Departmental Coversheet

UNIVERSITY OF OXFORD

BIOLOGICAL SCIENCES

Candidate Number	1015037
Supervisor or Advisor	**PROF E.J. MILNER-GULLAND**
Title	**A BIOLOGICAL FEASIBILITY ASSESSMENT FOR THE TRANSLOCATION OF PINE MARTENS (*MARTES MARTES*) TO CUMBRIA**
Type of Submission (Project Dissertation, Course Assignment Extended Essay or Course Assignment Abstract for Oral Presentation)	**PROJECT DISSERTATION**
Word Count (see word limits below)	**6973**

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Word limits

Project Dissertation: *Maximum 7,000 words*

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Abstract

1. The pine marten (*Martes martes* L.) is a semi-arboreal mustelid which was historically common across Britain but became rare in the 19th century due to persecution and habitat loss. Records have remained very rare in England and Wales, suggesting functional extinction. Pine martens were recently translocated to mid-Wales, and a further translocation is planned for Gloucestershire. Though southern Scottish populations appear to be spreading into northern England, it could well take decades for the pine marten to return naturally to the region.
2. There is growing interest in a reinforcement of the relict Cumbrian population. An informal partnership of conservation bodies and land managers has begun to investigate the possibility of such a project.
3. This study is the first formal assessment of the feasibility of a translocation of pine martens to Cumbria, as part of the above-mentioned investigation. Land cover, woodland fragmentation and high-risk roads were GIS-mapped, using IUCN reintroduction guidelines as a framework. The implications for pine marten habitat suitability, including woodland connectivity, carrying capacity and traffic mortality were assessed.
4. The most promising candidate reinforcement area is a woodland complex centred on Grizedale forest. It has sufficiently connected woodland cover, is close to other suitable habitat complexes, and is free from high-risk roads at its centre.
5. Future work should use landscape connectivity and resistance modelling, and a population viability analysis, to more rigorously assess the biological feasibility of a reinforcement. Ground-truthing to assess structural complexity and other metrics of habitat quality is also advised.

Contents

Introduction

Wider context

Against a backdrop of global biodiversity decreases and habitat destruction, it has become apparent that to maintain, restore or expand threatened ecosystems, conservation of remaining habitats and species is often insufficient. Therefore, restoration ecology and rewilding have embodied a growing movement to actively restore ecosystems, including their functions and services, from human-induced damage. Species translocations are increasingly utilised as a tool to do this, and as a method for species conservation in its own right (Soorae, 2018; Stringer *et al.*, 2018).

In Britain, animal translocations are occurring with increasing frequency. Memorable examples of the nine species reintroduced from outside Britain, and at least 24 translocated within Britain, between 1975 and 2015 include the white-tailed eagle (*Haliaeetus albicilla* L.), red kite (*Milvus milvus* L.) and otter (*Lutra lutra* L.) (Carter *et al.*, 2017). These are all examples of conservation translocations into a species' indigenous range; 'reintroductions' where a species is locally extinct, and 'reinforcements' where individuals of the species are present (IUCN/SSC, 2013).

Translocations can be high-risk undertakings, with the risk of detrimentally altering the ecology of the release habitat, introducing disease, or causing conflict between human stakeholders. Therefore, the decision to undertake a translocation project should be heavily informed by evidence, with rigorous assessments of biological and social feasibility and risk underlying the decision and subsequent planning, management and execution of the entire project. Best practice is detailed in reports from previous translocations, IUCN guidelines and reviews of the biology and ecology of the focal species and related species (Powell *et al.*, 2012; IUCN/SSC, 2013; Soorae, 2018).

The pine marten

The pine marten (*Martes martes* L.) is a member of the Mustelidae, a family including weasels, polecats and mink. It is described as tree-dependent but able to occupy fragmented habitat, and has a varied omnivorous diet which includes invertebrates, small rodents, fruit and nuts. The pine marten is found across most of Europe and Asia Minor, and was historically distributed across most of Britain. However, in the 1800s, factors such as pest control by gamekeepers and deforestation led to the rapid decline of British populations (Herrero *et al.*, 2016; Birks, 2017).

Since their nadir in the early 1900s, pine martens have successfully recolonised most of Scotland (Croose *et al.*, 2014), aided by a translocation to Galloway Forest in 1980-1 (Shaw and Livingstone, 1992), but records in England and Wales have remained unusual (Birks and Messenger, 2010). There have been rare records of juveniles, suggesting the presence of breeding individuals; for example, in

Shropshire (Edmunds, 2014; Shropshire Wildlife Trust, 2017) and Newtown, mid-Wales (Croose, 2012; MacPherson *et al.*, 2015). However, the sparseness and rarity of these records suggests that nationally, the pine marten was functionally extinct in England and Wales (Jordan, 2011), until 51 pine martens were translocated to Wales in 2015-17. As a result of this project, a breeding population has been established in Wales (MacPherson, 2018), and another translocation is planned for Gloucestershire (Stringer *et al.*, 2018).

Low densities of pine marten in England are assumed to have resulted in an extinction vortex: that is, inbreeding depression and poor success of normal social and mating systems have led to an irreversible decline in numbers. Therefore, it is generally assumed that any populations in England are easily below their minimum viable population, and are especially vulnerable to stochastic disturbances (Jordan, 2011; MacPherson *et al.*, 2014). Records indicate that there is currently no established population in England, though the Lake District, Northumbria and the North York Moors have occasional records (Birks, 2017). Although the pine marten is listed globally on the IUCN Red List as Least Concern (Herrero *et al.*, 2016), it is Critically Endangered in England (Mathews *et al.*, 2018).

The southern Scottish population is expanding into northern England (Croose *et al.*, 2014; Forestry Commission England, 2018). However, pine martens have a low reproductive rate, meaning the recolonisation of England from these populations could take decades. A report by the Vincent Wildlife Trust (Jordan, 2011) concluded that the full recovery of self-sustaining pine marten populations to their historical range can only be achieved by human intervention.

Study area

Cumbria is a county in north-west England with an area of 6767 km^2. Its population density of 74 inhabitants per km^2 makes it the second least densely populated county or unitary authority in England (ONS, 2018). Cumbria is a rural area, with the five most common land cover types including (in order of area) pastures, natural grasslands, moors and heathland, peat bogs and non-irrigated arable land (CORINE data,

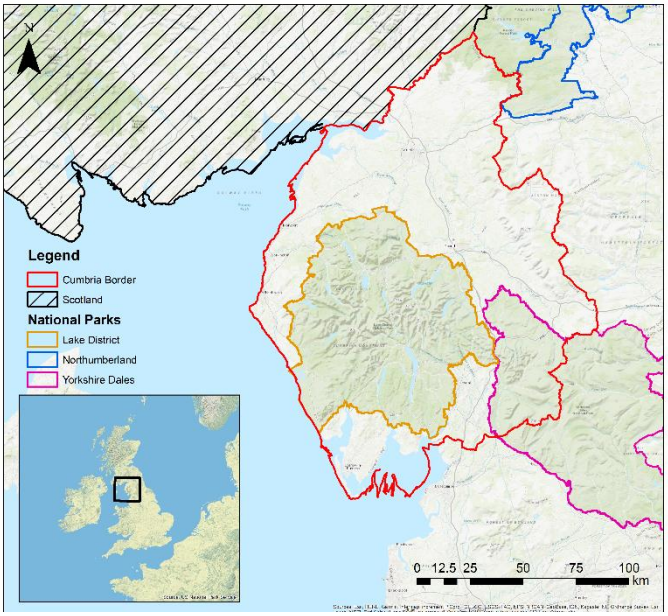

Figure 1: The location of Cumbria, with National Parks

European Environment Agency, 2012). It is one of the few areas in England where pine martens are still occasionally observed (Birks and Messenger, 2010; Mathews *et al.*, 2018).

The Lake District National Park covers 2362 km^2 of central and southern Cumbria, and 607 km^2 of the Yorkshire Dales National Park occupies the south-east (Natural England datasets from ArcGIS Online). The Lake District receives around 19 million visitors annually (Lake District National Park Authority, 2017). It is characterised by mountainous terrain, valleys, large lakes , its tourist industry and a traditional agro-pastoral system of sheep grazing, and was inscribed in 2017 as a UNESCO World Heritage Site (World Heritage Committee, 2017).

Cumbria is currently the subject of a multi-species reintroduction project, Back On Our Map (BOOM), led by the University of Cumbria with local communities and conservation bodies. Subject to the outcome of a 2018 application for a four-year Heritage Lottery Fund grant, the BOOM project aims to reintroduce up to 12 species to south Cumbria (University of Cumbria, 2018). A pine marten translocation is being considered as part of BOOM.

Whilst BOOM has been developing, there has been a mounting interest from conservation bodies (e.g. University of Cumbria, National Trust, Natural England, Forestry Commission (D. Brady, 2018, *pers. comm.*)) in the reinforcement of the Cumbrian pine marten population. This presents an opportune moment to investigate the feasibility of such a project.

Legal and political background for pine marten conservation efforts

The United Kingdom has a legal obligation under the Convention on Biological Diversity (1992, arts. 8(f) and 9(c)) to promote the recovery of threatened species, including, where appropriate, by reintroduction. Similarly, the UK is legally bound by the Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats, 1979, art. 11, para. 2a) to encourage the reintroduction of endangered native species, provided that a study is conducted to ascertain whether a reintroduction would be “effective and acceptable”. The UK’s obligations to these treaties will remain unchanged after Brexit, as the UK is a signatory to both, as part of the European Union and as a party in its own right.

At a national level, the pine marten is listed under Section 41 of the 2006 Natural Environment and Rural Communities Act as one of England’s most threatened species. The current UK Government’s 25-Year Environment Plan (25YEP) mentions the pine marten as a potential species for reintroduction. The 25YEP also clearly supports the investigation of reintroductions as a tool for species conservation, by pledging to develop a code and best practice guide for assessing and planning reintroduction projects (Defra, 2018).

The legal, ecological and political obligations for a concerted conservation effort for the pine marten in England and Wales are clear. It is also evident that a conservation translocation should be seriously considered to further these efforts.

The IUCN guidelines

The IUCN Guidelines for Reintroductions and Other Conservation Translocations (IUCN/SSC, 2013) are generally regarded as the gold standard for conservation translocations worldwide (e.g. National Species Reintroduction Forum, 2014; Defra, 2018). They outline best practice for all aspects of a translocation, and have been used as a planning framework for previous, ongoing and nascent UK translocation projects (Stringer *et al.*, 2018). It is imperative that the IUCN guidelines are diligently followed during the feasibility assessment, planning and execution of any potential translocation of pine martens to Cumbria.

Translocation terminology

According to the IUCN guidelines, any conservation translocation into an area where conspecifics are present is a 'reinforcement'. It has been established above that, although pine martens could be functionally extinct in Cumbria, they are certainly still present there. Therefore, this study will refer to the **reinforcement** of the Cumbrian pine marten population, or the **translocation** of pine martens to Cumbria. In the popular, governmental and legal literature cited in this study, the word 'reintroduction' has commonly been used. I interpret such references as referring more widely to 'population restorations' *sensu* IUCN/SSC (2013) – that is, translocations into indigenous range - depending on their context.

Research questions

The circumstances considered above show that a feasibility assessment for the translocation of pine martens to Cumbria would be timely and appropriate. Hence, the following research questions and sub-questions are proposed:

How should the biological feasibility of a reinforcement of the Cumbrian pine marten population be assessed in accordance with IUCN best practice?

- Does Cumbria have sufficient suitable habitat to support the survival and growth of a translocated population of pine martens?
- Where in Cumbria are candidate translocation areas located?
- What scientific evidence is needed in order to design and implement a successful translocation?

Methods

IUCN guidelines

In general, my research focussed on assessing habitat suitability and connectivity in Cumbria. Questions of logistics are outside the scope of this study and can be investigated once further funding is secured for BOOM or a separate reinforcement project.

The research for this study was framed around the following parts of the IUCN guidelines, though other aspects may be discussed throughout.

Table 1: Parts of the IUCN guidelines addressed by this study

Section	Detail (taken from IUCN guidelines)	Implementation in this study
5.1.1 Biological feasibility – Basic biological knowledge	• Necessary aspects of the biology and ecology of the candidate species should be reviewed • Information from candidate species or close relatives can inform models	An understanding of pine martens biology and ecology (based on a literature review) is essential to assess what constitutes suitable habitat.
5.1.2 Biological feasibility - Habitat	• Habitat suitability and availability should be assessed • All life stages should be considered • Ecological roles of candidate species should be assessed in relation to other species and human land-use	The pine marten's habitat preferences are matched with the habitat categories on a GIS land cover map of Cumbria. Suitable habitat is then mapped and quantified.
7.1 Selecting release sites and areas	• A release site should be practical in terms of logistics and animal welfare, and for community awareness and engagement • A release area should: • Meet all the species' biotic and abiotic requirements, • Be appropriate habitat for the life stage released and all life stages of the species • Be adequate for all seasonal habitat needs,	This study will not focus on specific release sites, but will create a list of candidate release areas based on biological feasibility, mostly habitat suitability and connectivity.

	• Be large enough to meet the required conservation benefit, • Have adequate connectivity to suitable habitat if that habitat is fragmented, • Be adequately isolated from sub-optimal or non-habitat areas which might be sink areas for the population	

Mapping land cover for Cumbria

Land cover for Cumbria was mapped using ArcMap 10.6. Multiple databases were trialled before the most suitable one was selected.

Table 2: Land cover databases trialled for use

Dataset	Description	Reference
CORINE	A pan-European inventory of land cover in 44 classes.	European Environment Agency, 2012
Land Cover Map (LCM)	Land cover for the UK, based on UK Biodiversity Action Plan Broad Habitats classes	Centre for Ecology & Hydrology, 2015
National Forest Inventory (NFI)	Inventory of forest or woodland patches that are 0.5ha or larger in area and 20m or more wide, with at least 20% tree canopy cover.	Forestry Commission, 2016

The Forestry Commission (FC) holds more detailed data about the land it manages on the Public Forest Estate, such as woodland age (Stringer *et al.*, 2018), but my requests for access to this dataset were unsuccessful.

Although it was the most recent dataset, NFI was found to be of little use for this study, as it covers only woodland habitats. In contrast, CORINE and LCM cover all land classes, meaning they could be used to study open habitats that pine martens use for dispersal and foraging. CORINE's nomenclature and land cover classification (Bossard *et al.*, 2000) were found to be more useful compared to LCM's in the context of the published literature on pine marten habitat preferences.

Fieldwork

After preliminary research and mapping, I conducted a six-day visit to Cumbria to ground-truth the GIS map and meet with parties involved in BOOM and pine marten translocation. This involved visiting several FC-managed woodlands and other suggested translocation sites, and meeting with representatives of BOOM, the RSPB and the FC.

The woodland sites visited were :

- Ennerdale: a valley managed by the Wild Ennerdale partnership, including United Utilities, the FC, Natural England and the National Trust. Wild Ennerdale is working to restore the Ennerdale landscape to a 'wilder' state by allowing native broadleaved woodland to grow, and by grazing with cattle rather than sheep.
- Grizedale: an FC woodland with walking and cycling trails
- Haweswater: an RSPB reserve surrounding Hawewater reservoir, with varied habitat including upland habitats and some native woodland
- Whinlatter: an FC woodland with walking and cycling trails

Figure 2: Woodland sites visited during fieldwork

Informal observations and discussions were made regarding the character of the woodland; terrain; human habitation; the landscape-scale connectivity and fragmentation of woodland patches; and correlation between on-the-map and on-the-ground land cover classification. Furthermore, discussions with ecologists and land managers gave indications about the attitudes of the Cumbrian public and other stakeholder groups towards pine marten translocation.

Review of pine marten habitat preferences and dispersal

A comprehensive literature review was required to determine what habitats are preferred by pine martens, and how well they are able to disperse between habitat patches.

This review also informed the selection of the CORINE land cover dataset for mapping based on the relevance of its land cover classes to the habitat described in the literature. I searched the Web of Science Core Collection using the search term "pine marten", and from the 369 results, I selected those sources relevant to pine marten habitat dispersal and connectivity. I also used a recent British book about pine martens (Birks, 2017) as a guide to relevant papers. Related grey literature and private publications were obtained from pine marten researchers. Research on closely related *Martes* species, especially the stone marten (*M. foina* Erxleben) and the well-studied American marten (*M. americana* Turton), is often used to supplement knowledge of pine marten biology. I therefore used a synthesis of *Martes* biology (Aubry *et al.*, 2012) to find such research.

Woodland fragmentation and connectivity

I mapped percentage woodland cover using ArcMap 10.6, to assess landscape-scale woodland connectivity for pine martens. The summed area of the three CORINE woodland classes (311-313: broad-leaved, coniferous and mixed forest) was calculated for 1km grid squares, and divided by the area of the grid. Grid area was usually $1km^2$, but where grids lay on the Cumbrian border, only the area that fell within Cumbria was assessed.

In the feasibility assessment for the Gloucestershire translocation (Stringer *et al.*, 2018), 1km grid squares were used as the unit for the connectivity analysis. This scale seems to be arbitrarily chosen, considering that when assessing woodland cover, Balestrieri *et al.* (2010, 2015) roughly based their $4km^2$ grid and $10km^2$ radius sizes on pine marten home ranges in Tuscany, Switzerland and Germany. Other studies have calculated woodland cover for whole study areas of e.g. $60km^2$ or $257km^2$ (Pereboom *et al.*, 2008; Caryl *et al.*, 2012). After a review of the literature, 1km grid squares were also used for this study's connectivity analysis, as recorded pine marten home ranges vary greatly (e.g. Caryl, 2008, table 3.3) and there is no clear quantitative indication of what scale should be used for woodland cover across a "landscape" *sensu* Moll *et al.* (2016). The use of 1km grid squares allows for direct comparison with the Gloucestershire woodland connectivity map.

Stringer *et al.* (2018) concluded that a landscape needs to have ≥20% forest cover to support a pine marten territory, but that woodland cover between 5 and 20% can be utilised by martens. After a literature review, I found this classification to be satisfactory for this study's connectivity analysis. However, I considered it useful to further stratify the less fragmented woodland into 20 to 40% cover, and 40 to 100% cover, based on the 40% upper bound of the critical woodland cover limit suggested by Moll *et al.* (2016). This means quality of woodland cover can be broadly assessed for Cumbria based on classes that are relevant to habitat suitability for pine martens.

Identifying and characterising habitat complexes

I defined clusters of core habitat as orthognally and diagonally contiguous blocks of squares with >20% woodland cover, 20% being the minimum woodland cover required for a landscape to be suitable for pine martens (Moll *et al.*, 2016). They will henceforth be referred to as 'habitat complexes' to make it clear that these are not contiguous blocks of woodland. Recorded pine marten home range sizes in the literature vary considerably, which makes it difficult to predict how many individuals a habitat complex could support (Stringer *et al.*, 2018). Upper and lower bounds of home range sizes were taken from approximately the first and third quartiles of records in a review of recorded home range sizes (Caryl, 2008), and rounded to the nearest km^2. These were then used to estimate potential carrying capacity of each complex.

Roads

Roads are a major dispersal barrier and cause of mortality for pine martens (Bright and Smithson, 2001; MacPherson *et al.*, 2014; Ruette *et al.*, 2015; Stuart and Lawton, 2015; Stringer *et al.*, 2018), therefore their potential impact should be assessed in woodlands being considered for translocation. I mapped major roads in Cumbria by their classification as Primary Road Network (PRN, i.e. roads of national, regional and county importance), non-PRN A roads, and B roads (Ordnance Survey, 2017). The dataset used was OS Open Roads (Ordnance Survey, 2018).

In the Ardennes in France, pine martens were found to stray on average 42m (s.d. 32m) from woodland habitat, though this study only monitored 8 individuals (Pereboom *et al.*, 2008). In Scotland, males and females strayed on average 75m and 35m from woodland respectively (Caryl, 2008). Considering the paucity of evidence on pine marten dispersal from woodland habitat, a distance of 42m was chosen as a somewhat arbitrary value to identify major and B roads running close to woodland in Cumbria. All major and B roads running within 42m of woodland were identified in ArcMap 10.6, and the portions which run through the 1km squares containing core pine marten habitat (>20% woodland cover) were identified as high-risk roads.

In comparison, Stringer *et al.* (2018) used 50m as their buffer distance, and did not use B roads. The Gloucestershire road assessment involved assessing tree canopy connectivity for all minor roads running close to woodland, and those road sections >1km from a tree canopy crossing were marked as high-risk roads. There was insufficient time to carry out such an assessment during fieldwork in Cumbria. B roads were therefore also included in the mapping of high-risk roads in Cumbria, to ensure that minor roads with greater risk to pine martens were included in the results.

I also used Department for Transport statistics (roadtraffic.dft.gov.uk/local-authorities/77) for 2017 to map records of traffic flow, as Annual Average Daily Flow, across Cumbria.

Results

Review of pine marten habitat preferences and dispersal

Traditionally, pine martens were thought to be habitat specialists, almost solely inhabiting extensive, mature, structurally-complex woodland. It is true that they prefer mature woodland, such as the predominantly native, mature (>45 years old), coniferous woodland often inhabited by Scottish martens. This is partly dueto the structural complexity of the ground vegetation in these woodlands, which offers foraging opportunities, and the availability of denning sites in arboreal cavities (Caryl *et al.*, 2012; Birks, 2017).

More recent research shows that while pine martens do prefer mature woodland, they also favour more open habitats. Scottish pine martens have been shown to exploit graminoid (grass-like herbaceous) vegetation for foraging. In particular, they favoured tussock grassland (defined as having a mean sward height of ≥30cm) and scrub (includes shrub, debris and regenerating stands). It has been demonstrated that pine martens select this habitat because it is rich in voles and other small mammals. (Caryl *et al.*, 2012; Caryl *et al.*, 2012).

This is consistent with a substantial body of evidence from across Europe that pine martens can persist well in fragmented woodlands, and may even prefer them where woodlands are structurally simple, with ground vegetation absent. In Scottish plantation forests, marten home ranges were found to be smallest when woodland cover was at 25-30% (Caryl *et al.*, 2012) Though care should be taken when linking home range size with habitat suitability, this result indicates that considerably fragmented woodland can support pine marten populations, and that some fragmentation may increase a forest's suitability for pine martens. **Table 4** (at end of Results) presents a selection of studies which have shown persistence of pine martens in fragmented woodlands. Of Importantly, Moll *et al.* (2016) suggest that a landscape with 20–40% woodland cover, with patches >0.25km^2 in size, will support martens, even near human development.

In some cases, pine martens inhabit extremely fragmented woodlands, surviving in as low as 4.1% woodland cover at Kinlochewe in Scotland (Balharry, 1993). Similarly, in northern Italy, pine martens can inhabit intensively cultivated plains where woodland is close to absent (Balestrieri *et al.*, 2010, 2015). This could be because pine martens exhibit considerable behavioural plasticity, allowing them to adapt quickly to different habitats (Mergey *et al.*, 2012). Birks and Messenger (2010) suggest that it is this behavioural plasticity, rather than a retreat from human persecution, that lies behind the active selection of rocky uplands, including Cumbrian fells, as refugia during the

distributional nadir of British martens in the early 20th century. Rocky uplands offer similar vertical microhabitats to mature woodland, such as denning sites in crevices (Webster, 2001).

Woodland fragmentation and connectivity

Figure 3 shows percentage woodland cover for 1km grid squares across Cumbria, which can be used to study woodland fragmentation and pine marten habitat connectivity. There are some clusters of core pine marten habitat across the county, but there is a noticeable absence of habitat in the centre of the Lake District, corresponding with the Cumbrian mountains. This could prevent dispersal of translocated pine martens between habitat north and south of the mountains.

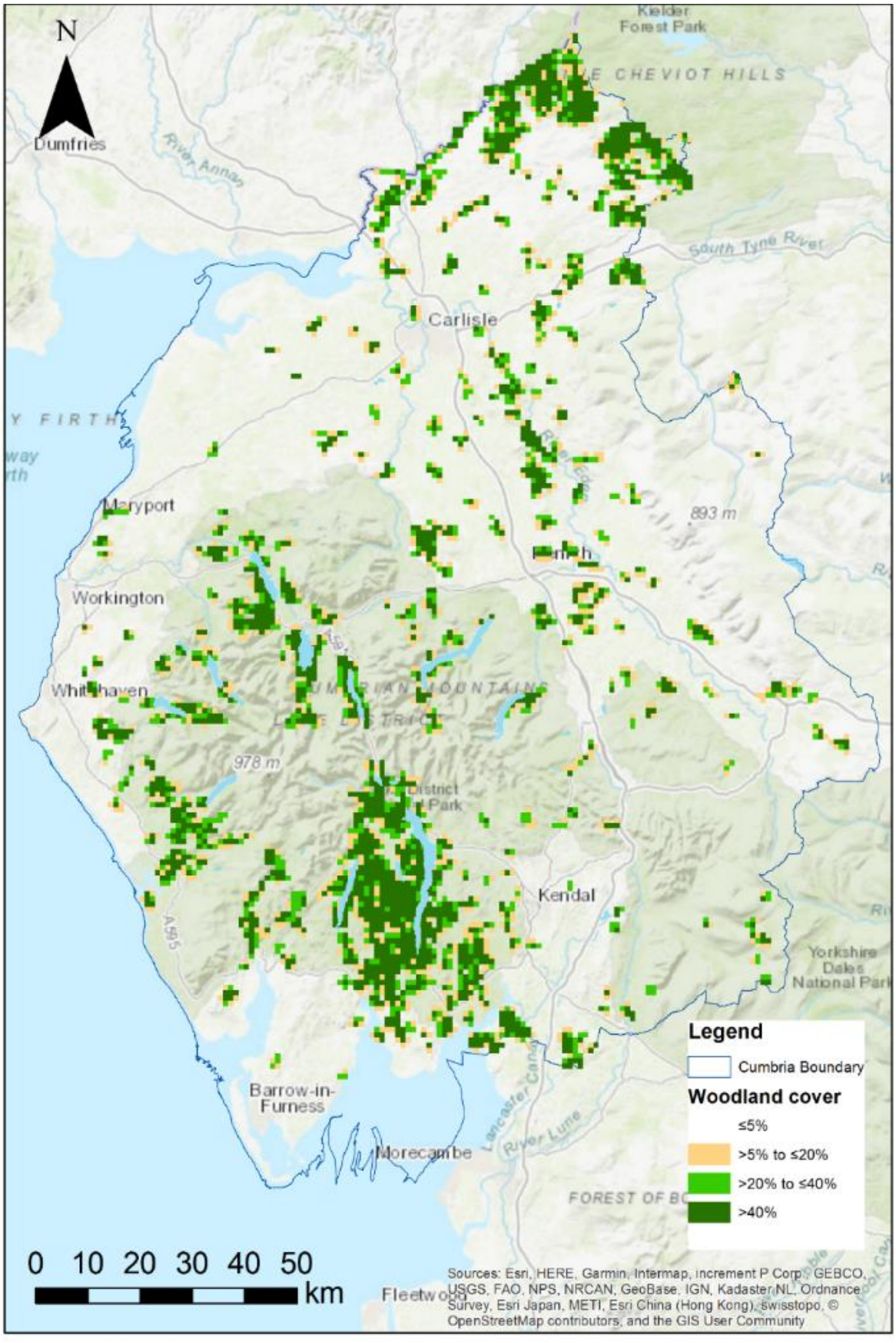

Figure 3: Woodland cover in Cumbria

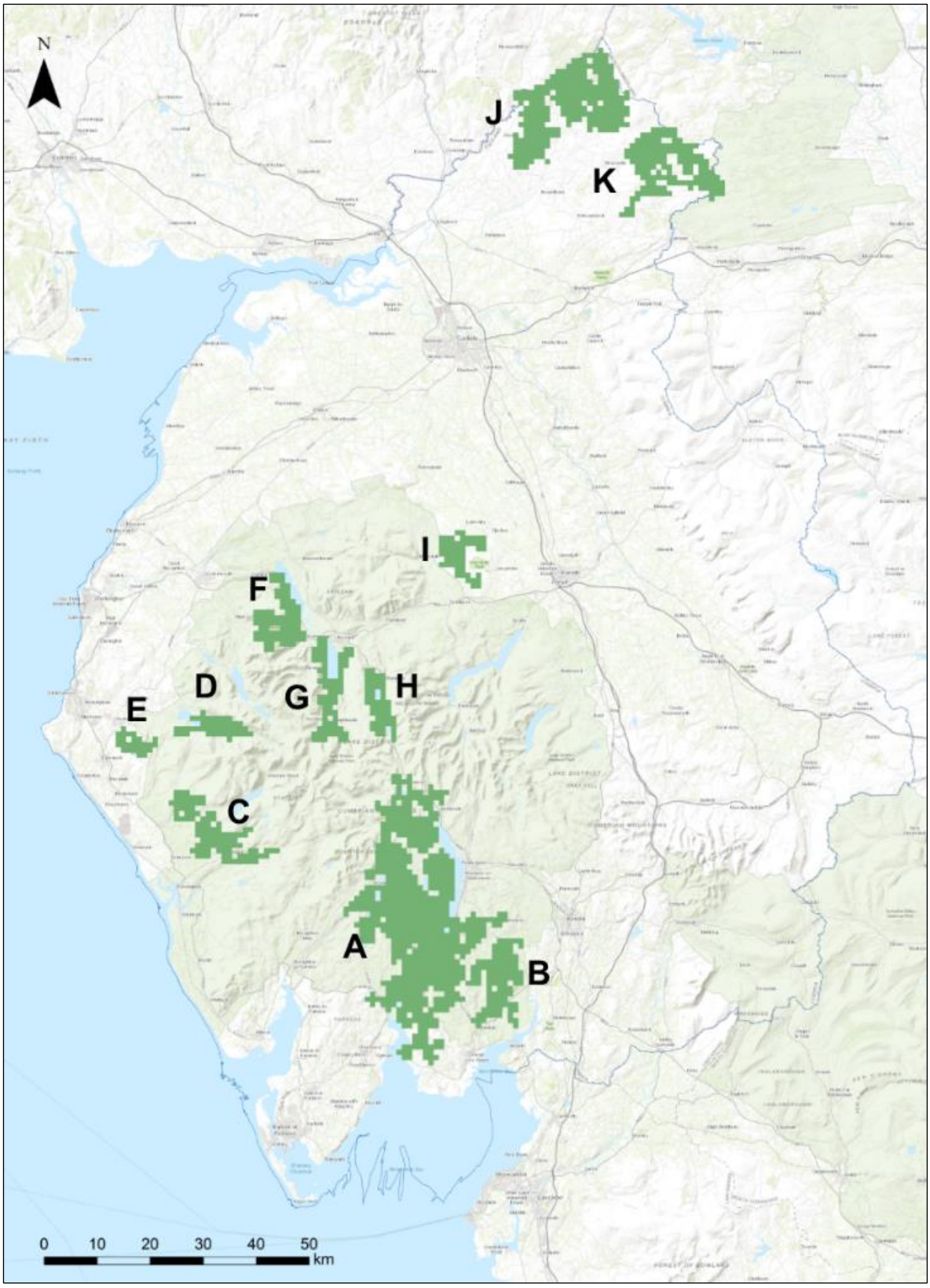

Figure 4: Habitat complexes

Habitat complexes

Figure 4 and table 3 show the characteristics and location of the identified habitat complexes. Though caution should be taken when inferring habitat suitability from these results, complexes A (around Grizedale, 529 km^2), J (near Penton, 199 km^2) and K (near Bewcastle, 122 km^2)clearly offer the highest potential carrying capacity of pine martens. Furthermore, complex B (near Cartmel Fell, 73km^2) is located close to complex A, meaning pine marten dispersal between the two areas is probable. Complexes J and K, located at the north-east border of Cumbria, are part of a network of woodland linked to Kielder Forest and Northumberland National Park, meaning they are likely to be colonised by the expanding Kielder pine marten population. Other habitat complexes have broadly similar areas and estimated carrying capacities.

Table 3: Characteristics of the identified pine marten habitat complexes

Habitat complex	Contiguous squares with >5% woodland cover	Squares in block with >20% woodland cover	Carrying capacity using 10 km^2 home range estimate (rounded to nearest integer)	Carrying capacity using 2 km^2 home range estimate (rounded to nearest integer)
A	638	529	53	265
B	101	73	7	37
C	100	80	8	40
D	44	33	3	17
E	26	22	2	11
F	79	62	6	31
G	75	59	6	30
H	50	41	4	21
I	51	38	4	19
J	246	199	20	100
K	146	122	12	61

Roads

Figure 5 shows major and B roads overlaid onto a map of woodland cover in Cumbria, to indicate where they lie in relation to potential pine marten habitat. At a county-wide scale, there are some obvious barriers to pine marten dispersal, especially the M6 motorway, a PRN road which runs directly through the county. Several other PRN roads separate north and east Cumbria from the rest

of the county, suggesting that pine martens moving between core woodland habitats are likely to find dispersal between north and east Cumbria and the Lake District difficult. The relevance of these roads to pine marten mortality depends on their proximity to habitat, and figure 6 demonstrates that traffic poses a higher threat for pine martens in north-western and south-eastern parts of complex A, and around high-risk roads running through complexes F, G and H.

Observation of traffic flow data points overlaid onto a road type map (fig. 7) indicate that traffic flow is broadly correlated with higher road classification. This is supported by a statistical analysis of Dutch pine marten roadkill records, which found that road type is a highly significant predictor of road mortality (Stringer *et al.*, 2018).

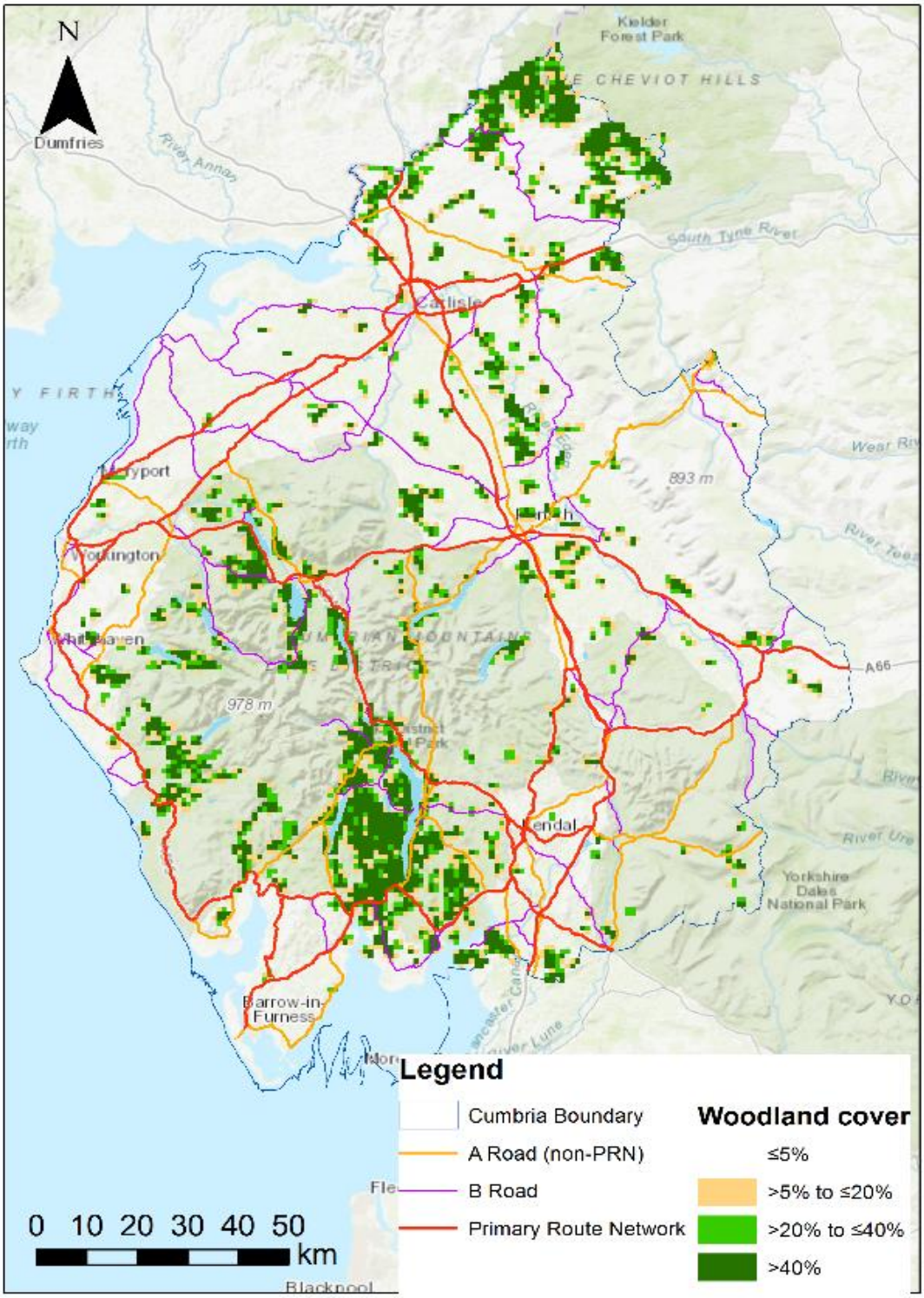

Figure 5: Major and B roads in Cumbria

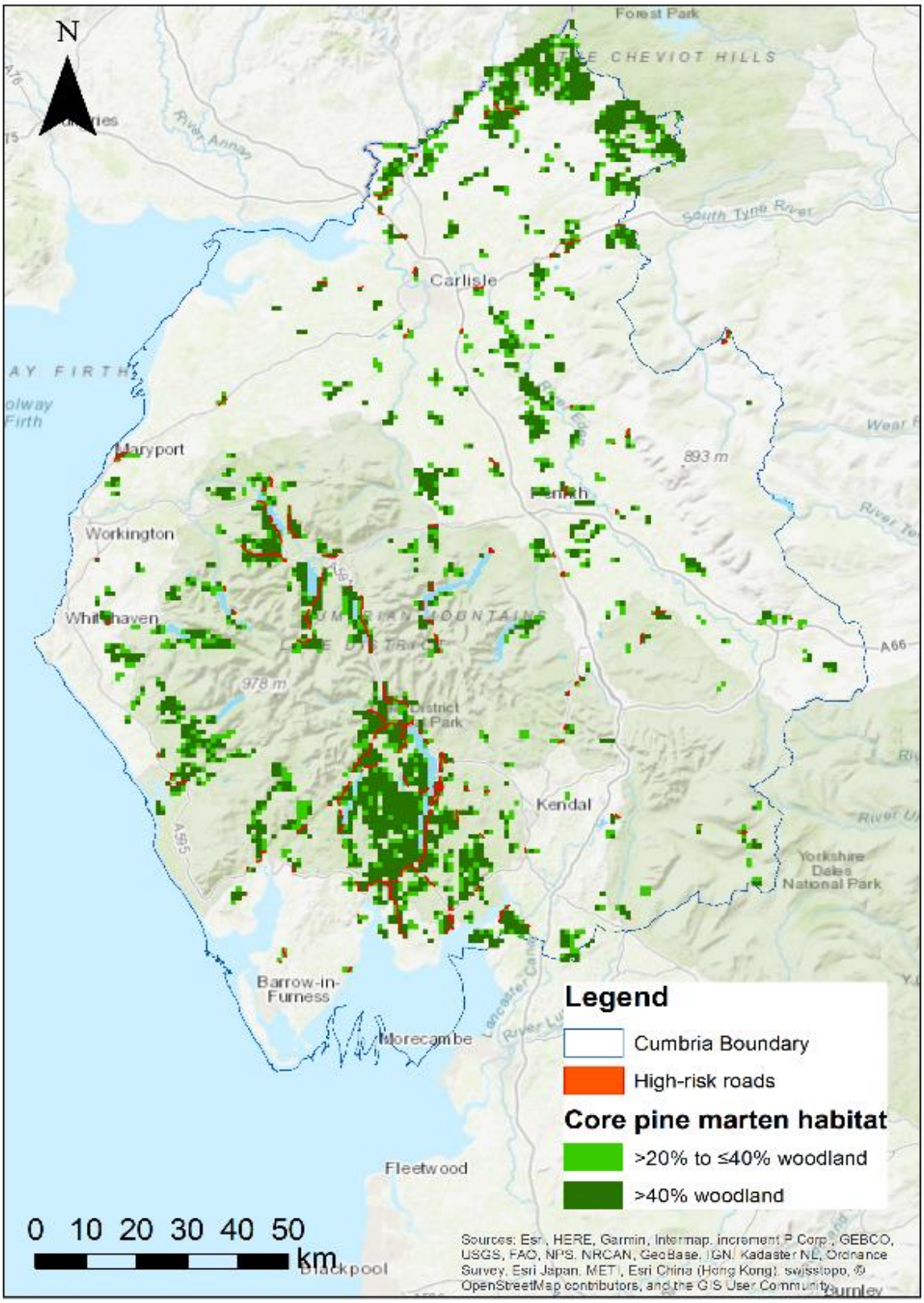

Figure 6: High-risk roads

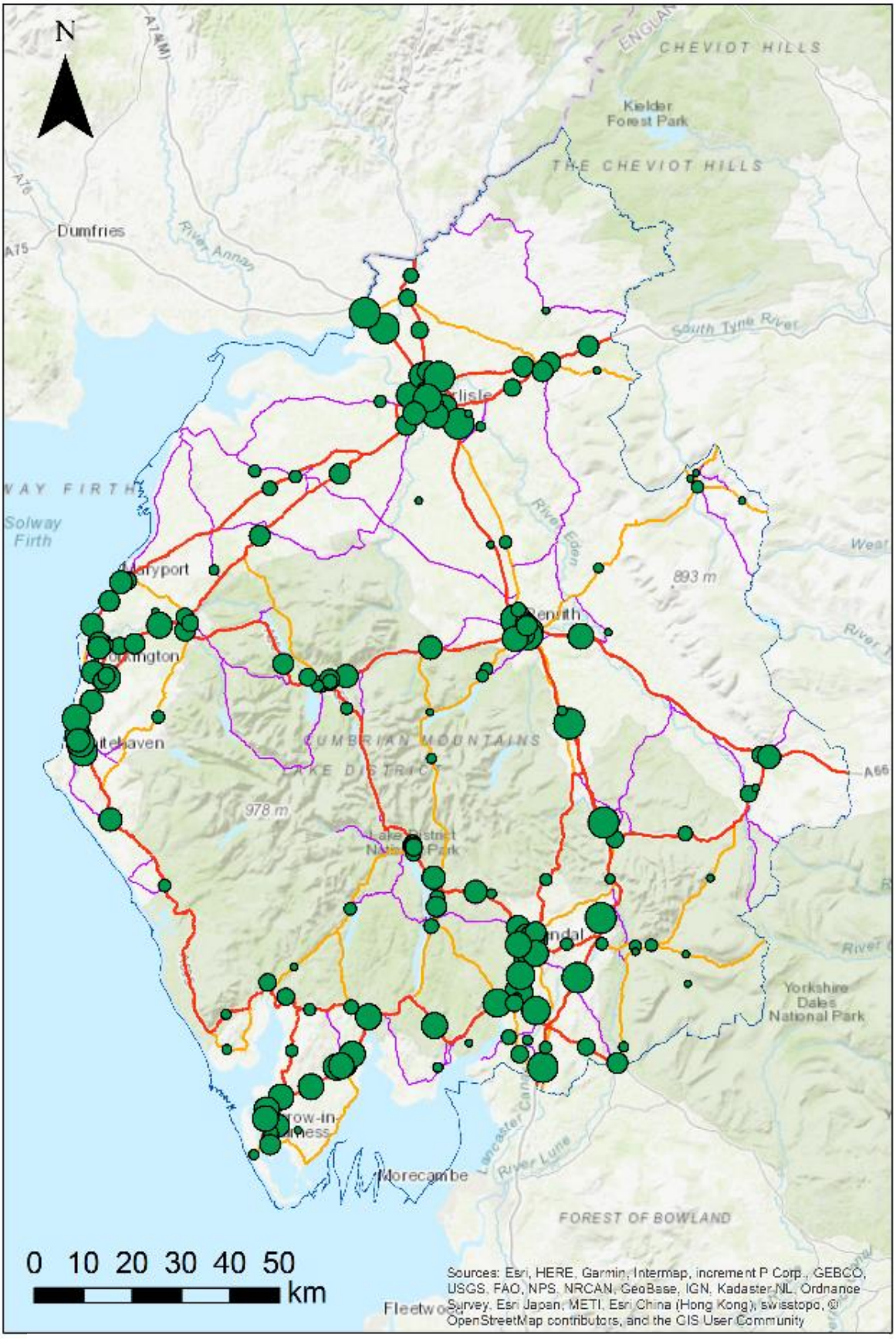

Figure 7: Annual Average Daily Flow of traffic, 2017. A larger circle size indicates a higher AADF record.

Summary of results

The results of the analyses carried out in this study suggest that there is sufficient connected woodland in Cumbria to support a translocated population of pine martens. There are several candidate areas for translocation, but habitat complex A, situated in and around Grizedale forest, is the most promising. It covers a large area, with a roughly estimated carrying capacity of 52-265 individuals, and is closely connected to habitat complex B. Furthermore, habitat complex A consists largely of FC land. This is advantageous because the FC is part of the partnership of conservation bodies interested in translocating pine martens to Cumbria.

Table 4: Examples of pine martens living in fragmented woodland (<40% woodland cover)						
Country	**Location**	**Habitat type**	**Woodland cover (%)**	**Mean woodland patch size**	**Notes**	**Reference**
Scotland	Scottish Highlands	Primarily conifer plantations Moorland/peatland/ agricultural matrix	20-40	0.25km^2	"Our predictions suggest pine martens will occupy habitat near human development or agricultural land, provided the broader area contains a baseline level of wooded habitat (i.e. 0.25 km^2 patches with a minimum of 20–40% wooded cover)"	(Moll *et al.*, 2016)
Scotland	Morangie	Lowland mixed conifer	36.9			(Caryl *et al.*, 2012, table 2)
Scotland	Kinlochewe	Fragmented upland conifer	4.1			(Balharry, 1993; Caryl *et al.*, 2012, table 2)
Scotland	Strathglass	Lowland mixed conifer	16.5			(Balharry, 1993; Caryl *et al.*, 2012, table 2)
Scotland	Novar	Lowland mixed conifer	18.3			(Halliwell, 1997;Caryl *et al.*, 2012, table 2)

France	Ardennes	Bocage (woodland groves, hedgerows, matrix of pasture and cultivated fields)	27	1.2 ha = 0.12 km^2		(Pereboom *et al.*, 2008)
France	Buzancy, Ardennes	Bocage (see above)	12	1.2 ha = 0.12 km^2		(Mergey *et al.*, 2011; Mergey-Barbe, 2011)
France	Bresse	Bocage (see above)	17	69 ha = 0.69 km^2	NB: bocage includes extensive, tree-lined hedgerows, unlike the smaller hedgerows common in Britain (Birks, 2017). "Weak and highly fragmented forested cover… is clearly not detrimental to the functional connectivity"	(Mergey *et al.*, 2012, table 4; Larroque *et al.*, 2016)
France	Ardennes	Bocage (see above)	23	181ha = 1.81 km^2	See above	(Mergey *et al.*, 2012)
France	Isère	Heterogenous woodland landscape – mountainous, with large towns	38	155ha = 1.55 km^2		(Mergey *et al.*, 2012, table 4)
Italy	W River Po plain	Deciduous riparian woodlands in an intensively cultivated plain	e.g. 2.4, 16.2		24 circular plots, each 10$km^{2.}$ Woodland cover not given for all plots, but "for 48.5% of records the percentage of woods… was less than 20%"	(Balestrieri *et al.*, 2010, fig. 3)

Italy	R. Ticino, Lombardy	Riparian woodland corridors in an intensively cultivated plain	0.9-57.8		21 grid squares, each 4km^2, many with less than 20% cover.	(Balestrieri *et al.*, 2015, table 3)
Spain	Basque Country	Mosaic of forestry plantations and remnant deciduous forests, agricultural and urban matrix	57 (see notes)		No figure given beyond whole-region (7235km^2) woodland cover, but woodland described as "fragmented", with areas of "high fragmentation", so woodland cover presumably less than 40% in places.	(Ruiz-Gonzalez *et al.*, 2015)

Discussion

Biological feasibility of a translocation, against the IUCN gold standard

I have undertaken the first stage of an assessment of the biological feasibility of a translocation of pine martens to Cumbria. Table 5 assesses how my study addresses the relevant sections of the IUCN guidelines (IUCN/SSC, 2013).

My study has laid the groundwork for further research, particularly more detailed analysis of promising candidate sites. Areas for further study are summarised here and discussed specifically under the following headings. **Factors affecting the reliability of the data and field surveys** underlying this assessment should be scrutinised and improved. At Grizedale and other candidate translocation areas, **field surveys** including ground-truthing work and tree surveys should take place: for example, assessments of structural complexity and tree age. Landscape-scale **dispersal potential** for pine marten populations should be investigated, and research into Cumbrian grey squirrels (*Sciurus carolinensis* Gmelin) gives useful insights into likely dispersal paths. **Modelling** will play an important role here; landscape connectivity and resistance modelling and PVA (population viability analysis) are essential for a more rigorous assessment of whether Cumbria has sufficiently connected habitat, of high enough quality, to suggest that a translocated population would establish successfully. Critically, a **social feasibility** assessment should also be conducted, and as part of this the community appeal of the pine marten's benefits for conservation of red squirrel (*Sciurus vulgaris* L.) should be assessed. This has added importance, since BOOM has submitted a bid to the Heritage Lottery Fund, which funds projects that affect natural and community heritage.

Table 5: Compliance of this feasibility assessment with IUCN guidelines

Section	Addressed by results?
5.1.1 Biological feasibility – Basic biological knowledge (Also Annex 5.1)	• Yes: pine marten habitat preferences and use of fragmented habitats have been reviewed, and used to inform mapping methodology and the conclusions drawn. • No: Modelling, such as resistance modelling and population viability analysis, should be conducted to confirm the suggestions made in this paper
5.1.2 Biological feasibility - Habitat	• Yes: Availability of habitat, and its connectivity, have been mapped and assessed

	• Yes: structural complexity (useful for denning sites), along with habitats required for the entire life cycle of the pine marten, were considered
7.1 Selecting release sites and areas	• Yes: Candidate release areas were based on size, woodland cover, and connectivity, taking into account potential mortality and dispersal barriers from roads

Factors affecting the reliability of the habitat suitability assessment

The CORINE dataset is from 2012, so land cover records could be out of date in some areas. Observations made during ground-truthing (fig. 2), and during drives around the Lake District, suggested that the CORINE 2012 land cover data is broadly representative of the current ground cover. Furthermore, the CORINE 2018 dataset was released in December 2018 (Copernicus Programme, 2018), meaning that analysis of woodland and other pine marten habitats in Cumbria could be repeated with a more current dataset if desired.

Clear-felling of plantation coupes on FC-owned land (e.g. Grizedale, Whinlatter) could present risks of large-scale pine marten habitat loss, but this is planned far in advance and could be predicted by liaising with FC officers, and possibly using FC datasets. Another limitation of the land cover data is that it does not show heterogeneity, structural complexity, tree size or tree age. These factors can greatly influence the suitability of a habitat for pine martens, for example for foraging for *Microtus* voles (Caryl *et al.*, 2012), or for denning sites, and are therefore important to take into consideration when determining the feasibility of a woodland for translocation. FC datasets hold information about tree age on FC land, but field surveys of candidate translocation sites are vital to obtain accurate data for non-FC woodland, and to validate FC datasets (Stringer *et al.*, 2018). Ground-truthing is also essential to establish the state of grassland – though mapped on CORINE as natural grassland, such habitats could be rotationally grazed, meaning they might not be in the tussocky state that pine martens prefer for foraging (Caryl, 2008).

Furthermore, my review of pine marten habitat preferences is based on records of pine martens from markedly differing latitudes and ecosystems – Scotland, Spain and Italy, for example. Therefore, caution should be exercised when making predictions of the suitability for pine martens of Cumbrian habitat based on a wide geographical range of studies. Findings and experiences from the Vincent Wildlife Trust's Pine Marten Recovery Project in Wales, including monitoring of the translocated pine martens by intensive radio-tracking and post-mortem examination of carcasses, will provide useful data and insights (MacPherson, 2017, 2018). These findings, from an ecologically,

geographically and climatically similar landscape to Cumbria, can further inform feasibility assessments for a Cumbrian translocation. A Pine Marten Conservation Handbook and papers based on the project's radio-tracking, disease risk analysis and stakeholder engagement are all due for publication shortly (J. MacPherson, 2018, *pers. comm.*). Any further assessment work for a Cumbrian translocation should take into account these and other findings from the Welsh translocation.

Field surveys to underpin feasibility assessments

As pine martens are so elusive, distribution surveys often rely on experts surveying transects of likely or known habitat and searching for scat, such as in recent Scottish distribution surveys (Croose *et al.*, 2013, 2014). This is difficult to standardise and open to sampling bias. Hence, several methods are often employed to reduce the uncertainty of surveys for pine martens and other *Martes* species, including DNA testing, GPS tracking, radio tracking, camera traps, hair traps and the use of sniffer dogs (Long and MacKay, 2012; Thompson *et al.*, 2012).

The assumptions of habitat suitability in this study are based on models and studies that use these imperfect survey techniques on differing habitats, often with inconsistent findings. Recorded pine marten home range sizes vary greatly between woodlands of different types (Caryl, 2008), making it difficult to draw any conclusions on the carrying capacity of Cumbrian woodlands. The models that inform translocation feasibility assessments are developed and tested using field data (Powell *et al.*, 2012; MacPherson *et al.*, 2014), but the imperfect field survey techniques for mustelids like the pine marten often produce limited data (Long and MacKay, 2012). This can reduce the reliability of the models, casting doubts on the conclusions drawn from them.

Insights on barriers to dispersal from grey squirrels

Pine martens and invasive grey squirrels are both woodland-dependent, semi-arboreal, opportunistic feeders and can persist in fragmented landscapes (Mathews *et al.*, 2018), therefore they often occupy the same habitats (Sheehy and Lawton, 2014; Sheehy *et al.*, 2018). Least cost modelling of grey squirrel habitat in Cumbria, empirically validated with genetic analysis and GPS telemetry, has indicated that the almost treeless terrain of the Cumbrian mountains at altitudes above 250m acts a barrier to grey squirrel dispersal. This validates the suggestions, drawn from figure 3, that the mountains of central Cumbria may functionally separate north and south Cumbrian pine marten populations. Dispersal routes into north Cumbria from Northumberland and the Scottish Borders have also been identified (Stevenson, 2012). This suggests that future pine marten populations in Kielder Forest, Northumberland, could use the same routes to enter northern Cumbria, as southern Scottish martens appear to be establishing themselves in Kielder (Forestry

Commission England, 2018). However, basic preliminary modelling has suggested that it could be several decades before pine martens reach Cumbria this way (D. Brady, 2018, *pers. comm.*).

Considering that translocations are often costly and work-intensive projects, and should only be undertaken where there is a clear conservation benefit (IUCN/SSC, 2013; Carter *et al.*, 2017), it seems that suitable sites south of the mountains should be prioritised for reinforcement as populations are much less likely to recover there by natural dispersal from recovering populations. Furthermore, the BOOM project, a potential source of funding and research, focusses on translocations in south Cumbria (University of Cumbria, 2018).

Modelling

Modelling is essential for a rigorous, quantitative and reliable assessment of landscape-scale connectivity and resistance, and for a PVA which can suggest the minimum number of individuals in a translocated population. Therefore I have reviewed some potential modelling or analysis software which might be used for future modelling work (table 6).

Table 6: Review of potential modelling and analysis software for future work

Modelling/analysis software	Description	Previous use for pine martens	Free?
FRAGSTATS (McGarigal *et al.*, 2012)	Landscape-scale fragmentation analysis	(Pereboom *et al.*, 2008; Mergey *et al.*, 2011, 2012; Larroque *et al.*, 2016)	Free
HexSim (Schumaker and Brookes, 2018)	Spatially explicit, individual-based life history simulator	(Stringer *et al.*, 2018)	Free
MaxEnt (Phillips *et al.*, 2017)	Maximum-entropy niche and distribution modelling	(MacPherson *et al.*, 2014)	Free
RAMAS Metapop (Akçakaya and Root, 2013)	Metapopulation modelling for PVA	None found	Paid
Vortex (Lacy and Pollak, 2014)	PVA software with speciality in modelling extinction vortices	(Stringer *et al.*, 2018)	Free

Building social acceptability

The IUCN/SSC (2013) emphasise that consideration of social, economic and political acceptability are vital for the success of a translocation. Failure to secure local community support can be highly detrimental to a project's success; in Ireland, many reintroduced white-tailed sea eagles were killed by poisoned fox bait, set by farmers who (ostensibly) did not want to stop poisoning the foxes that prey on their lambs. One eagle was even shot (O'Rourke, 2014). Hence, building social acceptability should be core to a Cumbrian translocation project, and this is where the charisma of both the pine marten and the red squirrel may be advantageous.

The native red squirrel, endangered in England (Mathews *et al.*, 2018) is a charismatic and popular animal in Cumbria. This is evidenced by the multiple Cumbrian volunteer groups that work to monitor and conserve it and sometimes, controversially, to cull invasive greys (Parrot *et al.*, 2009; Barkham, 2017; Lay, 2017). Sheehy *et al.* (2018) have shown that recovering Scottish pine marten populations directly suppress grey squirrel populations, resulting in an increase in occupancy by reds.

Despite control efforts, grey squirrels were detected at around 40% of sites in the North Lakes red squirrel stronghold complex in 2017 and 2018 (Sapsford, 2018). It is therefore likely that pine martens would help to conserve the charismatic red squirrel in Cumbria. Hence, the popularity of these two species, and the local distaste for grey squirrels, could significantly contribute to the social acceptability of a pine marten translocation project. Furthermore, it is important to involve the local community (especially land managers) from the outset, to make sure they feel their opinions are valued. This greatly contributed to the success of the Welsh translocation (D. Bavin, 2018, *pers. comm.*).

Conclusions and further work

It is imperative that translocations are based on extensive scientific groundwork so that they are ecologically and socially successful. Global guidelines, studies of the biology of the focal species and its close relatives, and experiences from previous translocations can all inform such groundwork. In this case, I have found that a woodland complex centred on Grizedale Forest offers the most promising candidate area for a reinforcement of the relict Cumbrian pine marten population. I recommend that further biological, ecological, social and disease risk feasibility assessments should be conducted to determine whether Cumbria presents a suitable area for a reinforcement project.

Translocations to mid-Wales and Gloucestershire are predicted to restore the pine marten to large swathes of Wales and parts of central England within 30 years. However, this leaves northern England almost free of pine martens for the foreseeable future. Thus, it is important to investigate a

translocation to Cumbria. It could aid the recovery of the pine marten in England and Wales and increase the likelihood of establishing a metapopulation across England, Wales and southern Scotland.

The British rewilding movement is currently enjoying a surge in interest, both from the public and within the ecology sector. It is not only pine martens that are involved; at recent rewilding conferences there has been talk of beavers, lynx, and wolves, and of landscape-scale rewilding projects. Set in this context, a Cumbrian pine marten translocation is a timely, interesting and inspiring project to investigate.

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Bibliography

Akçakaya, H. R. and Root, W. T. (2013) 'Ramas Metapop: Viability Analysis for Stage-structured Metapopulations (version 6)'. Setauket, New York: Applied Biomathematics.

Aubry, K. B. *et al.* (eds) (2012) *Biology and conservation of martens, sables, and fishers : a new synthesis*. Ithaca, NY: Cornell University Press. Available at: https://ebookcentral.proquest.com/lib/oxford/reader.action?docID=3138398&query= (Accessed: 27 June 2018).

Balestrieri, A. *et al.* (2010) 'Range expansion of the pine marten (Martes martes) in an agricultural landscape matrix (NW Italy)', *Mammalian Biology*, 75(5), pp. 412–419. doi: 10.1016/j.mambio.2009.05.003.

Balestrieri, A. *et al.* (2015) 'Distribution and habitat use by pine marten Martes martes in a riparian corridor crossing intensively cultivated lowlands', *Ecological Research*, 30(1), pp. 153–162. doi: 10.1007/s11284-014-1220-8.

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

Barkham, P. (2017) ‘Red squirrels: 5,000 volunteers sought to save species – and help kill invasive greys’, *The Guardian*, 24 February. Available at: https://www.theguardian.com/environment/2017/feb/24/red-squirrels-5000-volunteers-sought-to-save-species-and-help-kill-invasive-greys.

Birks, J. (2017) *Pine Martens*. Stansted, UK: Whittet Books.

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

Bossard, M., Feranec, J. and Otahel, J. (2000) *CORINE land cover technical guide – Addendum 2000*. Copenhagen, Denmark. Available at: https://www.eea.europa.eu/publications/tech40add.

Bright, P. W. and Smithson, T. J. (2001) ‘Biological invasions provide a framework for reintroductions: selecting areas in England for pine marten releases’, *Biodiversity and Conservation*, 10(8), pp. 1247–1265. doi: 10.1023/A:1016654725190.

Carter, I., Foster, J. and Lock, L. (2017) ‘The Role of Animal Translocations in Conserving British Wildlife: An Overview of Recent Work and Prospects for the Future’, *EcoHealth*, pp. S7–S15. doi: 10.1007/s10393-015-1097-1.

Caryl, F. M. (2008) *Pine marten diet and habitat use within a managed coniferous forest*. University of Stirling. Available at: https://dspace.stir.ac.uk/bitstream/1893/2261/1/Fiona Mae Caryl. Pine Marten Diet %26 Habitat Use Within A Managed Coniferous Forest.pdf (Accessed: 4 July 2018).

Caryl, F. M. *et al.* (2012) ‘The seasonal diet of British pine marten determined from genetically identified scats’, *Journal of Zoology*. Edited by A. Kitchener. Wiley/Blackwell (10.1111), 288(4), pp. 252–259. doi: 10.1111/j.1469-7998.2012.00951.x.

Caryl, F. M., Quine, C. P. and Park, K. J. (2012) ‘Martens in the matrix: the importance of nonforested habitats for forest carnivores in fragmented landscapes’, *Journal of Mammalogy*, 93(2), pp. 464–474. doi: 10.1644/11-MAMM-A-149.1.

Centre for Ecology & Hydrology (2015) *Land Cover Map 2015*. Available at: digimap.edina.ac.uk (Accessed: 29 July 2018).

‘Convention on Biological Diversity (opened for signature 5 June 1992, entered into force 29 December 1993)’ (1992), 1760 UNTS, p. 79. Available at: https://treaties.un.org/doc/Treaties/1992/06/19920605 08-44 PM/Ch_XXVII_08p.pdf (Accessed: 16 December 2018).

'Convention on the Conservation of European Wildlife and Natural Habitats' (1979) *ETS*, 104. Available at: https://www.coe.int/en/web/conventions/full-list/-/conventions/rms/0900001680078aff (Accessed: 16 December 2018).

Copernicus Programme (2018) *Corine Land Cover now updated for the 2018 reference year*. Available at: https://land.copernicus.eu/news/corine-land-cover-now-updated-for-the-2018-reference-year (Accessed: 28 December 2018).

Croose, E. *et al.* (2014) 'Distribution of the pine marten (Martes martes) in southern Scotland in 2013', *Scottish Natural Heritage Commissioned Report No. 740*. Available at: http://swiftecology.co.uk/publications/Distribution of the pine marten in southern Scotland.pdf (Accessed: 16 March 2018).

Croose, E., Birks, J. D. S. and Schofield, H. W. (2013) 'Expansion zone survey of pine marten (Martes martes) distribution in Scotland.', *Scottish Natural Heritage Commissioned Report No. 520*, p. viii + 47. Available at: https://www.nls.uk/e-monographs/2013/520.pdf (Accessed: 15 October 2018).

Croose, L. (2012) 'Pine Marten Update', *Vincent Wildlife News*, (November), p. 2. Available at: https://www.vwt.org.uk/wp-content/uploads/2015/04/vwt-newsletter-nov-2012.pdf (Accessed: 6 November 2018).

Defra (2018) *A Green Future: Our 25 Year Plan to Improve the Environment*. London. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf (Accessed: 16 December 2018).

Edmunds, S. (2014) *Shropshire pine marten report*. Available at: http://shropshireecology.co.uk/Pine_Martens_2014.pdf (Accessed: 25 September 2018).

European Environment Agency (2012) 'CORINE land cover data'. Available at: http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012.

Forestry Commission (2016) *National Forest Inventory*. Forestry Commission. Available at: https://www.forestry.gov.uk/inventory (Accessed: 23 May 2018).

Forestry Commission England (2018) 'Pine marten returning to Kielder Water & Forest [Press release]', 15 August. Available at: https://www.forestry.gov.uk/newsrele.nsf/webnewsreleases/861f68fd4f74dfaf802582ea00322d26 (Accessed: 27 September 2018).

Halliwell, E. C. (1997) *The Ecology of Red Squirrels in Scotland in relation to Pine Marten Predation*. University of Aberdeen, Scotland.

Herrero, J. *et al.* (2016) 'Martes martes', *The IUCN Red List of Threatened Species*. IUCN Global Species Programme Red List Unit, 2016, p. e.T12848A45199169. doi: 10.2305/IUCN.UK.2016-1.RLTS.T12848A45199169.en.

IUCN/SSC (2013) *Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0*. Gland, Switzerland. Available at: https://portals.iucn.org/library/efiles/documents/2013-009.pdf (Accessed: 16 March 2018).

Jordan, N. R. (2011) *A Strategy for Restoring the Pine Marten to England and Wales*. Available at: http://www.vwt.org.uk/wp-content/uploads/2015/04/jordan-n-2011-strategy-for-restoring-the-pine-marten-to-england-and-wales.pdf (Accessed: 16 March 2018).

Lacy, R. C. and Pollak, J. P. (2014) 'Vortex: A stochastic simulation of the extinction process'. Brookfield, Illinois, USA: Chicago Zoological Society. Available at: http://vortex10.org/Vortex10.aspx.

Lake District National Park Authority (2017) *Lake District facts and figures*. Available at: http://www.lakedistrict.gov.uk/learning/factsandfigures (Accessed: 28 December 2018).

Larroque, J. *et al.* (2016) 'Divergent landscape effects on genetic differentiation in two populations of the European pine marten (Martes martes)', *Landscape Ecology*, 31(3), pp. 517–531. doi: 10.1007/s10980-015-0281-6.

Lay, K. (2017) 'Red squirrel group: We're called racist for shooting greys', *The Times*, 10 July. Available at: https://www.thetimes.co.uk/article/red-squirrel-group-were-called-racist-for-shooting-greys-5z7b3gqt9.

Long, R. A. and MacKay, P. (2012) 'Noninvasive Methods for Surveying Martens, Sables, and Fishers', in Aubry, K. B. et al. (eds) *Biology and conservation of martens, sables, and fishers: a new synthesis*. Ithaca, NY: Cornell University Press, pp. 320–342.

MacPherson, J. *et al.* (2014) *Feasibility Assessment for Reinforcing Pine Marten Numbers in England and Wales*. Ledbury, Herefordshire. Available at: http://www.vwt.org.uk/wp-content/uploads/2015/04/Feasibility-Assessment-for-Reinforcing-Pine-Martens-in-England-and-Wales.pdf.

MacPherson, J. (2017) 'Pine Marten Translocations: The Road to Recovery and Beyond', *In Practice*, (95), pp. 32–36.

MacPherson, J. (2018) 'Pilot pine marten reinforcement in mid-Wales, UK', in Soorae, P. S. (ed.) *Global Reintroduction Perspectives: 2018. Case studies from around the globe.* Gland, Switzerland; Abu Dhabi, UAE: IUCN/SSC Reintroduction Specialist Group; Environment Agency - Abu Dhabi, pp.

233–237. doi: 10.2305/IUCN.CH.2018.08.en.

MacPherson, J., Bavin, D. and Croose, E. (2015) 'Return of the Native', *British Wildlife*, 26(3), pp. 154–159.

Mathews, F. *et al.* (2018) *A Review of the Population and Conservation Status of British Mammals. A report by the Mammal Society under contract to Natural England, Natural Resources Wales and Scottish Natural Heritage.* Peterborough.

McGarigal, K., Cushman, S. A. and Ene, E. (2012) 'FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps'. University of Massachusetts, Amherst, USA. Available at: http://www.umass.edu/landeco/research/fragstats/fragstats.html.

Mergey-Barbe, M. (2011) *Abondance des populations de Martre d'Europe (Martes martes) dans deux paysages distincts: le massif forestier et le bocage agricole*. Reims, France.

Mergey, M. *et al.* (2012) 'Linking habitat characteristics with genetic diversity of the European pine marten (Martes martes) in France', *European Journal of Wildlife Research*, 58(6), pp. 909–922. doi: 10.1007/s10344-012-0634-2.

Mergey, M., Helder, R. and Roeder, J.-J. (2011) 'Effect of forest fragmentation on space-use patterns in the European pine marten (Martes martes)', *Journal of Mammalogy*, 92(2), pp. 328–335. doi: 10.1644/09-MAMM-A-366.1.

Moll, R. J. *et al.* (2016) 'Clarifying habitat niche width using broad-scale, hierarchical occupancy models: a case study with a recovering mesocarnivore', *Journal of Zoology*, 300(3), pp. 177–185. doi: 10.1111/jzo.12369.

National Species Reintroduction Forum (2014) *The Scottish Code for Conservation Translocations and Best Practice Guidelines for Conservation Translocations in Scotland Version 1.1*. Available at: https://www.nature.scot/sites/default/files/Publication 2014 - The Scottish Code for Conservation Translocations.pdf (Accessed: 16 March 2018).

O'Rourke, E. (2014) 'The reintroduction of the white-tailed sea eagle to Ireland: People and wildlife', *Land Use Policy*. Pergamon, 38, pp. 129–137. doi: 10.1016/j.landusepol.2013.10.020.

ONS (2018) 'Population Estimates for UK, England and Wales, Scotland and Northern Ireland: Mid-2017'. Office for National Statistics. Available at: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland.

Ordnance Survey (2017) 'OS Open Roads User guide and technical specification'. Southampton. Available at: www.os.uk (Accessed: 26 December 2018).

Parrot, D. *et al.* (2009) *Review of red squirrel conservation activity in northern England*, *NECR019*. Sheffield.

Pereboom, V. *et al.* (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(9), pp. 983–991. doi: 10.1139/Z08-076.

Phillips, S. J., Dudík, M. and Schapire, R. E. (2017) 'Maxent software for modeling species niches and distributions'. Available at: http://biodiversityinformatics.amnh.org/open_source/maxent.

Powell, R. A. *et al.* (2012) 'Evaluating Translocations of Martens, Sables, and Fishers: Testing Model Predictions with Field Data', in Aubry, K. B. et al. (eds) *Biology and conservation of martens, sables, and fishers: a new synthesis*. Ithaca, NY: Cornell University Press, pp. 93–137.

Ruette, S. *et al.* (2015) 'Comparative survival pattern of the syntopic pine and stone martens in a trapped rural area in France', *Journal of Zoology*, 295(3), pp. 214–222. doi: 10.1111/jzo.12201.

Ruiz-Gonzalez, A. *et al.* (2015) 'Isolation by distance, resistance and/or clusters? Lessons learned from a forest-dwelling carnivore inhabiting a heterogeneous landscape', *Molecular Ecology*. Wiley/Blackwell (10.1111), 24(20), pp. 5110–5129. doi: 10.1111/mec.13392.

Sapsford, B. (2018) *2018 Annual Squirrel Monitoring Programme Results*. Gosforth, Newcastle upon Tyne. Available at: https://www.rsne.org.uk/sites/default/files/2018-10/FINAL_Annual Monitoring Report 2018.pdf (Accessed: 16 December 2018).

Schumaker, N. H. and Brookes, A. (2018) 'HexSim: a modeling environment for ecology and conservation', *Landscape Ecology*, 33, pp. 197–211.

Shaw, G. and Livingstone, J. (1992) 'The pine marten - its reintroduction and subsequent history in the Galloway Forest Park', *Transactions of the Dumfriesshire and Galloway Natural History and Antiquarian Society, 3rd Series*, 67, pp. 1–7.

Sheehy, E. *et al.* (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', *Proceedings of the Royal Society B: Biological Sciences*, 285(1874), p. 20172603. doi: 10.1098/rspb.2017.2603.

Sheehy, E. and 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. Springer Netherlands, 23(3), pp. 753–774. doi: 10.1007/s10531-014-0632-7.

Shropshire Wildlife Trust (2017) *Shropshire pine martens*. Available at: https://www.shropshirewildlifetrust.org.uk/pinemartenproject (Accessed: 25 September 2018).

Soorae, P. S. (ed.) (2018) *Global Reintroduction Perspectives: 2018. Case studies from around the globe*. Gland, Switzerland; Abu Dhabi, UAE: IUCN/SSC Reintroduction Specialist Group; Environment Agency - Abu Dhabi. doi: 10.2305/IUCN.CH.2018.08.en.

Stevenson, C. D. (2012) *Modelling habitat networks and dispersal in the grey squirrel Sciurus carolinensis*. University of Lancaster.

Stringer, A. P. *et al.* (2018) *The feasibility of reintroducing pine martens (Martes martes) to the Forest of Dean and lower Wye Valley*. Available at: https://www.gloucestershirewildlifetrust.co.uk/sites/default/files/2018-05/The feasibility of reintroducing pine martens to the Forest of Dean and lower Wye Valley.pdf (Accessed: 6 October 2018).

Stuart, P. and Lawton, C. (2015) 'Age estimation of roadkill Pine Martens (Martes martes) collected in Ireland', *Irish Naturalists' Journal*, 34, pp. 73–74. Available at: https://s3.amazonaws.com/academia.edu.documents/45099293/Age_estimation_of_roadkill_Pine_Martens_20160426-11628-wn1des.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1545868186&Signature=B9x03HBJBivpzuvruk4QJmW0zhQ%253D&response-content-disposition=inline%25 (Accessed: 26 December 2018).

Thompson, C. M. *et al.* (2012) 'The Use of Radiotelemetry in Research on Martes Species: Techniques and Technologies', in Aubry, K. B. et al. (eds) *Biology and conservation of martens, sables, and fishers: a new synthesis*. Ithaca, NY: Cornell University Press, pp. 320–342.

University of Cumbria (2018) *Back On Our Map*. Available at: https://www.cumbria.ac.uk/business/projects/south-cumbria-species-restoration/ (Accessed: 6 November 2018).

Webster, J. A. (2001) 'A review of the historical evidence of the habitat of the Pine Marten in Cumbria', *Mammal Review*, 31(1), pp. 17–31. doi: 10.1046/j.1365-2907.2001.00070.x.

World Heritage Committee (2017) 'Decision : 41 COM 8B.30. The English Lake District (United Kingdom of Great Britain and Northern Ireland)', in *Decisions adopted during the 41st session of the*

World Heritage Committee. Krakow, Poland. Available at: https://whc.unesco.org/en/decisions/6902 (Accessed: 28 December 2018).

Management Report

From the outset, I was keen for my research project to be in the field of restoration ecology or rewilding, but I was unsure how best to conduct a short undergraduate research project in a field where results can take years or decades to appear. I initially spoke to a few potential supervisors, who confirmed my concerns and suggested that it could be a good idea to research the biodiversity of an established rewilding or restoration project, such as the Knepp Castle Estate. However, I then came into contact with Back On Our Map and the Cumbrian pine marten translocation project through initial discussions with my supervisor, Prof E.J. Milner-Gulland. Prof Milner-Gulland's ex-student Lee Schofield, who now works in nature conservation in Cumbria, had contacted her asking if she knew of any students who would be interested in some initial social or biological feasibility assessment for the translocation.

I eventually spoke on the phone in March 2018 with Mr Schofield to discuss what my research project could entail, and we quickly decided that I would find a biological feasibility assessment more interesting than a social feasibility assessment. Following this I met with Prof Milner-Gulland, with Mr Schofield joining by phone. We decided more firmly on the structure of my project, going away with some wider reading to do. After this reading, planning was put on hold in the build-up to second year examinations.

After examinations in Trinity term I spoke with Deborah Brady, who works on the BOOM project at the University of Cumbria, to learn more about BOOM and the situation regarding pine martens in Cumbria. In particular, we discussed mapping and modelling approaches. A Memorandum of Understanding was proposed, and I wrote a two-page research proposal, with a draft timeline. At this point, the intention was for me to undertake modelling work, with RAMAS Metapop eventually chosen as the modelling software.

I then conducted a six-day visit to Cumbria in mid-July, where I met with Ms Brady and other people involved in BOOM. I found it incredibly useful and productive to see the landscape and woodlands, ground-truth land cover maps, and have in-depth discussions with Ms Brady and others. During my visit, it became clear that habitat mapping alone was taking up considerable time, and that it might be outside the scope of an undergraduate project to produce a full model. Ms Brady, Prof Milner-Gulland and I decided after the Cumbria visit that my project should aim to primarily assess the feasibility of a translocation using land cover mapping.

I took a break from project work in August-September while I was on a month-long degree field trip. During Michaelmas term, I used ArcMap to manipulate CORINE and create a land cover map for Cumbria. This was at times a laborious process because ArcMap is a memory-intensive software and

my computer has limited capacity, so the mapping took far longer than necessary. To remedy this in future, I would try and source a more powerful computer so that the mapping and data analysis could be quicker. I submitted a final draft to Prof Milner-Gulland during the Christmas vacation, and redrafted according to her comments before the submission date on Monday of Week 2, Hilary Term.

Throughout the course of my project, I sent update documents with revised timetables to both Prof Milner-Gulland and Ms Brady, to keep all parties up to date. I also met with Prof Milner-Gulland throughout. I attended rewilding conferences in Cardiff (October 2018) and Cambridge (January 2019) to get a picture of the climate surrounding conservation translocations in the UK, to learn more about the debate surrounding translocations, and to learn from the experiences of the Welsh pine marten translocation.