per ha in commercial forestry (Mayle et al., 2009). The desire for grey squirrel control expressed by farmers, landowners and the general public was associated with perceived benefits to the red squirrel (Gurnell et al., 2004) as a native species in urgent need of conservation action and an important part of their natural heritage. MacPherson et al. (2014) suggest that highlighting the native and historical presence of the pine marten could be a means of engaging the public and creating a sense of shared ownership and local pride in this species.

The public frequently stated that a pine marten population could ‘restore the natural balance of the ecosystem’. The awareness that small carnivores from higher trophic levels can have a positive impact on ecosystem health and wider biodiversity through their impact on invasive species (McDonald et al., 2007; Salo et al., 2008) is encouraging for this project and other carnivore reintroductions in the UK. However, concern was expressed by some respondents that a pine marten population may have a negative impact on local wildlife, especially young birds, and red squirrels. MacPherson et al. (2014) suggest that the concern for red squirrels could be a result of misinformation as evidence from areas where the red squirrel and pine marten co-exist demonstrates that the red squirrel makes up just a small proportion of the pine marten diet (Halliwell, 1997; Caryl et al., 2012; Sheehy and Lawton, 2014).

Poultry farming and gamekeeping are considered 'high risk' enterprises as pine marten are often perceived as a threat to livestock and game birds (Balharry and MacDonald, 1996). Very few respondents were involved in either enterprise (18%) and all the landowners involved in poultry farming or gamekeeping either strongly agreed or agreed to the recovery of the pine marten in the PRR. Ongoing engagement with the farming and field sports sectors is required to evaluate how their attitudes towards pine martens relate to land management practices and associated risks to native species. However, there was genuine concern for 'backyard hens', potentially because the smaller number of animals in a back yard set-up creates a stronger connection between animal and owner, more like a domesticated pet than livestock. Research suggests that as little as 1% of a pine marten's diet consists of poultry and that pine martens rarely predate poultry and gamebirds (Halliwell, 1997; Stahl et al., 2002). Various cost-effective mitigation measures can be deployed to prevent pine martens raiding chicken coops and pheasant release pens (Balharry, 1998) and therefore the risk to these enterprises from a recovering pine marten population is low.

The leading cause of pine marten extinction in Cumbria was predator control activities such as hunting with hounds, shooting and the use of poison bait (Langley and Yolen, 1977; Birks, 2020). Pine martens are now legally protected but are still threatened as a non-target species by legal pest control measures. It is common practice to use SGARs in farms to control pest populations which can either affect the pine marten directly or through secondary poisoning from the ingestion of poisoned prey (Alterio, 1996). From the Farm questionnaire, 50% of respondents admitted to using SGARs but almost all (94%) used them on a temporary basis only to control rodent outbreaks and restricted their use to within farm buildings thereby reducing the exposure and associated risk to pine martens. The use of traps has decreased over time as they are considered labour intensive and inefficient (Alterio, 1996); this was reflected in our results as just 8% of farmers admitted to using traps without excluders (which are designed to reduce non-target captures).

Ecotourism can generate substantial economic benefits for local communities by generating income through jobs, local accommodation, restaurants, and shops as well as wildlife experiences (Azimi, 2005; Stronza, 2009). One third of the farmers questioned had already diversified into ecotourism and 44.8% either agreed or strongly agreed that the pine marten could generate income in the area through ecotourism. The promotion of responsible models of ecotourism would highlight the potential economic benefits a pine marten population recovery could have in the area.

Although there are some concerns, mainly relating to the impact on native wildlife, the local community strongly support a pine marten recovery in the area, particularly if it were to contribute to the control of invasive grey squirrels. The threats associated with pest control appear to be minimal and there is strong evidence suggesting that factors relating to previous extinction have been overcome. This project has an unusually large amount of cross-sector support for a carnivore reintroduction, which should be harnessed as the basis for a longer-term engagement programme as part of a pine marten translocation initiative.

5. Conclusions

This feasibility study has provided robust evidence that the recovery of pine martens in Cumbria is likely to be successful. Our analyses showed that translocation of martens to south Cumbria is the most appropriate approach to expand the regional metapopulation, since recolonising martens from north-east Cumbria could take many decades to reach south Cumbria, and are unlikely to establish a viable population in the south without intervention.

We identified a potential recovery region in south Cumbria that contains sufficient areas of suitable habitat to support a viable population of pine martens, and which also has relatively low levels of mortality risks from roads and gaming interests. There is a good network of forested land in Cumbria to facilitate the movement of individuals from one area to another, and the restoration and creation of woodlands can further enhance the ability of pine marten populations to expand across this region and into neighbouring counties.

The assessments of the potential ecological impacts of restoring pine marten populations in Cumbria indicate that they are unlikely to pose a serious dilemma for threatened wildlife. The only high risk identified was the potential disturbance of large bat roosts, and medium risks included the predation of birds within nest boxes (both of which could be mitigated reasonably easily). The potential controlling impacts on non-native grey squirrels will likely have wide ranging positive impacts, especially for red squirrels. A translocation project should include detailed monitoring of pine marten diet and any impacts on local wildlife populations. Field data should also be collected to enable long term monitoring of potential impacts from pine marten releases on other species, including grey squirrels.

The public opinion surveys indicated widespread support for a pine marten recovery project. A pine marten publicity and awareness campaign will be initiated during and after translocations, which will include schools and other local community organisations and seek to actively engage with sections of the community who might perceive that they will be affected by an increased pine marten population.

We recommend that a translocation project should now be developed that will strengthen networks with local stakeholder groups, explore ecotourism opportunities, establish mitigation and exit strategies, and a post-release monitoring programme. A release methodology will be developed and the translocation of pine martens from Scotland will follow best practice protocols to minimise risks to donor populations, and founder animals should be sourced from areas with robust pine marten populations that have not been trapped for translocation purposes within the last five years.

6. References

Aaris-Sørensen, J. (1995) Road-kills of badgers (*Meles meles*) in Denmark. *Annales Zoologici Fennici* 32, 31-36. Finnish Zoological and Botanical Publishing Board.

Aber, B., Callas, R., Chapron, G., Clark, J., Copeland, J.P., Giddings, B., Inman, R., Ivan, J., Kahn, R., Long, C., Magoun, A., Mattison, J., Oakleaf, B., Odell, E., Persson, J., Reading, R., Sartorius, S., Schwartz, M., Shenk, T., Sirochman, M., Squires, J., Wait, S., Wild, M. & Wolfe, L. (2013) Restoration of Wolverines: Considerations for Translocation and Post-release Monitoring. 51.

Allouche, O., Tsoar, A. & Kadmon, R. (2006) Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology*, 43, 1223-1232.

Alterio, N., 1996. Secondary poisoning of stoats (Mustela erminea), feral ferrets (Mustela furo), and feral house cats (Felis catus) by the anticoagulant poison, brodifacoum. New Zealand Journal of Zoology 23, 331–338

Amar, A., Hewson, C., Thewlis, R., Smith, K., Fuller, R., Lindsell, J., Conway, G., Butler, S. and Macdonald, M. (2006) 'What's Happening to Our Woodland Birds?'

Ambrose-Oji, B., Dunn, M. & Atkinson, M. (2018) *Pine martens in the Forest of Dean: Stakeholder and public attitudes*. Forest Research report to Pine Marten Reintroduction Feasibility Project, Gloucestershire Wildlife Trust, Coleford.

Ancillotto, L., Serangeli, M.T. and Russo, D. (2013) 'Curiosity killed the bat: Domestic cats as bat predators', *Mammalian Biology*, 78(5), 369–373.

Andersson, M. & Erlinge, S. (1977) Influence of Predation on Rodent Populations. *Oikos* 29, 591–597.

Angelstam, P. (1986) 'Predation on Ground-Nesting Birds 'Nests in Relation to Predator Densities and Habitat Edge', *Oikos*, 47(3), 365–373.

Armstrong, D.P., Davidson, R.S., Dimond, W.J., Perrott, J.K., Castro, I., Ewen, J.G., Griffiths, R. & Taylor, J. (2002) Population dynamics of reintroduced forest birds on New Zealand islands. *Journal of Biogeography*, 29, 609-621.

Baines, D. (1996) The implications of grazing and predator management on the habitats and breeding success of black grouse *Tetrao tetrix*. *Journal of Applied Ecology*, 33, 54-62.

Balestrieri, A. et al. (2014) Distribution and habitat use by pine marten *Martes martes* in a riparian corridor crossing intensively cultivated lowlands. *Ecol. Res.* 30, 153–162.

Balestrieri, A., Remonti, L., Ruiz-González, A., Gómez-Moliner, B.J., Vergara, M. & Prigioni, C. (2010) Range expansion of the pine marten (*Martes martes*) in an agricultural landscape matrix (NW Italy). *Mammalian Biology-Zeitschrift für Säugetierkunde*, 75, 412-419.

Balestrieri, A., Remonti, L., Ruiz-González, A., Vergara, M., Capelli, E., Gómez-Moliner, B.J. and Prigioni, C. (2011) 'Food habits of genetically identified pine marten (Martes martes) expanding in agricultural lowlands (NW Italy)', *Acta Theriologica*, 56(3), 199–207.

Balharry, D. (1993) Factors affecting the distribution and population density of pine martens (*Martes martes L.*) in Scotland. PhD, University of Aberdeen.

Balharry, E. (1998) How to exclude pine martens from game and poultry pens. The Vincent Wildlife Trust, 1–8.

Balharry, E. A. & Macdonald, D. W. (1996) A cost effective method for protecting livestock against marten predation. *Scottish Nat. Herit. Res. Surv. Monit. Report. No 47*.

Balharry, E.A., McGowan, G.M., Kruuk, H. & Halliwell, E. (1996) *Distribution of pine martens in Scotland as determined by field survey and questionnaire.* Scottish Natural Heritage Survey & Monitoring Report No. 48, Edinburgh, UK.

Balmer, D., Gillings, S., Caffrey, B., Swann, B., Downie, I. & Fuller, R. (2014) *Bird Atlas 2007-11: the breeding and wintering birds of Britain and Ireland*. BTO Books, Thetford.

Baltrunaite, L. (2010) Winter habitat use, niche breadth and overlap between the red fox, pine marten and raccoon dog in different landscapes of Lithuania. *Folia Zool.* 59, 278–284.

Barthelmess, E. L. (2014) Spatial distribution of road-kills and factors influencing road mortality for mammals in Northern New York State. *Biodivers. Conserv.* 23, 2491–2514.

Bat Conservation Trust (2022) UK Bats. Available at: https://www.bats.org.uk/about-bats/what-are-bats/uk-bats (Accessed: 02 May 2022).

Baum, J.K. & Myers, R.A. (2004) Shifting baselines and the decline of pelagic sharks in the Gulf of Mexico. *Ecology Letters*, 7, 135-145.

Bellamy, P.E., Rothery, P., Hinsley, S.A. & Newton, I. (2000) Variation in the relationship between numbers of breeding pairs and woodland area for passerines in fragmented habitat. *Ecography*, 23, 130-138.

Birks, J.D. (2020) *Pine martens*. Whittet Books Ltd, Essex, UK. Reprint (with updates).

Birks, J.D., Messenger, J.E. & Halliwell, E.C. (2005) Diversity of den sites used by pine martens *Martes martes*: a response to the scarcity of arboreal cavities? *Mammal Review*, 35, 313-320.

Birks, J.D.S. & Messenger, J. (2010) Evidence of Pine Martens in England and Wales 1996-2007. The Vincent Wildlife Trust, Ledbury.

Bogdziewicz, M. & Zwolak, R. (2014) Responses of small mammals to clear-cutting in temperate and boreal forests of Europe: a meta-analysis and review. *European Journal of Forest Research*, 133, 1-11.

Bolton, M., Tyler, G., Smith, K. & Bamford, R. (2007) The impact of predator control on lapwing *Vanellus vanellus* breeding success on wet grassland nature reserves. *Journal of Applied Ecology*, 44, 534-544.

Boyce, M.S. (2018) 'Wolves for Yellowstone: dynamics in time and space', *Journal of Mammalogy*, 99(5), 1021–1031.

Brainerd, S.M. (1990) The pine marten and forest fragmentation: a review and general hypothesis. *Transactions of the Nineteenth International Conference of Game Biologists,* 421-434.

Brainerd, S.M. & Rolstad, J. (2002) Habitat selection by Eurasian pine martens *Martes martes* in managed forests of southern boreal Scandinavia. *Wildlife biology*, 8, 289-297.

Brainerd, S.M., Helldin, J.O., Lindstroem, E.R., Rolstad, E., Rolstad, J. & Storch, I. (1995) Pine marten (*Martes martes*) selection of resting and denning sites in Scandinavian managed forests. *Annales Zoologia Fennici,* 20, 182-182.

Brainerd, S.M., Helldin, J.O., Lindstrom, E., Rolstad, J., Buskirk, S.W., Harestad, A.S., Raphael, M.G. & Powell, R.A. (1994) Eurasian pine martens and old industrial forest in southern boreal Scandinavia. M*artens, sables, and fishers. Biology and conservation*. *Cornell University Press, Ithaca, New York* (eds S.W. Buskirk, A. Harestad, M.G. Raphael & R.A. Powell), pp. 343-354. Cornell University Press, New York, USA.

Bright, P.W. & Halliwell, E. (1999) Species Recovery Programme for the Pine Marten in England: 1996-1998. *English Nature Research Report No. 306*. English Nature, Peterborough.

Bright, P.W. & Harris, S. (1994) Reintroduction of the pine marten: feasibility study. *English Nature Research Reports*. English Nature.

Bright, P.W. & Smithson, T.J. (1997) Species Recovery Programme for the Pine Marten in England: 1995-96. *English Nature Research Report No. 240*. English Nature, Peterborough.

Bright, P.W. & Smithson, T.J. (2001) Biological invasions provide a framework for reintroductions: selecting areas in England for pine marten releases. *Biodiversity & Conservation*, 10, 1247-1265.

Broekhuizen, S. & Muskens, G. J. D. M. (2000) Sex-dependent dispersion in pine martens Martes martes in the central- and northern parts of The Netherlands. *Lutra* 43, 109–117.

Broome, A. C. & Johnson, A. (2000) An evaluation of the costs of grey squirrel bark-stripping damage in British Woodlands. *For. Comm. Tech. Pap*.

Brown, L. J. (20210) Investigation into the causes of black- throated diver *Gavia arctica* breeding failure on Loch Maree, 2006–2009. *Scottish Nat. Herit. Comm. Rep. No.379*.

Brzeziński, M., Rodak, Ł. & Zalewski, A. (2014) "Reversed" intraguild predation: red fox cubs killed by pine marten. *Acta Theriologica*, 1-5

Campbell, M.O.N. & Alvarado, M.E. (2011) Public perceptions of jaguars *Panthera onca*, pumas *Puma concolor* and coyotes *Canis latrans* in El Salvador. *Area*, 43, 250-256.

Caryl, F.M. (2008) Pine marten diet and habitat use within a managed coniferous forest. PhD, University of Stirling.

Caryl, F.M., Quine, C.P. & Park, K.J. (2012) Martens in the matrix: the importance of nonforested habitats for forest carnivores in fragmented landscapes. *Journal of Mammalogy*, 93, 464-474.

Caryl, F.M., Raynor, R., Quine, C.P. & Park, K.J. (2012) The seasonal diet of British pine marten determined from genetically identified scats. *Journal of Zoology*, 288, 252-259.

Caryl, F.M., Raynor, R., Quine, C.P. & Park, K.J. (2012) The seasonal diet of British pine marten determined from genetically identified scats. *Journal of Zoology*, 288, 252-259.

CBDC (2020) The Status of the Pine Marten (*Martes martes*) in Cumbria. Report by the Cumbria Biodiversity Data Centre.

Červinka, J., Riegert, J., Grill, S. & Šálek, M. (2015) Large-scale evaluation of carnivore road mortality: the effect of landscape and local scale characteristics. *Mammal Research*, 60, 233-243

Chamberlain, D.E., Glue, D.E. & Toms, M.P. (2009) Sparrowhawk *Accipiter nisus* presence and winter bird abundance. *Journal of Ornithology*, 150, 247-254.

Charles, W.N. (1981) Abundance of field voles (*Microtus agrestis*) in conifer plantations. *Forest and woodland ecology: an account of research being done in ITE* (eds F.T. Last & A.S. Gardiner), 135-137. NERC/Institute of Terrestrial Ecology, Cambridge.

Clevenger, A.P., Chruszcz, B. & Gunson, K. (2002) Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology,* 38, 1340–1349.

Cook, C., Morgan, D. & Marshall, D. (2010) Reevaluating suitable habitat for reintroductions: lessons learnt from the eastern barred bandicoot recovery programme. *Animal Conservation*, 13, 184-195.

Coope, R. (2007) A preliminary investigation of the food and feeding behaviour of pine martens in productive forestry from an analysis of the contents of their scats collected in Inchnacardoch forest, Fort Augustus. *Scottish Forestry*, 61, 3.

Côté, I.M. & Sutherland, W.J. (1995) The scientific basis for predator control for bird conservation. *English Nature Research Reports No.144*. English Nature, Peterborough.

Côté, I.M. & Sutherland, W.J. (1997) The effectiveness of removing predators to protect bird populations. *Conservation Biology*, 11, 395-405.

Croose, E. (2021) Back from the Brink: SP10 Final Report – Pine Marten (Northern England) Species Recovery Project.

Croose, E., Birks, J.D.S. & Schofield, H.W. (2013) Expansion Zone Survey of Pine Marten (*Martes martes*) Distribution in Scotland. Scottish Natural Heritage Commissioned Report No. 520.

Croose, E., Birks, J.D.S. and Martin, J. (2016) 'Den boxes as a tool for pine marten Martes martes conservation and population monitoring in a commercial forest in Scotland', p. 5.

Croose, E., Birks, J.D.S., Schofield, H.W. & O'Reilly, C. (2014) Distribution of the pine marten (*Martes martes*) in southern Scotland in 2013. Scottish Natural Heritage Commissioned Report No. 740.

Cumbria Biodiversity Data Centre (2017) Cumbria Mammal Atlas. Available at: http://www.cbdc.org.uk/uploads/Mammal_Atlas/Download/Atlas_Maps.pdf (Accessed: 02 May 2022).

Czeszczewik, D. (2004) Breeding success and timing of the Pied Flycatcher *Ficedula hypoleuca* nesting in natural holes and nest-boxes in the Białowieża Forest, Poland. *Acta Ornithol.* 39, 15–20.

de Groot, G. A., Hofmeester, T.R., La Haye, M., Jansman, H.A.H, Perez, M. & Koelewijn, H.P. (2016) Hidden dispersal in an urban world: genetic analysis reveals occasional long-distance dispersal and limited spatial substructure among Dutch pine martens. *Conserv. Genet.* 17, 111–123 (2016).

De Marinis, A. & Massetti, M. (1993) Distribution of the pine marten *Martes martes L.*, 1758 (Mammalia, Carnivora) on the island of Elba, northern Tyrrhenian sea. *Atti del VII Convegno dell'Associazione A. Ghigi per la Biologia e la Conservazione dei Vertebrati. Suppl. Ric. Biol. Selvaggina*, 21, 263-267.

De Marinis, A. M. & Masseti, M. (1995) Feeding habits of the pine marten *Martes martes* L., 1758, in Europe: a review. *1995* 7, 143–150.

DEFRA (2018) *A Green Future: Our 25 Year Plan to Improve the Environment.* London: DEFRA.

DEFRA (2021) England Trees Action Plan 2021 to 2024. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/987432/england-trees-action-plan.pdf (Accessed: 10 May 2022).

DEFRA (2021) Reintroductions and other conservation translocations: code and guidance for England.

Eaton, M., Aebischer, N., Brown, A., Hearn R., Lock, L., Musgrove, A., Noble, D., Stroud, D. & Gregory, R. (2015) Birds of Conservation Concern 4: the population status of birds in the UK, Channel Islands and Isle of Man. *British Birds*, 108, 708-746.

Elith, J., Graham, C.H., Anderson, R.P., Dudík, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.M., Peterson, A.T., Phillips, S.J., Richardson, K.S., Scachetti-Pereira, R., Schapire, R.E., Soberon, J., Williams, S., Wisz, M.S., & Zimmerman, N.E. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 29, 129-151.

England Trees Action Plan 2012-2024 (2021):

Errington P. L. (1946) Predation and vertebrate populations. *Q Rev. Biol*. 21, 144–77.

Evans, K.L. (2004) The potential for interactions between predation and habitat change to cause population declines of farmland birds. *Ibis,* 146, 1-13.

Ferris, R. & Carter, C. (2000). Managing Rides, Roadsides and Edge Habitats in Lowland Forests. Forestry Commission Bulletin 123.

Fletcher, K., Aebischer, N.J., Baines, D., Foster, R. & Hoodless, A.N. (2010) Changes in breeding success and abundance of ground-nesting moorland birds in relation to the experimental deployment of legal predator control. *Journal of Applied Ecology*, 47, 263-272.

Fletcher, K., Hoodless, A.N. & Baines, D. (2013) Impacts of predator abundance on red grouse *Lagopus lagopus scotica* during a period of experimental predator control. *Wildlife Biology* 19, 248-256.

Flowerdew, J.R., Shore, R.F., Poulton, S.M.C. and Sparks, T.H. (2004) 'Live trapping to monitor small mammals in Britain', *Mammal Review*, 34(1–2), 31–50.

Forestry Commission England & DEFRA. (2006) Towards a Forestry Commission England Grey Squirrel Policy. *Annex* 1–8.

Gill, R.M.A. and Fuller, R.J. (2007) 'The effects of deer browsing on woodland structure and songbirds in lowland Britain', *Ibis*, 149(s2), 119–127.

Gilpin, M.E. & Soulé, M.E. (1986) Minimum viable populations: processes of species extinction. *Conservation Biology: the science of scarcity & diversity* (eds M.E. Soulé & M.A. Sunderland), pp. 19-34. Sinauer Associates.

Gloucestershire Wildlife Trust (2022) Project pine marten. Available at: https://www.gloucestershirewildlifetrust.co.uk/project-pine-marten (Accessed: 15 May 2022).

Goszczyński, J. (1976) Composition of the food of martens. *Acta Theriologica*, *21*(36), 527-534.

Goszczyński, J. (1986) Diet of foxes and martens in central Poland. *Acta Theriologica*, 31, 491-506.

Gregory, R.D., Vorisek, P., Van Strien, A., Gmelig Meyling, A.W., Jiguet, F., Grilo, C., Ascensao, F., Santos-Reis, M. & Bissonette, J.A. (2011) Do well-connected landscapes promote road related mortality? *Eur. J. Wildl. Res.* 57, 707–716.

Grilo, C., Bissonette, J.A. & Santos-Reis, M. (2008) Response of carnivores to existing highway culverts and underpasses: implications for road planning and mitigation. *Biodiversity and Conservation*, 17, 1685-1699.

Gurnell, J., Venning, T., MacCaskill, B. & MacCaskill, D. (1994) The food of pine martens (*Martes martes*) in West Scotland. *Journal of Zoology*, 234, 680-683.

Halliwell, E.C. (1997) The ecology of red squirrels in Scotland in relation to pine marten predation. PhD, University of Aberdeen.

Hanley, N. & Spash, C.L. (1993) Cost-benefit analysis and the environment. Edward Elgar Cheltenham.

Hanski, I. (1998) Metapopulation dynamics. *Nature* 396, 41–49.

Harrington, L.A., Moehrenschlager, A., Gelling, M., Atkinson, R.P., Hughes, J. & Macdonald, D.W. (2013) Conflicting and complementary ethics of animal welfare considerations in reintroductions. *Conservation Biology*, 27, 486-500.

Helldin, J. O. (2000) Seasonal diet of pine marten *Martes martes* in southern boreal Sweden. *Acta Theriol. (Warsz).* 45, 409–420.

Hernandez, P.A., Graham, C.H., Master, L.L. & Albert, D.L. (2006) The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography*, 29, 773-785.

Hetherington, D. (2006) The lynx in Britain's past, present and future. *Ecos*, 27, 66.

Holt, A.R., Davies, Z.G., Tyler, C. & Staddon, S. (2008) Meta-analysis of the effects of predation on animal prey abundance: evidence from UK vertebrates. *PloS one*, 3, e2400.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/987432/england-trees-action-plan.pdf.

https://whoownsengland.org/2016/10/28/who-owns-englands-grouse-moors/

https://www.lakedistrict.gov.uk/__data/assets/pdf_file/0013/406210/Partnerships-Management-Plan-2020-2025-vFINAL.pdf

Hughes, S.S. (2012) Synthesis of *Martes* Evolutionary History. Biology and Conservation of Martens, Sables, and Fishers: A New Synthesis.

IUCN (2013) Guidelines for Reintroductions and Other Conservation Translocations. IUCN Species Survival Commission, Gland, Switzerland.

Jędrzejewski, W., Jędrzejewska, B. and Szymura, A. (1989) 'Food niche overlaps in a winter community of predators in the Białowieża Primeval Forest, Poland', *Acta Theriologica*, 34, 487–496.

Jedrzejewski, W., Zalewski, A. & Jedrzejewska, B. (1993) Foraging by pine marten *Martes martes* in relation to food resources in Białowieża National Park, Poland. *Acta Theriol. (Warsz).* 38, 405–426.

Jennings, A.P. & Veron, G. (2011) Predicted distributions and ecological niches of 8 civet and mongoose species in Southeast Asia*. Journal of Mammalogy* 92(2): 316-327.

Jennings, A.P. & Veron, G. (2015) Predicted distributions, niche comparisons, and conservation status of the spotted linsang (*Prionodon pardicolor*) and banded linsang (*Prionodon linsang*). *Mammal Research* 60: 107-116.

Jennings, A.P. & Veron, G. (2019) *Mongooses of the World*. Whittles Publishing, Scotland.

Jennings, A.P., Mathai, J., Brodie, J., Giordano, A.J. & Veron, G. (2013) Predicted distributions and conservation status of two threatened Southeast Asian small carnivores: the banded civet and Hose's civet. *Mammalia* 77: 261-271.

Jordan, N.R. (2011) A strategy for restoring the pine marten to England and Wales. The Vincent Wildlife Trust, Ledbury.

Jordan, N.R., Messenger, J., Turner, P., Croose, E., Birks, J. & O'Reilly, C. (2012) Molecular comparison of historical and contemporary pine marten (*Martes martes*) populations in the British Isles: evidence of differing origins and fates, and implications for conservation management. *Conservation Genetics*, 13, 1195-1212.

Juškaitis, R. (2007) Feeding by the common dormouse (Muscardinus avellanarius): a review. *Acta Zoologica Lituanica*, *17*(2), 151-159.

Kauffman, M.J., Varley, N., Smith, D.W., Stahler, D.R., MacNulty, D.R. & Boyce, M.S. (2007) Landscape heterogeneity shapes predation in a newly restored predator–prey system. *Ecology Letters,* 10, 690-700.

Kleef, H.L. and Tydeman, P. (2009) 'Natal den activity patterns of female pine martens (Martes martes) in the Netherlands', p. 12.

Kurki, S. and Lindén, H. (1995) Forest fragmentation due to agriculture affects the reproductive success of the ground-nesting black grouse Tetrao tetrix. *Ecography*, *18*(2), 109-113.

Kurki, S., Nikula, A., Helle, P. & Linden, H. (1998) Abundances of red fox and pine marten in relation to the composition of boreal forest landscapes. *Journal of Animal Ecology*, 67, 874-886.

Lacy, R.C. & Pollak, J.P. (2018) Vortex: A Stochastic Simulation of the Extinction Process. Version 10.3.1. Chicago Zoological Society, Brookfield, Illinois, USA.

Lake District National Park (2022) Lake District National Park Partnership's Management Plan 2020-2025. Available at: https://www.lakedistrict.gov.uk/__data/assets/pdf_file/0013/406210/Partnerships-Management-Plan-2020-2025-vFINAL.pdf (Accessed: 14 May 2022).

Lambin, X., Elston, D.A., Petty, S.J. & MacKinnon, J.L. (1998) Spatial asynchrony and periodic travelling waves in cyclic populations of field voles. Proceedings of the Royal Society of London. Series B: *Biological Sciences*, 265, 1491-1496.

Lambin, X., Petty, S.J. & Mackinnon, J.L. (2000) Cyclic dynamics in field vole populations and generalist predation. *Journal of Animal Ecology*, 69, 106-119.

Langley, P.J.W. & Yalden, D.W. (1977) The decline of the rarer carnivores in Great Britain during the nineteenth century. *Mammal Review*, 7, 95-116.

Lanszki, J., Zalewski, A. & Horvath, G. (2007) Comparison of red fox *Vulpes vulpes* and pine marten *Martes martes* food habits in a deciduous forest in Hungary. *Wildlife Biol.* 13, 258–271.

Lariviere, S. & Jennings, A.P. (2009). European Pine Marten *(Martes martes).* Family Mustelidae (Weasels and Relatives). In: D.E. Wilson & R. A. Mittermeier (Eds), *Handbook of the Mammals of the World. Volume 1: Carnivores*. Lynx Edicions, Barcelona, Spain.

Larroque, J., Ruette, S., Vandel, J. M. & Devillard, S. (2015) 'False heat,' big testes, and the onset of natal dispersal in European pine martens (Martes martes). *Eur. J. Wildl. Res.* 61, 333–337.

LDNPP Management Plan 2020-2025:

Lescureux, N., Linnell, J.D.C., Mustafa, S., Melovski, D., Stojanov, A., Ivanov, G., Avukatov, V., von Arx, M. & Breitenmoser, U. (2011) Fear of the unknown: local knowledge and perceptions of the Eurasian lynx *Lynx lynx* in western Macedonia. *Oryx*, 45, 600-607.

Lesiński, G., Gryz, J. and Kowalski, M. (2009) 'Bat predation by tawny owls *Strix aluco* in differently human-transformed habitats', *Italian Journal of Zoology*, 76(4), 415–421.

Lewis, J.C., Powell, R.A. & Zielinski, W.J. (2012) Carnivore translocations and conservation: insights from population models and field data for fishers (*Martes pennanti*). *PloS one*, 7, e32726.

Lima, S.L. & Dill, L.M. (1990) Behavioral decisions made under the risk of predation: a review and prospectus. *Canadian Journal of Zoology*, 68, 619-640.

Lindström, E.R., Brainerd, S.M., Helldin, J. & Overskaug, K. (1995) Pine marten-red fox interactions: a case of intraguild predation? *Annales Zoologici Fennici,* pp. 123-130. Helsinki: Suomen Biologian Seura Vanamo, 1964-.

Linnell, J.D.C., Rondeau, D., Reed, D.H., Williams, R., Altwegg, R., Raxworthy, C.J., Austin, J.D., Hanley, N., Fritz, H. & Evans, D.M. (2010) Confronting the costs and conflicts associated with biodiversity. *Animal Conservation*, 13, 429-431.

Lockie, J. (1961) The food of the pine marten, *Martes martes*, in West Ross-shire, Scotland. *Proceedings of the Zoological Society of London*, 187-195. Wiley Online Library.

Lockie, J.D. (1964) Distribution and fluctuations of the pine marten, *Martes martes* (L.), in Scotland. *The Journal of Animal Ecology,* 349-356.

Lynch, Á.B. & McCann, Y. (2007) The diet of the pine marten (*Martes martes*) in Killarney National Park. *Biology & Environment: Proceedings of the Royal Irish Academy*, 67-76. The Royal Irish Academy.

Macpherson, H.A. (1892) *A vertebrate fauna of Lakeland: including Cumberland and Westmorland with Lancashire north of the sands*. D. Douglas.

MacPherson, J. & Wright, P. (2021) *Long-term strategic recovery plan for pine martens in Britain*. The Vincent Wildlife Trust, Natural England, NatureScot. 1-72.

MacPherson, J., Croose, E., Bavin, D., O'Mahony, D., Somper, J.P. & Buttriss, N. (2014) *Feasibility Assessment for Reinforcing Pine Marten Numbers in England and Wales.* The Vincent Wildlife Trust, Herefordshire. 1–68.

Magdalena Wolf, C., Garland Jr, T. & Griffith, B. (1998) Predictors of avian and mammalian translocation success: reanalysis with phylogenetically independent contrasts. *Biological conservation*, 86, 243-255.

Manzo, E., Bartolommei, P., Rowcliffe, J.M. & Cozzolino, R. (2012) Estimation of population density of European pine marten in central Italy using camera trapping. *Acta Theriologica*, 57, 165-172.

Marchesi, P. (1989) Ecologie et comportement de la martre (Martes martes L.) dans le Jura Suisse. Dissertation, University Neuchatel, Institute de Zoologie: 1-185.

Marcstrom, V., Kenward, R.E. & Engren, E. (1988) The impact of predation on boreal tetraonids during vole cycles: an experimental study. *The Journal of Animal Ecology*, 859-872.

Maroo, S. & Yalden, D. (2000) The mesolithic mammal fauna of Great Britain. *Mammal Review*, 30, 243-248.

Marsh, A.C.W. and Harris, S. (2000) 'Partitioning of woodland habitat resources by two sympatric species of Apodemus: lessons for the conservation of the yellow-necked mouse (A. ¯avicollis) in Britain', *Biological Conservation*, p. 9.

Mathews, F., Kubasuewicz, L.M., Gurnell, J., Harrower, C.A., McDonald, R.A. & Shore, R.F. (2018) A Review of the Population and Conservation Status of British Mammals: Technical Summary. A report by the Mammal Society under contract to Natural England, Natural Resources Wales and Scottish Natural Heritage. Natural England, Peterborough.

Mayle, B. A., Proudfoot, J. & Poole, J. (2009) Influence of tree size and dominance on incidence of bark stripping by grey squirrels to oak and impact on tree growth. *Forestry* 82, 431–444.

Medlock, J. M. & Leach, S. (2015) A. Effect of climate change on vector-borne disease risk in the UK. Lancet Infect. Dis. 3099, (2015).

Messenger, J., Croose, L., Turner, P. & O'Reilly, C. (2010) The Vincent Wildlife Trust and Waterford Institute of Technology Pine Marten Scat DNA Survey of England and Wales 2008-2009. The Vincent Wildlife Trust, Ledbury, Herefordshire.

Mikula, P., Hromada, M. and Tryjanowski, P. (2013) 'Bats and Swifts as food of the European Kestrel (Falco tinnunculus) in a small town in Slovakia', *Ornis Fennica*, pp. 178–185.

Moll, R.J., Kilshaw, K., Montgomery, R.A, Abade, L., Campbell, R. D, Harrington, L.A., Millspaugh, J.J., Birks, J.D.S. & Macdonald, D.W. (2016) Clarifying habitat niche width using broad-scale, hierarchical occupancy models: a case study with a recovering mesocarnivore. *J. Zool.* doi:10.1111/jzo.12369.

National Gamekeepers' Organisation, Scottish Gamekeepers' Association & Game and Wildlife Conservation Trust. (2011) *Gamekeepers and Wildlife*.

Natural England (2015) Green Bridges. Natural England Commission Report NECR181.

N, Azimi., 2005. The Economics Of Tourism - Maximising The Benefits Of Ecotourism For The Locality 3, 43–51.

Newson, S., Leech, D., Hewson, C., Crick, H. and Grice, P. (2010) 'Potential impact of grey squirrels Sciurus carolinensis on woodland bird populations in England', *Journal of Ornithology*, 151, 211–218.

Newton, I. (1993) Predation and limitation of bird numbers. *Current Ornithology*, 11, 143-198.

Newton, I. (1998) *Population limitation in birds*. Academic press, London.

NSRF (2014) The Scottish Code for Conservation Translocations. Scottish Natural Heritage.

O'Rourke, E. (2014) The reintroduction of the white-tailed sea eagle to Ireland: People and wildlife. *Land Use Policy*, 38, 129-137.

Obuch, J. (2012) Assemblages of bats in deposits of the Dobšinska Ice Cave, Slovensky raj National Park, Slovakia. *Vespertilio* 16, 205–210.

Olsen, L.H. (2013) *Tracks and Signs of the Animals and Birds of Britain and Europe*. Princeton University Press.

Packer, J. J. & Birks, J. D. S. (1999) An assessment of British farmers' and gamekeepers' experiences, attitudes and practices in relation to the European Polecat *Mustela putorius*. *Mamm. Rev.* 29, 75–92.

Paine, R. T. (1966) Food Web Complexity and Species Diversity. *Am. Nat.* 100, 65–75).

Paterson, W.D. & Skipper, G. (2008) The diet of pine martens (*Martes martes*) with reference to squirrel predation in Loch Lomond and the Trossachs National Park, Scotland. *The Glasgow Naturalist*, 25, 75-82.

Pereboom, V., Mergey, M., Villerette, N., Helder, R., Gerard, J. & Lode, T. (2008) Movement patterns, habitat selection, and corridor use of a typical woodland-dweller species, the European pine marten (*Martes martes*), in fragmented landscape. *Canadian Journal of Zoology*, 86, 983-991.

Pinemarten.ie (2022) Pine martens and ecotourism. Available at: https://pinemarten.ie/the-pine-marten/pine-martens-and-ecotourism/ (Accessed: 20 June 2022).

Phillips, S.J., Anderson, R.P. & Schapire, R.E. (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, 190, 231-259.

Powell, R.A., Lewis, J.C., Slough, B.G., Brainerd, S.M., Jordan, N.R., V. Abramov, A.V., Monakhov, V., Zollner, P.A. & Turakami, T. (2012) *Evaluating translocations of martens, sables, and fishers*. *Biology and Conservation of Martens, Sables, and Fishers: A New Synthesis*.

Power, J. (2015) Non-invasive genetic monitoring of pine marten (*Martes martes*) and stone marten (*Martes foina*) in and around the nietoperek bat hibernation site. PhD thesis, Waterford Institute of Technology.

pp. 31-36. Akateeminen kirjakauppa.

Pulliainen, E. (1981) Winter habitat selection, home range, and movements of the pine marten (*Martes martes*) in a Finnish Lapland forest. *Worldwide furbearer conference* (eds J.A. Chapman & D. Pursley), pp. 1068-1087. Frostburg, Maryland, USA.

Pulliainen, E. & Ollinmaki, P. (1996) A long-term study of the winter food niche of the pine marten *Martes martes* in northern boreal Finland. *Acta Theriol. (Warsz).* 41, 337–352.

Pulliam, H.R. (2000) On the relationship between niche and distribution. *Ecology Letters*, *3*, 349-361. Raes, N., Roos, M.C., Slik, J., Van Loon, E.E. & Steege, H.t. (2009) Botanical richness and endemicity patterns of Borneo derived from species distribution models. *Ecography*, 32, 180-192.

Raptor Persecution UK 2017: https://raptorpersecutionscotland.wordpress.com/2017/03/16/pine-marten-caught-in-spring-trap-on-highland-shooting-estate/

Razgour, O., Hanmer, J. & Jones, G. (2011) Using multi-scale modelling to predict habitat suitability for species of conservation concern: the grey long-eared bat as a case study. *Biological conservation*, 144, 2922-2930.

Reading, R.P. & Clark, T.W. (1996) Carnivore reintroductions: an interdisciplinary examination. *Carnivore behavior, ecology, and evolution*, 2, 296-336.

Reading, R.P. & Kellert, S.R. (1993) Attitudes toward a Proposed Reintroduction of Black-Footed Ferrets (*Mustela nigripes*). *Conservation Biology,* 7, 569-580.

Ripple, W.J. and Beschta, R.L. (2012) 'Trophic cascades in Yellowstone: The first 15years after wolf reintroduction', *Biological Conservation*, 145(1), 205–213.

Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M. & Nelson, M.P. (2014) Status and ecological effects of the world's largest carnivores. *Science*, 343, 1241484.

Ritchie, E.G., Elmhagen, B., Glen, A.S., Letnic, M., Ludwig, G. & McDonald, R.A. (2012) Ecosystem restoration with teeth: what role for predators? *Trends Ecol. Evol.* 27, 265–271.

Rosell, F. & Hovde,B. (1998) Pine Marten, *Martes martes*, as a Eurasian Beaver, *Castor fiber*, Lodge Occupant and Possible Predator. *The Canadian Field-Naturalist*, 112, 535-536.

Roy, S., Milborrow, J., Allan, J. & Robertson, P. (2014) Pine martens on the Isle of Mull–Assessing risks to native species. *Scottish Nat. Herit. Comm. Rep. No. 560.*

RSPB (2012) Black grouse numbers on the rise in Scotland. http://www.rspb.org.uk/news/details.aspx?id=308115.

Ruczyński, I. & Bogdanowicz, W. (2005) Roost cavity selection by *Nyctalus noctula* and *N. leisleri* (Vespertilionidae, Chiroptera) in Białowieża primeval forest, Eastern Poland. *Journal of Mammalogy*, 86, 921-930.

Ruette, S., Vandel, J.M., Albaret, M. and Devillard, S. (2015) Comparative survival pattern of the syntopic pine and stone martens in a trapped rural area in F rance. *Journal of Zoology*, *295*(3), 214-222.

Ruiz-Gonza´lez, A., Gurrutxaga, M., Cushman, S.A., Madeira, M. J., Randi, E. & Go´mez-Moliner, B. J. (2014) Landscape genetics for the empirical assessment of resistance surfaces: The European pine marten (*Martes martes*) as a target-species of a regional ecological network. *PLoS One* 9.

Russell, AaronJ.M. and Storch, I. (2004) 'Summer food of sympatric red fox and pine marten in the German Alps', *European Journal of Wildlife Research*, 50(2).

Sainsbury, K.A, Shore, R.F., Schofield, H., Croose, E., Campbell, R.D. & McDonald, R.A. (2019) Recent history, current status, conservation and management of native mammalian carnivore species in Great Britain. *Mammal Review*, 49, 171-188.

Salo, P., Korpimäki, E., Banks, P.B., Nordström, M. & Dickman, C.R. (2007) Alien predators are more dangerous than native predators to prey populations. *Proceedings of the Royal Society B: Biological Sciences*, 274, 1237-1243.

Salo, P., Nordström, M., Thomson, R.L. and Korpimäki, E. (2008) Risk induced by a native top predator reduces alien mink movements. *Journal of Animal Ecology*, *77*(6), 1092-1098.

Schaefer, T. (2004) Video monitoring of shrub-nests reveals nest predators. *Bird Study* 51, 170–177.

Scottish Natural Heritage (2010) Assessing the economic impacts of nature based tourism in Scotland. Commissioned Report 398.

Scottish Natural Heritage (2014) *Living with pine martens*. The Vincent Wildlife Trust, Ledbury, Herefordshire.

Seiler, A. (2003) *The toll of the automobile: Wildlife and roads in Sweden*. PhD thesis, Swedish University of Agricultural Sciences.

Shaw, G. & Livingstone, J. (1994) The Pine Marten: Its reintroduction and subsequent history in the Galloway Forest Park. *Trans. Dumfriessh. Gall. Nat. Hist. Antiq. Soc.* 67, 1–7.

Sheehy, E. & Lawton, C. (2014) Population crash in an invasive species following the recovery of a native predator: the case of the American grey squirrel and the European pine marten in Ireland. *Biodiversity and Conservation*, 23, 753-774.

Sheehy, E., Sutherland, C., O'Reilly, C. & Lambin, Xavier. (2018) The enemy of my enemy is my friend: native pine marten recovery reverses the decline of the red squirrel by suppressing grey squirrel populations. Proc. R. Soc. B 285: 20172603.

Slough, B.G. (1994) Translocations of American martens: an evaluation of factors in success. *Martens, sables, and fishers: biology and conservation.* (eds S.W. Buskirk, A. Harestad, M.G. Raphael & R.A. Powell), pp. 165-178. Cornell University Press, Ithaca, NY.

Smith, R.K., Pullin, A.S., Stewart, G.B. & Sutherland, W.J. (2010) Effectiveness of predator removal for enhancing bird populations. *Conservation Biology,* 24, 820-829.

Sorace, A., Petrassi, F. & Consiglio, C. (2004) Long-distance relocation of nestboxes reduces nest predation by Pine Marten *Martes martes*: Capsule Clutches of hole-nesting passerines suffer less predation if nestboxes are moved by 800–3000 m. *Bird Study*, 51, 119-124.

Speakman, J. (2008) 'The impact of predation by birds on bat populations in the British Isles', *Mammal Review*, 21, 123–142.

Stahl, P., Ruette, S. & Gros, L. (2002) Predation on free-ranging poultry by mammalian and avian predators: field loss estimates in a French rural area. *Mamm. Rev.* 32, 227–234.

Stoate, C. & Szczur, J. (2001) Could game management have a role in the conservation of farmland passerines? A case study from a Leicestershire farm. *Bird Study*, 48, 279-292.

Stoate, C. & Szczur, J. (2006) Potential influence of habitat and predation on local breeding success and population in Spotted Flycatchers *Muscicapa striata*: Capsule Breeding abundance in woodland increased following predator removal. *Bird Study*, 53, 328-330.

Storch, I., Lindstrom, E. & De Jounge, J. (1990) Habitat selection and food habits of the pine marten in relation to competition with the red fox. *Acta Theriologica*, 35, 311-320.

Strachan, R., Jefferies, D.J. & Chanin, P.R.F. (1996) Pine Marten Survey of England and Wales 1987-1988. Joint Nature Conservation Committee.

Stringer, A.P., MacPherson, J., Carter, S., Gill, R., Ambrose-Oji, B., Wilson, R., Kelsall, P., Feirn, W.G., Galbraith, L.C., Hilário, C.M., Parry, G. & Taylor, A. (2018) *The feasibility of reintroducing pine martens (Martes martes) to the Forest of Dean and lower Wye Valley*. Gloucestershire Wildlife Trust, The Vincent Wildlife Trust, Forestry Commission. 1-108.

Stronza, A., 2007. The Economic Promise of Ecotourism for Conservation. Journal of Ecotourism 6, 210–230.

Summers, R.W., Green, R.E., Proctor, R., Dugan, D., Lambie, D., Moncrieff, R., Moss, R. & Baines, D. (2004) An experimental study of the effects of predation on the breeding productivity of capercaillie and black grouse. Journal of applied Ecology, 41, 51

Swets, J.A. (1988) Measuring the accuracy of diagnostic systems. *Science*, 240, 1285-1293.

Tapper, S. (1992) *Game heritage: an ecological review from shooting and gamekeeping records*. Game Conservancy Fordingbridge, UK.

Tapper, S., Potts, G. & Brockless, M. (1996) The effect of an experimental reduction in predation pressure on the breeding success and population density of grey partridges *Perdix perdix*. *Journal of applied Ecology*, 33, 965-978.

Taylor, B. D. & Goldingay, R. L. (2010) Roads and wildlife: Impacts, mitigation and implications for wildlife management in Australia. Wildl. Res. 37, 320–331.

Taylor, P. (2013) *Beyond conservation: a wildland strategy*. Routledge, London.

Terborgh, J. et al*. (2001)* Ecological Meltdown in Predator-Free Forest Fragments. *Science.* 294, 1923–26.

Tharme, A.P., Green, R.E., Baines, D., Bainbridge, I.P. & O'Brien, M. (2001) The effect of management for red grouse shooting on the population density of breeding birds on heather-dominated moorland. *Journal of Applied Ecology*, 38, 439-457.

Thomson, D.L., Green, R.E., Gregory, R.D. & Baillie, S.R. (1998) The widespread declines of songbirds in rural Britain do not correlate with the spread of their avian predators. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 265, 2057-2062.

Tishechkin, A.K. and Ivanovsky, V.V. (1992) 'Status and breeding performance of the Osprey Pandion hahaetus in northern Byelorussia', 69, p. 6.

Treves, A., Naughton-Treves, L. & Shelley, V. (2013) Longitudinal analysis of attitudes toward wolves. *Conservation Biology*, 27, 315-323.

Treves, A., Wallace, R.B. & White, S. (2009) Participatory planning of interventions to mitigate human–wildlife conflicts. *Conservation Biology*, 23, 1577-1587.

Trussell, G.C., Ewanchuk, P.J. & Matassa, C.M. (2006) Habitat effects on the relative importance of trait and density-mediated indirect interactions. *Ecology Letters*, 9, 1245-1252.

Turner, C. & Sage, R. (2003) Fate of released pheasants. in *The Game Conservancy Trust - Review of 2003* 74–75.

Twining, J.P., Montgomery, I., Fitzpatrick, V., Marks, N., Scantlebury, D.M. and Tosh, D.G. (2019) 'Seasonal, geographical, and habitat effects on the diet of a recovering predator population: the European pine marten (Martes martes) in Ireland', *European Journal of Wildlife Research*, 65(3), p. 51.

Twining, J.P., Montgomery, W.I. & Tosh, D.G. (2020) The dynamics of pine marten predation on red and grey squirrels. *Mammalian Biology*, 100, 285-293.

UK Forestry Commission (2011) The UK Forestry Standard: the Government's approach to sustainable forestry. *Edinburgh: Forestry Commission*.

UK Government 2021, https://www.gov.uk/government/publications/wild-birds-licence-to-kill-or-take-for-conservation-purposes-gl40/list-of-endangered-woodland-birds

Valkama, J., Korpimäki, E., Arroyo, B., Beja, P., Bretagnolle, V., Bro, E., Kenward, R., Manosa, S., Redpath, S.M. & Thirgood, S. (2005) Birds of prey as limiting factors of gamebird populations in Europe: a review. *Biological Reviews*, 80, 171-203.

Valkama, J., Korpimäki, E., Arroyo, B., Beja, P., Bretagnolle, V., Bro, E., Kenward, R., Manosa, S., Redpath, S.M. & Thirgood, S. (2005) Birds of prey as limiting factors of gamebird populations in Europe: a review. Biological Reviews, 80, 171-203.

Velander, K.A. (1983) Pine Marten Survey of Scotland, England and Wales: 1980-1982. The Vincent Wildlife Trust, London.

Walankiewicz, W. (2002) Breeding losses in the Collared Flycatcher *Ficedula albicollis* caused by nest predators in the Białowieża National Park (Poland). *Acta Ornithol.* 37, 21–26.

Watts, K. (2006) British forest landscapes: the legacy of woodland fragmentation. *Quarterly Journal of Forestry*, 100, 273-279.

Webster, J.A. (2001) 'A review of the historical evidence of the habitat of the Pine Marten in Cumbria', *Mammal Review*, 31(1), 17–31.

Weidinger, K. (2009) Nest predators of woodland open-nesting songbirds in central Europe. *Ibis (Lond. 1859).* 151, 352–360.

Whittingham, M.J. & Evans, K.L. (2004) The effects of habitat structure on predation risk of birds in agricultural landscapes. Ibis, 146, 210-220.

Who owns England (2016)

Who owns England (2018) https://docs.google.com/spreadsheets/d/1qrIYaFAn4ts3XjMIM3YOZ9Jbr2q7h17G47qe5qJoIDM/edit#gid=0

Wilson, C.J. (2004) Could we live with reintroduced large carnivores in the UK? *Mammal Review*, 34, 211-232.

Wisz, M.S., Hijmans, R., Li, J., Peterson, A.T., Graham, C. & Guisan, A. (2008) Effects of sample size on the performance of species distribution models. *Diversity and Distributions*, 14, 763-773.

Wolf, C.M., Griffith, B., Reed, C. & Temple, S.A. (1996) Avian and mammalian translocations: update and reanalysis of 1987 survey data. *Conservation Biology*, 10, 1142-1154.

Woodland Trust (2019) Osprey egg raid attempt by pine marten discovered. Available at: https://www.woodlandtrust.org.uk/blog/2019/07/osprey-egg-raid-attempt/ (Accessed: 10 May 2022).

Young, R.P., Davison, J., Trewby, I.D., Delahay, R.J. & Doncaster, C.P. (2006) Abundance of hedgehogs (*Erinaceus europaeus*) in relation to the density and distribution of badgers (*Meles meles)*. *Journal of Zoology* 269, 349-356.

Zalewski, A. (1997) 'Factors affecting selection of resting site type by pine marten in primeval deciduous forests (Białowieża National Park, Poland)', *Acta theriologica*, 42, 271–288.

Zalewski, A. (2001) 'Seasonal and sexual variation in diel activity rhythms of pine marten Martes martes in the Bia³owie¿a National Park (Poland)', p. 10.

Zalewski, A. (2005) 'Geographical and Seasonal Variation in Food Habits and Prey Size of European Pine Martens', in Harrison, D.J., Fuller, A.K., and Proulx, G. (eds) *Martens and Fishers (Martes) in Human-Altered Environments*. New York: Springer-Verlag, pp. 77–98.

Zalewski, A. (2007). Does size dimorphism reduce competition between sexes? The diet of male and female pine martens at local and wider geographical scales. *Acta Theriologica*, 52 (3), 237-250.

Zalewski, A., Jedrzejewski, W. & Jedrzejewska, B. (1995) Pine marten home ranges, numbers and predation on vertebrates in a deciduous forest (Białowieża National Park, Poland). *Annales Zoologici Fennici*, 131-144. Helsinki: Suomen Biologian Seura Vanamo, 1964-.

Zalewski, A., Jędrzejewski, W. & Kelt, D. (2006) Spatial organisation and dynamics of the pine marten *Martes martes* population in Białowieża. *Ecography (Cop.).* 29, 31–43.

7. Appendices

Appendix 1. Legal status of the pine marten

The pine marten is a protected species listed in Schedules 5 & 6 of the Wildlife and Countryside Act 1981 (as amended).

"*It is an offence to intentionally or recklessly:*

- *kill, injure or take a pine marten*
- *damage, destroy or obstruct access to a nest or den – i.e., any structure or place which such an animal uses for shelter or protection*
- *disturb such an animal when it is occupying a nest or den for shelter or protection (except when this is inside a dwelling house)*

Possession, sale and transport offences are ones of strict liability (they don't require intention or recklessness). It is an offence to:

- *possess or control, sell, offer for sale or possess or transport for the purpose of sale any living or dead pine marten or any derivative of such an animal*

It is also an offence to knowingly cause or permit any of the above acts to be carried out."

The pine marten is also listed as a UK BAP priority species, Natural England S41 Species of Principal Importance. A priority action for this species is to:

"*Consider reintroductions into areas where there are no extant populations and where there is (or will be) suitable habitat to support self-sustaining populations.*"

Internationally, the pine marten is listed under Annex V of the European Union Habitats Directive and Appendix III of the Bern Convention. This means that any capture of them in the wild is limited to ensure it does not impact their conservation status.

Appendix 2. Farmer/Landowner Questionnaire

Pine Marten Reintroduction Feasibility Study
Farmer/Landowner Questionnaire

Q1. How would you categorize your enterprise? (please select more than one answer if appropriate)	Dairy and/or beef	Sheep	Pigs		
	Poultry-housed	Poultry-free range	Commercial shoot		
	Private shoot	Not applicable	Other-please specify…………..		
Q2. Are you a farm tenant or a farm owner?	Tenant	Owner	Not applicable		
Q3. If you own or manage a shoot, please indicate the number of birds that you release per year.	Less than 1000	Between 1,000 and 10,000	More than 10,000	Not applicable	
Q4. If you farm free range poultry, please indicate the total flock size.					
Q5. I would like to see the recovery of pine marten populations in south Cumbria.	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Q6. Please indicate why you are in favour of or against the recovery of pine marten populations in south Cumbria					
Q7. Farmers and gamekeepers should be free to control pine marten	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Q 8. Reintroduction should be used as a method to support the recovery of pine marten populations in south Cumbria.	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Q9. Do you think pine martens would threaten or benefit other species of native wildlife in south Cumbria?					
Q10. Has the farm that you own or manage diversified to make money from tourism (e.g., Bed and breakfast or self-catering accommodation)?	Yes	No			

Q11. Pine martens could generate additional income for farmers and landowners as an ecotourism attraction.	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Q12. A pine marten population could have a negative impact on my business	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Q13. Have you seen evidence of pine marten in south Cumbria?	Live pine marten sighting	Dead pine marten sighting	Pine marten field signs (scats/tracks)	No	
Q14. Please provide details of the sighting or field signs (date/location/description/photos)					
Q15. If you have seen evidence of pine marten in south Cumbria we would be grateful if you could provide your name/phone number/email so that we can speak to you about your encounter.					
Q16. Have you used any of the following legal pest control measures in the last 12 months? (Please select more than one answer if appropriate)	Shooting	Tunnel traps	Second generation anticoagulant rodenticides (SGARs)	None	Other (please specify)
Q17. If you use tunnel traps, do you fit excluders to avoid catching non-target, protected species such as hedgehogs and pine martens?	Yes	No	Not Applicable		
Q18. Please choose one of the following options:	I only use SGARs on a temporary basis in response to an increase in the number of pest species.	I use SGARs on a permanent basis to prevent losses from pest species.	Not applicable		
Q19=. Please choose one of the following options:	I only use tunnel traps on a temporary basis in response to an increase in the number of pest species.	I use tunnel traps on a permanent basis to prevent losses from pest species.	Not applicable		

Appendix 3. Public Questionnaire

Pine Marten Reintroduction Feasibility Study
Public Questionnaire

Before you read the information sheet had you heard about pine martens?	Yes		No		
Where did you hear about pine marten (please circle multiple sources if appropriate)?	Website / Social media /School, college, university / Newspaper, magazine / Television / Radio / Friends and family / Can't remember / Other				
I am concerned about the loss of native wildlife in the United Kingdom.	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
We should recover native species that were once found in the UK but have become extinct.	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
I would like to see the recovery of pine marten populations in south Cumbria.	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
Please indicate why you are in favour of or against the recovery of pine marten populations in south Cumbria					
Reintroduction should be used to bring pine marten back to south Cumbria.	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
Pine martens should be left to find their own way from southern Scotland to suitable habitat in south Cumbria	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
Do you think a reintroduced population of pine marten would threaten or benefit other species of native wildlife in south Cumbria?					
Recovering pine marten populations in the forests of south Cumbria would enrich my experience of nature	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
The reintroduction of pine marten to south Cumbria will increase the number of visitors to the area.	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
If your answer indicates an increase in visitor numbers would that bring benefits or cause problems for local residents?					

Would a reintroduced pine marten population have any impact on you or your business?				
Have you seen evidence of pine marten in south Cumbria?	Alive	Dead	Field signs	No
Please provide details of your sighting or field signs (date/location/photos) and a brief description if possible.				
Please provide your name/phone number/email if you are happy to be contacted by the BOOM project team.				

Classification Questions

Your responses to the following questions help us to understand the views of different groups within the population. Please fill in any questions that you are comfortable with.										
What age are you?	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+		
Are you?	Female	Male	Other	Undisclosed						
How do you describe your ethnicity?										
Are you?	A resident of South Lakeland	On holiday or visiting from outside the area	Other							
Do you live in?	An urban area	A rural area	Please provide below the first 4 characters of your postcode (we can't identify where you live from this information):							
For the next 2 questions please tick more than one sector / organisation if appropriate										
Do you work in any of the following sector(s) of the rural economy?	Farming	Forestry	Gamekeeping	Leisure/tourism	Estate management	Wildlife conservation	Other			
Are you a member of any of these organisations?	**NFU** (National Farmers Union)	**RSPB** (Royal Society for Protection of Birds)	**BASC** (British Association of Shooting and	**Woodland Trust**	**CWT** (Cumbria Wildlife Trust)	**CLA** (The Country Land and Business Association)	**GWCT** (Game and Wildlife Conservation Trust)	**NT** (National Trust)	**NGO** (The National Gamekeepers Organistion)	

Data collected will be used for the purposes of this research. Your contact details, if given, will only be used for communications by the University of Cumbria BOOM project.

Appendix 4. BOOM Pine Marten Feasibility Study, Information Sheet

BOOM Pine Marten Feasibility Study
Information Sheet

What is reintroduction?

Reintroduction is the intentional movement of an animal for conservation purposes to part of its geographic range where the species was historically and naturally present but has since gone extinct.

What is a pine marten?

A pine marten is a small cat sized mammal that is related to otters, stoats and weasels with brown fur and a cream throat patch or 'bib'. Females start to breed at two to three years of age and typically have small litters of no more than three kits that are born in April. The kits remain with their mother until they disperse to find their own territory in the autumn and early winter of the same year.

Where do they live?

Pine martens are good climbers and prefer woodland habitats with plenty of old trees as they seek out den sites in hollow tree cavities to raise their kits. They can also be found in more open landscapes such as forest edges and young conifer plantations if there is some degree of tree cover.

Has the British population changed over time?

Pine martens were once prevalent throughout mainland Britain, however, by the late 19th century, the species was restricted to the northwest of Scotland with isolated populations in upland areas of northern England and Wales. During the 20th century Scottish pine martens have recovered well but populations continue to decline in England and Wales prompting two recent reintroduction projects in mid-Wales and the Forest of Dean.

What do they eat?

They eat a wide variety of plant and animal-based foods depending on what is seasonally abundant. Small mammals such as voles form a major part of their diet, but they will also eat birds, insects, fruit such as blackberries and carrion. Pine martens are more efficient at killing grey rather than red squirrels. Recent evidence suggests that where both squirrel species coexist with pine martens the red squirrel population will grow at the expense of the greys.

Do they kill pheasants and free-range chickens?

Pine marten will kill gamebirds and free-range chickens if the opportunity arises. However, they pose less of a threat than foxes as pine martens are solitary in nature, occupy large territories and are therefore never abundant even in favourable habitat. Modifications to fenced enclosures, hen houses and pheasant release pens such as the use of line wire electric fencing will effectively exclude pine martens.

Are they protected?

Pine martens are legally protected under The Wildlife and Countryside Act 1981. It is therefore illegal to kill, injure or take a pine marten from the wild without a licence. It is also illegal to damage, destroy or obstruct access to a marten den site and to disturb a pine marten when it is occupying a den site

Is BOOM reintroducing the pine marten to south Cumbria?

A pine marten reintroduction in south Cumbria could help to link the populations in southern Scotland with the reintroduced populations in Wales and the Forest of Dean towards a national recovery of the species. The focus of the BOOM project is to study the feasibility of a pine marten reintroduction. However if the study demonstrates public support and suitable habitat for a reintroduction, the implementation and movement of animals from Scotland could be undertaken with additional funding and a wider collaboration of project partners.

How do you reintroduce pine marten?

The findings of the feasibility study will either support or recommend against a reintroduction in south Cumbria. If the evidence is in favour of a reintroduction, a licence could be submitted to NatureScot to catch and move pine martens under strictly controlled conditions from strong populations in Scotland to be released and closely monitored in the forests of south Cumbria.