The feasibility of reintroducing pine martens (*Martes martes*) to the Forest of Dean and lower Wye Valley

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Executive Summary

In summer 2016, Gloucestershire Wildlife Trust, The Vincent Wildlife Trust, and the Forestry Commission, supported by Forest Holidays and the Woodland Trust, began a collaborative project investigating the feasibility of reintroducing pine martens (*Martes martes*) to the Forest of Dean and lower Wye Valley. Pine martens are one of Britain's rarest mammals, and are predominantly restricted to Scotland and a recent reintroduction to Wales. They are a member of the weasel family that live at low density (1 per 100ha is considered a high-density population). Their main prey are small mammals, but they are a generalist omnivore with a broad and varied diet, for instance eating large quantities of berries when in season.

Species conservation: From 2015 to 2017, The Vincent Wildlife Trust successfully translocated 51 martens from Scotland to central Wales. Previous pine marten reintroductions show that increasing the size of the founder population, and the number of locations where releases occur, greatly improves the chance of population establishment. For instance, increasing the size of a release from 60 to 100 individuals has been predicted to more than double the chance of success. Our own population modelling shows that a release in the Forest of Dean will decrease the 50 yr extinction risk of the overall population from 22% to 5%. This is due to two populations mutually reinforcing each other with migrating individuals, decreasing extinction risk, the risk of inbreeding, and increasing overall levels of genetic diversity.

This study further investigated the potential costs and benefits of a reintroduction:

Biological feasibility – Here we assessed the suitability of habitat and modelled whether a stable population of pine martens could live in the release region. We identified a region of suitable habitat, with the capacity to support a core population of nearly 200 individuals. Foxes and roads may be key sources of mortality, however road density is comparable with areas of the Netherlands which support healthy pine marten populations. Our population viability analysis showed that a minimum of 40 animals would be required. Due to geographical barriers and limited dispersal corridors, a reintroduced population is most likely to predominantly expand to the west and north, before expanding to the east. This would reduce the time taken to link with the current Welsh population, and makes the Forest of Dean and Wye Valley area an advantageous location for increasing metapopulation success.

Ecological feasibility: The reintroduction of a generalist predator can have numerous positive effects for an ecosystem. By limiting the population size of our most common species they can let rarer species thrive, an important balancing effect for ecosystems. Pine martens have also been shown to have a negative effect on invasive non-native grey squirrels. In central Ireland, the natural recolonisation of the pine marten has led to the local extinction of grey squirrels from six counties. Results from Scotland suggest that pine martens may be influencing grey squirrel populations in a similar manner there. An ecological risk assessment was also completed to assess any risks to rare and protected species. The only high risk identified was the potential disturbance of large bat roosts within buildings. Any reintroduction project should include a mitigation and conservation plan for the horseshoe bat population in the region to address this risk.

Socio-economic feasibility: As a charismatic mammal, pine martens could be a useful tool in engaging people with nature and increasing ecotourism to the area, as well as potentially benefiting forestry businesses due to a reduction in grey squirrel numbers. However, enclosed populations of poultry such as pheasants and chickens, near or within woodlands, may be at risk from pine marten predation. Evidence is lacking as to how often they pose a threat in comparison to other predators such as foxes and mink. A reintroduction project would need to continue to work closely with gamekeepers and those involved in game sports to investigate potential mitigation options.

Community consultation: Community support is essential for the reintroduction to proceed. Results from initial formal stakeholder interviews completed by an independent project partner suggested a broad support for the principles behind the project. Many stakeholders suggested that potential concerns could be addressed by the detailed monitoring of impacts post-release. An on-street survey was thought to be the most robust methodology for surveying local opinion, and showed 71% in favour of the reintroduction, 3% against, and 26% undecided. This was further supported by an online opinion survey, and collecting feedback at community events. The shooting community clearly had greater concerns about the potential reintroduction than the wider community, however there was still support among this group, with 46% in favour, 32% against, and 22% undecided.

1. Project goals and justification

1.1 Context

The European pine marten (*Martes martes*) is a mustelid found across Europe, from Ireland to Russia. However, due to historical trapping by Victorian gamekeepers, coupled with loss of habitat, its range in Britain was severely reduced. By the early 20th century they were restricted to the North-West coast of Scotland, and some scattered pockets in England and Wales [1]. Since then the pine marten has recovered in Scotland, and is now found across much of northern Scotland [2]. However, the population has not recovered in England and Wales [3].

The pine marten is still the second rarest native carnivore in the UK and a UK S41 priority species. The IUCN assessment of European pine marten argue its biggest threat is still from hunting and persecution across its range [4]. It has been the subject of several conservation initiatives. For instance, pine martens were reintroduced into Galloway Forest, in southern Scotland, in 1980 [5]. This population has expanded slowly, but pine martens are now found in a scattered distribution across much of southern Scotland [2]. Creating a second stable population in the UK outside Scotland would greatly improve their conservation status in the UK [6]. Hence, in 2014 a study assessed the feasibility of reintroducing pine martens to England and Wales [7]. This was followed by a reintroduction of 51 individuals into central Wales. Establishing a second population could be useful to maximise the chance of metapopulation establishment and success in Wales and west England. This is for two key reasons:

- Inbreeding depression and a lack of genetic diversity are key concerns in conservation biology due to their range of potential impacts on individual and population fitness [8]. Maintaining genetic variation also helps maintain long term adaptive potential. This is important so that a population can evolve and adapt to future threats such as climate change [9]. The 51 animals released into central Wales are unlikely to constitute a population that will be able to avoid inbreeding depression. An example of this is seen in a similar reintroduction of 85 American marten (*Martes americana*) into Michigan, USA [10]. This population showed clear signs of moderate inbreeding after 20-25 years, and reinforcement of this population will likely be essential for long term survival.
- Meta-populations consist of multiple semi-isolated populations, reinforcing each other through migration. Natural stochastic variation within a single population becomes less important to population stability when within a wider meta-population, as fluctuating populations may be reinforced by other populations. The Wales/west England pine marten metapopulation likely currently consists of a single major reintroduced population in central Wales, with the possibility of some small scattered populations within dispersal range [3]. The establishment of a second major population within the metapopulation will greatly improve the likelihood of long term metapopulation persistence [11] (see 3.6 for further details).

The alternative to a conservation translocation is to allow the Scottish pine marten population to expand naturally. However, the Welsh population is not expected to be reinforced by Scottish pine martens for >30 years (see Chapter 3). Indeed, the Scottish population may never reach Wales with current levels of habitat quality in the intervening regions [7]. Hence, a further reinforcement of the broader Welsh / west England population is recommended, to avoid inbreeding depression and increase metapopulation stability.

1.2 Has the cause of extirpation been removed?

Historical trapping was the main cause of population extirpation, principally to increase the abundance of wild game birds for shooting [12]. Intensive rear and release methods for game birds have been employed since 1961, and the numbers of pheasants (*Phasianus colchicus*) released and shot have continually grown since this time. A recent estimate showed 37 million pheasants released per year [13]. As the preference for releasing birds has become more common, so the preference for shooting wild birds has declined. The former is associated with much less intensive predator control. Indeed, the switch towards releasing birds has been predicted to have led to a reduction in trapping effort by 45%-75% between 1976 and 1997 [14]. This resulted in the pine marten recovering in Scotland, which was further accelerated by their full legal protection in 1988. Other persecuted species, such as the European polecat (*Mustela putorius*), have also recovered across Wales and England.

The pine marten now has full legal protection (see Chapter 2), and it is illegal for gamekeepers to trap pine martens. However, the current frequency of accidental/illegal trapping is unknown. Excluders for pine martens can be fitted to traps to prevent accidental pine marten capture [15], however their use is not thought to be universal [16]. A key requirement of this feasibility study, then, is to assess local gamekeepers' attitudes, geographical location and abundance, to estimate whether the original cause of extirpation has been removed.

1.3 The Forest of Dean and lower Wye Valley

The Forest of Dean has been previously proposed as a reintroduction site for pine martens on a number of occasions [6,7]. The last records of pine martens in Gloucestershire are from 1860 [1]. In 1829 '*Journal of a Naturalist*' by John Leonard Knapp lamented the decline of the pine marten in Gloucestershire, but wrote "*Yet our martens linger with us still, and every winter's snow becomes instrumental to its capture, betraying its footsteps to those who one acquainted with the peculiar trace which it leaves*".

This document will attempt to assess the costs and benefits of a reintroduction to the Forest of Dean and Wye Valley in comparison to the status quo. Hence, it is important to assess how quickly the species may recolonise the area [17]. The nearest population to the potential release area is in central Wales (<100 km) and a small potential population in Shropshire (<50 km). In Chapter 3 we model how quickly pine martens may naturally recolonise the Forest of Dean area, based on the rate of range expansion of the Scottish population [2].

There are several advantages to a managed pine marten reintroduction to the Forest of Dean in the short term, in comparison to an unmanaged natural recolonization of pine marten in the medium term (see 3.7). As part of the managed reintroduction a full analysis of the risks and benefits of a reintroduction must take place (this document). If a reintroduction does take place, the review of risks leads to a formal and necessarily well-resourced monitoring strategy and an adaptive management strategy. These closely monitor the impact of any reintroduced species on the local ecosystem and on local community interests, and mitigate against any issues that occur [17,18]. These strategies are less likely to be implemented in the event of a natural recolonization or illegal release (e.g. wild boar, *Sus scrofa*, in the Forest of Dean, UK).

1.4 Aims

The key aim of a reintroduction would be:

- *To create a stable population of pine martens in the Forest of Dean and lower Wye Valley, connected to the population in central Wales, with overall positive impacts for both wildlife and people*

The key aim of this document is to assess the feasibility of such a reintroduction, including the full assessment of the biological suitability of the area, and the ecological and socio-economic costs and benefits of a reintroduction.

2. Legal review

The pine marten is a protected species listed in schedules 5 & 6 of the Wildlife and Countryside Act 1981 (as amended). In practical terms this is interpreted by Scottish Natural Heritage as:

"*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." [19]

As it is illegal to capture a pine marten from the wild, a Scottish Natural Heritage licence will be required for the project to capture animals from the wild in Scotland. If the animals have been legally obtained in Scotland then a licence is not required for their transport through England to the release site.

Internationally, the pine marten is also 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.

The pine marten is also listed as a UK BAP priority species, Natural England S41 Species of Principal Importance, and is also specifically mentioned in DEFRA's "A Green Future: Our 25 Year Plan to Improve the Environment". Also, a priority action for the species (as an S41 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.*"

It is up to the Home Office to decide whether the project is for scientific purposes or not. If it is we will need to apply for a Home Office licence (under the *Animals Scientific Procedures Act 1986)* to sedate and immobilise the captured animals (needed to fit monitoring collars). If it is not then the sedation may be an act of veterinary surgery under the Veterinary Surgeons Act (VSA).

A Natural England licence for the release of the species is not needed as this is viewed as a species already normally resident in the UK. As the project is being led by a non-governmental body, and does not need formal authorisation from Natural England, a Habitats Regulations Assessment is also not required.

3. The biological feasibility of a pine marten reintroduction

3.1 The biology and habitat requirements of pine martens

Abstract

Pine martens require woodland in which to survive, however they will exist in highly fragmented landscapes. It is estimated that 20% of a landscape needs to be woodland to support a pine marten population. Mean pine marten density ranges between 0.1 and 0.87 per km^2, and any greater than this is considered a very high density. Density has been shown to be predicted by winter temperature and habitat quality. The key predictors of habitat quality are food, shelter, and the risk of mortality. Pine martens are a generalist omnivore which consume a wide range of foods including small mammals (e.g. rodents), medium mammals (e.g. squirrels and rabbits), large mammals (e.g. carrion), birds (e.g. corvids and passerines), plant material (e.g. berries) and invertebrates (e.g. beetles). Despite this broad diet, preferred species dominate, sometimes with half of all yearly intake being made up *Microtus* voles and berries. Shelter is important for natal-den sites. Arboreal tree cavities are particularly important for this purpose and are most often found in old deciduous woodland. There are a variety of mortality risks to pine martens including people, foxes, and road traffic. This review helps identify which habitat features are important to assess to predict whether the Forest of Dean area is a suitable site for a pine marten reintroduction.

3.1.1 Biology

The European pine marten (*Martes martes*) is a semi-arboreal mammal, closely related to stoats, polecats, and other mustelids. The genus *Martes* first appeared 6.8 - 7.7 million years ago, with the European pine marten appearing 1.6 - 1.8 mya [20]. Pine martens have a maximum lifespan in the wild of 10 – 15 years [21,22]. They are sexually dimorphic with females (960-1116g, 62 - 64cm nose to tail) smaller than males (1360 – 1587g, 69-71cm nose to tail) [23,24]. Female gestation is 8-9 months, however this incorporates a 6-7 month delay in egg implantation [22].

Pine martens give birth to between 1 and 5 kits ($\bar{x}$ = 2.74 kits in the Netherlands [22]). In the Netherlands, parturition occurred in the last quarter of March and the first half of April. Natal dens were then used for between 45 to 70 days dependent on the number of kits [25]. After leaving the den the kits stay with the mother, and are fully grown after 6-8 months, although fully grown testes may only develop later [26]. Sub-adult separation from the mother occurs in late winter (between February 17th – March 17th in Bresse, France) [26]. In a region of France with high trapping mortality, sub-adult survival probability was similar to adults (49% chance of survival per year) [27]. However, importantly males may be more likely to die as sub-adults than females. Dispersal is difficult to record, but a range of dispersal distances have been recorded (see 3.7).

3.1.2 Home range and density

Pine martens maintain territorial home ranges, and do not tolerate overlap with territories of individuals from the same sex [22]. Males have a larger home range size than females. In Scotland, mean home range size for populations has varied between 3 - 32.9km^2 for males, and 0.7 - 9.8km^2 for females [28]. This range is replicated in continental Europe, with mean home range size for a population ranging between 1.8 - 28.6km^2 for males, and 1.4 - 9.8 km^2 for females across a variety of habitats from Spain to Poland [29]. In Ireland much, smaller home ranges have been observed (e.g. 0.42km^2 for males and 0.20km^2 for females) [28]. The ecology of the species in Ireland may be quite different from the UK and continental Europe. There are fewer mustelid competitors in Ireland, such as weasel (*Mustela nivalis*) and polecat (*Mustela putorius*). There is also a much less diverse small mammal community, and in particular a lack of native voles [22]. This may result in a different dietary niche for pine marten, with fewer small mammals eaten, and significantly more earthworms, invertebrates and, potentially, fruit eaten [30,31]. This is a possible cause of the very small home range sizes observed there.

The density of a population has been shown to vary widely, for instance in continental Europe mean population density across a range of sites was 0.2 per km^2, with a maximum population density of 0.865 per km^2 [29]. In Scotland, density has been shown to vary between 0.12 - 0.82 per km^2 across four different populations [32]. The highest density of European pine martens is reported from Ireland. A recent survey showed densities between 0 and 2.6 pine martens per km^2 of forest habitat, although the majority of sites had densities of ≤1 per km^2 [33]. This may be due to warm winters [29] or, as previously discussed, a different dietary niche and reduced competition.

Broadly for territorial animals it is thought that home range size decreases with increasing habitat quality. This is because smaller home ranges are less costly to defend, hence they are preferred if the habitat is good enough [34]. This has been shown in pine martens, with female home range size known to reduce in response to a greater abundance of rodents [29]. Pine marten population density has been shown to be predicted by mean monthly winter temperature (November to March) and seasonality in continental Europe [29]. If this also applies to the UK, then there is the potential for a high-density population (e.g. >0.5 per km^2) as predicted by the warm winter temperature. However, this model has not been tested here. Other known predictors of pine marten density include the abundance of voles [29], in particular in winter [35], and the availability of carrion [35]. Density is also likely to be impacted by other factors influencing habitat quality such as causes of mortality. The high abundance of foxes in the UK [12], and the relatively high density of roads (in comparison to other pine marten areas within the UK) in the potential release area may limit population density.

3.1.3 Habitat preferences

Historically pine martens have been viewed as old-forest specialists [36], however, further research has shown that they are highly adaptable and may utilise a range of habitats [37]. Forest cover seems to be a requirement of good pine marten habitat [37–41], and may be coniferous, mixed, or deciduous in composition [7,36,40,42,43]. However, coniferous woodland plantations that have not been thinned (e.g. <45 yrs old), do not have a diverse ground flora and foraging opportunities may be restricted [28]. Indeed, mature forest is often viewed as preferred habitat [28,44], perhaps due to the presence of a well-developed understory [36,43,45] and the presence of coarse woody debris [44]. Hence, variations in woodland structure can have a powerful influence on prey diversity, abundance, and availability, which will in turn dictate how suitable a woodland stand is for pine marten.

Trees are thought to be essential for pine marten predator escape, and habitat suitability declines with increasing distance from woodland [37,39]. However, scrub, tussocky grassland, and hedgerows are often excellent for voles, pine martens' primary prey, and are often utilised [7,28,46–48]. Indeed, in the early 20th century pine martens were restricted in the UK to the NW Highlands of Scotland [1]; an area dominated by these more open habitats.

It has been shown that pine martens will predominantly only forage into open habitats within a certain distance of woodland, with males travelling on average further into more open habitats (males $\bar{x}$ =

75.1 m, females $\bar{x}$ = 30.4 m) [46]. Hence, pine martens often forage along the forest edge, and this is likely to be a key component of good quality habitat [38,41,46,48]. Also, watercourses are thought to be important habitat corridors for pine martens and have been shown to be a predictor of good habitat [39,49].

Pine martens do avoid some habitat types, in particular open ground, such as agricultural land, heathland, cleared, and open areas [40,41,47,48,50,51]. Human population density itself is not thought to alter pine marten habitat quality [39], however urban areas and anthropogenic structures are avoided by pine martens [51,52]. Roads decrease, but are not a barrier to, dispersal [52,53] and do not influence habitat quality [39]. Interestingly, wetlands may also impede dispersal but are not a strict barrier to movement [52].

3.1.4 Fragmented habitat

It has been shown that pine martens can live in highly fragmented habitats [46]. Indeed the importance of non-woodland habitat for pine martens has been shown in a range of studies [7,37,46,54]. For instance, 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 [46].

As previously discussed, home range size can be an important predictor of habitat quality, as individuals may defend smaller territories in high quality habitat. In Scotland it has been shown that home range size was smallest where woodland cover was between 25% and 30% of the landscape, although pine martens still survived in areas with only 4.1% woodland cover [46]. In Bresse, France, 21% forest cover is thought to be low, but not inhibiting to population connectivity [53]. Similarly, 17% of old stage dense forest cover in a landscape is thought to be a critical threshold for American marten (*Martes americana*) [55]. These figures are supported by a study from Poland, where it was concluded that circa 2 km^2 of woodland is needed for a pine marten to establish a territory [29]. Assuming a maximum female territory size of 9.8 km^2 [29], this corresponds to a minimum woodland percentage of 20.4%. These figures are also supported by a recent prediction of pine marten habitat in Scotland, which showed that the probability of pine martens occupying an area remains high even with relatively modest amounts of woodland cover [37]. The authors suggest that 20% of a landscape needs to be woodland, with >0.25 km^2 woodland patches, for pine marten survival. Hence, when modelling landscape scale habitat features in the Forest of Dean surrounding area, woodland cover of >20% may be useful for determining pine marten macro-habitat suitability (see 3.2).

A key influence on the use of fragmented landscapes in the UK by pine martens may be the threat of predation by red fox (*Vulpes vulpes*). It is thought that a key reason for pine marten woodland preference is predator escape [56]. Hence, in areas with a low density of red foxes, preference for woodland habitat may diminish, with pine martens more able to explore open habitats at a lower risk (see 3.1.7).

Landscape scale features, such as the percentage of woodland cover, are useful predictors of the broad availability of habitat (macro-habitat features). However, the importance of more specific habitat features also needs to be assessed (micro-habitat features). A recent full review of European pine marten habitat selection [36] supported the hypothesis that pine martens select habitat on the basis of three factors:

- Food availability (see 3.1.5)
- Shelter – Well insulated resting and denning sights (see 3.1.6)

- Mortality risk (see 3.1.7)

3.1.5 Diet

Over 46 studies have investigated the diet of pine martens across continental Europe [57], with four studies of diet specifically within Scotland [28,32,58]. Pine martens are a generalist omnivore, eating a wide range of different food species. They have been shown to have the broadest dietary niche of any British mustelid. Indeed, due to the niche breadth of the pine marten, and their preference for voles, counter-intuitively the mean mass of their mammalian prey (121g) is smaller than both weasels (201g) and stoats (508g) [31]. The broad groups eaten include small mammals (e.g. rodents), medium mammals (e.g. squirrels and rabbits), large mammals (e.g. deer and sheep as carrion), birds (e.g. corvids and passerines), plant material (e.g. berries) and invertebrates (e.g. beetles). The proportion of these different food groups within pine marten diet is highly variable between different locations, even within Scotland (see Table 1), as measured by the frequency of occurrence of food items in pine marten scat. When interpreting these data, it should be remembered that the frequency of occurrence of food items is biased towards small prey with a large proportion of recoverable remains.

Table 1. The proportion of different food groups within pine marten diet, based on the minimum and maximum frequency of occurrence in faecal samples taken from four study locations in Scotland [28,32,58], and the mean across Europe [57], and predicted proportions in the Forest of Dean based on latitude [57].

Species group	Min % (Scotland)	Mean % (Europe)	Max % (Scotland)
Small mammals	25	44	58
Medium & large mammals	2	7	12
Birds	11	14	22
Invertebrates	11	10	41
Plant material	3	19	33
Herptiles	0	*	10

*Not comparable

There is also variation in the types of food eaten in different seasons. The most commonly reported variation is the increase in berries eaten in the autumn. For instance in a study in Scotland, consumption of plant material (predominantly berries) increased to 64% of diet in the autumn, in comparison to a year-round average of 32%, with a concurrent decrease in bird consumption (18% yearly average, 3-6% in autumn) [28]. The same study also showed an increase in small mammal consumption in the winter and spring (30% yearly average, 52% in winter and spring). There is large geographic variation between the proportion of different food groups in the diet, and this variation is also found in studies in Europe. Much of this variation is thought to be explained by the abundance and availability of a food type within the ecosystem, with the most common species and food groups more likely to be eaten [28,59–61].

Small mammals are frequently reported as the most common food group eaten. In continental Europe three genera of small mammals are commonly taken – *Apodemus*, *Microtus,* and *Myodes*, with the last of these the preferred species [57]. In the UK these groups consist of the wood mouse (*Apodemus sylvaticus*) and yellow-necked mouse (*Apodemus flavicollis*), the field vole (*Microtus agrestis*), and the bank vole (*Myodes glareolus*). In Scotland the large majority (e.g. 77% [28]) of small mammals taken are *Microtus* voles [28,32,58]*.* This is somewhat unexpected as *Microtus* voles are specialists of grasslands, whereas *Myodes* are specialists of the forest habitats that pine martens require (see Caryl 2008 [28] for possible explanations).

Within each food group a range of species may be taken. For instance within the birds (Aves), common species found in woodland are often eaten such as wood pigeon, *Columba palumbus* (the most frequently eaten bird in a study in north Scotland [32]), goldcrest (*Regulus regulus*), wren (*Troglodytes troglodytes*), thrushes (*Turdus* spp), tits (*Parus* spp), and jays (*Garrulus glandarius*) [32,62]. The fruiting species that are most commonly taken in Scotland are rowan (*Sorbus aucuparia*), and bilberry (*Vaccinium myrtillus*). However, other berries that are known to be eaten include cherries (*Prunus* spp), blackberries (*Rubus fruticosus*), and ivy berries (*Hedera helix*) [57,63]. The most commonly taken invertebrates are often beetles (*Coleoptra*), although other species that may be taken include wasps (*Hymenoptera*), which includes pollen taken from their nests [64].

Despite this variation in diet, pine martens tend to specialise on certain common species. For instance in a study in Scotland, 48.5% of yearly diet was made up of just three species; rowan berries (*Sorbus aucuparia*), bilberry (*Vaccinium myrtillus*), and *Microtus* voles [28].

In continental Europe, it is thought that the broad composition of a pine marten's diet can be predicted by the latitude of the population [57]. If used to predict diet in the Forest of Dean, this would result in a composition of small mammals – 56%, medium & large mammals - 7%, birds – 13%, invertebrates – 6%, plant material – 16%. However, this is likely to be inaccurate due to the influence of the maritime climate on the UK. This prediction is also likely to vary, in particular as vole numbers and availability are often highly variable. Interestingly, in times of low vole numbers pine martens will compensate by eating greater numbers of alternative prey. This may be a range of different foods, however in Poland on a similar latitude to the Forest of Dean there was a switch towards amphibians [57]. Previous studies into the habitat suitability and levels of food availability in the Forest of Dean have shown the area is likely to be abundant in both habitat and food [7,65]. Our own assessment of habitat and prey availability are described in sections 3.2 and 3.4.

3.1.6 Shelter

It is thought that pine martens need shelter for resting, breeding, and thermoregulation. Resting sites are found in a wide variety of different locations. These include squirrel dreys, birds' nests, log piles, cavities within trees (often enlarged woodpecker holes), wind-thrown trees, root plates of wind-thrown trees, burrows, rocky outcrops, and buildings [25,66,67].

Natal dens are used to rear young during the first 45 to 70 days of life, and it is thought that a longer denning period is associated with a higher number of kits [25,67]. Tree cavities were highly preferred for natal-dens in continental Europe (e.g. used >95% of the time in comparison to other den-site locations) and usually elevated off the ground at a height of three to twelve metres [25,42,67]. This is likely because of the high level of protection from predators, and the thermal insulation that tree cavities provide. In contrast, tree cavities were used infrequently (9.8%) in Scotland [66]. Instead dens were often found in rocky outcrops, snagged branches of wind-thrown trees, and man-made structures. This has led leading conservationists to believe that a lack of suitable natal den sites was forcing pine martens to use inadequate locations, and may be a reason for poor population performance [66].

Old-growth deciduous habitat is rare in Scotland and this may have been a reason for the lack of appropriate denning sites. In Poland, pine martens used cavities in deciduous trees >40 cm diameter at breast height (DBH) 99.7% of the time [42]. Although >40cm DBH spruce, *Picea* spp., was abundant, it was not thought to contain high numbers of cavities. The majority of cavities used occurred in lime, *Tilia* spp. (38%, $\bar{x}$ = 74.6cm DBH, range 40-110cm), and oak, *Quercus* spp (29%, $\bar{x}$ = 85.6cm DBH, range 44-150cm), with 33% found in other deciduous trees. Importantly this study compared the use of different tree species to their abundance in the landscape, and found that lime and oak were the only preferred species. Hornbeam, *Carpinus* spp, was non-preferred, while all other deciduous species were used in proportion to their abundance [42]. Arboreal cavities in coniferous species were only observed very rarely in Poland. However, in similar studies, natal dens were observed in larch (*Larix* spp.), Scots pine (*Pinus sylvestris*), beech (*Fagus* spp) and oak in the Netherlands [25], and aspen (*Populus tremula*) and pine (*Pinus* spp) in Norway [67]. Although, the sample size in both these studies was too small to identify which tree species were preferred. The use of 'preferred species' may be a misnomer, as it is likely that these trees simply provide more cavities, rather than cavities of deciduous species being preferred over cavities of coniferous species [68].

Tree cavities used by pine martens are often old black (*Dryocopus martius*) or green woodpecker (*Picus viridis*) nest chambers [25,67], and it is thought their use may be more common in managed woodland with fewer suitable natural cavities. Black woodpecker holes are oval and large (110-120mm × 80-110 mm), but the species is not found in the UK. However, greater spotted woodpecker (*Dendrocopos major*) and green woodpecker are found in the UK. Their nest holes are much smaller than *D. martius* (48-76mm for *D. major,* 44-57mm for *P. viridis* [69]), but overlap with the smallest of holes that pine martens can fit through (45 – 58mm) [70]. Indeed, it has been reported that greater spotted woodpecker holes are too small for pine martens when initially created [71]. However, woodpecker holes are often created in soft or decaying wood [71] and hole degradation can be swift [72]. Hence, woodpecker holes may quickly become large enough for pine martens. Indeed, this may be a reason that woodpeckers rarely reuse nest sites, preferring to create new holes each year [73]. Greater spotted woodpeckers prefer trees with an average DBH of 58.9 cm [71], and investigation into other cavity nesting birds also shows a preference for trees >60cm DBH [68]. Large standing dead trees are also important for cavity nesting birds. In old growth forest the removal of large standing dead wood can reduce hole density from 40/ha to 6-15/ha in deciduous stands and as low as 1/ha in coniferous stands [68].

3.1.7 Mortality risks

Mortality rates are an important consideration when evaluating pine marten habitat, as they may increase the chance of population extirpation despite other factors indicating high quality habitat [56,65]. Pine martens breed only once per year and have a slower reproductive rate than other smaller mustelids [74]. This makes them particularly vulnerable to increases in mortality rates, with adult survival a key predictor of population persistence [75] (also see 3.6).

Post release mortality, particularly within the first year post-release and during the establishment phase of a reintroduction, is a crucial influence on reintroduction success. Poor population performance can quickly lead to reintroduction failure. A high risk of mortality can be compensated for by enlarging the release cohort (the animals which are released), so that the population more quickly reaches sustainable levels that can compensate for mortality levels. However, if mortality levels are too high a sustainable population size may be unreachable. Hence predicting potential rates of post-release mortality is essential to estimate the risk of population extinction and the design of the release cohort (see 3.6).

Trapping

Trapping, shooting, and poisoning, predominantly by gamekeepers was the main cause of the species extirpation from much of Scotland, England and Wales by 1920 [1]. It has been argued that game keeping has reduced since that time [7]. However, the annual pheasant bag has been estimated to have increased from 25 per km^2 to 150 per km^2 between 1900 and 1980, with an estimated 37 million birds currently released every year in the UK [13,76]. However, this also reflects a change in shooting habits since the Victorian period when pine martens were originally extirpated. Victorian gamekeepers focused on shooting wild game birds [77], in comparison to the modern day focus on shooting released reared birds [76]. Gamekeeping for wild game birds involves a great deal more predator control across a landscape, in comparison to the release of reared birds which often only involves predator control in proximity to rearing pens [78].

Modern day predator control largely focuses on spring traps set within a tunnel. The pine marten is a protected species, where causing injury or death to an individual either intentionally or recklessly is illegal. Excluders are devices placed on traps to exclude polecat and pine marten [15]. When setting traps for other species reasonable precautions must be in place to prevent capture of protected species. However, this has not been tested in the courts. Despite being illegal, an anonymous 1999 survey showed that 91% of gamekeepers within the range of polecats had trapped them [16]. Trapping remained the largest recorded cause of pine marten mortality prior to their formal protection [79]. These data show that many shoots are unlikely to properly fit excluders on their traps.

Foxes

Intra-guild predation by foxes has been identified as a potential limiter of pine marten population size [56]. The data for this come predominantly from Sweden where a disease outbreak caused a severe reduction in red fox numbers. This was thought to be the cause of a concurrent increase in pine marten numbers [56]. This study also found direct evidence of red fox predation on pine martens at sixteen different events [56]. Interestingly, evidence suggests that pine marten population growth was due to a reduction in predation rather than competitive release [50].

This effect may be constrained to specific areas. For instance, a study in Finland found no evidence of red fox influencing pine marten population density at a landscape scale [47]. It has been hypothesised that red fox are more likely to predate pine martens at higher latitudes and areas with colder winter temperatures [42]. This is because pine martens are more likely to den in underground burrows during colder months [67,80], potentially leaving them more exposed to ground-dwelling predators during these times. This is backed by data from Poland where, despite many kilometres of snow tracking data of red foxes and pine martens, pine marten predation by red fox has not been recorded [42]. However, this may be a result of the lack of woodland fragmentation in this region (see 3.1.4).

Alongside the high levels of woodland fragmentation in Britain, pine martens may also be at greater risk of predation by red fox due to the pine marten's preference for *Microtus* voles**.** This may result in pine martens being more likely to utilise non-forest habitats in Britain, meaning a higher likelihood of them coming into contact with red fox [50,81]. In addition, in the UK it is thought that red fox populations, due to mesopredator release, may be over four times as numerous as the historical environment [12] (although this does not seem to be true of the Forest of Dean – see 3.4). Hence, the impact of foxes on pine martens is an important consideration when assessing population sustainability. The density of foxes in the Forest of Dean is estimated in section 3.4.

Roads

Road mortality has been studied for a variety of wildlife species. It is thought that three key predictors of mammalian road mortality are roadside vegetation, traffic volume, and road bends / road sinuosity [82–85]. Roadside vegetation is a key factor as it predicts where suitable habitat comes into contact with the road network [82]. Roads kills are thought to be most common where traffic is at intermediate intensities (2500 – 10000 Annual Average Daily Flows). This is because roads with higher intensities of traffic act as a complete barrier to animal movement, and the chance of encounter is lower on roads with lower traffic volumes [86]. Mammals are also more likely to be killed at bends in roads, rather than straight sections [83–85]. This may be because individual animals cannot see approaching traffic at these locations, and drivers may not see wildlife.

Pine marten will frequently utilise trees whose canopies link across roads as suitable crossing points [87], and the existence of suitable crossing places is thought to reduce road mortality. For instance, arboreal mammals are less likely to be killed on roads where there is arboreal habitat connectivity over a road (i.e. where the tree canopy is connected) [83], and specially designed wildlife bridges over roads have previously been used by pine martens in both the Netherlands and Japan [88]. Also, *M. americana*, stone marten (*Martes foina*), and fisher (*Martes pennanti*) have all been shown to use culverts or underpasses underneath roads [89–91]. Indeed, underpasses may improve habitat connectivity if the road is viewed as a significant barrier to movement [91]. Interestingly, *M. americana* preferred culverts that were more open (width x height), but of shorter height, perhaps mimicking the species preference for a complex understory [90]. Fencing along roads is also thought to reduce mortality and can be used to direct individuals towards safe crossing points [92].

Roads are thought to be an important cause of mortality in pine martens [7,27,65,93–95]. For instance, in France 35% of recorded pine marten deaths were vehicle collisions [27]. Although in Scotland only 8% of recorded deaths, where the cause of death was known, were the result of road mortality [79]. This was in an area with low road density and traffic. There are patterns as to which individuals are more likely to be killed on the roads. For instance, dispersing individuals are thought to be more likely to be killed on roads [93,96], as resident individuals learn where 'safer' crossing points are and repeatedly use them [97]. Also, it is thought that males rather than females are more likely to be killed on the roads. For instance, in Italy 60% of 55 pine marten killed on the roads were male [39], while in the Netherlands 81% of road killed martens were male [98]. Our own analysis (see 3.3) showed that 67% of 1827 incidences of road mortality were males. This may be due to male martens dispersing for longer distances and hence coming into contact with a greater number of novel road crossings [98,99].

The potential relative impacts of poisoning/trapping, fox predation, and road mortality in Britain have previously been assessed [65]. They predicted that while fox mortality and poisoning/trapping in the Forest of Dean are likely to be within sustainable levels, road mortality is predicted to be high. The risk of road mortality in the Forest of Dean area is evaluated in 3.3. This also includes a previously unmapped feature of potential importance - the number of potentially safe road crossings in the Forest of Dean. These may be provided by tree branches linking over roads (arboreal connectivity), culverts, or underpasses [89]. Exploring potential mitigation strategies, such as artificial road crossings for wildlife, should be explored in the event of a reintroduction taking place.

3.2 Habitat maps

Abstract

Habitat quality and extent are key predictors of reintroduction success. The three key components of suitable habitat for pine marten are the availability of food, the availability of suitable denning and resting sites, and the risk of mortality (3.1). Here we attempt to assess the extent of suitable pine marten macro-habitat and denning sites in the Forest of Dean and Wye Valley potential release region (PRR). In addition, landscape connectivity is a key predictor of whether a pine marten population in the PRR will link with other pine marten populations in Wales and west England. Hence, a map of habitat connectivity across this region was produced. 17508 ha of Highly Suitable Woodland, 6394 ha of Suitable Woodland, and 3818 ha of scrub and grassland within 50m of suitable woodland was identified, totalling 27720 ha of suitable habitat. Naturally occurring den sites are likely to be broadly distributed across the Forest of Dean, however, there are a number of outlying areas where natural cavities may not be available. The landscape connectivity map shows good potential connectivity with the nearby Afan habitat block. However, there are low levels of habitat connectivity between the Forest of Dean main block and the Wye Valley. Hence, there are potential opportunities for improving landscape woodland habitat connectivity, not only for pine marten but a wide variety of woodland species.

Introduction

To decide whether a reintroduction should go ahead, conservationists must determine whether a population can survive in the release area. The quality and extent of habitat is a key factor in determining this. Indeed, habitat quality has been shown to be a key predictor of reintroduction success [100]. To predict the quality of habitat within release areas, to estimate carrying capacity, landscape connectivity, and identify the most suitable areas for release, habitat maps are typically created. Here, four maps were created to identify specific components that are required for pine marten population survival:

- Habitat suitability map
- Den site availability map
- Landscape connectivity map
- Landscape resistance map

Habitat suitability map

The Forest of Dean and Wye Valley has previously been identified as an area of potentially high quality habitat [7]. Due to the importance of ensuring that release areas are within high quality habitat, a more detailed assessment of pine marten habitat in the area is presented here. This uses the macro-habitat requirements of pine marten (see 3.1) to predict the abundance of high quality foraging habitat.

Den-site availability map

Historically, a lack of suitable denning sites may have led to poor population performance in the UK [66]. Hence, here we attempt to map the distribution of woodland that may contain high quality denning habitat. Certain types of woodland are more likely than others to contain tree cavities – preferred den sites for pine martens (3.1.6). Older and deciduous woodland is thought to contain a much higher abundance of den sites in comparison to younger and coniferous woodland. It is essential for an establishing population to have a suitable complement of available den sites. Hence, this map could be used to identify the extent and number of artificial den sites that would need to be created (e.g.

through den boxes, veteran tree management, standing dead wood creation, etc) before reintroduction.

Landscape connectivity map

A key goal of the project is to assess the feasibility of creating a self-sustaining population of pine marten that connect with other populations in the Wales and west England area. In order to visually assess the habitat connectivity between these areas, a landscape scale map was also created to assess connectivity between the Forest of Dean and the other closest blocks of suitable pine marten habitat [7].

Landscape resistance map

In contrast to the *Landscape connectivity map,* which identifies good dispersal habitat, it was thought useful to also identify poor dispersal habitat. This has been previously investigated for the pine marten population in northern Spain using a resistance map [52]. Resistance maps predict which parts of a landscape are more likely to be difficult for a dispersing individual to move through [101].

Methodology

Habitat suitability map

This rule-based habitat map identifies suitable foraging sites for pine martens using macro-habitat features such as the age and type of woodland (i.e. coniferous or deciduous). Male and female pine martens differ in their use of the landscape. For instance, male home ranges cover a greater area and intrude more often and to a greater extent on open landscapes, while females have more conservative foraging patterns [46]. As the purpose of the map is to assess carrying capacity and the potential breeding population, the map uses parameters for female pine martens.

Forestry Commission woodland datasets were used to identify suitable habitat on the Public Forest Estate (managed by the Forestry Commission) within the Forest of Dean area. The National Forest Inventory (NFI) [102] dataset was used to identify suitable habitats outside the Public Forest Estate. All habitat between the rivers Usk and Severn was identified.

Highly Suitable Woodland:

- Deciduous woodland >17 years old and coniferous >45 years old was identified. Deciduous woodland of all ages is thought to be a preferred habitat of pine martens. In mature coniferous woodland >45 years old, thinning allows light to penetrate to ground level, and a more favourable understory for pine martens and their prey becomes apparent [28].
- The NFI dataset used for areas outside the Forest of Dean does not contain the age of woodland, hence only broadleaved woodland is included here.

Suitable Woodland:

- Closed canopy coniferous woodland (17-45 years old) was identified. This has been identified as a non-preferred but still utilised habitat [28]. This is because, while this habitat provides the required woodland for pine martens, it provides very few micro-habitat requirements. Food abundance within this habitat is likely low, due to a lack of understory, forest structure, or ground cover.
- The National Forest Inventory dataset used for areas outside the Forest of Dean does not contain the age of woodland, hence coniferous woodland of all ages is included here.

Edge habitat:

- Scrub or rough grassland in proximity to existing woodland was identified [28]. Scrub and rough grassland has been identified as useful habitat [7,37]. Rough tussock grassland (height >40cm) is excellent vole habitat, and is excellent pine marten habitat when within close proximity to woodland [28]. Female pine martens were shown to travel a mean distance of 30.4 m into open habitats, and a mean maximum distance of 93.7 m [46]. Hence here we identify scrub and rough grassland within 50m of woodland to reflect the importance of edge habitat for females. This category includes restocked/replanted areas <17 years old.

All areas not identified as within these habitat types are assumed to be poor quality habitat for pine marten. A full description of the GIS methodology used is available on request.

Core Reintroduction Area

- A core area of habitat containing well-connected habitat was identified. 1km squares with >20% woodland were identified (see *Landscape Connectivity map*). All squares which were not connected (>1km from another square) to the Forest of Dean and Wye Valley were excluded. The woodland blocks within the remaining squares was identified, and a polygon around these features was created.

Den-site availability map

The purpose of this map was to identify areas in which naturally occurring potential natal den sites may already exist. A lack of denning sites has been identified as a potential reason for poor population performance in Scotland [66]. Also, den boxes are costly and highly visible structures that may attract unnecessary disturbance in the PRR. Hence, in the event of a decision to reintroduce pine martens it would be prudent to minimise den box distribution, and concentrate them in areas where already existing opportunities for denning are predicted to be low.

All lime and oak trees predicted to have a mean DBH >60cm (see 3.1.6) were mapped and classified as High-Quality Denning Areas. All deciduous trees predicted to have a mean DBH >40cm were mapped and classified as Medium-Quality Denning Areas. To estimate the growth rate of deciduous trees, three groups of oak were selected, aged 75, 101, and 138 years old. The DBH of a minimum of 10 oaks from each group was measured, and a linear regression used to estimate the mean age at which trees reached 60 cm DBH. Suitable data for this analysis was only available for the Public Forest Estate, and hence is restricted to that area.

In addition, identifying the location of rocky outcrops may be useful to identify potential, but poor quality, denning sites. All rocky outcrops including scowles, quarries, and mineral workings were also identified and mapped. These were sourced from Forestry Commission data and Regionally Important Geological Sites.

It was thought useful to briefly assess potential female pine marten home ranges that may exist without any suitable denning habitat. Female home range size is highly variable and, while some smaller estimates exist, the smallest within a review of studies [29] was 1.4 km^2. A circular home range of this size would have a diameter of 1.34 km, hence any suitable habitat within the Forest of Dean that was greater than 1.34 km from high quality denning habitat was identified.

Landscape connectivity map

The Vincent Wildlife Trust feasibility study [7] identified six potential release regions (PRRs) across Wales and England. These regions were proposed due to the abundance of suitable habitat within them. Assuming a widespread meta-population, with population centres within these PRRs, it is reasonable to assume that any potential natural migration and reinforcement of the Forest of Dean and Wye Valley population would come from these areas in the long term. The closest potential release region is the Afan PRR; a distance of 30km from Abercynon at the eastern boundary of the Afan PRR to the Wentwood on the western boundary of the Core Reintroduction Area. In comparison the second closest is the Tywi; a distance of 60km from Cray on the eastern boundary of the Tywi PRR to the Wentwood.

The route between from the Afan PRR to the Forest of Dean and Wye Valley contains multiple urban areas, resulting in poor scores on its predicted habitat quality [7]. Hence, a detailed assessment of the connectivity between these PRRs is worthwhile to inform estimates of natural reinforcement of any future Forest of Dean and Wye Valley pine marten population.

A habitat map looking at the connectivity of habitats between these PRRs was produced. The percentage of existing woodland (derived from the NFI) within all 1km square blocks, across south Wales and western England was calculated using GRASS within QGIS [103]. Squares were allocated into one of three woodland categories; <5%, 5 to <20%, ≥20%. It is thought that ≥20% of a landscape needs to be woodland to support a pine marten territory, although pine martens have been found in landscapes with as little as 5% woodland cover (see 3.1.4).

Landscape resistance map

A resistance map replicating a methodology used in northern Spain was also developed [52]. Resistance maps are used to identify how difficult a landscape may be to traverse for a dispersing individual. Here we simply attribute values to land cover classes derived from the Corine land cover map (Source: European Environment Agency, 1:200000). This map provides a useful comparison to the *habitat connectivity map*.

Results

Habitat suitability map

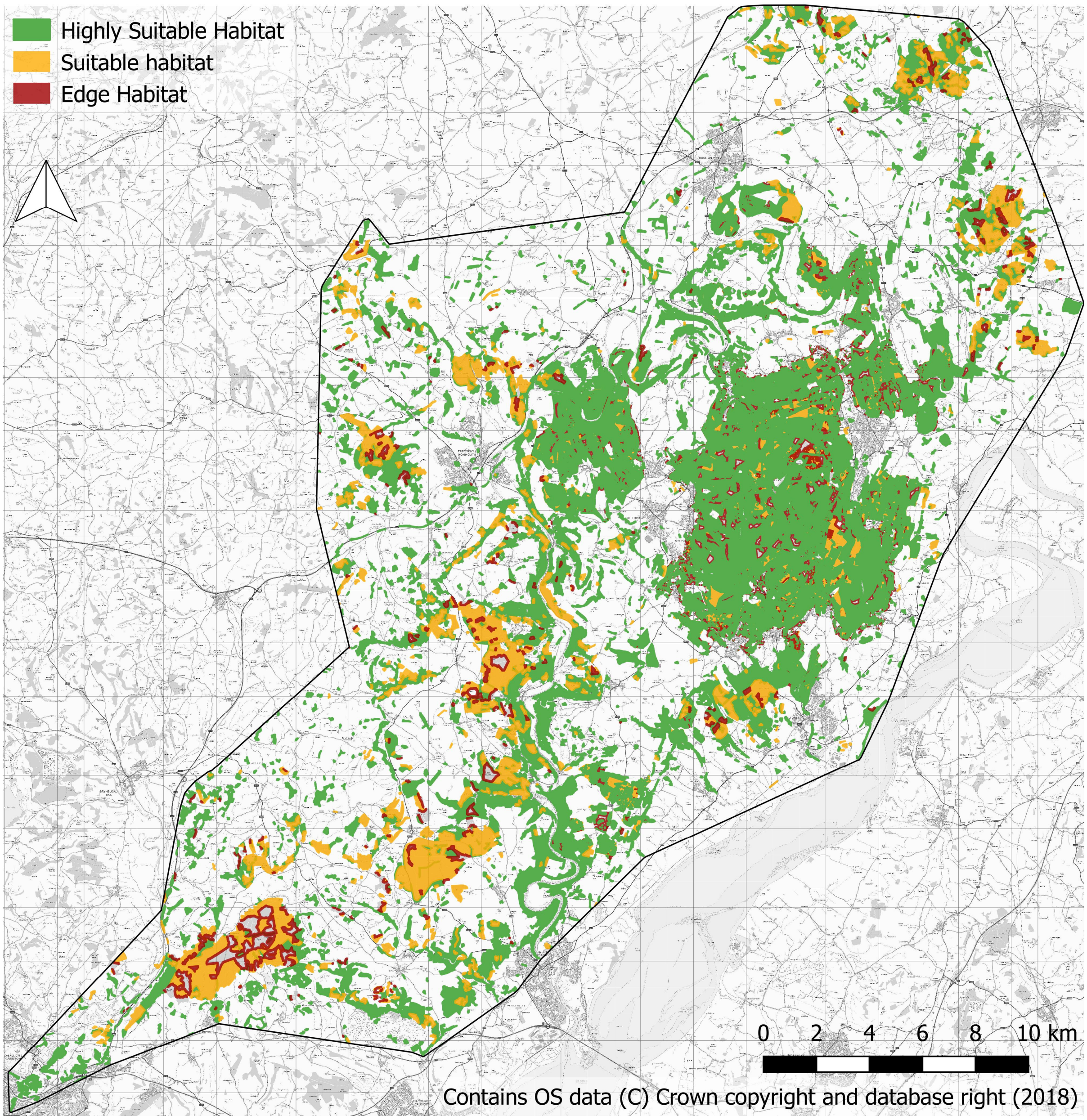

Figure 1. Forest of Dean and lower Wye Valley habitat map showing suitable habitat for pine martens within a Core Reintroduction Area (outlined). Edge Habitat identifies scrub and grassland within 50m of suitable habitat.

In the wider area including the Forest of Dean, Wye Valley, Wentwood, and other areas immediately surrounding the Forest of Dean there was a combined total of 17508 ha of Highly Suitable Woodland, 6394 ha of Suitable Woodland, and 3818 ha of Edge Habitat (see Table 2), totalling 27720 ha. Highly Suitable Woodland was distributed across the Forest of Dean and the wider landscape (see Figure 1). On a landscape scale, habitat was clearly concentrated on the Forest of Dean, Wye Valley, and Wentwood areas, with 84% of all suitable habitat found within a Core Reintroduction Area of 80624 ha.

Table 2. Areas of suitable pine marten habitat

Area	Habitat type	Area (ha)
Forest of Dean	Highly Suitable Woodland	7056
	Suitable Woodland	1171
	Edge Habitat	2440
Wye Valley	Deciduous woodland	5642
	Coniferous woodland	2578
	Edge Habitat	542
Wentwood	Deciduous woodland	715
	Coniferous woodland	795
	Edge Habitat	450
Other woodlands	Deciduous woodland	4095
	Coniferous woodland	1850
	Edge Habitat	385

Den-site availability map

The results of the ground truthing indicated that the mean age at which oak reached 60cm DBH was 125.5 years, and the predicted earliest age at which a tree could reach that size was 90 years old (see Figure 2). The mean age at which oak reached 40cm DBH was 83 years. This is likely to be influenced by a range of factors, but should give a reasonable indication of arboreal cavity density. This size was also used as an estimate for all deciduous species.

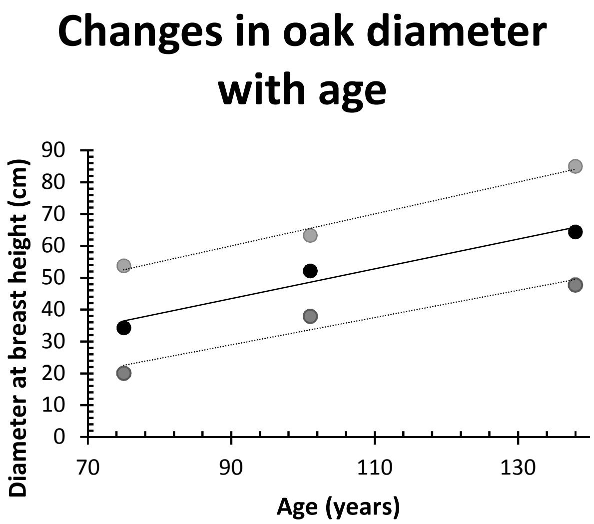

Figure 1. Changes in oak diameter at breast height with respect to age. Points display the mean and range at a given age.

Oak and lime trees estimated to be on average greater than 60 cm DBH (i.e. ≥125 years old) were found to have a broad distribution across the Forest of Dean. These areas were viewed as potential 'High Quality Denning Areas', and covered an area of 920 ha. This is predominantly made up from the 'Nelson Oaks' planted in the early 1800s, which now make up one of the largest areas of old oak woodland in the UK [104]. The total area of suitable pine marten habitat not within 1.34 km of High Quality Denning Areas was 540 ha, and predominantly found to the south of the Forest of Dean (see Figure 3).

Deciduous species estimated to be on average greater than 40cm DBH (i.e. ≥83 years old) were also found to have a broad distribution across the Forest of Dean. These areas were viewed as 'Medium Quality Denning Areas', and covered an area of 1923 ha. All suitable pine marten habitat on the Public Forest Estate was within 1.34km of Medium Quality Denning Areas.

Landscape connectivity map

The landscape connectivity map showed that habitat from the Forest of Dean and Wye Valley to the Afan PRR was clearly more abundant than to the Tywi PRR. In the Core Reintroduction Area, 350 km squares (42% of the landscape) with >20% woodland were identified, with 594 km squares (47% of the landscape) in Afan, and 320 km squares (29% of the landscape) in the region connecting the two (see Figure 4).

Importantly, habitat fragmentation in some of the main habitat blocks was low. For instance, in the Forest of Dean main block 52km^2 of contiguous squares with >70% woodland exists.

The landscape connectivity map showed low levels of local habitat connectivity between the Forest of Dean and the Wye Valley. Between these two large woodland areas, twenty-nine 1km squares lack 20% woodland (outside of urban areas). To improve woodland cover in all these areas to 20%, 298 ha of woodland would need to be created. Alternatively, there are three potential habitat corridors that could be established, which would require 3.7, 7.9, and 6.1 ha of woodland creation to reach 20% woodland cover.

Landscape resistance map

The landscape resistance map shows much higher levels of landscape resistance than in northern Spain [52] where the methodology for this map was created (see Figure 5). It also contrasts with the landscape connectivity map by highlighting areas where pine marten dispersal may be more difficult.

Discussion

The habitat suitability map gives a broad indication of the quantity of habitat in the Forest of Dean, Wye Valley, Wentwood, and surrounding areas. This will be particularly useful for estimating the carrying capacity for the area. However, the map uses broad macro-habitat features, such as the type and age of woodland, to predict habitat quality. A more detailed assessment of habitat quality is needed that considers specific aspects of habitat, such as the abundance of preferred food species (e.g. voles). These more specific aspects of habitat quality are assessed in section 3.4.

There is a healthy population of foxes in the potential release region (see 3.4). Foxes are a key predator of pine martens, and it is thought that martens may be vulnerable to predation in open areas where there are no trees for escape. Hence, it is useful to note the low level of fragmentation within the key woodland areas of the Forest of Dean and Wye Valley.

The den site map is a useful indicator that potential denning habitat may be widespread across the Forest of Dean. However, there are several assumptions that the map is based on. Most importantly, the map relies heavily on data from ancient woodland in continental Europe. This is an area where black woodpeckers are found and their holes are often utilised by pine martens. Woodland in these areas may also have a different age structure. Black woodpeckers are not found in the UK, and this may change the availability or distribution of den sites. Hence, a ground-truthing exercise, investigating the number of potential cavities in the identified areas is described in section 3.4. In the event of a reintroduction, den boxes would still be a valuable tool in ensuring that suitable den sites are available. This map may be useful in determining their density and distribution. However, den boxes require on-going investment to provide a long-term solution to a lack of suitable den-sites. Hence, tree veteranisation should be investigated for areas lacking suitable den-sites.

The landscape connectivity map, in combination with habitat quality map, showed low levels of local woodland habitat connectivity between the Forest of Dean and the Wye Valley. Here we identified the quantities of woodland that would need to be created to improve habitat connectivity between the Forest of Dean and the Wye Valley. While the specific figures may be skewed by the location of $1km^2$ squares, it is clear that with relatively small areas of habitat creation (e.g. 17.7 ha for three woodland corridors), woodland connectivity on a landscape scale could be improved for pine marten. However, future research should also investigate the numbers of trees outside woodlands, such as hedgerow trees, to further investigate levels of connectivity.

Finally, it is important to consider the changing nature of our climate and whether predicted future temperatures will influence reintroduction success and habitat quality. Pine marten populations currently extend well into southern Europe including Sicily. Hence, we do not expect the effects of climate change to impact population persistence in the Forest of Dean and Wye Valley.

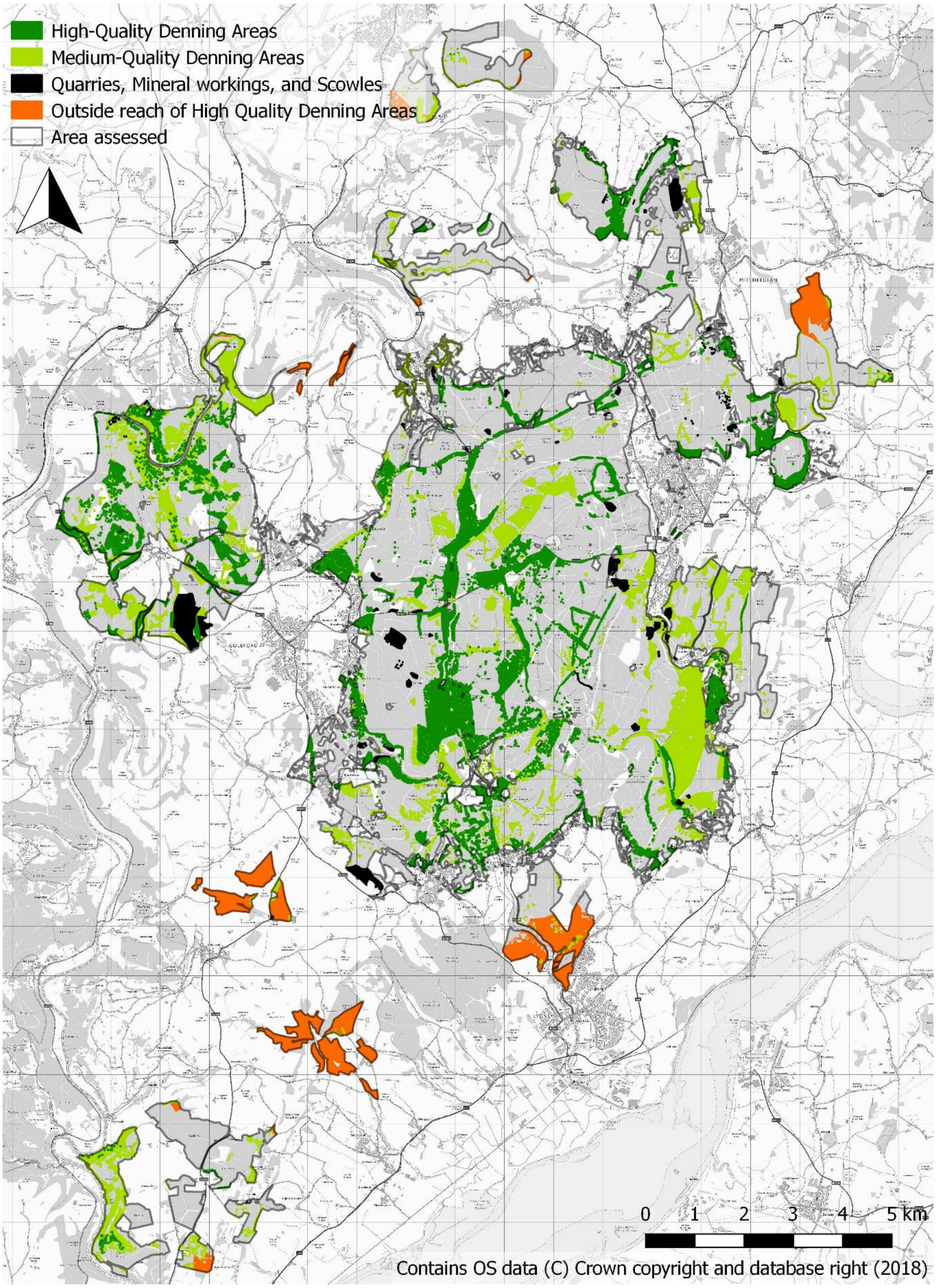

Figure 3. Pine marten natal den site availability map showing potential denning areas within the Forest of Dean main block. Areas that may contain a female pine marten home range without suitable natal den sites are also identified.

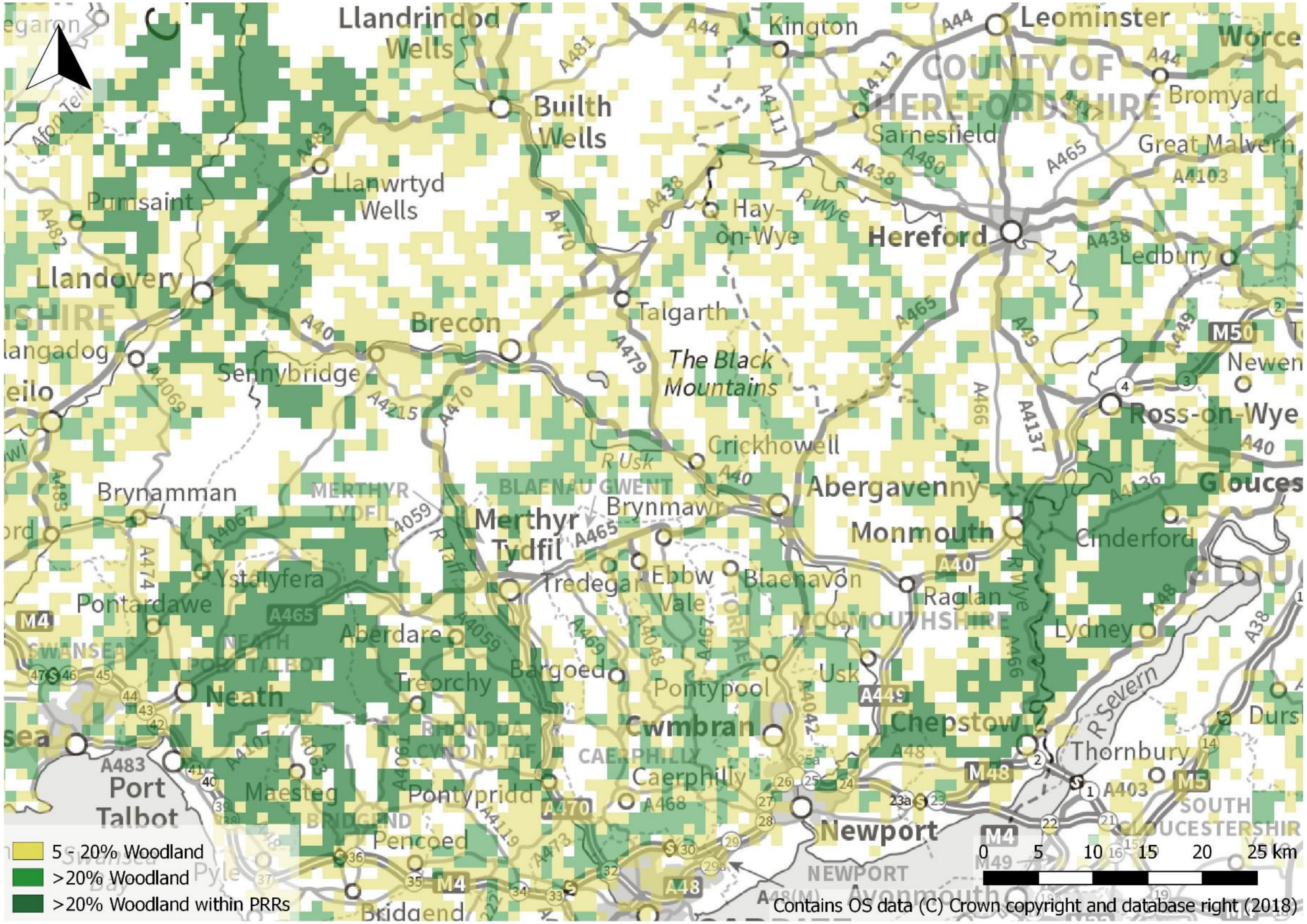

Figure 4. Landscape scale habitat connectivity in south Wales and western England based on percentage woodland cover within 1km² squares. PRR – Potential Release Region as identified by The Vincent Wildlife Trust.

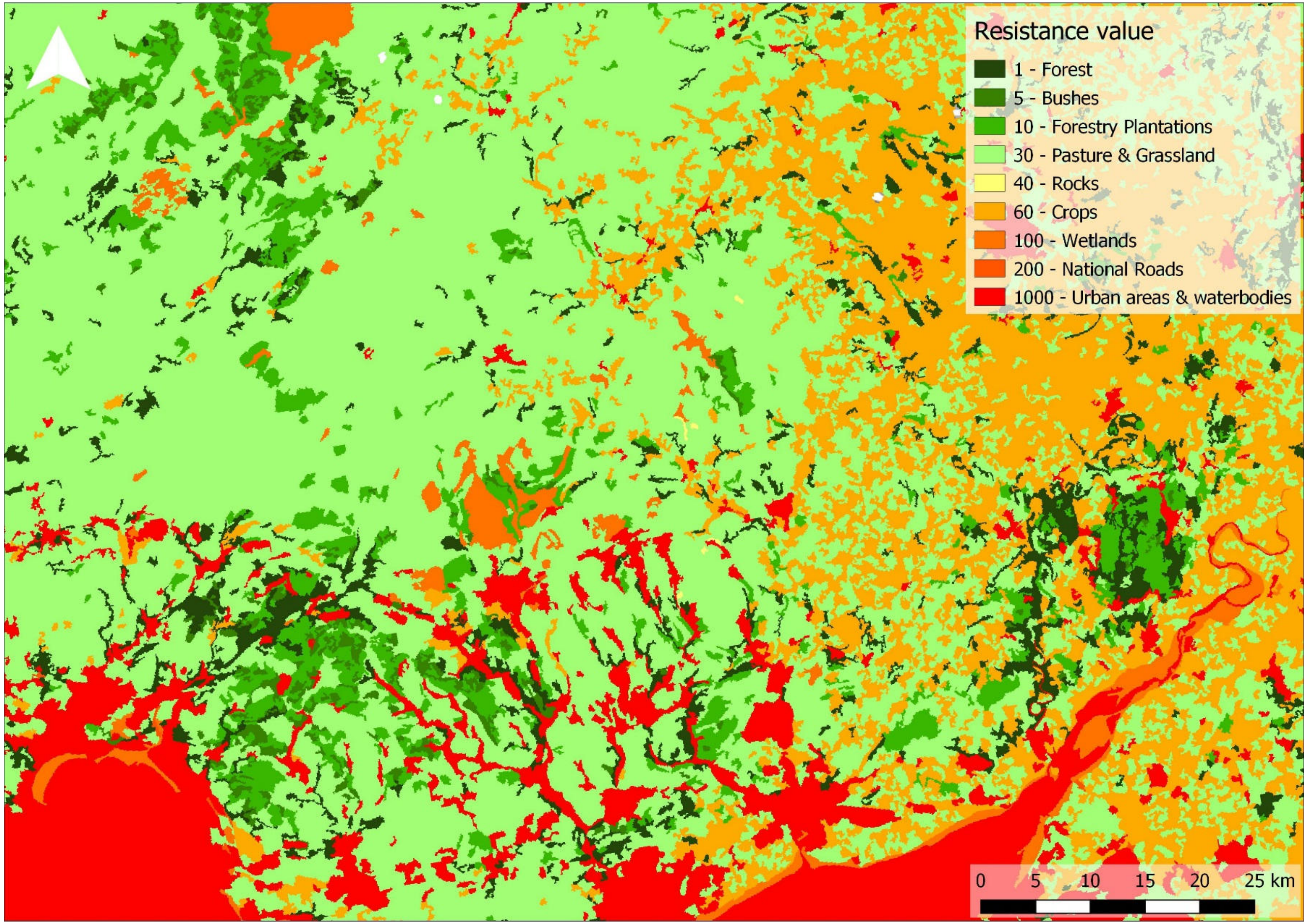

Figure 5. Landscape resistance map showing the difficulty pine martens may have in traversing different landscape types. Developed using data from Corine land cover map (Source: European Environment Agency, 1:200000).

3.3 Road mortality

Abstract

Roads are thought to be an important cause of mortality in pine martens. Road density has previously been identified as greater within the Forest of Dean than other areas of the UK with pine marten populations, and a key risk to reintroduction success. Several pine marten populations exist in the Netherlands, which also has the 3rd highest national density of roads in Europe. Here we investigate whether pine marten age or sex influences the risk of road mortality, what types of road are the riskiest to pine martens, and the level of road density that pine marten populations exist alongside. We discovered that motorways and primary roads kill far more martens than their abundance in the Netherlands would predict, while Tertiary and Unclassified roads kill far less. Pine marten populations exist across a wide range of road densities. Areas of high road density may be acting as ecological traps (areas where pine marten populations are not inherently self-sustaining, but reliant on migration from elsewhere), or populations may be able to persist despite high levels of road mortality. This could be because female pine martens are much less likely to suffer road mortality than males. The density of high risk roads within the Forest of Dean is lower than the mean density of high risk roads found alongside pine marten populations in the Netherlands. Hence, we do not predict that road density will preclude pine marten population establishment. On a local scale there are several key road sections, particularly in the Forest of Dean rather than the Wye Valley, where mitigation could be applied to reduce road mortality.

Introduction

Roads are thought to be an important cause of mortality in pine martens [7,27,65,93–95]. For instance, in France 35% of recorded pine marten deaths were vehicle collisions [27]. If the level of mortality from roads is too high, this may increase the chance of population extinction, or preclude the establishment of a reintroduced population. The density of roads in the Forest of Dean and Wye Valley potential release region (PRR) has previously been identified as a cause for concern [7]. This is because of the region's high levels of traffic and high density of roads in comparison to regions of the UK where pine martens are currently established.

There are a number of populations of pine martens in the Netherlands [105] (see Figure 6). Furthermore, it has one of the highest road densities in Europe. For example, in 2008 the density of the total road network in the Netherlands was the 3rd highest in Europe (3.3% - km road/ km² land area), while the UK was 9th (1.8%) [106]. Human population density is also comparable, with 503 people per km² in the Netherlands and 413 per km² in England. To ascertain whether the density of roads in the PRR would preclude population establishment, data on pine marten distribution and road mortality from the Netherlands was used. Four questions were addressed:

A. *Which pine marten sex and age classes are more vulnerable to road mortality?*
B. *What types of road have the highest risk to pine marten?*
C. *What is the gradient of road density within which pine marten populations survive in the Netherlands? How does the PRR and Britain compare?*
D. *Where is road risk greatest in the Forest of Dean and Wye Valley?*

Methods

This report used data from the Dutch National Database Flora and Fauna (NDFF [107]). The NDFF dataset is an extensive dataset of all records of pine marten in the Netherlands. At the time of use it had 9854 records of pine martens, of which 3303 were roadkill. Non-roadkill records included sightings, photos, videos, trapping, live trapping, and camera trapping.

OpenStreetMap is a "free, editable map of the whole world that is being built by volunteers largely from scratch and released with an open-content license" [108]. OpenStreetMap was used to identify roads and road type in both the UK and the Netherlands.

A. Which pine marten sex and age classes are more vulnerable to road mortality?

The age and sex of pine martens killed on roads was reported within the NDFF dataset. Unfortunately, this could not be compared to background demographics or sex ratio to see whether a specific demographic component or gender was killed more often than expected. This was due to methodological biases when collecting data. It is assumed during the interpretation of results that the background population sex-ratio was 50:50.

B. What types of road have the highest risk to pine marten?

Roadkill data was linked to the nearest road type (n =2703) with 600 roadkill samples rejected due to a lack of geospatial accuracy. Some types of road were more common than others. The Ivlev Electivity Index (Electivity = $(r_i - P_i) / (r_i + P_i)$, where r_i is relative abundance of pine martens dying on a road type, and P_i is the roads relative abundance across the country) was used to assess whether a road type was more, or less, likely to kill a pine marten in comparison to that road's abundance across the Netherlands [109].

C. What is the gradient of road density within which pine marten populations survive? How does the PRR and Britain compare?

The density of roads that may pose a risk to pine martens was calculated for 10km by 10km squares across the Netherlands. First, roads were converted to raster squares measuring 10m by 10m. The number of these road squares within a 10km by 10km square was then calculated to give a road density for that square. This is expressed as the percentage of 10m by 10m squares identified as roads within a 10km by 10km square; a Road Density Percentage (RDP). Please note that this means road density squares that overlap coastlines, and countries not part of the study, are unreliable.

The presence of a pine marten population within a given square (10km by 10km) was based upon ≥10 records of pine marten from that square which were not roadkill. Roadkill was excluded to reduce bias towards areas in which many pine martens are killed on the roads, rather than towards areas with a pine marten population. The density of roads within squares harbouring a pine marten population was then compared to road density in the PRR and the UK.

D. Where is road risk greatest in the Forest of Dean and Wye Valley?

Road mortality has previously been identified as a key area of concern for pine martens in the PRR [7,65]. A previous assessment was useful in identifying the density of roads in the PRR that were within woodlands [7]. This is developed here, using the types of road that were identified as high risk in the Netherlands, and the existence of suitable crossing locations (i.e. where trees link over roads and suitable underpasses [87]). This map attempted to predict where the risk of road mortality in the potential release region is greatest.

Motorways and primary roads within 50m of woodland, within the core reintroduction area, were identified. These roads were then clipped to pine marten habitat (1km squares with >20% woodland, see 3.2). The remaining road sections were driven along, and tree canopy connectivity assessed. All locations where the tree canopy joined (<1m distance) were identified. Any remaining road section >1km from a suitable tree canopy crossing was identified as a High-Risk Road.

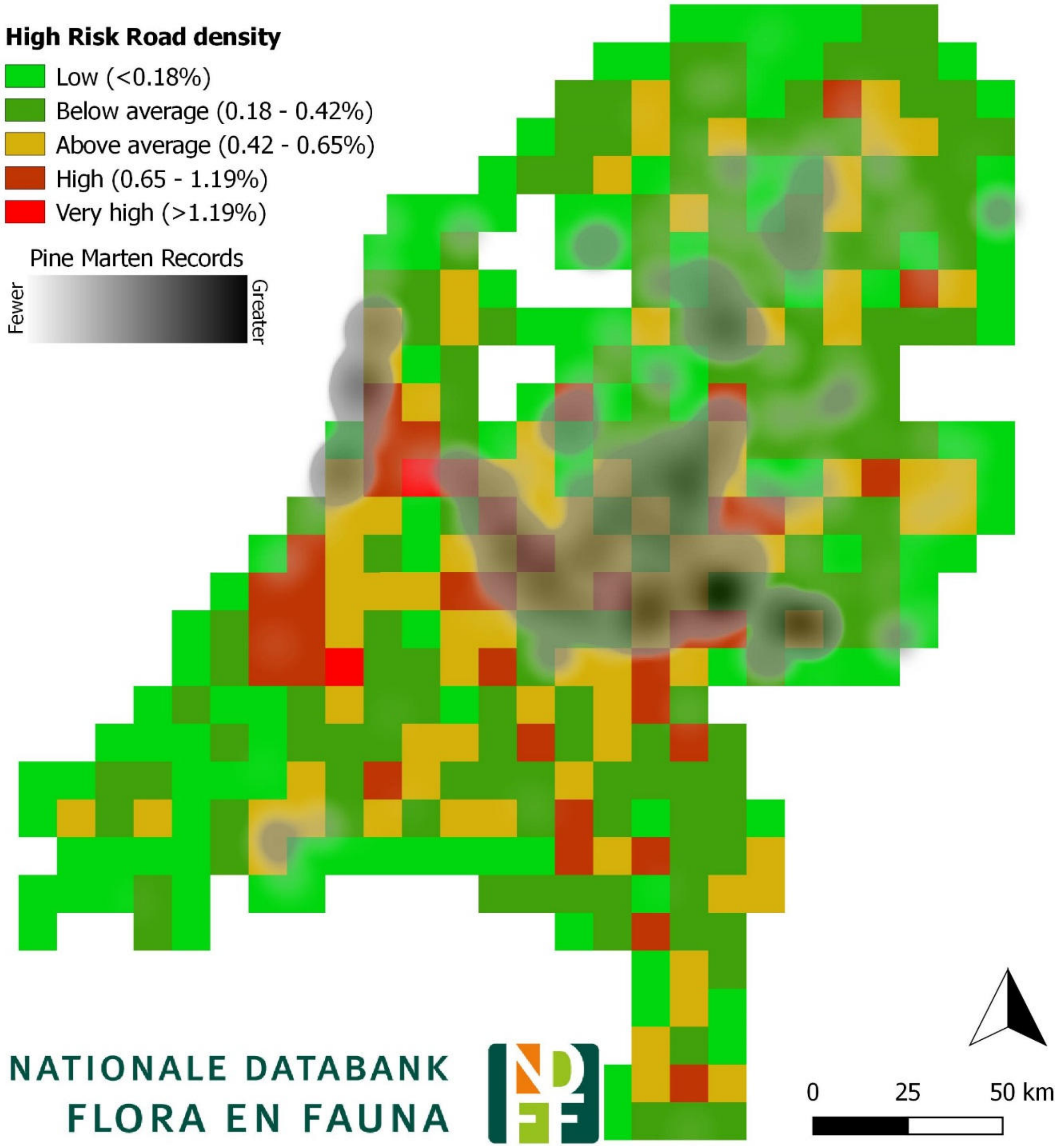

Figure 6. Motorway and primary road density in the Netherlands within 10km by 10km squares. Road density is shown in respect to the mean road density that pine marten populations live alongside (rather than the national average). The number of pine marten records from an area (excluding records from road kill) are shown as a greyscale heatmap. © OpenStreetMap contributors.

Results

3302 records of pine marten road mortality were available. The sex of the individual was identified in 1827 of these cases, with 67% being male. Age was identified in 1958 cases, with 76% being adult, 2% sub-adult, and 21% juveniles. However, the criteria for age differentiation was unknown, hence the adult class may contain numerous sub-adults. Of adult cases, 76% were male, and of juveniles, 59% were male. The population sex ratio and age structure to which these results should be compared was unknown.

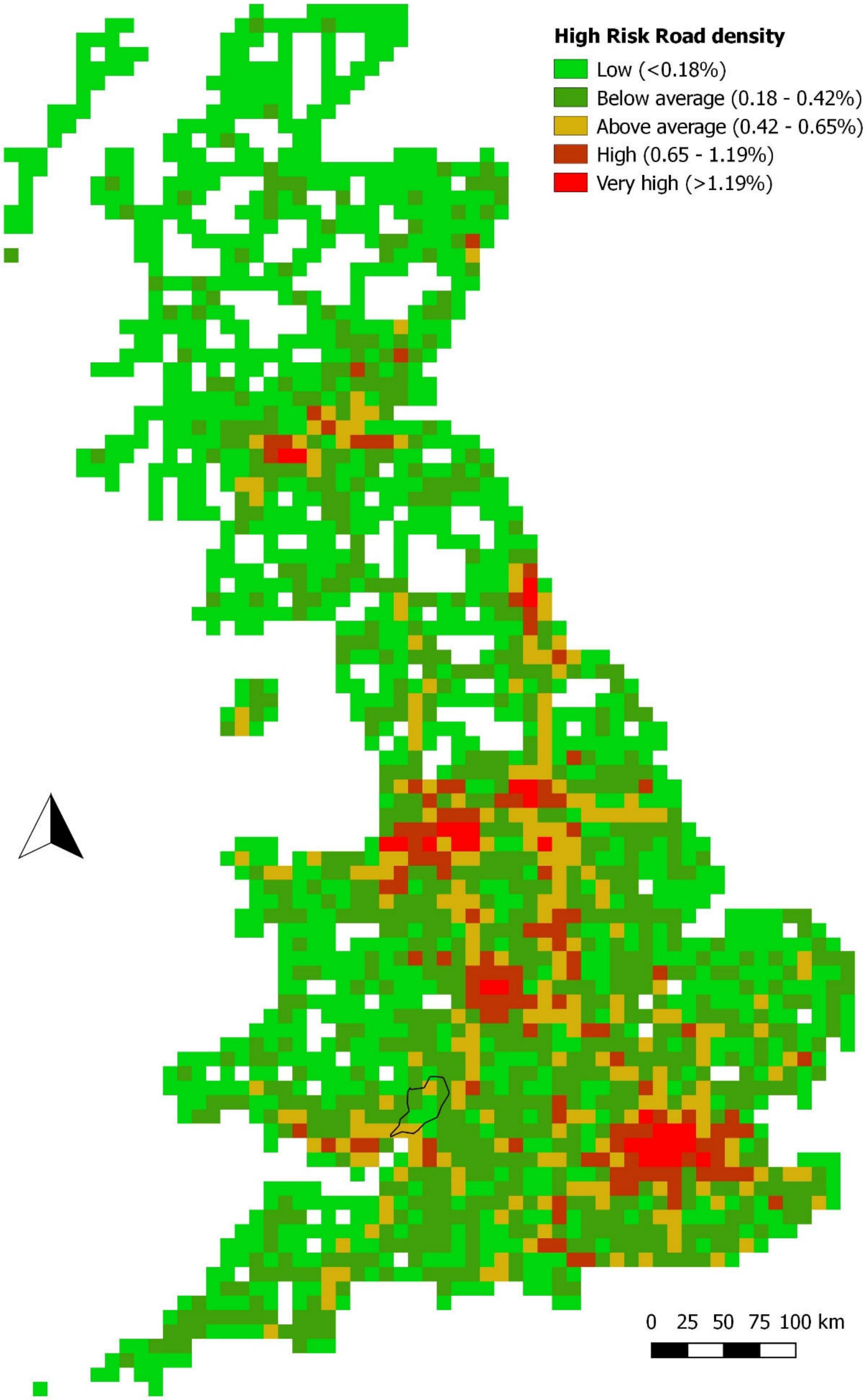

Figure 7. Motorway and primary road density in the UK within 10km by 10km squares. Road density is shown in respect to the mean road density that pine marten populations live alongside in the Netherlands. The Core Reintroduction Area (see 3.2) is outlined. © OpenStreetMap contributors.

A. Which pine marten sex and age classes are more vulnerable to road mortality?

Males (n = 1219) were twice as likely as females (n = 608) to be found dead on the roads. Indeed, adult males (n = 913) were three times more likely to be found than adult females (n= 293). This conclusion assumes that the adult sex-ratio of the population is 50:50. Sex ratio could not be determined as different methods of population census produced conflicting results. For instance, captured individuals had a male biased sex-ratio of 71:29, while photos & videos had a female biased sex ratio of 35:65. Bold male individuals may be more likely to be captured, while sexing from photos may be unreliable.

B. What types of road have the highest risk to pine marten?

Road type was a clear predictor of mortality (Chi^2 contingency test $p<0.001$). Motorways and primary roads killed more pine martens than their abundance across the landscape would predict, resulting in high electivity indexes (see Table 3). These two road types made up only 13% of roads, but resulted in 66% of all road deaths, and were clearly highly risky to pine martens in comparison to other road types. Secondary roads had a standard level of risk, meaning that the number of pine martens killed on them was almost exactly that predicted by their abundance in the landscape. Tertiary and unclassified road types made up 74% of all roads, but accounted for only 21% of pine marten road deaths.

Table 3. Numbers of pine marten killed on different road types in the Netherlands. The Ivlev Electivity Index is a value between -1 and 1, and is used to convey the riskiness of a road type to pine martens.

All	Number killed	% killed	Road length*	Electivity
Motorway	1059	39%	7%	0.69
Primary	731	27%	6%	0.65
Secondary	332	12%	13%	-0.04
Tertiary	388	14%	32%	-0.38
Unclassified	191	7%	42%	-0.71
Residential[&]	1			

*Road length represents the percentage of all roads within the Netherlands that are of that type. Percentage road length within only pine marten population areas (see C.) was also used and gave very similar electivity indexes.

[&]Due to low numbers killed an electivity index was not calculated.

C. What is the gradient of road density within which pine marten populations survive? What is the highest density of roads? How does the PRR, and indeed Britain compare?

The high density of roads in the Netherlands in comparison to the UK was clearly visible (see Figure 6 and Figure 7). Pine marten populations existed in areas with a wide range of road densities. Mean RDP for the motorways and primary roads with pine marten populations in the Netherlands was 0.42% (range 0.04 - 1.19%). In comparison, mean RDP for the same road types in the PRR was 0.26% (range 0.11 – 0.42%).

Mean RDP for motorways, primary, and secondary roads with pine marten populations in the Netherlands was 0.79% (range 0.06 – 2.22%). In comparison, mean RDP for the same road types in the PRR was 0.47% (range 0.22 – 0.72%).

D. Where is road risk greatest in the Forest of Dean and Wye Valley?

Motorways and primary roads within 50m of woodland totalled 149.9km in the core reintroduction area, with 58.8km (39%) found in >20% woodland habitat squares, and >1km from a suitable arboreal crossing. Figure 8 clearly identifies several areas which should be the focus of mitigation efforts should pine martens be reintroduced to the area.

As an indication of the potential effectiveness of this risk analysis, the location of traffic accidents involving wild boar collisions was compared to the prediction of road risk. 44 of 47 (94%) reported wild boar road traffic accidents (RTAs) in the Forest of Dean in 2015 occurred on motorways and primary roads, with the remaining 3 occurring on secondary roads. No wild boar RTAs occurred on other roads.

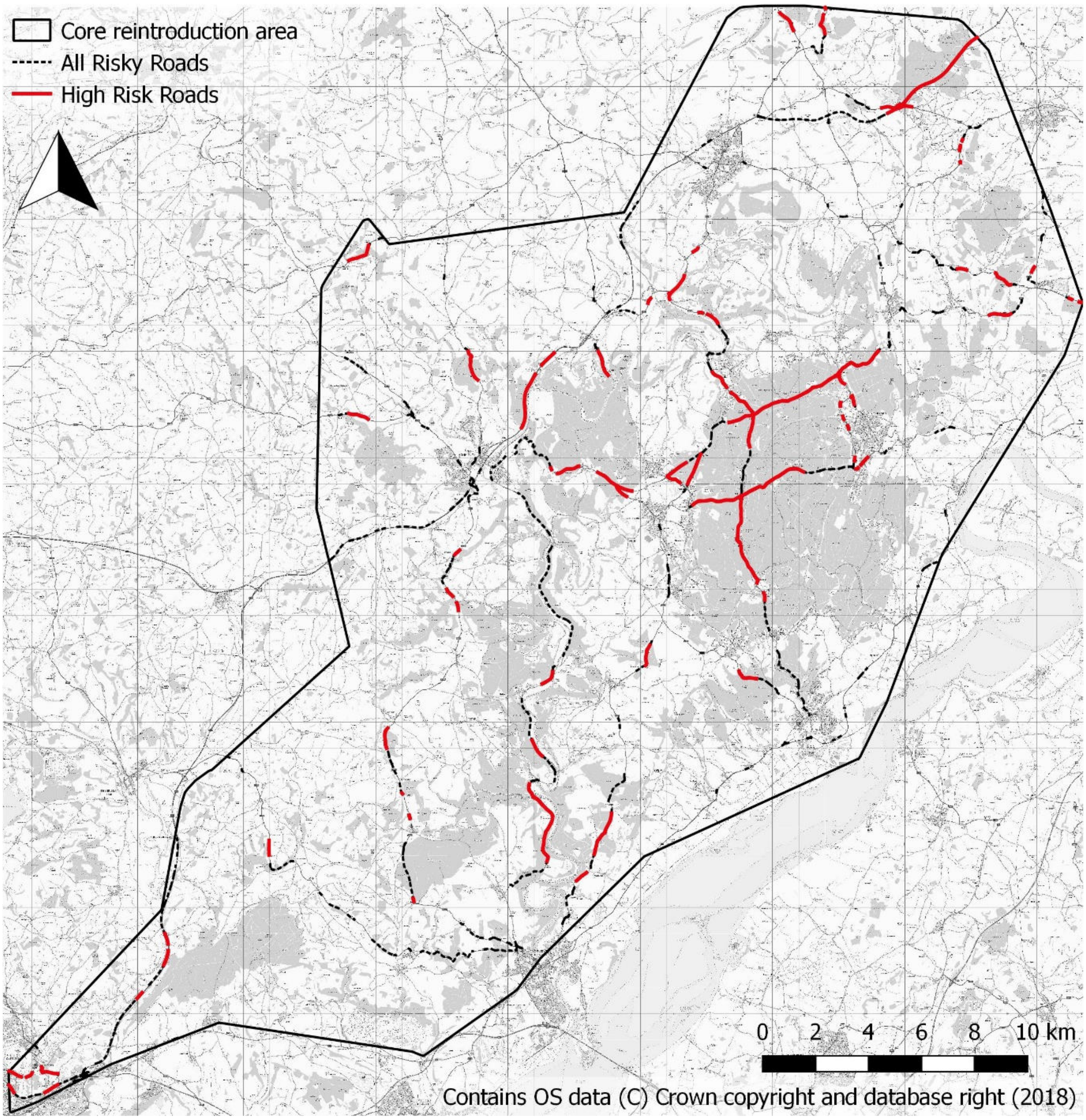

Figure 8. All Risky Roads (motorways and primary roads within 50m of woodland within the core reintroduction area), and High-Risk Roads (those roads also within >20% woodland and >1km from a safe crossing) in the release region.

Discussion and next steps

The bias towards male martens being more likely to be killed on the roads is supported by evidence from elsewhere [39,98]. This result has important implications when assessing the impact of road mortality on population stability. This is because adult male survival is not a key predictor of the likelihood of population extinction, while adult female survival is very important (see Chapter 3.6). However, if the sex-ratio of the adult population is changed, then Fishers theory of sex allocation would predict that more males may be born than females to compensate for this [110]. This may have potentially detrimental effects on population performance.

The likelihood of road mortality is clearly influenced by road type, with mortality more likely on motorways and primary roads. This was partially predicted by the literature. However, for some species motorways have been viewed as a total barrier to movement, hence mortality has been low [86]. This does not appear to be the case for pine martens. These data are useful to predict which roads in the PRR will be a high risk for pine martens if a reintroduction is undertaken.

Pine marten populations were found on the outskirts of several major cities, including Arnhem, Apeldoorn, and Utrecht, and within a range of road densities. Using these data, pine marten populations could exist in large parts of the UK if other habitat requirements were met.

Road density was clearly higher in the PRR than other areas of the UK currently supporting pine marten populations (e.g. Scottish Highlands). However, much of the PRR was below the mean road density for pine marten populations living in the Netherlands. An area to the north of the PRR does have a marginally above average road density (RDP 0.42%). This is primarily due to the presence of the M50 and A40 in this area. Overall these data predict that road density in the PRR would not preclude population establishment. However, an elevated risk of road mortality should be considered during reintroduction decision-making.

The majority of road sections in the Wye Valley were in reasonable proximity to safe arboreal road crossings. However, of the four longest High-Risk Road sections, three were within the Forest of Dean. These included the A4136 between Nailbridge and Worrall Hill, the B4234 alongside Cannop ponds, and the B4226 between Speech House and Coleford.

This analysis seems to be a useful indication of potential road mortality across the UK. However, there are numerous limitations to this study that highlight areas for future research. For instance, traffic volume and speed between the UK and the Netherlands was not directly compared, as we assumed that that road type was a predictor of traffic volume and speed. There is a difference between the speed limit of roads in the UK and the Netherlands. While broadly comparable, the Netherlands does have a higher speed limit on its motorways (81mph vs 70 mph), and a lower speed limit on its primary roads (50 mph vs 60 mph). Also, green bridges in the Netherlands are abundant in comparison to the UK [111], and their potential effect on road mortality was not incorporated..

An ecological trap is an area of poor quality habitat that still attracts an individual [112]. For instance, this may be an area that an individual perceives as high-quality habitat, however there is an aspect of that habitat that means mortality is unexpectedly high. When assessing road density on a landscape scale the interpretation of results must consider high road density areas acting as ecological traps. For instance, while a pine marten population may be found alongside a high road density that does not mean that the population is stable. It may be supported by immigration from a neighbouring pine marten population, without which it would go extinct. During the interpretation of our results we viewed any road density greater than the mean road density found alongside pine marten populations in the Netherlands as a potential ecological trap. However, this level may be inadequate, and a lower actual threshold may result in our conclusions being flawed.

Population stability within the largest habitat patches will be key to metapopulation stability. Hence, reducing mortality in these areas will be the highest priority. The two largest habitat patches exist within the Wye Valley, and the Forest of Dean, the latter of which is also an area of high road risk.

Reducing road risk in this area could improve the likelihood of reintroduction success. Road mitigation measures include arboreal crossings, warning road users of potential wildlife-vehicle collisions through improved signage, improving existing culverts or creating dedicated wildlife underpasses/crossings, and reducing habitat quality along road sides by increasing verge width, and decreasing trees and shrubs along road verges [49].

3.4 Ground truthing of habitat maps

Introduction

A variety of surveying techniques were employed to test the quality of habitat for pine martens within the Potential Release Region. These studied:

Habitat structure - an assessment of habitat structure, based on previous surveys in Scotland and Wales [7,28]. Results were compared with The Vincent Wildlife Trust survey in central Wales.

Small mammal abundance - An assessment of rodent numbers was completed. These are a key prey item, and rodent abundance is a key predictor of pine marten population performance [29].

Den sites - An assessment of the abundance of suitable arboreal cavities that could be utilised for den sites.

Fox density – An assessment of fox density in the Forest of Dean. This was initially viewed as a concern due to the additive potential effects of fox predation and road mortality on pine marten population stability (see 3.3).

Habitat

Methods

Stratified random sampling was used to survey habitat across the Public Forest Estate. 98 survey plots were randomly distributed within 5 key habitat types. The number of plots per habitat type was determined by the abundance of that habitat type across the Forest of Dean. The five habitat types were:

- Edge grassland and scrub, <17 years old, within 50m of woodland
- 17-45 year old coniferous
- 17-45 year old deciduous
- >45 year old coniferous
- >45 year old deciduous

Each circular plot had a 5m radius measured using a measuring tape. Within the plot a variety of attributes were assessed:

Forest type and structure:

- *Forest type* - Broadleaf, conifer, mixed, moorland, improved grassland, clear-fell (veg below knee height), shrub (between knee height and head height).
- *Canopy layers* - Single or multi layered.

***Ground cover and dead wood*:**

- *Dominant ground cover*: this was assessed by eye for the whole plot and categorised as:

Grass <40cm	- Graminoid species with a mean sward height of <40cm.
Tussock >40cm	- Graminoid species with a mean sward height of >40cm.
Bilberry	- *Vaccinium myrtillus* as dominant ground cover.
Bracken	- *Pteridium* sp as the dominant ground cover.
Clear-fell	- Clear fell debris as the dominant ground cover.
Shrubs	- Gorse, Rhodedendron, bramble etc as the dominant ground cover.

Heather	- *Erica* sp or *Calluna* sp as the dominant ground cover.
Moss	- Bryophyta as the dominant ground cover.
Needle litter	- Needle litter as the dominant ground cover.
Leaf litter	- Leaf litter as the dominant ground cover.

- *Tussock grass ground cover percentage*: percentage tussock grass cover was estimated by eye as a proportion of the total plot.
- *Boar disturbance:* Percentage of the plot that was freshly disturbed by boar (i.e. no regrowth from disturbed area).
- *Vegetation Height*: Vegetation height (in cm) – measured at 1m intervals across the diameter of the plot, and then averaged.
- *Course woody debris:* Presence or absence of course woody debris across plot – assessed simply by presence, where 0= no debris, 1= fine twigs/branches, 2=coarse woody debris (>7cm diameter) present and 3=both fine and coarse woody debris present.
- *Number of fallen tree stems or root plates present in the plot*: Number of fallen tree stems >7cm or root plates present in the plot – counted individually.

Fruiting trees and shrubs:

- *Number of fruit bearing trees*: Number of fruit bearing trees – counted individually. This included young fruit bearing trees and saplings that would mature in time.
- *Percentage cover of fruiting shrubs:* Fruit producing shrubs were estimated by eye as a proportion of the total vegetation cover in the plot.

Basal area and tree spacing:

- *Basal Area*: The basal area was calculated from the centre of the plot with a wedge prism relascope, by turning 360° and counting the trees. When looking through the relascope, trees become laterally displaced to a varying degree, and this determines whether they are included in the count. If displacement overlaps the tree it is counted as 1, if bark aligns then it is counted as a ½, if they don't overlap then the tree is not counted.
- *Tree space index:* This index was calculated by dividing the basal area by the number of trees with a diameter at breast height >7cm within the plot [28].

Results

98 plots were surveyed between Sep' 2017 and Mar' 2018.

Forest type and structure: The main species composition of the surveyed woodlands in central Wales was conifer (>50%) and mixed woodlands (>10%). The previous habitat map (see 3.2) identified nearly equal proportions of conifer and broadleaved on the Public Forest Estate. Our plots showed the composition to be conifer (19%), broadleaved (42%) and mixed woodlands (33%). The key reason for the lower quantity of conifer than predicted was that 39% of plots mapped as conifer plantation were instead mixed woodlands. 72% of plots within areas identified as broadleaved woodland had multiple, rather than single, canopy layers, while 44% of plots within areas identified as conifer had multiple canopy layers.

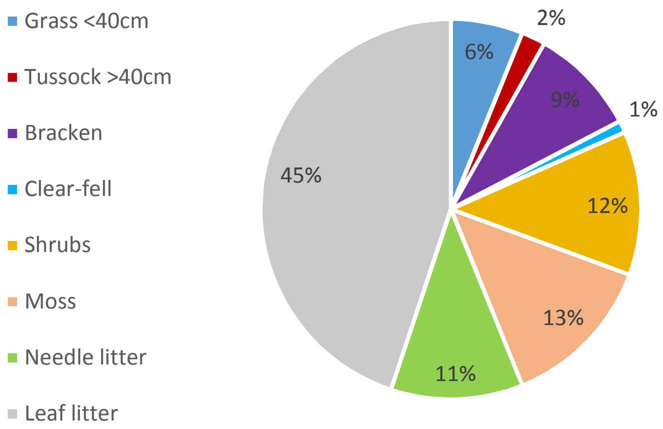

Figure 9. Dominant ground cover across plots within the Forest of Dean

Ground cover and dead wood: The dominant ground cover of 45% of plots was leaf litter. Anecdotally, where leaf litter was a dominant, commonly found secondary species included species such as ivy (*Hedera helix)*, bluebells (*Hyacinthoides non-scripta*), and wild garlic (*Allium ursinum*). The next most frequently found dominant ground covers were moss (13%), shrubs (12%), and needle litter (11%). In comparison, moss was the most commonly found dominant ground cover in central Wales (39%), followed by tussock (14%), bilberry (13%), and needle litter (11%). Tussock ground cover in the Forest of Dean was found in 32% of plots. Within these plots it was found to cover on average 15% (range 0-80%) of the ground. Fresh boar disturbance was found in 27% of plots. Within these plots, on average 15% (range 0-75%) of the ground was freshly disturbed.

Ground vegetation height followed the same pattern in the Forest of Dean as central Wales, with mixed woodlands having the tallest ground vegetation (mean height 19cm), followed by broadleaved (mean height 15cm) and conifer (mean height 12cm). Vegetation height was lower in the Forest of Dean across all three habitats (mean conifer 12cm vs 15cm, mean broadleaf 15cm vs 20cm, mean mixed 19cm vs 33cm), however this may have been because surveys occurred at different times of year (autumn/winter vs spring).

Some woody debris was found in >95% of plots. However, large stems (>7cm diameter) were only found in 30% of plots. The mean number of large stems in plots where they were found was 2.7.

Fruiting trees and shrubs: Fruiting shrubs were found on 60% of plots, with a mean ground cover in plots where they were present of 23%. Fruiting trees were found in only 17% of plots, with a mean number of 2 trees in plots where they were found.

Basal area: A basal area ≥33m^2/ha has been identified as poor-quality habitat for pine martens [28]. This does not mean that woodland with a basal area <33m^2 is high quality habitat, as there are other factors that may make it of poorer quality. Only a few plots with a basal area indicating poor habitat quality were found, indeed only 5% of surveyed plots had a basal area of ≥33m^2. A 'tree space index' was also calculated to compare to the VWT survey of central Wales habitat. The majority of sites in central Wales had a tree space index of <4, while 59% of our survey plots were >4, suggesting a landscape with larger trees with larger spaces between.

Small mammals

Methods

This study was completed by a University of Gloucestershire Master's student (See Feirn 2018 for full methodology and results [113]). Twenty-five longworth traps were placed in a 5 by 5 square grid, with 10 m between traps. Traps were baited with grains, apple pieces, and peanut butter. Hay was provided. Traps were left overnight for 12 hours. Captured small mammals were identified, recorded, and immediately released at the trapped location. Trapping occurred between September and November 2017. This replicates previous studies (see Table 4), and coincides with peak rodent abundance [114].

Twenty-one trapping locations were used for a total of 525 trap nights. Trapping locations were randomly located across three habitat types:

- Grassland & scrub within 50m of woodland
- Coniferous 17-45 yr old woodland
- Deciduous woodland

Results

Across the 21 sites, the mean number of rodents caught was 8.8 per 100 trap nights ($\bar{x}$ n/100TN), with some variability between different habitat types (range 6.9 – 11.4 $\bar{x}$ n/100TN). Predominantly wood mice and yellow-necked mice were captured, with low numbers of field and bank voles. The abundance compares favourably with studies from across Europe investigating rodent populations in areas with healthy pine marten populations (see Table 4).

Table 4. Abundance of rodents (mean captures per 100 trap nights) within pine marten habitat across Europe from a review of studies [29] in comparison to the Forest of Dean.

Location	**$\bar{x}$ n/100TN**
Poland	5.6
Scotland	2.5 to 3.8
Norway / Sweden	1.7
Finland	2.3
Forest of Dean	**8.8**

Den sites

Methods

Three ¼ha plots of both 200yr and 100 yr old oak were surveyed for arboreal cavities from the ground with binoculars. Ladders were used to further assess the percentage of holes that, after being viewed from the ground, were subsequently found to not be suitable for pine martens. This was usually because, from the better perspective of a ladder with a torch, the feature was not a cavity of suitable depth or size.

Results

22% of trees within old oak plots, and 4% of trees within the young oak plots were identified as having possible cavities from the ground. 41% of potential cavities identified from the ground were found to be suitable cavities. There were estimated to be 15.9 suitable cavities per ha within the old oak plots, in comparison to 2.7 suitable cavities per ha within the younger oak plots. This indicates that the medium quality den-site habitat may contain few natural cavities in comparison to the high-quality den-site habitat identified in 3.2.

Fox density estimate

Methods

This study was completed by a University of Gloucestershire Undergraduate student (See Galbraith 2018 for full methodology and results [115]). Between May and December 2017, thirty-eight randomly allocated camera trap sites were located across the Public Forest Estate. All sites were located within woodland.

Spypoint Force-10 trail cameras were used, fixed at 30cm from the ground, and orientated towards a random direction. To determine effective detection distance, at each site a reference image with marker posts at 2.5m intervals was taken [116]. Sites were not baited. Cameras were deployed for ~two months.

A Random Encounter Model [117] was used to determine fox density. Only periods where foxes were active were used. A range of estimates of fox movement data were used [118].

Results

Twenty-three camera trap sites produced usable results, totalling 34,582 hours of monitoring data. The remaining sites could not be utilised due to theft, camera failure, or the camera being moved. 78% of sites captured an image of a fox. Across the trapping sites, fox density was estimated as 0.19 (0.16 ± 0.22) foxes per km^2 (see Figure 10).

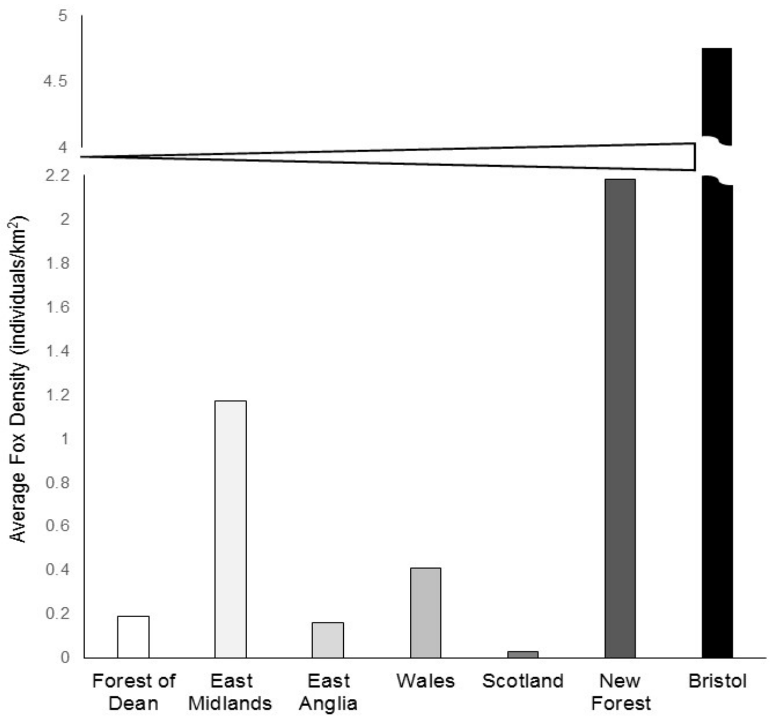

Figure 2. Fox density estimates for sites in the UK. The broken Y axis shows the large difference between the density in Bristol compared to the other sites. Forest of Dean: 0.19/km^2, East Midlands: 1.17/km^2, East Anglia: 0.16km^2, Wales: 0.4km^2 [119], Scotland: 0.025/km^2 [4], New Forest: 2.18/km^2 [120], Bristol: 4.75/km^2 (Averaged from 4.0-5.5/km^2 in 2002-2004 [121]). From Galbraith (2018) [115].

Discussion

Habitat: Overall the results of the habitat survey were mixed. With few purely conifer stands (16%), the composition of the forest was broadly good. Also, as plantation forests are often planted at the same time (unless continuous cover forestry is used) they are often associated with being all the same age and a single canopy. However, many plots had multiple canopy layers, in particular within broadleaved woodland areas. The most commonly recorded dominant ground cover was leaf litter. This study also supports previous studies showing that the volume of large dead wood in some areas of the Forest of Dean is poor [122]. Hence, the provision of more large woody debris would be useful, and has previously been shown to directly affect pine marten hunting success [44].

Small mammals: The rodent trapping revealed that rodent abundance in the area was high. The population of rodents in the Forest of Dean would support a healthy pine marten population. The low numbers of field and bank voles during trapping may reflect study methodology or design, but should be further investigated. A study in Poland found that rodent abundance predicted pine marten density [29]. Using their predictions, Forest of Dean pine marten density would be predicted to be 0.63 per km^2. However, this prediction would not take into account the warm winter temperature in the Forest of Dean, which is another key predictor of pine marten population density [29].

Den sites: Despite being an ancient hunting forest, most of the Forest of Dean has been managed for timber which may have involved removal of cavity trees. As a result, a survey to ground-truth the den site map produced in 3.2 was considered essential. The results here reveal that the 'High-quality denning areas' are likely to have numerous suitable arboreal cavities. However, 'Medium-quality denning areas' probably need to age before abundant suitable cavities will start to appear. Hence, den boxes may be required in all areas not in proximity to 'High-quality denning areas'.

Fox density: When this feasibility study was initiated, road mortality was identified as a key potential risk to population establishment. Hence, it was thought useful to identify the level of the potential risk from fox mortality as well. However, the risk of road mortality was assessed in section 3.3, and thought to be lower than expected. Hence, the results of this fox density analysis became of less importance. The results reported here indicate fox density is medium to low in comparison to other areas of the UK. Mortality factors, such as foxes and roads, may increase the extinction risk of the population (see section 3.6). However, they are not here predicted to be an impediment to population establishment.

3.5 Release area criteria

A variety of criteria may be used to identify suitable release areas. These include levels of food, shelter, mortality risks, potential disturbance, a lack of local migrant sinks, and similarity of habitat to the source population.

The North American pine marten has been the subject of several studies looking at post release movement and dispersal after translocation. Due to the ecological similarities between the species, indeed with some authorities classifying them as the same species [22], these may be useful indications of movement in European pine marten. Average post-release movements following reintroductions ranged from 4.6km [123] to 20.8km [124], and males do seem to make greater post-release movements than females [124,125]. The largest post-release movements observed however are much higher (e.g. 149km [123]).

There are two methods of release used in translocations; soft-release where an individual is kept in captivity at the release site for a number of days before release, and quick-release where individuals are released immediately. It has been argued that soft-release reduces post-release dispersal in pine martens [124], however other studies have not been able to replicate this effect and argue for a quick-release which may reduce stress levels [125,126].

The recent translocation of pine martens to the forests of central Wales is a useful example of investigating post-release movements. Dispersal has been predominantly along wooded valleys, which has also been found elsewhere [39,49]. The majority of individuals stayed reasonably local to the release site, however a single individual dispersed a distance >100km. Interestingly this single individual was one of the first to be released and likely did not encounter any other martens on its journey.

The Forest of Dean and Wye Valley potential release region is approximately 20-30 km in length, and 10-15 km in width. Hence, with average post release movements from 4.6km [123] to 20.8km [124] there will be little influence of specific release site on post-release territory establishment.

3.6 Ecological Carrying Capacity and Population Viability Analysis

Abstract

Estimating the potential ecological carrying capacity (ECC) of the Forest of Dean area was essential to inform a population viability analysis (PVA). The PVA predicts whether a stable population of pine martens could establish in the area. Here the PVA was also used to assess the impacts of a second population in Wales/west England, and the impact of release cohort size on the likelihood of population establishment. Three methods were used to estimate ecological carrying capacity; abundance of available habitat and estimated pine marten density, abundance of available habitat and estimated pine marten home range size, and a HexSim spatially-explicit population model. Vortex was used for the PVA. The mean ECC across three different methods was 195.7 individuals. Using the range of ECC estimates resulted in a density across the Core Reintroduction Area of between 0.07 and 0.43 pine martens per km^2. The PVA showed that an ECC lower than 195.7 would increase extinction risk. Adult mortality was also a key factor in influencing extinction risk. A second release into the Wales/West England region greatly reduced the long-term extinction risk of the meta-population, from 0.22 to a minimum of 0.05. A release cohort of between 40 and 60 individuals gives a high likelihood of population survival for 20 years, but release numbers should be adaptive to observed mortality rates.

Introduction

The Ecological Carrying Capacity (ECC) of a species in an area is the size of the maximum stable population that can live there [127]. Populations may exceed carrying capacity, in particular if a species has a density-vague response to resources [128]. However, populations will not be stable when exceeding ECC.

Estimating the potential ECC of the Forest of Dean release region is essential to predict whether a stable population can be established in the area. ECC can be predicted by comparing areas which have already reached carrying capacity with the release region. Population traits, such as species density, can be compared. Also, as territories do not overlap significantly for pine martens of the same sex, home-range size can be used. Here we use both approaches as well as comparing estimates with a modelling approach used in the next Chapter.

Population Viability Analysis (PVA) uses the ECC of an area and species life history traits to assess the risk of a population going extinct. This is essential for a reintroduction project to predict the likelihood of population success. Different scenarios can also be tested to see how uncertainty of estimates of ECC affects the chance of success. Road mortality has previously been identified as a potential risk (see 3.3). The impact of this mortality on the likelihood of success was tested.

This Chapter attempts to answer:

a) What is the potential ECC of the potential release region?
b) What influence do carrying capacity and mortality have on the probability of population establishment?
c) What is the impact of a second major reintroduced population within the Wales/west England metapopulation?
d) How does release cohort size affect the probability of population establishment?

Methods

a) What is the potential ECC in the release region?

ECC can be estimated in several different ways. Here we use three different methods to give a broad range of estimates. These are:

- *Density:* The density of pine martens in a variety of habitats has previously been estimated (see 3.1). We first calculated the abundance of different types of suitable habitat for pine martens (see 3.2). We then estimated the potential density of a pine marten population with these areas based on a broad estimate of habitat quality. The estimated ECC was then assessed based on these estimated densities. Previous density estimates will have incorporated both adults and juveniles.
- *Home range:* The home range of pine martens in a variety of habitats has previously been estimated (see 3.1). We first calculated the abundance of suitable habitat for pine marten (see 3.2). We then calculated how many female home ranges this quantity of habitat would support, and then assumed a 50:50 sex ratio to calculate potential population size and hence ECC. This predicts only the adult ECC.
- *HexSim:* Spatially-explicit population models can be useful in predicting the size and spread of a reintroduced population. We used our HexSim pine marten model (see 3.7) to predict the ECC for pine martens in the Forest of Dean area only. This area contained 323 one-kilometre squares of suitable habitat. Two scenarios were run, these assumed that habitat was either high quality or low quality (see 3.7). The model was run 20 times for each scenario. The model allowed us to predict both adult ECC, and total population size (i.e. including juveniles).

b) What influence do carrying capacity and mortality have on the probability of population establishment?

Vortex is computer software commonly used for PVA and has been previously used for a wide variety of species including pine martens. Powell *et al.* 2012 developed a population model using Vortex, specifically usable for marten reintroductions [129]. Here we use this model due to its applicability to our scenario. It has previously been shown to be a reasonable estimate of real world scenarios. For instance, pine marten generation time (the mean age of parents of those born in the current year) has been estimated as 5.75 years [4]. The Powell *et al.* 2012 model produced a generation time close to this of 5.15 years. A stable age distribution was used, but modified to ensure all animals were ≥2 years old as juveniles would not be translocated. 1000 iterations were used over a 50-year period.

There have been a number of approaches to population modelling of *Martes* populations in the past [75,129]. Parameters for these models have all been thoroughly sourced from the literature, but do vary in key model parameters. For instance, adult survival is a key population parameter, but studies have used a range of figures from 70% to 88% yearly survival. However, estimates of adult survival from the study of a population in Bresse, France, put it as low as 49% [27]. The Powell *et al* 2012 model is distinguished from other models [75,129] in that it has a high estimate of juvenile mortality (65% per year), but a low estimate of adult mortality (12% per year). Hence, the effect of changes in adult mortality on intrinsic population growth rate (lambda) were also investigated.

It is often argued that population modelling should not be used to specifically estimate the extinction risk of a population [130,131], but rather investigate the relative extinction risks of different scenarios. Hence, we compared our release scenarios with a baseline model. Our baseline model had an ECC of 1000 individuals, and a release cohort size of 1000 individuals, standard mortality parameters were used, all other parameters were kept the same. When testing the impact of ecological carrying capacity on the likelihood of reintroduction success, the release cohort size was kept at 60 individuals to mimic a potential reintroduction.

Road mortality is a key concern within the Forest of Dean release region. This has been shown to most likely affect adult males rather than adult females at a ratio of 3:1 (see 3.3). High mortality rates were tested with female mortality increased by 2.5% and male mortality increased by 7.5%. Very high mortality rates were also tested with female mortality increased by 5% and male mortality increased by 15%. It has also been argued that road mortality to more likely to impact dispersing sub-adults the greatest. Hence, the influence of varying the mortality rate within individuals aged 1-2, and adults, were tested separately.

c) What is the impact of a second major reintroduced population within the Wales/west England metapopulation?

One of the potential goals for a conservation translocation is for the reintroduced population to link with already established populations. This should give rise to overall greater metapopulation stability. Here we compare the metapopulation extinction risk of two pine marten populations in comparison to one. We also test the influence of a range of migration rates between these two populations on extinction risk.

d) How does release cohort size affect the probability of population establishment?

Finally, we simulate a reintroduction scenario to the Forest of Dean using a variety of release cohort sizes, and potential mortality rates. If both the Welsh and Forest of Dean populations become established, migration between the populations is expected, conservatively, to become common within 20 years (see 3.7). Hence, migration between populations was scheduled to start between populations after 20 years, with 2% of a population migrating per year.

Results

a) What is the potential ECC in the release region?

Our three different methods of estimating ECC produced broadly similar estimated ranges. Using the density method, ECC was predicted to be between 113 and 245, using the home range method ECC was predicted to be between 55 and 370 (see Table 5), and using the HexSim model adult ECC was predicted to be between 100 and 291 (see Table 6). The mean predicted ECC from all results was 195.7. This would result in a mean density within suitable habitat of 0.71 per km^2, and a density of 0.24 per km^2 within the entirety of the Core Reintroduction Area. Using the range of ECC estimates resulted in a density across the Core Reintroduction Area of between 0.07 and 0.43 per km^2.

b) What influence do carrying capacity and mortality have on the probability of population establishment?

The influence of adult survival on the intrinsic population growth rate (lambda) of the model was tested. Lambda using the original model was 1.16, and was reduced to 1 when adult survival was at 67%.

Table 5. Ecological carrying capacity in the release region as estimated by the abundance of suitable habitat, density, and home range [29].

Area	**Habitat type**	**Area (km^2)**	**Density estimate (per km^2)**	**Estimated ecological carrying capacity**			
				Using density		**Using home range**	
				Min	**Max**	**Min ($10km^2$ home range)**	**Max ($1.5km^2$ home range)**
Forest of Dean	Highly Suitable Woodland	70.56	0.5-1	35.3	70.6	14.1	94.1
	Suitable Woodland	11.71	0.1-0.5	1.2	5.9	2.3	15.6
	Edge Habitat	24.4	0.5-1	12.2	24.4	4.9	32.5
Wye Valley	Deciduous woodland	56.42	0.5-1	28.2	56.4	11.3	75.2
	Coniferous woodland	25.78	0.1-0.5	2.6	12.9	5.2	34.4
	Edge Habitat	5.42	0.5-1	2.7	5.4	1.1	7.2
Wentwood	Deciduous woodland	7.15	0.5-1	3.6	7.2	1.4	9.5
	Coniferous woodland	7.95	0.1-0.5	0.8	4	1.6	10.6
	Edge Habitat	4.5	0.5-1	2.3	4.5	0.9	6.0
Other woodlands	Deciduous woodland	40.95	0.5-1	20.5	41	8.2	54.6
	Coniferous woodland	18.5	0.1-0.5	1.9	9.3	3.7	24.7
	Edge Habitat	3.85	0.5-1	1.9	3.9	0.8	5.1
	Totals	277.2		113	245.3	55.4	369.6

Table 6. Ecological carrying capacity in the Forest of Dean area as estimated by HexSim.

	Low Quality Habitat		High Quality Habitat	
	Mean size	Density (km^{-2})	Mean size	Density (km^{-2})
Adult population	99.9	0.19	291.2	0.57
Population (inc. juveniles)	186.1	0.36	561.2	1.09

The effect of errors in the estimation of ECC were also tested. When ECC was lower than the mean predicted level (195.7), extinction risk rose greatly (see Figure 11). However, when ECC was higher than the mean predicted level, extinction risk only improved minimally in comparison.

As expected, the chance of a population's extinction increased with increasing time (see Figure 12). Sub-adult mortality had a much smaller effect on extinction risk than adult mortality. Very high adult mortality more than doubled extinction risk at every time point.

c) What is the impact of a second reintroduced population within the Wales/west England metapopulation?

Using a single population at the mean ECC (195.7) the index of extinction rate was 0.23 (dropping to 0.22 when a second empty population with 2% migration is included– see Figure 14). Using two populations of the same size with no migration between, the index of extinction risk dropped to 0.09. Furthermore, migration between populations lowered the extinction risk to 0.05 (see Figure 13).

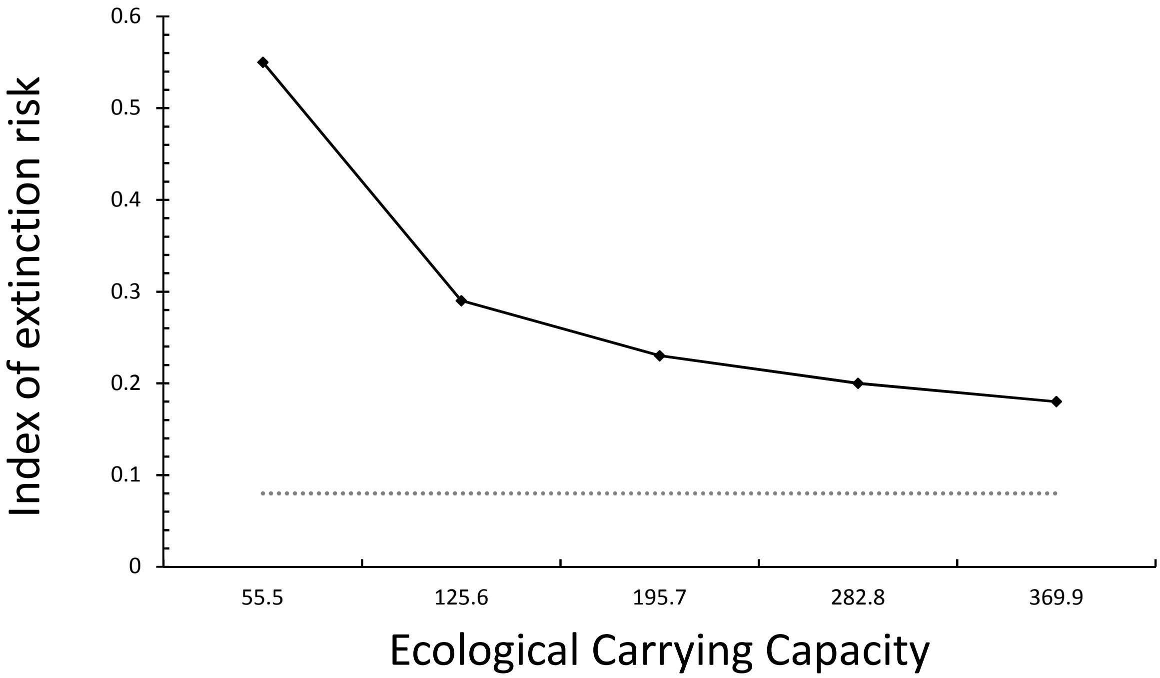

Figure 11. The effect of ecological carrying capacity on extinction risk. A baseline scenario with ECC at 1000 and a release cohort size of 1000 is shown for comparison (dotted line).

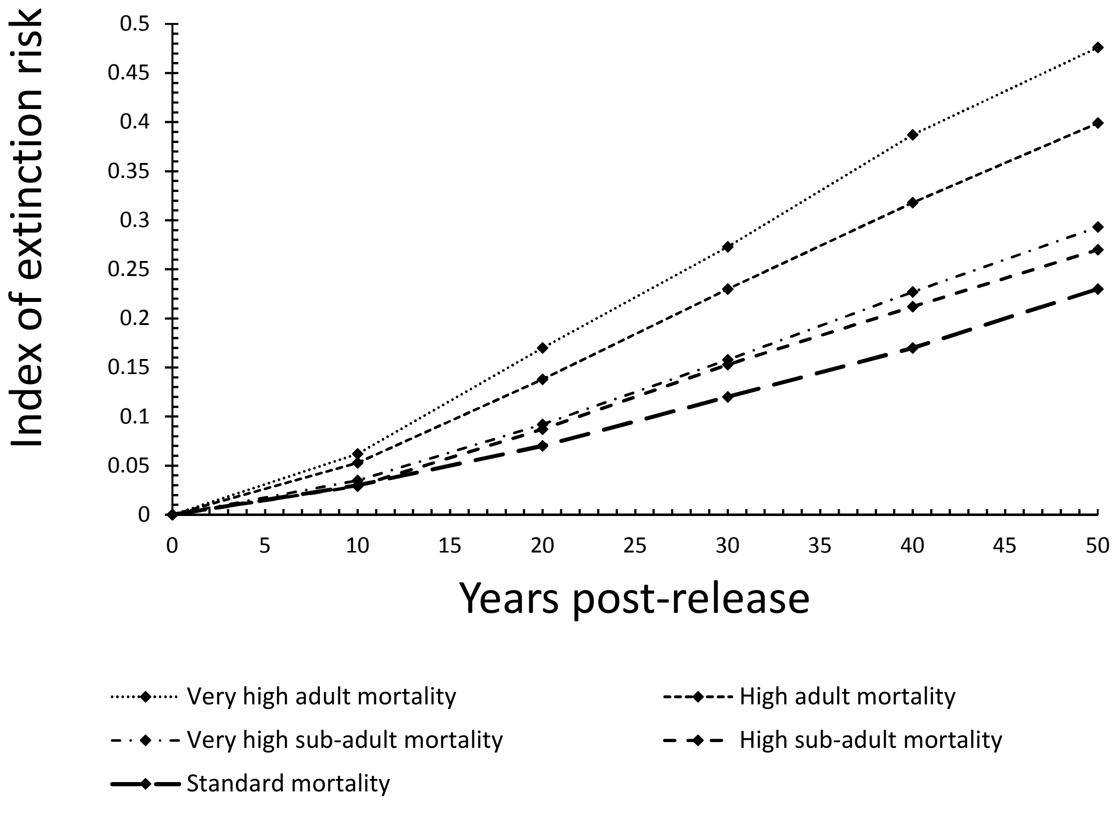

Figure 12. The change in the risk of population extinction over time. How the relationship changes in a variety of scenarios covering differing mortality rates in sub-adults and adults is presented.

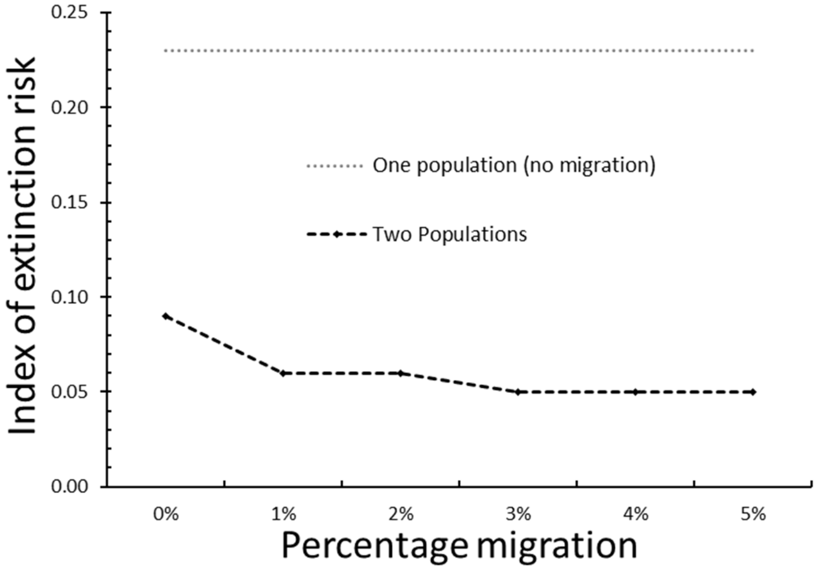

Figure 13. Effect of multiple populations and migration between those populations on the index of extinction risk

d) How does release cohort size affect the probability of population establishment?

Metapopulation extinction risk fell for all release scenarios (see Figure 14a). However, in a scenario with very high mortality rates and just 20 animals released, the extinction risk of the Forest of Dean population was 0.38 (see Figure 14b). With standard rates of mortality even the smallest release cohort tested had a better chance of population establishment (over 20 years) than the current population in Wales (over 50 years). Increasing the size of a release cohort from 20 to 40 individuals had a large impact on extinction risk (reduced by 0.09 in the standard mortality scenario and 0.17 in the very high adult mortality scenario). Increasing the size of a release cohort from 40 to 60 individuals had less of an effect (reduced by 0.04 in the standard mortality scenario and 0.08 in the very high adult mortality scenario).

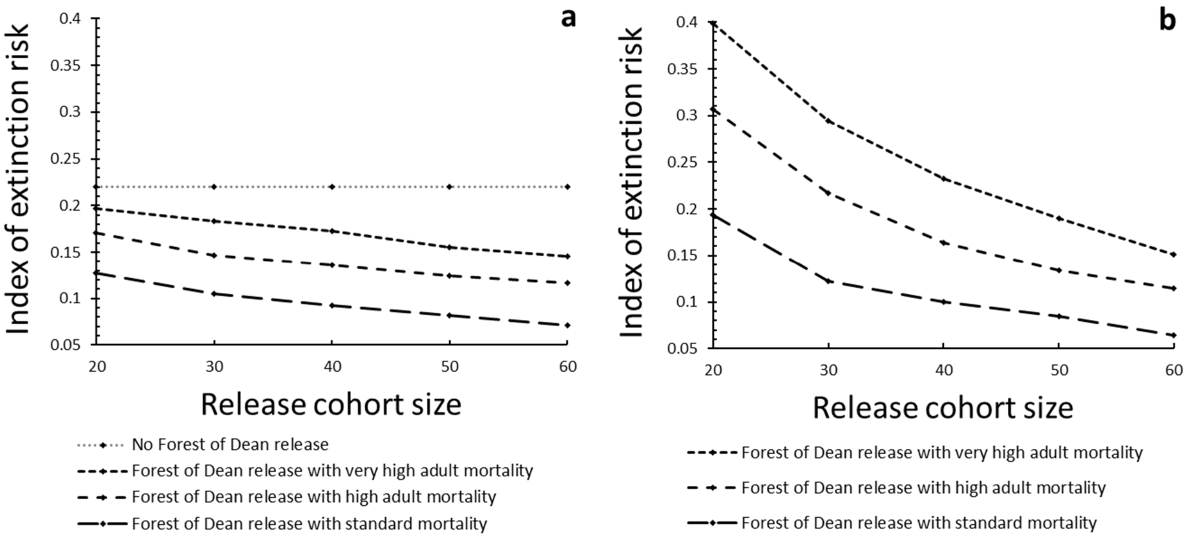

Figure 14. a) Metapopulation extinction risk over 50 years with and without a Forest of Dean reintroduction. Forest of Dean reintroduction scenarios are presented with a variety of adult mortality rates (see methods). b) Extinction risk over 20 years (before expected significant migration between populations) for the Forest of Dean population. Scenarios with a variety of adult mortality rates and release cohorts are presented.

Discussion

Here we produced a range of estimates for the ecological carrying capacity of the potential release region. These fit well with estimates for other areas. For instance, it has previously been estimated that 250 ha of suitable woodland are needed per breeding pair of pine martens in Scotland [58]. Using this figure would estimate an ECC of 221.8, a figure which falls within all our estimates of ECC. The mean density of pine martens across a range of sites across Europe was 0.2 km^{-2} [29]. This was the same as our density estimate across the Core Reintroduction Area. Another historical estimate of ECC used a density of 0.67 individuals per km^2 of woodland [3,12]. This would result in an ECC of 160 in our release region.

We used multiple different methods due to potential errors associated with all our methods. For instance, our estimate using home ranges did not consider the likely scenario that there would be gaps between different home ranges. The use of three different methods makes our final estimate more reliable. However, caution should be used during the interpretation of results.

The lowest carrying capacity estimates, and scenarios with high adult mortality, carried a high extinction risks. If the reintroduction goes ahead, long-term monitoring of the population will be essential. Density estimates from this long-term monitoring will be useful to investigate actual ECC.

The creation of a second population within Wales/west England clearly reduced the likelihood of metapopulation extinction. This was due to having two chances of individual population success. Also, migration between the two populations further decreased extinction risk. This may have been due to the mutual reinforcement provided by migration between the populations, as well as the reduction in inbreeding and increase in population genetic variability that this may provide.

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 same study predicted through modelling that increasing the size of a release cohort from 60 to 100 individuals more than doubles the chance of success [129]. Here we argue that a second release into the Forest of Dean fulfils these criteria. A reintroduction of between 40 and 60 individuals, adaptive to observed rates of mortality, should maximise the likelihood of success. However, a key factor in metapopulation establishment will be whether the two populations will be able to geographically link, and mutually reinforce each other over the short to medium term. This is explored in the next Chapter.

3.7 Dispersal potential

Abstract

For any reintroduction project, it is essential to predict whether a proposed reintroduction site will be naturally recolonised, and whether a reintroduced population will link with already established populations. Here we developed a spatially-explicit population model using *HexSim* to predict how pine marten populations may grow and expand. Firstly, model parameters were derived from the literature and the sensitivity of the model to different model parameters tested. Then the model was tested on range expansion data from the last 30 years in Scotland, and parameters changed to best fit the historical scenario. The model was then used to predict the range expansion from the current central Wales population, and the range expansion from a release into the Forest of Dean and Wye Valley over the next 30 years. The initial model developed from the literature accurately predicted historical range expansion in Scotland (TSS 0.90), and was improved by increasing mean dispersal distance to produce a final model (TSS 0.92). Using this model, the current central Wales population was predicted to expand and colonise the Forest of Dean potential release region. It is plausible, but unlikely, for the region to be colonised immediately. However, within 21 years there is a high likelihood that the region will be colonised. When simulating a release into the Forest of Dean, the population range was predicted to overlap with the central Wales population by year 15, with multiple areas overlapping by year 20. By year 30 the population had expanded across Wales, with significant expansion into central England.

Introduction

It is useful to predict how a successful reintroduced population may expand its geographic range. This is for a variety of reasons such as helping to predict population stability (see 3.6) and how the population may link with a wider meta-population. Also, it can help identify areas in which the species may have an ecological impact. Furthermore, it is useful for identifying areas where socio-economic costs and benefits may be realised.

HexSim [132] (previously PATCH) is a spatially-explicit population model used to predict population performance and range expansion. It has been used to assess potential reintroduction strategies in a range of mammals in North America such as elk (*Cervus canadensis*) [133], wolves (*Canis lupus*) [134], and fisher (*Martes pennanti*) [135]. HexSim model's individuals and their traits, such as survival, reproduction, movement, dispersal, and home range (predicted by habitat quality), to ultimately predict population growth and range expansion. Here we develop a HexSim model for pine martens in the UK, to investigate three key questions:

- How accurately can the historical expansion of pine martens in Scotland be predicted by a HexSim model?
- How quickly will pine martens naturally recolonise the Forest of Dean release region without a reintroduction to the area?
- How would a reintroduced pine marten population to the Forest of Dean expand over the 30 years post release, and when would it link with the already established central Wales population?

Methods

Developing the HexSim model

HexSim simulates individuals and their life histories within a map of hexagons. Each hexagon is assigned a value relating to habitat quality (in this case woodland percentage). Multiple hexagons are assigned to an individual's home range. HexSim then simulates each individual within a population, including their survival, reproduction, and the dispersal of young. To simplify the model, here we use a female-only model. Male mate availability is not expected to be a limiting factor to population growth [22]. Hence, the model only attempts to investigate the distribution of the female population, not any associated dispersing males. Males are expected to disperse further than females and hence the model will likely underestimate the area a pine marten population would reside in if a reintroduction goes ahead [136]. However, the core population will always be restricted by where both sexes reside. All models were run 50 times, for 30 years.

Habitat quality, minimum range resource, and home-range

Here we used the Landscape Connectivity Map (see 3.2) to estimate habitat quality. This uses the percentage of woodland within 1km^2 to estimate habitat quality. Each 1km square was converted to a single hexagon. All hexagons with >20% woodland were treated equally. Hence, each hexagon of the base map had a value between 0 and 0.2. This measure of habitat quality is highly simplistic and future models could use more advanced Species Distribution Models.

The *Minimum Range Resource* parameter within HexSim is used to predict individual home range size. Female home range has been shown to vary between 0.7 and 9.8km^2 [29]. We tested the mid-point of these, with habitat requirements met when all of a 5.25km^2 home range had >20% woodland, equivalent to a *Minimum Range Resource* of 1.05. A 'perfect' habitat map was generated to test for the validity of the model with these parameters. This scenario had a uniform distribution of the highest quality of habitat (>20% woodland) across a 1000km^2 area. Using this habitat map, the model resulted in a population density of 0.56 pine marten per km^2, which is within the expected range (see 3.1). For instance, density in Scotland has been estimated between 0.12 - 0.82 per km^2 [32].

Life history parameters

The population and life history parameters from Powell *et al* 2012 were used [129] so that the model could be compared with the previous chapter (see 3.6).

Juvenile dispersal

Due to differing costs associated with dispersing through different habitats, and searching behaviours for high quality habitat [137], real world pine marten juvenile dispersal is unlikely to be in a straight line, but instead meandering. Hence, actual, meandering, 'dispersal distance' can be very different from straight-line 'displacement distance'. Within HexSim the user defines dispersal distance, but then must test the model in different landscapes to determine the resulting mean straight-line displacement distance. Displacement distance was ground-truthed using the 'meters displaced' HexSim report.

Dispersal is highly variable, and evidence shows that approximately half of pine martens do not disperse, instead (sometimes after exploratory movements) staying local to the mother's home range [26]. Displacement distance may differ between males and females [98], and has been recorded over a variety of distances from 2.3km to 214km [26,138]. Female dispersal in the Netherlands was found to be on average 5km (+/- 2.1km) for dispersing individuals [26]. It is thought that an open landscape does not limit dispersal [139], although it may be that males are more willing to cross open landscapes than females [46]. It has been found that American pine martens disperse shorter distances in more open habitat due to higher associated mortality rates, and hence dispersal through mature woodland is often further [138].

Here we tested a range of mean displacement distances between 4-8km. We also tested the influence of dispersing individuals being repelled from landscapes with <1% woodland, or being attracted to landscapes with >5% woodland.

Barriers to movement

Large tidal rivers may be assumed to be an impediment to pine marten movements. The River Severn and its estuary, and the Rivers Wye and Usk may influence pine marten movements in the event of a reintroduction. However, pine martens have previously utilised large road bridges that have high volumes of traffic. Most notably, pine martens colonised the Isle of Skye soon after the road bridge was built. They can also cross standing water to at least a distance of *c.*150m [140]. Hence, tidal areas of these rivers were incorporated into the HexSim model as barriers to movement, except where a bridge crossed the river in proximity to suitable pine marten habitat. This included the two larger River Severn bridges. The shorter original Severn crossing is 1.6km. For comparison, the Skye bridge is 0.57km in length.

Sensitivity analysis

Sensitivity analyses varied four key model parameters to see whether the modelled range expansion was highly influenced by any single model parameter. The four key parameters tested were:

- *Minimum range resource*: This determines the minimum quantity of habitat needed to establish a home range. The *Minimum range resource* was varied between 0.14 and 1.96. In uniformly high-quality habitat, this would result in home-range size between 0.7 and 9.8 km^2.
- *Hexagons Range-Eligible if Value is At Least:* This model input is equivalent to the minimum amount of woodland needed in an area for that area to become eligible to be part of a home range. Values were varied between 0% and 20% woodland within 1km^2.
- *Dispersal habitat*: Dispersing individuals can be attracted to woodland habitat (along a linear gradient with <5% woodland having no attraction and >20% woodland having the maximum attraction), repelled from open areas (<1% woodland), or both.
- *Dispersal distance*: Juvenile dispersal distance was modified so that mean displacement distance was between 4km and 8km.

Testing the model with historical Scottish data

The HexSim model is reliant on accurate species-specific parameters, which we drew from the literature. However, all population models are a simplification of reality and should be validated. Hence, we also compared model scenarios to real world observations to ensure model validity and plausibility. The historical pine marten population range expansion in Scotland was systematically recorded, with three major surveys between 1980 and 2012. This was used to test and refine the HexSim model accuracy. The 1980-1982 pine marten survey of Scotland [141] was used as the starting locations for the HexSim model and ran for 30 years. The top 90% most commonly occupied hexagons from 50 model runs were tested against the extent of pine marten range in the 2012 survey [2] . The True Skill Statistic (TSS) was used to test for errors in the final prediction [142]. The TSS tests for both the probability that the model will correctly classify a presence and the probability that the model will correctly classify an absence, with a TSS of 1 showing a perfect model.

The 2012 pine marten survey of Scotland identified the presence or absence of pine martens within hectads (10km by 10km squares). We considered testing the model performance against occupied hectads. However, there were numerous unoccupied hectads. These may be due to multiple factors such as natural population fluctuations, poor habitat, or survey effort. As our key aim was to accurately predict the rate of range expansion, we instead used occupied hectads to predict the overall range of pine martens. We then tested the model against this predicted range (see Figure 16).

Future scenarios

We then used the HexSim model to predict the range expansion of the recently reinforced Welsh pine marten population. This included investigating the rate at which they may naturally recolonise the Forest of Dean release region. We also attempted to predict how a population of pine martens released into the Forest of Dean and Wye Valley may grow, disperse, and link with the wider meta-population. As the model was developed using the Scottish historical range expansion, these predictions assume that any reintroduced populations will grow and expand in a similar manner.

A population of 23 females from central wales and 3 in Shropshire was used as the starting population to predict expansion from the current Welsh population. A founder population of 20 females was used for a theoretical release into the Forest of Dean and lower Wye Valley. Release sites were located in woodland patches across the potential release region.

Results

Sensitivity and uncertainty testing

Key model parameters were tested to determine their influence on model results (see Figure 15). Home range size did have an influence on model outcomes when extreme values were used (see Figure 15a). The amount of woodland that could be used for a home range had little impact on results (see Figure 15b). Dispersal distance had a variable, but generally positive impact on rates of range expansion (see Figure 15c).

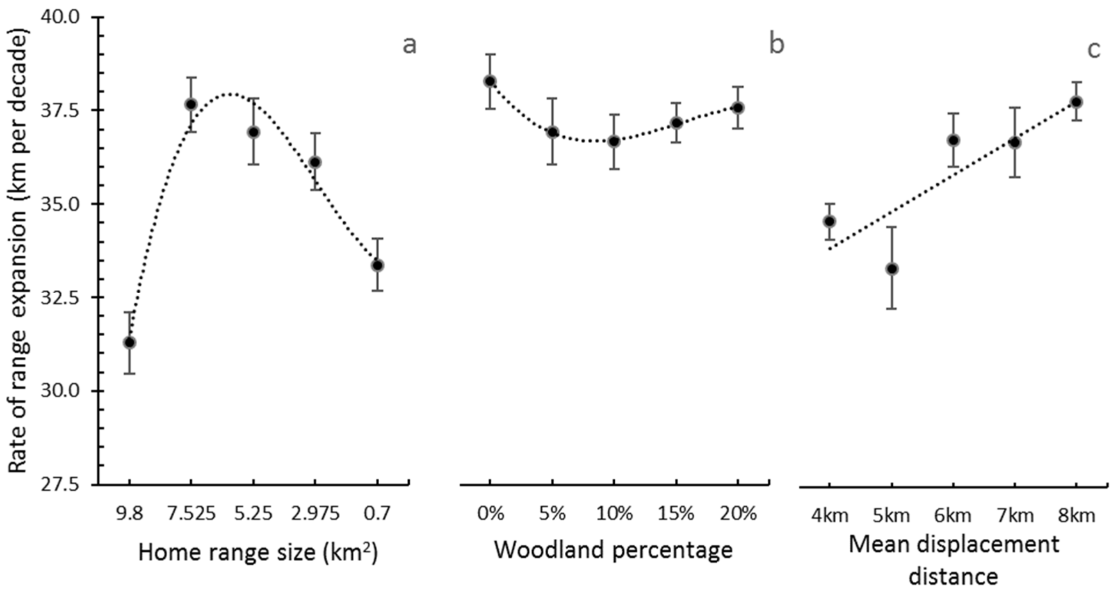

Figure 15. Influence of a) home range size (determined by minimum range resource), b) Minimum habitat value to be eligible for a home range, c) displacement distance (determined by juvenile dispersal), on model outcomes.

The original model (see Table 7) had reasonable predictive power, with a TTS of 0.90. However, by modifying juvenile dispersal distance (from 6km to 8km) the model could be improved. For the best model (see Table 7), 96% of presences and 96% of absences were correctly attributed, for an overall TSS of 0.92 for the top 90% of predicted locations (see Figure 16). The original model also had a higher specificity than sensitivity. This indicated the model was slightly under-estimating the rate of range expansion. The best model had a balanced specificity and sensitivity, indicating that the rate of range expansion within this model was optimal.

Testing the model with historical Scottish data

Table 7. HexSim model parameters and model performance when predicting historical range expansion in Scotland

	Original Model	**Best model**
Minimum range resource	1.05	1.05
Hexagons Range-Eligible if Value is at least	0.05	0.05
Dispersal habitat	No repulsion by open areas No attraction to woodland	No repulsion by open areas Attraction to woodland
Mean displacement distance	6km	8km
Sensitivity*	0.93	0.96
Specificity†	0.97	0.96
True Skill Statistic	**0.90**	**0.92**

*the probability that the model will correctly classify a presence
†the probability that the model will correctly classify an absence

We also tested the influence of dispersing individuals being repelled from landscapes with <1% woodland, or being attracted to landscapes with >5% woodland. Repelling severely impacted model performance in Scotland, reducing the TSS by 0.1. Woodland attraction had no impact on model predictions tested by TSS, but was thought to improve biologically realism and hence included.

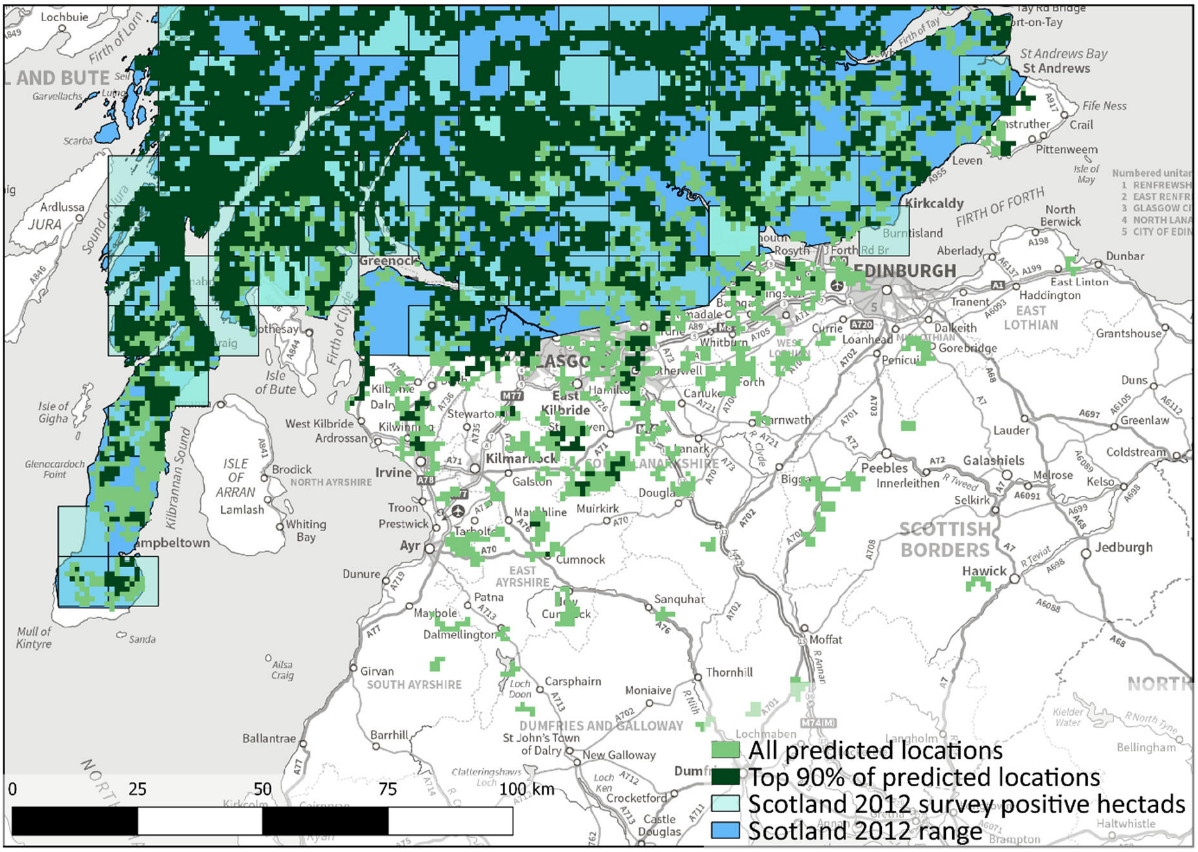

Figure 16. HexSim model predictions of 2012 pine marten range in Scotland. The HexSim model was started using locations from 1980-82 pine marten survey of Scotland and run for 30 years.

Future scenarios

The Forest of Dean potential release region was immediately colonised by some models, and after 15 years had been colonised multiple times. However, the region was first identified within the top 90% of predicted locations at year 21. By year 30, >10 separate locations within the region had been identified within the top 90% of predicted locations (see Figure 17). When simulating a release into the Forest of Dean, the population range was predicted (i.e. top 90% of predicted locations) to overlap with the central Wales population by year 15, with multiple areas overlapping by year 20. By year 30 the population had expanded across Wales, with some expansion into central England.

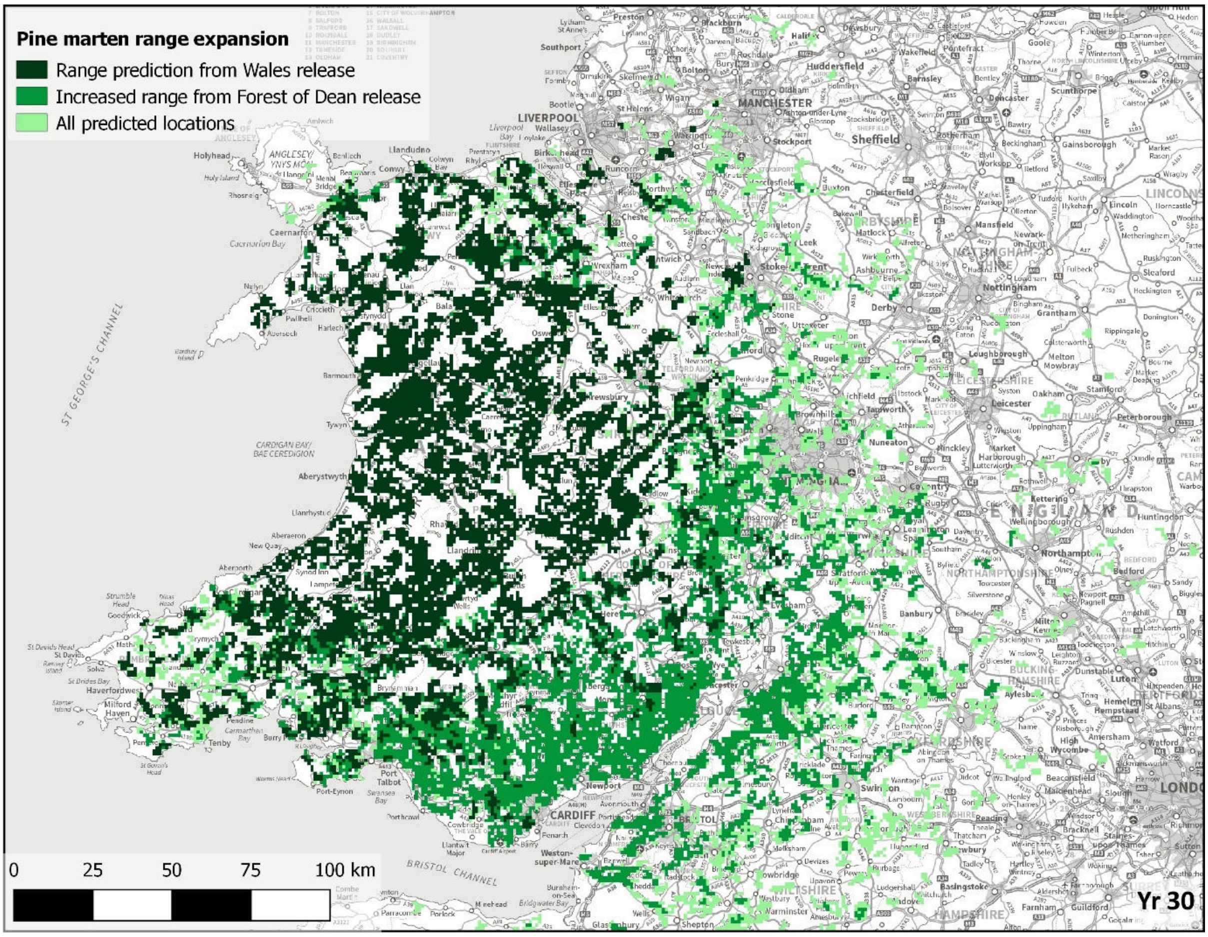

Figure 17. Predicting the range of pine martens in 30 years if reintroduction projects are successful.

Discussion

Due to the accuracy of the model when predicting range expansion in Scotland, the development of a HexSim pine marten population model was a useful tool in predicting future range expansion. However, it should be remembered that all future predictions were based on the population performing and behaving in the same manner as the historical Scottish population. Also, this model attempts to predict the future range of the female population, not males. Males may be more adventurous in their dispersal, and may colonise a much wider range than predicted here.

The model predicts that a reintroduced population will be likely to merge with a central Wales population in within 15-20 years' time. This is an important consideration for population viability analysis (see 3.6).

The population was highly stable using the HexSim model in comparison to the Vortex model used in the previous chapter. For instance, the extinction rate of different scenarios was frequently zero. The two models work in very different ways with Vortex working purely with the mathematics of populations and no spatial component. HexSim model's individual territories, but does not allow overlap between territories. It is important to specifically identify the questions being asked by the different approaches. Hence, while the HexSim model developed here does seem to be robust at predicting range expansion if the population is successful, it may be less accurate at predicting the likelihood of population success.

3.8 Provenance and genetic considerations

Much of Europe, including the UK, was recolonised by pine martens after the last ice age from a single refugia, now representing a central-northern European phylogroup [143,144]. Four key factors should be considered when determining the provenance of a reintroduced population [17,145]:

1. *Local adaptation*

The IUCN reintroduction guidelines recommend utilising individuals that most closely resemble the extirpated population. This is to maximise the probability that reintroduced individuals will be locally adapted to the release site, and that they will also fulfil the same ecosystem function. In this case it has previously been assessed that it would be justified to source from populations in either Scotland or Ireland [146].

2. *Inbreeding depression*

Inbreeding depression can have severe impacts on reintroduction success. The IUCN reintroduction guidelines outline that it may be a result of: "*sampling a source population with low genetic diversity (typically small / isolated populations), biased sampling of a single source population, genetic bottlenecks in the translocation process, and unequal survival, establishment and reproductive output in the destination area*" [17]. To avoid inbreeding depression, it is recommended that individuals are sourced from a range of source populations.

Pine marten in the UK have historically been through a severe population bottleneck [1]. This is reflected in their genetics, with lower levels of genetic diversity found in Scotland in comparison to continental Europe [147]. Inbreeding depression is accounted for in our population model (see 3.6). Usefully, this reintroduction would establish a second population of pine martens in Wales/west England. Migration between these populations would reduce the likelihood of inbreeding. If the effects of inbreeding become apparent, further reinforcement of the population may be required from either Scotland or Ireland.

3. *Outbreeding depression*

Outbreeding depression is where individuals adapted to two separate environments breed, resulting in offspring poorly adapted to a single environment, or with genetics that are incompatible. It could also be explained as the first stage in the divergence between populations that could eventually lead to speciation and infertile offspring [148,149].

There is clear genetic structure between Scottish, Irish, and continental pine marten populations, revealing the potential for outbreeding depression [147]. For now, Scottish populations should be sourced for the potential Forest of Dean reintroduction, to ensure there is compatibility (no outbreeding depression) with the central Wales population.

4. *The ability to evolve and adapt to future changing environments.*

Small populations are vulnerable to genetic drift which can reduce the overall genetic diversity of a population. Low levels of genetic diversity can make it more difficult for a population to adapt to future changing environments, for instance those altered through climate change. It can also decrease a populations ability to adapt to disease [150].

Migration between the two populations will decrease the impact of genetic drift experienced by each population during the establishment phase, and hence the overall loss of genetic variation. To enhance short term levels of overall genetic diversity, populations in Scotland which have not been used for the VWT translocation should be utilised. Long term genetic monitoring should investigate whether a lack of genetic diversity in the reintroduced populations becomes an issue. Particularly if there is lack of migration between the two populations. If genetic diversity were thought to be an issue in the future, Irish or Scottish stock could be considered to reinforce the population.

Conclusions

The current policy of sourcing stock from Scotland for re-establishing populations in Wales and England should continue. Due to the risk of outbreeding depression, the only reason to source from other populations would be to increase genetic diversity or to increase the ability of the population to adapt to a changing future climate.

4. The ecological feasibility of a pine marten reintroduction

Abstract

Predation is a fundamental component of a healthy ecosystem, and predator reintroductions have been shown to have a variety of positive effects such as increasing habitat quality and function, and increasing overall species richness. All native species at a reintroduction site will have evolved alongside the reintroduced predator, and have adapted to avoid predation. No examples of a reintroduced species having a negative ecological impact could be found. However, it is still important to assess the risk to rare and protected species in the Forest of Dean and Wye Valley from a pine marten reintroduction. We first investigated how the modern environment differs from the environment in which species co-evolved. We also built a database of pine marten diet, consisting of 18210 analysed scats. We used this to evaluate whether there was any interaction between pine martens and potentially at-risk species. The only high risk identified was the potential disturbance of large bat roosts within buildings. Medium risks included the predation of birds within nest boxes. The next step in the reintroduction project will be to develop a monitoring and adaptive management strategy. This will review potential mitigation strategies for these identified risks, to see the plausibility, effectiveness, and cost of any mitigation.

4.1 Potential ecological benefits

The importance of predation

Predation is a key component of a healthy ecosystem, and the reintroduction of a native predator can have profound positive impacts for ecosystem restoration [151,152]. Indeed, with increasing density and diversity of generalist predators, comes increasing prey population stability [153,154]. In particular, generalist predators, such as pine martens, can have a stabilising effect on prey populations that reduces large fluctuations [154]. This is because generalist predators are most likely to eat what is most common, and this can have an important balancing effect on ecosystems. For instance, in the Netherlands it was found that the presence of the predator guild (foxes, pine martens, stone martens, and polecats) capped the population density of rodents. This in turn led to a decrease in tick abundance and tick-borne disease including Lyme disease (*Borrelia burgdorferi*) [155].

Examples of the importance of predation come from a range of sources [156]. Famously, sea otter (*Enhydra lutri*) predation keeps herbivorous sea urchin (*Strongylocentrotus* spp.) populations in check. Without sea otters, sea urchin populations may increase dramatically, which has led to large reductions in kelp forest habitats and decreases in associated fish stocks [157,158]. There are also numerous examples where a lack of predation has let terrestrial herbivore populations grow without control, this means plants cannot escape herbivory, and plant survival is much reduced [159,160]. Indeed a lack of predation has led to what has been described as 'Ecological Meltdown' [160]. This balancing of the ecosystem by predators is an important ecological function. Indeed, the suppression and control of predators has been shown to promote the success of invasive species [161].

A range of different impacts could result from the reintroduction of pine martens. Of fundamental importance is that every native species has lived and evolved alongside European pine marten for over a million years [20]. Indeed, it is thought that pine martens were once the UK's second most numerous carnivore [12]. This evolutionary history means that pine martens are a fundamental missing piece of our natural heritage, and their potential importance within ecological communities should not be understated. Positive ecosystem impacts can result due to a variety of mechanisms:

Predator-mediated competition: Anti-predator strategies come in a range of different forms. Examples include camouflage, herding, vigilance, nest-site selection, foraging-site selection, flight patterns, etc.

Any species investing resources in anti-predator strategies, or decreasing resource intake to lower predation risk, is at a competitive disadvantage if predation risk is not present. For instance, when a predator is not present a species which invests in a low number of highly protected young will lose out to a competitor which produces high numbers of at risk young. Hence, if two species are in competition, the balance of competition may change due to the presence or absence of a predator. A good example of this comes from California. When predatory starfish (*Pisaster ochraceous*) are present, a diverse seabed community exists. However, when they are removed mussel populations dominate, reducing biodiversity [162].

Predator protection hypothesis: This may be best described as 'the predator of my predator is my friend'. For instance, firecrests (*Regulus ignicapilla*) are not a common component of goshawk (*Accipiter gentilis*) diet. Firecrests have been found to be more likely to nest near a goshawk nest, as the goshawk will provide protection against other predators, such as jays (*Garrulus glandarius*) [163]. This has been observed for a variety of species [164–166].

Trophic cascades: When a predator is removed from an ecosystem, prey populations may inflate and prey behaviour may change. This may have a variety of further effects on the species that the prey influence at lower trophic levels, which is known as a trophic cascade. For instance, when wolves (*Canis lupus*) were reintroduced to Yellowstone National Park they influenced elk (*Cervus canadensis*) abundance and spatial behaviour. This led to herbaceous vegetation in specific areas escaping browsing pressure, with subsequent habitat restoration occurring in these areas. This resulted in larger populations of both bison and beavers, with further subsequent benefits expected for a range of amphibians, invertebrates, and fish [159]. Hence, trophic cascades can have widespread implications for a variety of species. Trophic cascades are thought to be common occurrences [167], however detailed knowledge of an ecosystem is required to show and record their effects.

Pine marten and grey squirrels

Reintroducing native predators has previously been shown to be an effective tool in decreasing the impacts of invasive non-native species [161,168–170]. Pine marten, in particular, are thought to have a controlling influence on grey squirrel (*Sciurus carolinensis*) populations. The first evidence for this comes from central Ireland, where pine martens have been recolonising their former range following legal protection. Pine martens have been shown to have clear impacts on grey squirrel populations in areas they have recolonised [171]. More recent evidence has now shown that the grey squirrel has been extirpated from six counties in central Ireland [172]. Also, during a recent camera trap study in Northern Ireland, grey squirrels and pine martens were never both found at the same camera trap location [173].

The mechanism for this interaction has not yet been determined. It is likely to be partially due to direct predation, but it may also be caused by non-lethal, non-consumptive effects associated with the landscape of fear [174,175]. To speculate, grey squirrels may increase their vigilance and decrease their foraging time when pine martens are present in an area. Also, pine martens may need to reach a specific density to cause grey squirrel extirpation [175], alternatively pine marten may cause a highly localised reduction in grey squirrel numbers in areas where pine marten are resident [171].

Ireland and Northern Ireland differ ecologically in some key respects from mainland Britain. In particular, voles (Arvicolinae) are usually a key component of pine marten diet (see 3.1), but there are no vole species native to Ireland. This has led to suggestions that pine marten may predate more heavily on squirrels in Ireland than in mainland Britain. However, recent results from studies in Scotland reveal that pine martens are having the same effect on squirrels there, suppressing grey squirrel populations and allowing reds to recover [176]. As a result, it appears that the effect of pine martens on squirrels may not be dependent on the assemblage of small mammals available as prey.

The extirpation of a species by a predator is a rare event. Usually the co-evolutionary history between species means an evolutionary arms race has developed which stops one species gaining a significant advantage over the other. However, extirpation may occur when there is a lack of co-evolutionary history. For instance, non-native mammalian predators have devastated bird populations in New Zealand because of a lack of evolutionary experience with such predators [177]. Similarly, grey squirrels have no experience of a marten-like predator in their native range in North America [22], making them vulnerable to population extirpation.

The control or eradication of grey squirrels will be of great ecological benefit for a variety of reasons. Grey squirrels are an invasive non-native species that have a range of detrimental impacts on the ecology of an area. In particular, the reduction in grey squirrel populations in Ireland has greatly benefited red squirrel conservation status [171]. The impact of pine marten predation on red squirrels does not impact red squirrel population success due to their historical evolution alongside each other. Hence, when pine marten come back into an area, red squirrels seem to thrive. This is a good example of the differing effects of compensatory vs additive predation (see 4.2).

A variety of further species may also benefit from grey squirrel extirpation. For instance, grey squirrels may be an important nest predator of birds, with potential subsequent impacts on bird populations [178]. Hawfinch (*Coccothraustes coccothraustes*) and lesser spotted woodpecker (*Dryobates minor*) are also negatively associated with grey squirrel density. This may not be directly through predation, but could be ecosystem modification by grey squirrels resulting in poorer quality habitat for the species [179]. Finally, grey squirrels are thought to be in competition with a range of species due to the food resources they consume. For instance, in some areas of the UK 96% of hazelnuts are eaten by grey squirrels [180]. The release of resources currently consumed by grey squirrels may have a range of positive implications for native biodiversity.

4.2 Ecological risk assessment

Reintroductions of native species that led to negative ecosystem impacts were reviewed. The IUCN produce a regular report of reintroductions worldwide [181–185]. These have summarised 300 reintroduction projects, and 37 of these were predator reintroductions. Many of these projects reported fears by local conservationists of negative ecological impacts resulting from a predator reintroduction. However, no examples of a reintroduced species having a negative ecological impact could be found. In addition, a detailed literature review could also find no examples. Furthermore, a call to academics worldwide on the 'Researchgate' website produced no examples. Hence, the inherent risk associated with the impacts of species from reintroductions is very low.

The only negative examples of impacts from reintroductions were associated with the practice of translocations or other species associated with the translocation. For instance, negative examples have involved the spread of disease [186], parasite treatment programs causing parasite extinctions [187], and habitat modification by the reintroduction project having negative effects on rare species already at the site [188].

How does predation affect populations?

Predation is a normal process in ecology, a key function within a healthy ecosystem[152,153,189,190], and as discussed in the previous section can have a variety of positive effects. However, it is important to assess the risk of a predator having a negative effect on specific species.

Compensatory predation: There are several situations in which predation will not have an impact on the population of a species. This is known as compensatory predation. This occurs in cases where a predated individual would have died of other causes, or would not have contributed to a population (for instance the old, weak, or sick). This also occurs where an individual's loss from a population releases resources that allows other individuals from the same species to survive or be more successful [191,192]. For instance, if a first nesting attempt fails, a second may be attempted which would not have occurred otherwise.

Predation even in significant quantities can have no effect on population performance. For instance, some bird populations can double in size during the breeding season, hence will remain stable even if they lose half of all individuals [193]. There are a variety of examples of compensatory predation. For instance, sparrowhawks (*Accipiter nisus*) were extirpated from large areas of the UK for up to 30 years due to the use of organochlorine pesticides in the mid-20th century [193]. However, when populations recovered detailed analysis showed no impact of this recolonising predator on songbird populations [194].

Additive predation: Predation is additive, rather than compensatory, when it is a source of mortality that the population cannot compensate for. This means that the predation negatively impacts on population performance. Recognised examples of additive mortality often come when environmental traits that have already undermined a prey population, and from invasive non-native species such as mammalian predators in New Zealand[195].

Whether predation is compensatory or additive will be highly dependent on a wide range of factors, such as current levels of predation, current limiting factors to prey population growth, the life stage predated, and many more. For instance, predation on juveniles and eggs is more likely to be compensatory as mortality at this stage is inherently high for a variety of non-predation reasons [193].

Ecological Risk Assessment

All native species living in the Forest of Dean evolved alongside pine martens for between 1 and 1.5 million years, with the genus *Martes* evolving 5.5 - 6.2 million years ago [20]. It was not until just a few hundred years ago that pine martens were lost from much of the wider British landscape [1]. Indeed, pine martens were thought to historically be the second most numerous predator in the UK [12]. This means that species will have adapted to avoid pine marten predation. For example, bird nest site selection is thought to be primarily determined by predator avoidance [196].

However, the modern environment is different from the historical environment in several ways. For instance, habitat structure may differ, which may impact on the ability of a species to avoid predation. Some species, such as woodpigeons, magpies, and foxes [12,197–199] are living at higher densities, while many species are much reduced, and this is reflected by their conservation status. The reintroduction of a native species may help to restore ecosystem functioning and help with the recovery of some species (see 4.1). However, it is important to assess the risk to rare or protected species, to ensure that modern interactions between species will not differ from the interactions that occurred when the species previously lived alongside each other.

Pine marten diet is very broad (see 3.1), and the species they consume are directly linked to that species abundance in an ecosystem [28,59–61,200]. Indeed, generalist predators specialise on their most common prey, taking them in disproportionate quantities to their abundance in the landscape [201]. However, it is important to assess specific species of conservation concern to ensure that pine martens don't act as specialists with respect to any of these species i.e. actively searching for them even when rare.

Methods

Speculation about potential and theorised ecological interactions following reintroductions can be extensive [181]. Speculating about which potential interactions may have the greatest effect is often severely biased by its subjective nature, and unhelpful during a risk assessment process. Here we attempt to assess risk in the potential release region (PRR) based on a rigorous evidence-based approach [17]:

- First, a list of species to assess was created. This was based on qualifying features of Special Areas of Conservation, and all Annex IV species. Red and Amber list bird species that live in the PRR were identified. All species where the PRR represented >0.5% of the British breeding population (by area) were selected for further analysis (see [7]). Furthermore, expert recommendation (e.g. RSPB) was sought to ensure all locally at-risk species were assessed.
- Second, a risk assessment was performed for each of the species on this list, based on an extensive review of the available evidence. The risk assessment asked - What is the likelihood a risk will occur, and what will the impact be if does occur? These questions were assessed by collecting evidence in several specific areas:
    - *Spatial analysis*
        - Is there range overlap between pine marten and the identified species e.g. in continental Europe?
        - What is the predicted range overlap in the release area?
    - *Evidence of interaction - Is there any evidence of an interaction between pine marten and the identified species, or evidence of other interactions?*
        - This included a full literature review of European pine marten diet. Seventeen studies that identified pine marten diet down to species level were identified from across Europe. The studies were from Finland[60], Germany[202], Italy[203,204], Poland[61,205–207], Scotland[28,32,58,208], Spain[209,210], Sweden[50,62], and Switzerland[211]. Each paper assessed on average 1138 scats (range 64 - 5677), for a combined total of 18210 pine marten scats.
        - Competition review (are marten in competition with the identified species?).
        - Trophic cascade review (is the identified species under pressure from, or dependent on, a species that will be influenced by pine marten?).
        - Predator-mediated competition review (is the identified species in competition with a species influenced by pine marten?).
    - *Modern environmental differences - How does the modern environment differ from the historical environment in which the species co-evolved?*
        - For instance, will predation of nests in bird boxes be greater than nests in cavities?
    - *How does the predicted interaction between pine marten and the identified species compare with other interactions?*
        - For instance, will predation by pine marten be significant in comparison to the levels of predation already occurring?

Evidence from a wide range of sources was collated. Evidence from studies on European pine marten was prioritised. However, due to the genetic similarity between the species [20,22,212], evidence from the sable (*Martes zibellina*), Japanese marten (*Martes melampus*), and North American marten (*Martes americana*) was also considered. Evidence from stone marten (*Martes foina*) was not used. This is because, as pine and stone marten live alongside each other across continental Europe, they must necessarily harbour different ecological niches. There is an incomplete understanding of how these niches overlap [213]. This means evidence from stone marten may represent a part of their ecological niche that they may have specifically evolved to decrease competition with European pine marten. Hence, evidence of the stone marten ecological niche is an unreliable predictor of the European pine marten ecological niche.

It has been hypothesised that, due to a lack of stone marten in the UK, the European pine marten in the UK may broaden its niche to include the stone marten niche. This may be experimentally tested by observing pine marten becoming non-dependent on woodland [213]. Recent investigations shows this to not yet be the case [37], with evidence showing pine martens utilising the similar range of woodland matrices as in continental Europe [214] (also see 3.1).

Results

Birds

Eggs and nestlings: In areas where pine martens are common, they are known to be an important predator of open-nesting songbirds. For instance, in Europe they have been found to be responsible for 14 - 37% of nest predation events of open nesting songbirds depending on the study. Other major nest predators were jays, *Garrulus glandarius*, (29-60% of nest predation), greater spotted woodpecker, *Dendrocopos major*, (2-13%), and buzzards, *Buteo buteo*, (1-13%), with smaller amounts of predation by other *Carnivora*, small mammals, wild boar (*Sus scrofa*), other corvids, raptors and owls [215,216].

Pine marten predation on the nests of cavity nesting birds has also been previously recorded as important, with pine marten responsible for 19.7% of nest predation events. This is similar to that recorded for woodpeckers (20.5%) in the same study [217]. Prey are known to move to holes with smaller entrances to prevent predation where it occurs [68].

There are a wide variety of potential predators of ground nesting bird nests in the PRR. The potential avian predators include raven, crows, jackdaws, magpies, and jays, while the potential mammalian predators include feral wild boar, fox, badger, polecat, mink, stoat, weasel, grey squirrels, and rodents [218]. In a study in southern Sweden, pine marten were an insignificant predator of ground nesting birds in woodland (<1%), with jays, ravens, hooded crows, and badgers the key predators [219]. Nest predation is most likely to be caused by the most common predator in that area [219]. Hence, in the Forest of Dean feral wild boar are likely to have a much greater impact than pine marten.

Pine marten have been previously implicated in the poor reproductive performance of capercaillie (*Tetrao urogallus*) in Scotland [220]. However, the same study also identified that it's methodology biased the results, with nest video-recording artificially inflating nest predation [220]. Previous and subsequent studies have all concluded that climate change, and high densities of carrion crow (*Corvus corone*) and foxes (*Vulpes vulpes*), caused by mesopredator release [12], are the key predictors of poor population performance in capercaillie in Scotland [221–223]. Indeed, capercaillie reproductive performance has declined across its range [224].

The overall impact on levels of nest-predation is difficult to predict. For instance, grey squirrels have been previously identified as being a potential cause of woodland bird decline or population suppression [178,179,225–227]. Nest predation by pine martens may be offset by a reduction in grey squirrels (see 4.1). A reduction in grey squirrels may also result in goshawk switching to predate more jays (see goshawk assessment), a key nest predator. Hence, due to a variety of uncertain effects overall impacts cannot be predicted, and will only be determined by post-release monitoring.

Bird boxes: Nest boxes may highlight the location of a nest in comparison to a cavity nest. Moving nest boxes reduces predation rates, indicating that pine martens do learn where nest boxes are and revisit them [228]. Nest box holes are too small (28mm) for pine marten head entry (45mm+) [229]. However, pine marten arm entry is possible. Pine marten arm length is ~15cm [230], hence any nest within that distance may be at risk. In Poland, pine martens were responsible for 37% of nest predation events in natural cavities, and 78% of nest predation events in nest boxes where the predator was identified [231]. Overall the predation rate by all predators was lower in natural cavities than in nest boxes (47% v 65% of nests) [231]. Interestingly, conservationists still use nest boxes significantly in this area. Using this single study, a nest in a natural cavity would have a 17% chance of being predated by a pine marten, while a nest in a box would have a 51% chance of being predated by a pine marten. Pine marten predation of crested tits (*Lophophanes cristatus*) within nest boxes is also viewed as an issue in Scotland [232].

Adults: Pine martens are a less important predator of adult birds. For instance in Białowieża Forest, Poland, buzzards, tawny owls (*Strix aluco*), goshawks (*Accipiter gentilis*), and sparrowhawks (*Accipiter nisus*) contributed 78.5% of all predation on adult and fledglings, with pine marten contributing an additional 6.2% [233]. This is important as predation on adults is more important to population stability than predation on juveniles [192,193].

Table 8. Evidence of any potential interactions with Red and Amber list bird species that live in the Forest of Dean and lower Wye Valley

Species	*Reason for inclusion*	*Spatial overlap in Europe and predicted in PRR*	*Evidence of interaction*	*Modern environmental differences*	*Levels of predation by other predators*
Hawfinch (Coccothraustes coccothraustes) *	Red list bird species with 5.3% of UK population in the PRR.	Extensive overlap across continental Europe. In particular in Białowieża forest in Poland, where very high densities of hawfinch exist alongside a healthy pine marten population [197,234]. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	Hawfinch predation was observed in a single study, and indeed only within a single scat, in the Białowieża forest in Poland. Despite hawfinch being one of the most numerous birds in the study area [197,234], there they make up just 0.4% of pine marten diet [235]. Four other studies of areas where hawfinch was present found no evidence of predation.	Only conservation status.	Avian predators, in particular jays, are the most predominant nest predators of hawfinch in the UK (Kirby W. Pers. comm.). Hawfinch are also negatively associated with grey squirrel density [179]. See Birds introduction for a broad review of other predators of open nesting songbirds.
Turtle Dove (*Streptopelia turtur*) *	Red list bird species with 0.5% of UK population in the PRR. Although, there are no very recent records of turtle dove in the PRR	There is extensive overlap between pine marten and turtle dove across continental Europe. As turtle dove utilise open woodland, levels of overlap in the PRR are likely to be extensive if turtle dove do return.	No evidence of pine marten predation of turtle dove could be found.	Only conservation status.	See Birds introduction for a broad review of other predators of open nesting songbirds.

Table 8. Evidence of any potential interactions with Red and Amber list bird species that live in the Forest of Dean and lower Wye Valley

Species	*Reason for inclusion*	*Spatial overlap in Europe and predicted in PRR*	*Evidence of interaction*	*Modern environmental differences*	*Levels of predation by other predators*
Goshawk (*Accipiter gentilis*) *	RSPB priority species for the Forest of Dean	There is extensive overlap between pine marten and goshawk across continental Europe, and with closely related *Martes* spp across Asia and North America. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	No evidence of pine marten predation of goshawk could be found, but pine marten may be a nest predator of undefended nests [236]. There was evidence of goshawk predation on pine marten [237]. There may be an influence of pine marten on goshawk diet due to the potential impact on grey squirrles. Grey squirrels can be a major component of goshawk diet in the UK [238]. In areas without grey squirrels, birds often dominate goshawk diet (e.g. 86 - 95% of diet [239–241]), and the most common species taken are woodpigeon (*Columba palumbus*), crows (*Corvus corone*), rooks (*Corvus frugilegus*), and thrushes (*Turdus* spp)[239–243].	Only conservation status.	Pine marten predation unlikely.

Table 8. Evidence of any potential interactions with Red and Amber list bird species that live in the Forest of Dean and lower Wye Valley

Species	*Reason for inclusion*	*Spatial overlap in Europe and predicted in PRR*	*Evidence of interaction*	*Modern environmental differences*	*Levels of predation by other predators*
Lesser Spotted Woodpecker (*Dryobates minor*) [&]	Red list bird species with 1.1% of UK population in the PRR.	There is extensive overlap between pine marten and lesser spotted woodpecker across continental Europe. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	No evidence of pine marten predation of lesser spotted woodpecker could be found.	Nest box use is minimal (see pied flycatcher for review).	Lesser spotted woodpecker are negatively associated with grey squirrel density [179]. See Birds introduction for a broad review of other predators of cavity-nesting birds.
Pied Flycatcher (*Ficedula hypoleuca*) [&]	Red list bird species with 0.9% of UK population in the PRR.	There is extensive overlap between pine marten and pied flycatcher across continental Europe. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	Pied flycatcher predation was observed at a single study in the Białowieża forest in Poland, contributing up to 0.52% of pine marten diet [235]. Pied flycatchers were abundant in the study area [197,231]. Five other studies of areas where pied flycatcher were present found no evidence of predation [60,62,206,207,244].	Conservation status. Pied flycatchers are known to utilise nest boxes extensively in the PRR (see text for review).	See Birds introduction for a broad review of other predators of cavity-nesting birds.
Marsh Tit (*Poecile palustris*) [&]	Red list bird species with 0.6% of UK population in the PRR.	There is extensive overlap between pine marten and marsh tit across continental Europe. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	No evidence of pine marten predation of marsh tit could be found.	Marsh tits are unlikely to use nest boxes (see text for review).	See Birds introduction for a broad review of other predators of cavity-nesting birds.

Table 8. Evidence of any potential interactions with Red and Amber list bird species that live in the Forest of Dean and lower Wye Valley

Species	*Reason for inclusion*	*Spatial overlap in Europe and predicted in PRR*	*Evidence of interaction*	*Modern environmental differences*	*Levels of predation by other predators*
Willow Tit (Poecile montanus) [&]	Red list bird species with 0.5% of UK population in the PRR.	There is extensive overlap between pine marten and willow tit across continental Europe. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	Willow tit was found to be predated during a 16-year study of pine marten diet in Finland, forming 0.22% of diet there [60]. Willow tits are abundant in Finland, with an estimated 0.6 – 1 million breeding pairs across the country [245]. Five other studies of areas where willow tit was present found no evidence of predation [62,205–207,211].	Willow tits are unlikely to use nest boxes (see text for review).	See Birds introduction for a broad review of other predators of cavity-nesting birds.
Redstart (*Phoenicurus phoenicurus*) [&]	Amber list bird species with 4.5% of UK population in the PRR.	There is extensive overlap between pine marten and redstart across continental Europe. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	No evidence of pine marten predation of redstart could be found.	Redstarts may use nest boxes (see text for review).	See Birds introduction for a broad review of other predators of cavity-nesting birds.

Table 8. Evidence of any potential interactions with Red and Amber list bird species that live in the Forest of Dean and lower Wye Valley

Species	*Reason for inclusion*	*Spatial overlap in Europe and predicted in PRR*	*Evidence of interaction*	*Modern environmental differences*	*Levels of predation by other predators*
Woodcock (*Scolopax rusticola*) †	Red list bird species with 0.7% of UK population in the PRR.	There is extensive overlap between pine marten and woodcock across continental Europe. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	Woodcock predation was found in two studies located in southern Sweden and Scotland, where woodcock made up 0.22% and 0.21% of the diet respectively. Interesting, In Scotland predation was predominantly (80%) in the winter, when woodcock numbers across the UK swell from an estimated 110000 to 1.4 million birds. Seven other studies of areas where woodcock was present found no evidence of predation [58,205–208,211,246].	Only conservation status.	See Birds introduction for a broad review of other predators of ground-nesting birds.
Wood Warbler (*Phylloscopus sibilatrix*) †	Red list bird species with 0.7% of UK population in the PRR.	There is extensive overlap between pine marten and wood warbler across continental Europe. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	No evidence of pine marten predation of wood warbler could be found.	Only conservation status.	See Birds introduction for a broad review of other predators of ground-nesting birds.

Table 8. Evidence of any potential interactions with Red and Amber list bird species that live in the Forest of Dean and lower Wye Valley

Species	*Reason for inclusion*	*Spatial overlap in Europe and predicted in PRR*	*Evidence of interaction*	*Modern environmental differences*	*Levels of predation by other predators*
Yellow Wagtail (*Motacilla flava*) †	Red list bird species with 0.5% of UK population in the PRR.	Yellow wagtails are not woodland dependent. Their range overlaps extensively with pine marten range across continental Europe, but levels of local spatial overlap are unknown and cannot be predicted in the PRR.	No evidence of pine marten predation of yellow wagtail could be found.	Only conservation status.	See Birds introduction for a broad review of other predators of ground-nesting birds.
Tree Pipit (*Anthus trivialis*) †	Red list bird species with 0.5% of UK population in the PRR.	There is extensive overlap between pine marten and tree pipit across continental Europe. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	No evidence of pine marten predation of tree pipit could be found.	Only conservation status.	See Birds introduction for a broad review of other predators of ground-nesting birds.
Nightjar (*Caprimulgus europaeus*) †	Amber list bird species with 1.9% of UK population in the PRR.	There is extensive overlap between pine marten and nightjar across continental Europe. However, as nightjar predominantly use clearings, levels of local spatial overlap are unknown. In the Forest of Dean nightjars' are predominantly associated with heathland, a habitat type that pine marten are negatively associated with [247].	No evidence of pine marten predation of nightjar could be found. Interestingly, nightjar populations on Forestry Commission land in Galloway are very successful [248], and this area is also a stronghold for the pine marten in southern Scotland following a reintroduction [2,5].	Only conservation status.	See Birds introduction for a broad review of other predators of ground-nesting birds.

Table 8. Evidence of any potential interactions with Red and Amber list bird species that live in the Forest of Dean and lower Wye Valley

Species	*Reason for inclusion*	*Spatial overlap in Europe and predicted in PRR*	*Evidence of interaction*	*Modern environmental differences*	*Levels of predation by other predators*
Woodlark (*Lullula arborea*) †	Amber list bird species with 1.3% of UK population in the PRR.	There is extensive overlap between pine marten and woodlark across continental Europe. However, as woodlark predominantly use clearings, levels of local spatial overlap are unknown. In the Forest of Dean woodlark are predominantly associated with heathland, a habitat type that pine marten are negatively associated with [247].	No evidence of pine marten predation of woodlark could be found.	Only conservation status.	See Birds introduction for a broad review of other predators of ground-nesting birds.
Nightingale (*Luscinia megarhynchos*) †	RSPB priority species for Forest of Dean	There is extensive overlap between pine marten and nightingale across continental Europe. As a woodland specialist levels of overlap in the PRR are likely to be extensive.	No evidence of pine marten predation of nightingale could be found.	Only conservation status.	See Birds introduction for a broad review of other predators of ground-nesting birds.

* Open nesting species

& Hole-nesting species

† Ground nesting species

Birds Risk assessment

Evidence of predation was found for four bird species of conservation concern (see Table 8). No bird species of conservation concern was specialised on by pine martens, all evidence of predation was in areas or at times when the species is abundant, and even when evidence of predation was found the proportion of a species in the diet was very low (<1%). Hence, the likelihood of impacts on the adults of all species is viewed as low (see Table 9).

Nest predation by pine marten may be more significant:

Open nesting birds: Pine martens are a predator of open-nesting birds. However, due to impacts on other potential nest predators, overall impacts on levels of nest predation are unknown (See Birds introduction).

Cavity nesting birds: Pine martens are a predator of cavity-nesting birds in natural cavities, but overall impacts on levels of predation are unknown (See Birds introduction). Pine martens are likely to be an important predator of cavity-nesting birds in artificial boxes.

Ground nesting birds: The impact of pine marten on ground nesting birds is predicted to be insubstantial, with impacts from other species much more important.

Table 9. Risk assessment for birds

Bird group of conservation concern	**Likelihood of risk**	**Impact of risk**		**Overall Risk**
		When compared to other predators	**Age consumed***	
Open nesting eggs & juveniles	Medium	Low-med *(Unknown effects on other-predator abundance)*	Low	2
Natural cavity nesting eggs & juveniles	Medium	Low-med *(Unknown effects on other-predator abundance)*	Low	2
Box nesting eggs & juveniles	Medium	High (*other predators insignificant*)	Low	3
Ground nesting eggs & juveniles	Low	Low	Low	1
All species - adults	Low	Low	Medium	2

*Predation on juveniles may be less likely to impact population stability than predation on adults [193]

Mammals

Bats (*Chiroptera*)

Reason for inclusion: Annex IV species and qualifying feature of local SACs.

Spatial overlap in Europe: All species overlap through much of mainland Europe, and high levels of overlap are expected in the PRR.

Evidence of interaction: Our meta-analysis revealed that of 18210 scats studied, only 3 (0.02%) contained bats. In all three studies that found bats, only a single remain was found [60,205,246]. These results concur with other reviews of diet which found that the consumption of bats by pine marten was minimal (0.01%) [249], or not mentioned [57]. The studies here covered an array of different regions from across Europe and included regions with known high bat populations, such as Bavaria, and pristine habitats such as the Białowieża Forest in Poland. It is unknown whether the few records are from opportunistic carrion, or active searching and hunting for bats.

There is evidence of bat consumption by pine marten in specific situations. One of the largest bat roosts in Europe at Nietoperek, Poland (where an estimated 35000+ bats roost and hibernate) is predated or scavenged by pine martens [250]. 37% of pine marten scats found here contained bat DNA, indicating that bats are a significant portion of pine marten diet in this area. As scats may contain 1.4 - 3.4 prey items [32], this may equate to between 10-26% of pine marten diet by the ten pine marten that were found to be predating bats in this area. The species predated were *Myotis daubentonii*, *Myotis myotis*, *Myotis nattereri*, *Myotis mystacinus*, and *Plecotus auritus*. Pine martens are likely to eat any bat carrion they come across, but scratch marks on the walls indicate that they may also take torpid bats from their roosts where climbing is possible. The site had numerous entrances, and evidence of pine martens was clustered closest to the entrances. The predation at this single site was not thought to be impacting bat population performance as the number of bats recorded at Nietoperek continued to rise [250].

A second case of bat predation by pine marten was found at a cave in Slovakia. Evidence was predominantly found close to the entrance (0-20m), with some further evidence up to 140m into the cave. Predation was again not thought to be impacting on the population [251]. In Turkey, although evidence of predation was not observed, evidence of a *Martes* spp was found within caves, with scats found 300m into a cave (E. Coraman pers. comm.).

Modern environmental differences: Bats utilise several different structures that were not present in the historical environment. Primarily these are buildings, artificial bat roosts, and bat boxes.

Pine marten are known to utilise attic space, particularly in modern houses (R. Raynor pers. comm.) as natal-den sites, probably due to a lack of suitable alternatives [66]. It has been hypothesised that this may bring pine martens into greater interactions with bats. However, four studies of the diet of the Scottish pine marten population, which combined analysed 5691 scats, found no bat remains. However, in Ireland two summer roosts of lesser horseshoe bats (*Rhinolophus hipposideros*) have been disturbed by pine marten, with bats not returning to a roost site until the marten had vacated/been excluded (S. Biggane pers. comm.). This had unknown effects on population performance. Similar disturbance effects may be expected at artificial bat roosts.

The entrance of a bat box is too small for pine marten head entry. Arm entry may be possible, but bat boxes are generally too deep for marten to be able to reach roosting bats. As bat box use is widespread, if predation of bat boxes was frequent you would expect bat remains to occur in scats.

Levels of pine marten predation in comparison to other predators: Annual mortality for bats in the UK varies between 20-33% depending on species [252]. The most significant predators of bats worldwide are avian predators [253], and in the UK are tawny owl, barn owl, long-eared owl, and kestrels [254–258]. Indeed, tawny owls have been known to specialise on bats at cave entrances. In an exceptional case, 22-89% of tawny owl pellets were found to contain bat remains in Slovakia [251]. Another potentially significant predator of bats are domestic and feral cats, with the overall level of predation highly dependent on local density [259,260]. There are some other interesting examples of predation of hibernating bats by wood mice [261] and great tits [262]. Also, otter (*Lutra lutra*) scats have been found to contain bat remains in a mineshaft in Wales, which may be a maternally learnt behaviour [263].

Forest roosting bats risk assessment: Predation levels of bats within woodland are expected to be the same as historical levels. Evidence shows very low levels of pine marten predation on bats. The impact if this does occur is also expected to be low, as single congregations of bats will not reach the size found in buildings or caves.

Building roosting bats risk assessment: Likelihood - Buildings are a modern construction which did not exist in the historical environment. Disturbance, rather than predation, has been known to occur. However, the likelihood and regularity of disturbance is unknown. The likelihood of attic exploration for den sites by pine marten is thought to be linked to availability of suitable den sites [66]. The single example of this risk occurring happened in an area with very low levels of woodland cover, and woodland type was predominantly conifer plantation [247]. Hence, these landscapes may have had very low levels of suitable den sites outside buildings.

Impact – Disturbance of a bat roost has previously caused the entire roost to disperse to an unknown location(s). However, once the pine marten had been excluded the roost returned. This disturbance event had an unknown effect on population performance. If the disturbance event had occurred at a large maternity roost with young unable to fly, the disturbance could have had a major influence on population performance for that year.

Cave/mine roosting bats risk assessment: Through the development of this risk assessment it was clear that two competing methodologies resulted in different outcomes for the assessment of risk to bats in underground systems (see Table 10).

Likelihood - Bats are a very rare occurrence in pine marten diet, and only two incidences of predation/scavenging in underground systems could be found. Evidence from Neitoperek indicates bat roosts closer to a cave entrance may have a higher risk of being encountered by a marten than those at a greater distance from a cave entrance.

Arguments for higher impacts:

- Hypothesis that horseshoe bats would be highly vulnerable to pine marten predation.
- Hypothesis that pine martens could cause 100% mortality of underground roosts.

Arguments for lower impacts:

- It is rare to find a native predator impacting on the conservation status of a prey population. Examples are constrained to meso-predator release, and apparent competition associated with predators with narrow ecological niches [264].
- In the two examples where predation/scavenging in underground systems was observed, bat populations were expanding.
- As a natural structure, only minimally modified by man, predation levels of bats within caves are expected to be the same as historical levels. Currently there is no evidence that differences in the modern environment will affect the relationship between bats and pine martens.

Table 10. Risk assessment for bats

Type	Likelihood	Potential impact	Risk (Out of 5)
Large building roost	Medium[&]	High	4
Medium building roost	Medium[&]	Medium	3
Small building roost	Medium[&]	Low	2
Cave/mine roost	Low*	Low-High	2-4†
Forest roosting bats	Low	Low	1

Roost size determines potential impact on the population, either through disturbance or predation. Roost type determines likelihood of interaction (see text).

*but dependent on distance to the cave entrance.

[&]Potentially dependent on availability of alternative den sites.

†Awaiting more detailed review of available evidence.

Hazel Dormouse (*Muscardinus avellanarius*)

Reason for inclusion: Annex IV species

Spatial overlap in Europe and predicted in PRR: Extensive evidence of overlap between pine marten populations and hazel dormouse from Italy. There is also some evidence of overlap in other areas, and overlap likely widespread across continental Europe. Hazel dormice are present but not widespread in the Forest of Dean, but are found in higher abundance along the Wye valley (K. Caster pers. comm.).

Evidence of interaction: Three studies found evidence of hazel dormouse predation by pine marten in Italy, Switzerland, and Germany. The frequency of occurrence of hazel dormouse within pine marten diet was 3.7%[203], 0.5%[211], and 1.6% [202] respectively. However, five other studies where hazel dormouse were present found no evidence of predation by pine marten[61,204,206,207,265]. Levels of predation are linked to the abundance of dormice in an area [203]. Dormice populations within the study area in Italy are widespread [266], hence 3.7% is the highest level of predation that can be expected.

Hazel dormice are in direct competition with grey squirrels for hazelnuts, a primary food source [267]. The impact of this competition may be significant, with an estimated 96% of hazelnuts eaten by grey squirrels [180]. Hence, a reduction in grey squirrel numbers by pine marten may benefit hazel dormice.

Modern environmental differences: Dormouse boxes are a key difference between the modern environment and the environment in which the species co-evolved. However, as dormouse boxes are placed with entrances holes towards the tree, it would be assumed that a pine marten's head or arm entry would be severely restricted. The use of dormouse boxes in areas with pine martens is frequent and widespread [268], and their use is still actively encouraged by conservationists in these areas [266]. If lids are properly secured, predation in dormouse boxes is not expected.

Levels of pine marten predation in comparison to other predators: Two key predators of dormice are foxes and feral cats. The frequency of occurrence of dormice in fox diet has been recorded as between 0.6-6.6% of diet [202,269], and for feral cats has been recorded as high as 9% [269]. Other predators are known to include badgers, dogs, wild boar, and adders [269].

Polecat (*Mustela putorius*)

Reason for inclusion: Expert recommendation

Spatial overlap in Europe and predicted in PRR: As a widespread habitat generalist, overlap between polecat and pine marten is likely widespread across continental Europe. Spatial overlap within the PRR is also expected to be extensive.

Evidence of interaction: There was no evidence of pine marten predation on polecat. The polecat dietary niche has a larger component of medium sized mammals such as rabbits, and a much larger herptofauna component. In comparison, pine martens take on average a smaller prey size than both stoats and polecats. They also take a larger proportion of fruit, invertebrates, and carrion in comparison to other British mustelids. Hence, while pine marten and polecat do share a broad niche overlap, the dietary niche of the pine marten is actually most closely related to weasels [31], while polecats are thought to be in closer competition with mink and stoats [31].

Modern environmental differences: Conservation status

Levels of pine marten predation in comparison to other predators: n/a.

Eurasian otter (*Lutra lutra*)

Reason for inclusion: Annex IV species.

Spatial overlap in Europe and predicted in PRR: As a habitat specialist, but with a widespread distribution, overlap between European otters and pine martens is likely widespread across continental Europe. There will be overlap along watercourses within the PRR.

Evidence of interaction: There was no evidence of pine marten predation on otter. Dietary overlap is minimal.

Modern environmental differences: Conservation status

Levels of pine marten predation in comparison to other predators: n/a.

Risk assessment

While some predation of hazel dormice has been recorded, it is always at low levels and insignificant in comparison to the impact of other predators. There may be benefits to dormice due to a potential reduction in grey squirrel numbers. No impacts on polecat or European otter are predicted (see Table 11).

Table 11. Risk assessment for other mammal species

Species	**Potential impact**	**Likelihood**	**Risk (Out of 5)**
Hazel Dormouse	Low	Medium	2
Polecat	Low	Low	1
European otter	Low	Low	1

Other species:

Other Annex IV species excluded from risk assessment due to lack of the species in the release region are natterjack toad (*Bufo calamita*), pool frog (*Rana lessonae*), sand lizard (*Lacerta agilis*), smooth snake (*Coronella austriaca*), little ramshorn whirlpool snail (*Anisus vorticulus*), Fisher's estuarine moth (*Gortyna borelii lunata*), and wildcat (*Felis silvestris*).

Great Crested Newt

Reason for inclusion: Annex IV species.

Spatial overlap in Europe and predicted in PRR: Overlap between great crested newt and pine martens is likely widespread across continental Europe. There will be overlap in specific areas within the PRR.

Evidence of interaction: There was no evidence of pine marten predation on great crested newt.

Modern environmental differences: Conservation status

Levels of pine marten predation in comparison to other predators: n/a.

No interaction is expected.

Large blue butterfly

Reason for inclusion: Annex IV species.

Spatial overlap in Europe and predicted in PRR: Levels of overlap between large blue butterfly (a grassland specialist) and pine marten populations is unknown. A large blue butterfly population exists approximately 30km from the PRR.

Evidence of interaction: There was no evidence of pine marten predation on large blue butterfly.

Modern environmental differences: Conservation status

Levels of pine marten predation in comparison to other predators: n/a.

No interaction is expected.

Discussion

Woodland bird populations in Scotland (where pine martens are abundant) have continually showed an increasing healthy population growth since 1994 [270]. In comparison, woodland bird populations in England have continued to decline [179]. A pine marten reintroduction to the PRR would increase the overall species richness of the region, potentially increase habitat quality through impacts on other species, and increase ecosystem functioning by creating a more complete predator guild. Indeed, the reintroduction of native predators has been shown to have profound potential benefits for the local ecosystem.

Native species in the Forest of Dean have been avoiding pine marten predation for over a million years, and would not be here if they didn't have strategies to avoid that predation. This is reflected by the lack of examples of predator reintroduction having a negative ecological impact on any species of conservation concern. However, there are key differences between the modern environment and the environment in which species co-evolved which must be identified and assessed. Here we take a risk assessment approach as recommended by the IUCN *Guidelines for Reintroductions and Other Conservation Translocations* [17].

The only high risk identified was the potential disturbance of large bat roosts within buildings which had the potential to impact population performance. Medium risks included the potential disturbance of medium-sized bat roosts within buildings and predation of birds within nest boxes. The risk of predation of large bat roosts within mines or caves impacting population performance was variable dependent on risk assessment methodology.

With any risk assessment procedure, there is an inherent uncertainty due to incomplete evidence. For instance, there are several shortcomings of traditional Mustelid dietary analysis – large prey items and prey with few hard parts are often thought to be underestimated. A detailed monitoring and adaptive management strategy will be needed to determine whether risks have occurred, their extent, and what mitigation can be effectively employed. Also, a reintroduction project must fully review potential mitigation strategies for these identified risks, to see the plausibility, effectiveness, and cost of any mitigation. There are also opportunities with mitigation plans, for instance preventing pine marten entry to building bat roosts may prevent entry to a range of other predators, potentially boosting population growth. Finally, a fully costed exit strategy should be completed, to be triggered if risks occur and mitigation proves unsuccessful. A reintroduction project is preferable to the predicted natural recolonisation, where monitoring and mitigation would be unlikely to occur (as with polecat).

5. The socio-economic feasibility of a pine marten reintroduction

Abstract

Pine martens are found across much of Scotland, Ireland, and continental Europe, and have a range of both costs and benefits to local communities. For instance, pine martens are a charismatic species that are used to promote ecotourism at a variety of locations in Scotland. Pine martens could also be used as a “gateway species” to increase peoples’ engagement with nature, which could have a variety of positive societal benefits. Due to the quantity of woodland in the area that is managed for forestry, and the detrimental impacts that grey squirrels have, the controlling impact of pine martens on this non-native species could have a broad range of economic benefits for the local forestry industry. The predation of captive poultry or pheasants, kept next to or within woodlands, was identified as a potential source of human-wildlife conflict. However, rates of incidence are unknown, and defences to stop fox predation will be highly useful in also preventing pine marten predation. Pine martens are also known to den in roofs in Scotland, but this is not a major source of conflict, unlike the high levels of conflict caused by stone martens denning in roofs in continental Europe. There was broad support from the local community for the project. An on-street survey was thought to be the most robust methodology for surveying this, and showed 71% in favour of the reintroduction, 3% against, and 26% undecided. The shooting community clearly had greater concerns about the potential reintroduction than the wider community, however there was still support among this group, with 46% in favour, 32% against, and 22% undecided.

Introduction

It is important when considering the reintroduction of a species that potential impacts on local communities are properly assessed. This should include the potential benefits as well as the potential costs for people living alongside the reintroduced species [17]. A previous reintroduction to central Wales by The Vincent Wildlife Trust was in an area of low population density (see Figure 18). The proposed reintroduction to the Forest of Dean and lower Wye Valley is in area with a higher urban population in direct contact with woodland (see Figure 19). The major urban conurbations in the potential release region include Monmouth (population 10508), Coleford (pop. 8359), Cinderford (pop. 8494), and Lydney (pop. 8766), with the larger urban areas of Chepstow (pop. 12413) to the south and Gloucester to the east (pop. 128500[271]). However, as seen in Figure 20 the area has an insignificant human population density when compared to a major population of pine martens found in the Netherlands to the east of Utrecht (pop. 330772) and to the south-west of Amersfoort (pop. 151534).

The European pine marten has a broad distribution across northern Scotland, Ireland, and much of continental Europe. Human-wildlife conflict with the species is broadly well understood in these areas. Here we identify the potential socio-economic costs and benefits of a pine marten reintroduction based on a review of the available literature.

5.1 Potential socio-economic benefits

Ecotourism

Pine martens are a charismatic species that are used to promote ecotourism at a variety of locations in Scotland. They readily come to feeding stations associated with tourist accommodation, cafes, or at dedicated wildlife hides. The pine marten would add to the value of the area as a photography destination, and as a place to enjoy nature and wildlife.

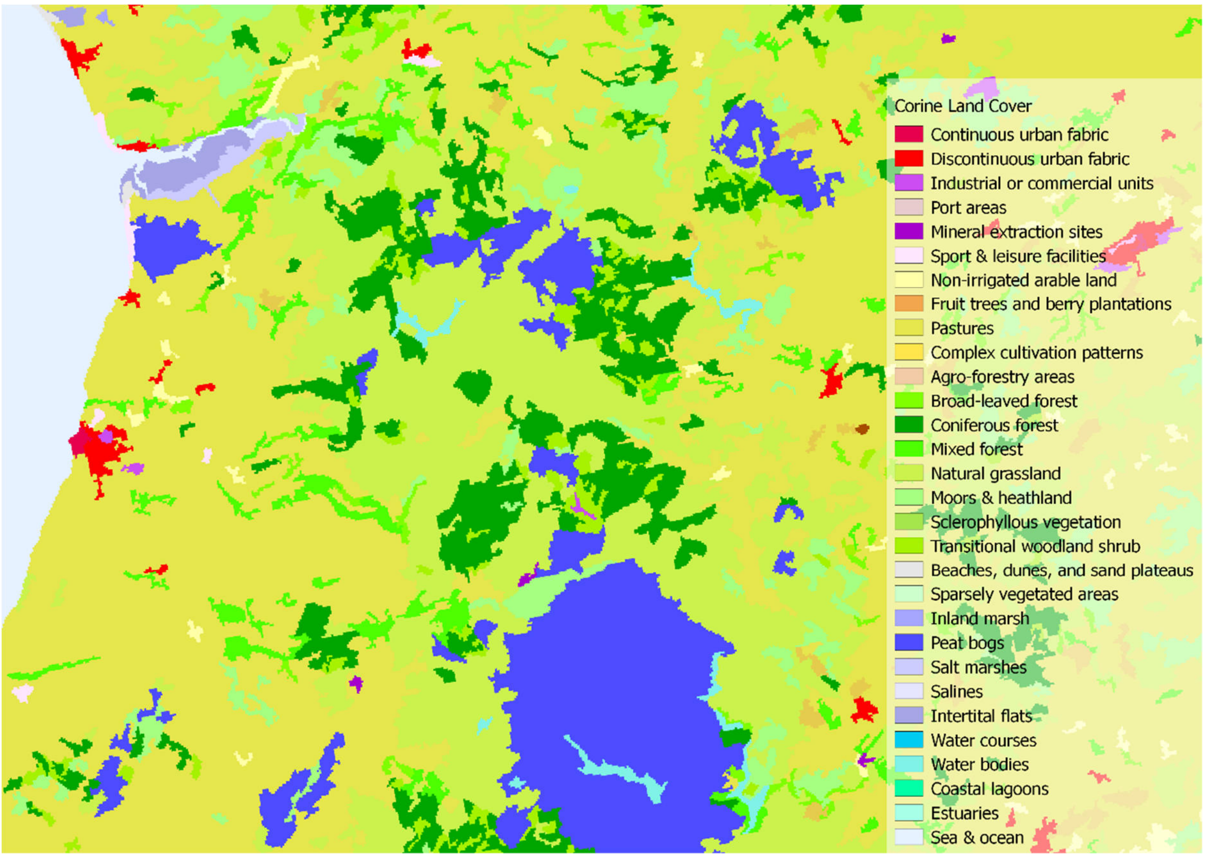

Figure 18. Corine land cover map (Source: European Environment Agency, 1:200000) of The Vincent Wildlife Trust release area in central Wales.

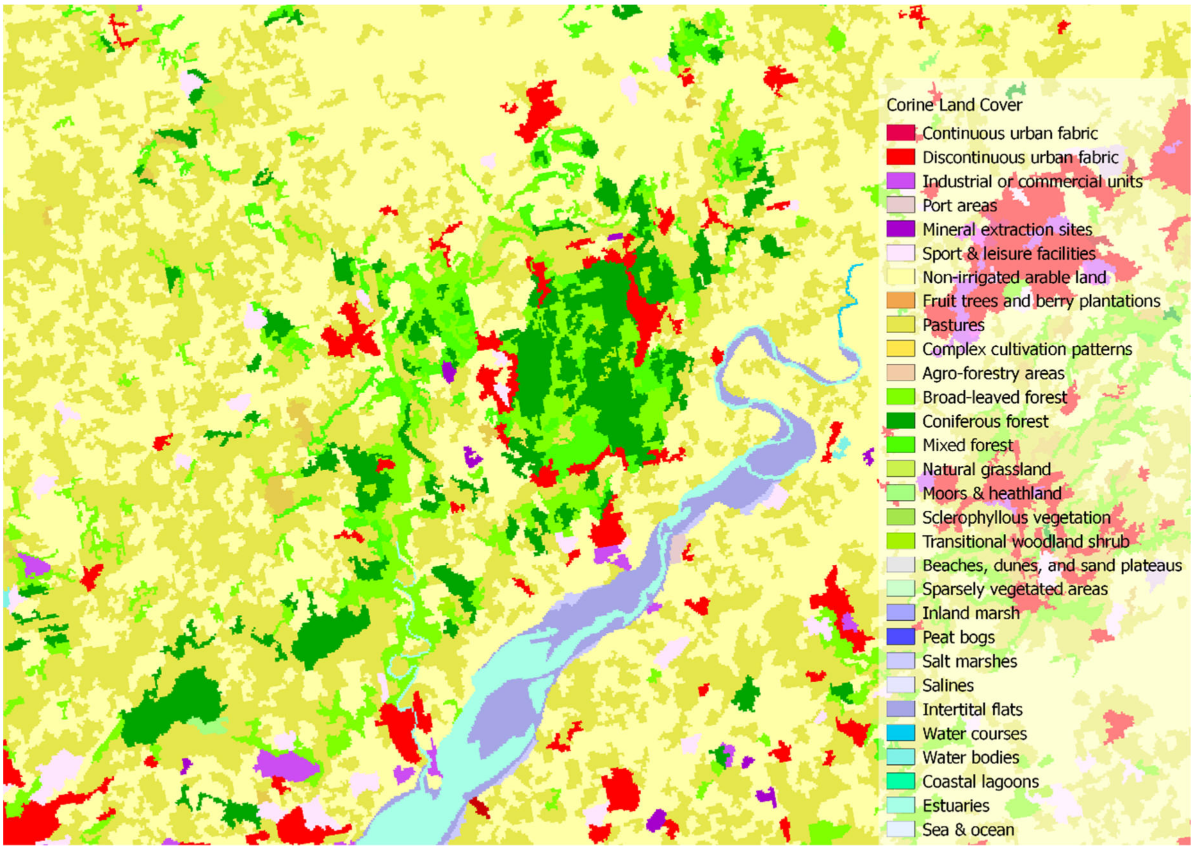

Figure 19. Corine land cover map (Source: European Environment Agency, 1:200000) for the Forest of Dean and lower Wye Valley.

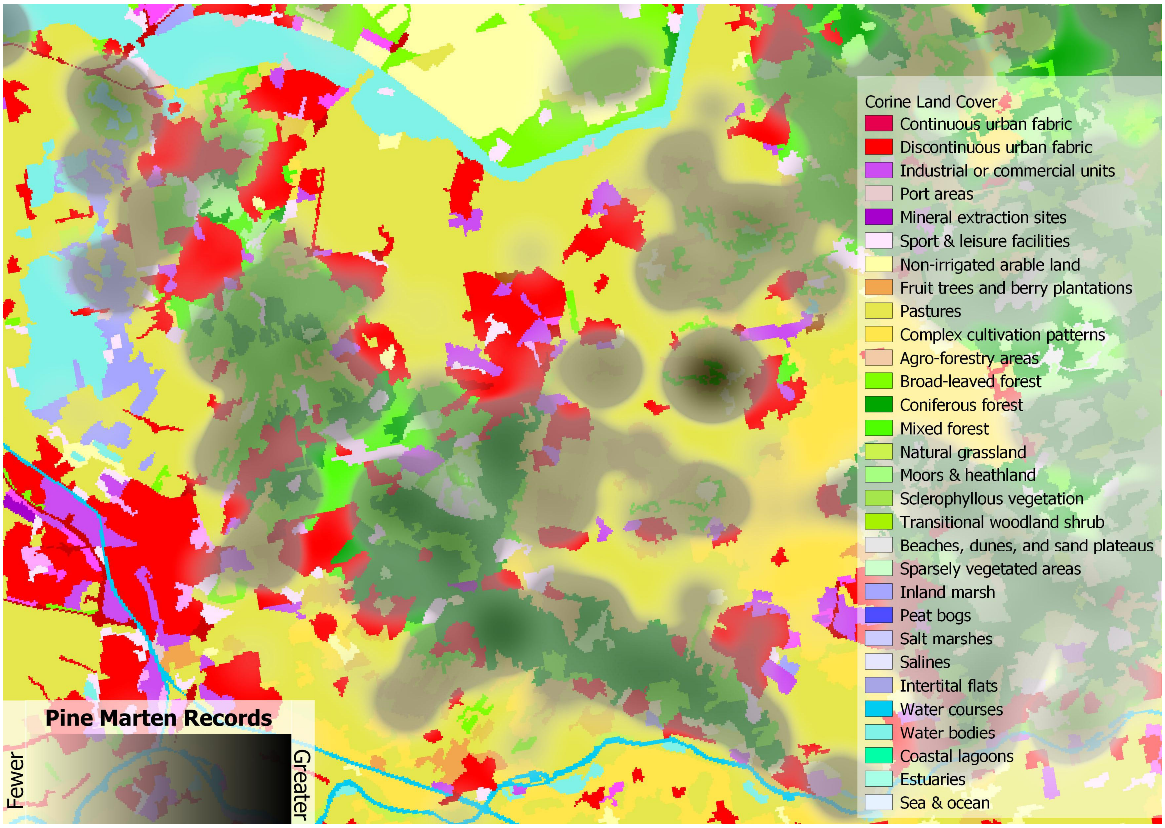

Figure 20. Corine land cover map (Source: European Environment Agency, 1:200000) for central Netherlands area between Utrecht and Amersfoort. The number of pine marten records from an area (excluding records from road kill) are shown as a greyscale heatmap (see Chapter 3.3) [107].

There are potential risks associated with encouraging ecotourism and feeding wildlife. Human disturbance may have an influence on pine martens. For instance, pine martens in tourist areas of a national park have been shown to have higher stress hormone levels in comparison to an area without tourists [272]. However, we do not know whether this effect had an impact on levels of distress (the physically debilitating results of stress) or population performance. Evidence from the Netherlands shows that pine marten populations can persist alongside a high density of roads and people (see 3.3). This is also an important consideration when considering the ecotourism potential of pine martens.

There are also potential risks when feeding wildlife. These are often associated with feeding wildlife in urban areas. With pine martens this may increase the likelihood of pine martens denning within houses, or the potential for domestic poultry predation [273]. Responsible wildlife tourism should be actively encouraged and communicated as part of any reintroduction project. This is particularly important due to observed stress levels in pine martens.

Increasing engagement with nature

We know that increasing engagement with biodiversity and nature can have major positive benefits for the wellbeing of individuals [274–276]. These include any activity in a natural environment, which can be more beneficial for both physical and mental health than the same activity in an urban setting [274].

The reintroduction of pine martens may encourage individuals to visit the release region and visit more green spaces. This could be further encouraged, for instance by providing sites to view pine martens. As discussed in the previous section, pine martens will readily visit feeding stations. However, this is usually crepuscular or nocturnal behaviour, and to minimise any potential stress to the animals will likely be only accessible to a small proportion of local communities and the wider public. Providing information on pine martens, videos, or live webcams may be a useful way to engage larger numbers of people. Interestingly, interaction with nature does not need to be within nature, for instance watching nature through TV or computer screens can also be beneficial. In this way, webcams showing pine martens may be useful on their own as a device to better engage people with nature [277], in addition to being a useful medium to encourage people outdoors. Hence, there are a variety of ways in which pine martens could be used as a "gateway species" [278], to help engage people with nature and also encourage greater use of green spaces. This could have a variety of societal benefits.

Grey squirrel control

The invasive non-native grey squirrel (*Sciurus carolinensis*) is known to strip bark from trees. This can have severe impacts on tree growth and timber quality, and can cause tree death. In 2000, grey squirrel damage was thought to reduce the value of UK forestry by £10 million [279].

The damage caused by squirrels (see Figure 21) was surveyed in the Forest of Dean across four tree species. Trees 15-40 yrs old were surveyed, and only scars that had not healed over were recorded. The species with the greatest proportion of trees damaged was beech (*Fagus sylvatica*), with 96% of trees having squirrel damage. Norway spruce (*Picea abies*) had the lowest proportion of trees damaged (26%), while 75% of sweet chestnut (*Castanea sativa*), and 72% of oaks (*Quercus* spp), were damaged. The severity of damage also differed between species, with the most severely damaged species being beech, followed by oak, sweet chestnut and then Norway spruce. Hence, a large proportion of planted timber stocks in the Forest of Dean are being affected by damage from grey squirrels.

Figure 21. Multiple years of bark stripping by grey squirrels on a young oak tree

Grey squirrel damage of this magnitude has serious consequences for forest management. Grey squirrel bark wounds weaken the timber and reduce saw-log lengths, reducing saleable value. They also expose the tree to drought stress, decay and insect attack. Perhaps the most serious form of damage are bark wounds in the crown - these may result in stem breakage or loss of apical dominance in turn leading to stem deformities, reduced growth rates and ultimately death of the tree from suppression, drought or decay. Grey Squirrels target the most dominant, fastest growing trees in a stand and cause more damage after thinning, when trees experience reduced competition. Previous studies of grey squirrel damage have estimated the loss of yield to be in the range of 1-4 metric tonnes ha^{-1} per year [280]; however investigations of the long-term effects of squirrel damage have been hampered by the difficulties of measuring yield loss that can be attributed uniquely to squirrel damage. It has so far proved impossible to establish a controlled comparison of growth between damaged and undamaged stands and as a result estimates of the loss of yield from squirrel damage have proved contentious and considered to be underestimates [281].

Traditional methods of grey squirrel control have included trapping and poisoning. However, it is debateable whether control of the animal in this way is cost effective - due to the intensive trapping effort needed to have an impact on grey squirrel populations [282]. Many foresters and landowners consider that investment in broadleaved planting is now very questionable and this has resulted in a reduction in new plantings from broadleaved trees to conifers [283].

Pine martens may have an impact on grey squirrel numbers if reintroduced to the potential release area (see Chapter 4 for review). Due to the quantity of woodland in the area that is managed for forestry, this could have a broad range of economic benefits for the local forestry industry. It could also have a positive effect on the quantity of native tree-planting, with subsequent positive effects for people and wildlife.

Grey squirrels are also known to be an important host for nymphs of the tick *Ixodes ricinus*, and a reservoir host for Lyme disease (*Borrelia burgdorferi*) [284]. It has previously been shown that predators similar to pine martens suppress *I. ricinus* populations on small mammals and Lyme disease prevalence [155]. This effect is thought to be caused by predators limiting the population density of small mammals, and/or reducing small mammal movements which reduces tick success. This effect may be further amplified by the potential impacts of pine martens on grey squirrels.

5.2 Socio-economic risks

Scottish Natural Heritage identify conflict with pine martens in three key areas. These are the pine marten's tendency to utilise roof spaces as den sites in Scotland, the predation of chickens, and the predation of pheasants within release pens [285]. Here we further investigate these risks, as well as risks to free-living game birds.

Denning within roofs

Pine martens are known to utilise roof spaces within inhabited buildings as den sites. However, there is a question of whether they utilise these spaces in Scotland because of a lack of suitable den sites within woodland [66]. For instance, in areas of continental Europe arboreal cavities are the dominant natal-den sites (see Chapter 3). Scottish Natural Heritage estimate that they receive on average 5-6 enquires per year about pine martens within roof spaces, with a peak in March/April. Evidence from continental Europe could not be found. This is because the stone marten (*Martes foina*) is known to utilise roof spaces often for denning [286,287]. Stone marten are also more likely to inhabit urban areas [288], hence published literature focuses on the stone marten rather than the pine marten as a source of human-wildlife conflict.

The Forest of Dean has extensive areas where natural cavities for den-sites are likely to be extensive (see Chapter 3). If den boxes are also utilised in areas where natural den sites are thought to be lacking, this may reduce the likelihood of pine marten occupying roof spaces within inhabited buildings.

However, the risk will always be present and an adaptive management strategy must be developed so that it can be employed if the risk occurs.

Wild game birds

A review in Scotland showed that the key game birds taken by pine marten were pheasants, woodcock (*Scolopax rusticola*), and mallards (*Anas platyrhynchos*)[32]. However, all were taken in low numbers, and pine martens are unlikely to impact their populations. The low level of importance of free-living game birds in pine marten diet was also supported in a previous review [289]. A full review of potential impacts on woodcock is available in Chapter 4.

The study of pine marten diet in Scotland found pheasant 33 times out of 4006 items found (<1% of food items) [32]. Also, a five year study in Hungary showed that foxes are more likely to predate pheasants in comparison to pine marten, indeed no evidence of pine marten predation on pheasants was found [290]. As a proportion of diet, foxes were also shown to eat more pheasants than pine martens in central Poland [291]. Pine martens live at low density across a landscape. Hence, predation on released pheasants at the levels discussed is unlikely to impact shooting interests. In particular as on average 62.5% of all released pheasants are not shot [292]. However, impacts may occur if a pine marten enters a release-pen, poultry coupe, or enclosed area where multiple kills may occur. This is further discussed below.

Mandarin ducks

Mandarin ducks (*Aix galericulata*) are a non-native but common feature in the Forest of Dean. As pine marten predate mallards it is likely that they will also predate mandarin ducks. However, the level of predation expected is unlikely to impact on the population. Pine marten proof nest boxes for cavity nesting ducks have been produced in Scotland for goldeneye ducks (*Bucephala clangula*), and could be used if predation becomes an issue.

Free range poultry

A detailed study of the impacts from a variety of different predators on free-ranging poultry across 60 farms was conducted in Bresse, France [293]. This area is known for its free-ranging chicken production and its healthy pine marten population [53,294]. There was minimal protection against predators on the study farms. Chickens were put away at night and "…*tend to be raised in fenced fields. These wire mesh fences are designed to restrict poultry movement and not to exclude predators*" [293]. The estimated average loss of stock to predators was 6.3% per year, with the highest losses when the chickens were between 5 & 11 weeks of age. Avian predators were responsible for 24% of all losses to predators, while canids (including foxes and dogs) were responsible for 61% of all losses to predators. Mustelids (including pine marten, stone marten, polecats, stoats, and weasels) were responsible for only 2% of losses to predators. However, 10% of losses were to carnivores which could not be identified, and the cause of loss was not identified in a further 19% of cases. Foxes and pine martens can be legally culled in France, but the local level of culling had no effect on poultry losses. These data do show the low impact pine marten are likely to have on free-range poultry businesses in comparison to the current threat posed by foxes.

Captive poultry and pheasant release pens

Pine martens have been known to take captive poultry and pheasants from release pens [273,295,296]. However, estimating whether these are a rare event or a more common occurrence has proven difficult. A dietary study of pine marten in Scotland found chicken 4 times out of 4006 items found (<1% of food items) [32]. The low level of importance of domestic poultry in pine marten diet was also supported in a previous review [289]. In central Poland, foxes ate three times more domestic chicken than pine martens as a proportion of diet [291].

It is likely that standard methods of preventing predator access to chicken coupes, for species such as foxes, mink, and polecats, would be effective in preventing pine marten access as well. The key difference between pine marten and predators already in the area is that pine martens are more effective climbers. Hence, pens would need to prevent access over the top of fences to fully prevent pine marten access [296].

On a landscape level, the risk of captive poultry predation may increase due to the presence of pine marten. However, as evidence for their effects is not widespread, the increase in risk is not likely to be dramatic. However, this may be of little consolation to the low numbers of small-holders who will be directly impacted by pine martens. An adaptive management strategy should be implemented to reduce the risk further if possible, and react to those that are affected.

The Forest of Dean has previously been assessed as an area with low levels of pheasant rearing and release [7]. This was predominantly due to the amount of land managed by the Forestry Commission. This is reinforced by a camera trap survey that found very few pheasants across the public forest estate. However, there are several shoots in the wider landscape. Pine martens' impacts are not so frequent or impactful as to prevent pheasant rearing from occurring. Indeed, pheasant rearing and release is common across many areas of Scotland with healthy pine marten populations [297]. A survey of the attitudes of members from the British Association for Shooting and Conservation, and the National Gamekeepers Organisation in the release region is detailed in the next section. In the event of a pine marten reintroduction a detailed adaptive management strategy would be needed to reduce and prevent human-wildlife conflict.

5.3 Attitudes to pine marten reintroduction

Previous consultations

Natural England in partnership with BASC completed a public opinion survey in 1999 across six potential reintroduction sites including the Forest of Dean (see Table 12). This showed that 89% of the general public supported a pine marten reintroduction, with 65% of gamekeepers and 64% of farmers also supportive [6]. For the Forest of Dean specifically, 92% (n = 61) of the general public and 71% (n = 48) of farmers were in favour of a reintroduction.

Table 12. Reasons for support or opposition for the translocation of pine martens to the Forest of Dean in 1999. All reported figures are percentage responses [6]

Reason for support	Public	Farmers
Protect a rare spp	27	27
Native spp	16	14
Conservation	13	8.5
Diversity	11	11
Balance of nature	9	8
See one	4	7
Children	2	1
Control rabbits etc	0.5	2
Grey squirrels	0.3	0
Other	3	1
No opinion	14	21

Reason for opposition	Public	Farmers
Extra predator	19	35
Songbirds	19	9
Unsuitable area	12	9
Money wasted	7	4
Red squirrels	5	3
Spread naturally	5	6
Gamebirds	2	6
Too rare for removal	2	0.7
TB	0	2
Compete e.g. Owls	0	1
Balance of nature	0	1
Other	12	8
No opinion	17	15

The Vincent Wildlife Trust conducted a public opinion survey in advance of their proposal to translocate pine martens to Wales to support the fragmented population found there. Using three different methodological approaches, 91% of respondents supported the translocation [298].

A variety of reasons were given for supporting the project (see Table 13). Both surveys broadly agreed, with the conservation of pine martens and the restoration of a native species seen as prime reasons for translocation. Of interest was that the control of the grey squirrels, often cited as a key positive influence, was not sighted highly as a reason for translocation in both surveys.

Table 13. Reasons for support or opposition for the translocation of pine martens into Wales [298]

Reason for support	Percentage
They are a native species	22.6%
Increase biodiversity	17.3%
Prevent extinction	14.9%
Restore natural balance	9.7%
General support for wildlife/conservation	8.1%
Duty/moral obligation	5.5%
For the next generation	3.1%
Grey squirrel/pest control	3.0%
Wish to see them in the wild	2.7%
Economic benefits	1.9%
Other	11.4%

Reason for opposition	Percentage
Predation of wildlife	34.9%*
Lack of sustainable habitat/fragmentation	18.6%*
Economic costs	14%*
Let nature take its course	9.3%*
Other	23.3%*

*Modified to exclude factors that are not relevant to the Forest of Dean and Wye Valley i.e. the existence of a fragmented population in Wales prior to translocation.

The key concern of those opposing the translocation was the predation of wildlife. Hence, an assessment of the potential influence of pine marten predation (see Chapter 4), the monitoring of predation in the event of a reintroduction, and a fully costed exit strategy, may be useful tools in addressing these concerns.

Public opinion in the Forest of Dean

Three methods to assess the attitudes of local communities to the reintroduction of pine martens to the Forest of Dean were utilised. These were:

- Collection of feedback forms (n = 148) at local community meetings
- Online survey (n = 279, although 72 responses from outside the release region were not used) advertised to 11687 people within 20km of Coleford through social media
- An on-street survey (n = 265) run by an independent project partner (Forest Research – see accompanying document)

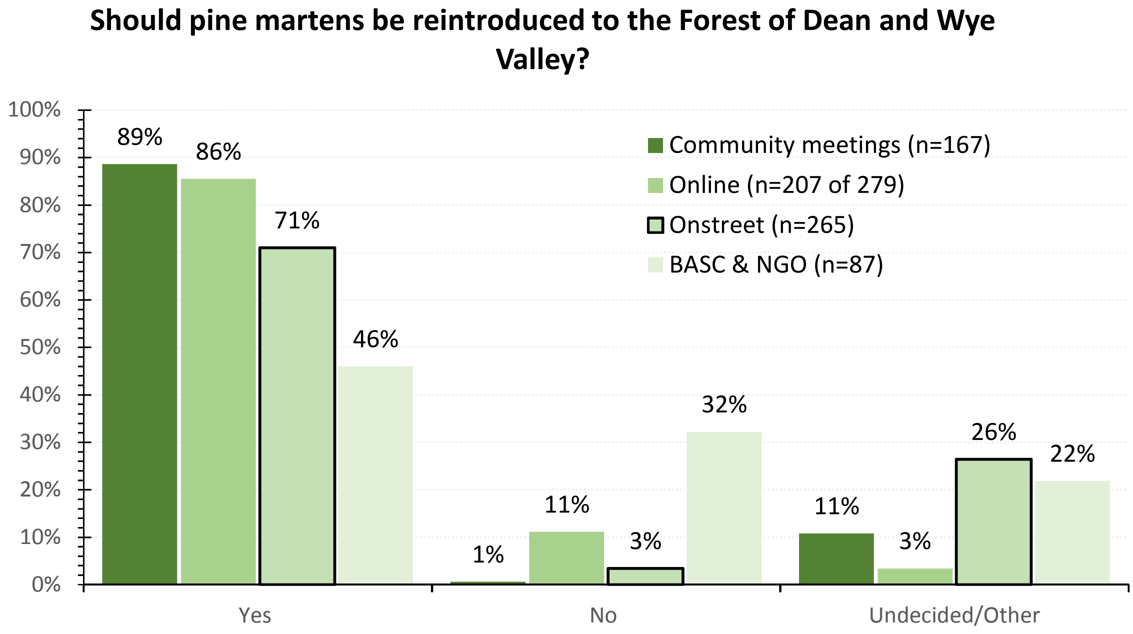

Figure 22. Results from public opinion surveys in the Forest of Dean and Wye Valley. The on-street survey is outlined, and was thought to have the most robust and unbiased methodology. BASC & NGO refers to a survey of the membership of the British Association for Shooting and Conservation and the National Gamekeepers Organisation (see text).

The on-street survey and online survey also collected broad details about where the respondents were based. Hence, only those living within the release region were included in the final results. Results showed a clear support for the project from the local community (see Figure 22). The on-street survey was thought to be the most robust methodology, with the least bias when surveying the opinions of the local community. A report by Forest Research accompanies this feasibility study [299], which goes into far more detail about the attitudes and opinions of local communities. They also analyse any differences between rural and urban areas in the region.

The results were very similar to The Vincent Wildlife Trust public opinion survey [298]. Their survey only reported those either for or against (rather than including undecideds), and showed between 85% and 99% support. If we remove the undecideds from our surveys, we had very similar results, with levels of support between 89% and 99%.

Consultation with shooting communities

In 2011, a wide-ranging survey conducted by the National Gamekeepers Organisation and the Game & Wildlife Conservation Trust attempted to survey the attitudes of gamekeepers to all wildlife species including predators. 78% of gamekeepers living alongside pine martens believed they had a detrimental effect on the numbers of game birds, and 76.3% believed they had a detrimental effect on wildlife [297]. Interestingly, grey squirrels were culled on 96.3% of shoots. Hence, due to the impact of pine marten on grey squirrel populations, there is the possibility of a positive impact for landowners from pine marten reintroduction.

During the development of this feasibility study we worked closely with the British Association for Shooting and Conservation (BASC) and the National Gamekeepers Organisation (NGO) to survey their members in the release region. The two organisations have numerous members across the potential release region, representing a variety of shoots. However, only very few shoots in the region are located on the public forest estate. The survey was physically mailed to members within the release region, but emailed to BASC members if this was an option. The anonymous survey consisted of a cover sheet from the respective organisation, a page of information summarising the biology of pine martens and the key conclusions from this feasibility study, then six questions. The questions asked for the responders' role within shooting communities and whether they were in favour of the reintroduction. The survey also asked participants to rank the potential benefits and costs of a reintroduction, and to rank what could be provided by a reintroduction project that would most assist them.

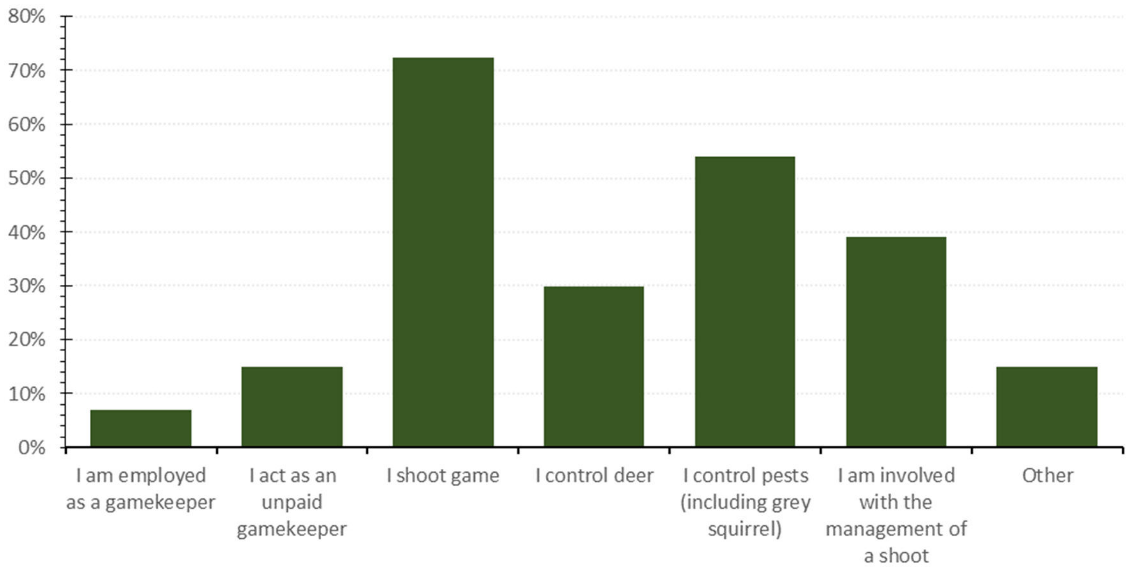

Figure 23. Responders to survey of BASC and the NGO members asked, 'Please select the options that best describe you (multiple answers may apply)?'

Eighty-seven responses to the survey were received. Those who responded had a range of roles within the shooting community (see Figure 23). 46% of respondents were in favour a reintroduction, 32% were against, and 22% were undecided (see Figure 22). However, those directly involved with game management (responding 'I am employed as a gamekeeper', 'I act as an unpaid gamekeeper', or 'I am involved with the management of a shoot') were less supportive, with 36% in favour, 36% against, and 28% undecided (n=36).

Table 14. Ranked perceived benefits and concerns regarding pine marten reintroduction by the members of BASC and the NGO

	Benefits	**Concerns**
1	Grey squirrel/pest control	Predation of wildlife, including woodland birds
2	They are a native species	Predation of captive gamebirds (pre-release)
3	Prevent extinction	Disturbance of gamebirds at roost
4	Restore natural balance	Predation of gamebirds (post-release)
5	General support for wildlife/conservation	Interference with nature
6	Increase biodiversity	Competition with other native predators
7	Wish to see them in the wild	Predation of other captive birds
8	For the next generation	They may den in attics
9	Duty/moral obligation	Lack of suitable habitat/fragmentation
10	Economic benefits	Disease risk
11		Other economic costs

Reasons for support or opposition were varied (see Table 14), with the potential impact on grey squirrels perceived as a clear potential benefit. The highest ranked concern was the predation of wildlife, followed by the predation of captive gamebirds and the disturbance of gamebirds at roost (see Table 14). 32% of responders had no concerns, while 28% saw no benefits of a pine marten reintroduction.

Table 15. Summary of rankings when members of BASC & the NGO were asked "As part of a reintroduction, a mitigation plan would be put in place to help mitigate potential impacts of pine martens over the 5 years of the project. Which of the following suggestions do you think would be useful for you?"

Rank	Mitigation
1	A 'Gamekeeper Day' with speakers from Scotland on their experiences of living alongside pine martens
2	Trap & translocation of specific problem animals
3	Information regarding what management techniques to protect game/poultry are legal, including advice on management from Scotland
4	Information on the location of released martens (released individuals would be monitored by radio collar for the 1st year after release)
5	Compensation for the loss of captive poults taken by pine martens (would only be available for the 5 years of the reintroduction project)
6	Free pine marten excluders for traps (pine martens are a protected species and it is illegal to trap them without a licence)
7	Loans of camera traps to monitor whether pine martens are investigating your game/poultry
8	Free experimental deterrents e.g. outdoor radios, motion-activated lights, daylight-activated pop-hole door, etc

These results indicate that, while the shooting community clearly has greater concerns about the potential reintroduction than the wider community, there is still support among this group. However, those most directly involved with game management are more cautious of the reintroduction plan. Any reintroduction project should have a detailed Human-Wildlife Conflict mitigation strategy. A range of options were ranked as part of the survey (see Table 15), and few further ideas were proposed. A mitigation strategy would be to help address the concerns of the shooting community and mitigate negative impacts that may occur.

6. Conclusions and recommendations

Biological feasibility (Chapter 3):

- Large areas of suitable habitat exist in the release region, with a potential population of just under 200 individuals.
- The abundance of a key food group, small mammals, is high in comparison to other areas with healthy pine marten populations. Habitat quality was variable, but with numerous areas of good habitat structure, such as mixed canopy layers with a good understory. However, provision of more large woody debris may increase pine marten hunting opportunities.
- Potential den-sites were abundant in specific areas of old deciduous woodland. In particular, the older oak stands which are found in several areas. A reintroduction project should provide den boxes in those areas without suitable denning habitat.
- Road density was below the average density of roads found alongside healthy pine marten populations in the Netherlands, and fox density was low to medium in comparison to other areas of the UK. A reintroduction project should include detailed monitoring of the population for mortality levels.
- It was predicted that if the central Wales pine marten population successfully establishes that the Forest of Dean and Wye Valley would be colonised multiple times within 20 years, and support a healthy pine marten population within 30 years. However, establishing a second population alongside the Welsh population would greatly increase the likelihood of overall metapopulation establishment and success.
- Landscape connectivity maps indicated that connectivity between the Forest of Dean, Wye Valley, and Wentwood could be improved. This should be further investigated, as it could provide benefits for all woodland wildlife.

Ecological feasibility (Chapter 4):

- Predation is a fundamental component of a healthy ecosystem, and predator reintroductions have been shown to have a variety of positive effects such as increasing habitat quality and function, and increasing overall species richness.
- Potential controlling impacts on non-native grey squirrels could have wide ranging positive impacts.
- All native species at a reintroduction site will have evolved alongside the reintroduced predator, and have adapted to avoid predation. The risks of native predators to the conservation status of their prey is low.
- A review of 300 species reintroductions worldwide could not find a single negative ecological impact resulting from the reintroduced species.
- A detailed ecological risk assessment investigated how the modern environment differs from the environment in which species co-evolved. We also built a database of pine marten diet, consisting of 18210 analysed scats.
- The only high risk identified was the potential disturbance of large bat roosts within buildings. Medium risks included the predation of birds within nest boxes. A reintroduction project should include detailed monitoring of pine marten diet and any impacts on local wildlife populations. In addition, a conservation and mitigation plan should be developed, to mitigate any impacts on local horseshoe bat populations, and those at-risk birds which nest in bird boxes.
- A reintroduction project is preferable to a natural recolonisation, where monitoring and mitigation of the species would be unlikely to occur (as with polecat).

Socio-economic feasibility (Chapter 5):

- Pine martens are a charismatic species that are used to promote ecotourism at a variety of locations in Scotland.
- Pine martens could be used as a “gateway species” to increase peoples’ engagement with nature, which could have a variety of positive societal benefits.
- Due to the quantity of woodland in the area that is managed for forestry and the detrimental impacts that grey squirrels have, the controlling impact of pine martens on this non-native species could have a broad range of economic benefits for the local forestry industry.
- The predation of captive poultry or pheasants, kept next to or within woodlands, was identified as a potential source of human-wildlife conflict. However, rates of incidence are unknown, and defences to stop fox predation will be highly useful in also preventing pine marten predation.
- Pine martens are also known to den in roofs in Scotland, but this is not a major source of conflict, unlike the high levels of conflict caused by stone martens denning in roofs in continental Europe.
- There was broad support from the local community for the project. The on-street survey was thought to be the most robust methodology, and showed 71% in favour, 3% against, and 26% undecided.
- A reintroduction project should develop a detailed adaptive management strategy to mitigate negative impacts that may occur, and maximise the potential benefits of the reintroduction.

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