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Original Investigation

Pine marten (*Martes martes*) distribution and abundance in Ireland: A cross-jurisdictional analysis using non-invasive genetic survey techniques

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ABSTRACT

On the Island of Ireland, pine martens (*Martes martes*) exist at the western edge of their global geographic range in the least forested region of Europe. The species has undergone substantial declines in abundance and distribution during the 20th century. Here, we report on the first cross-jurisdictional (Republic of Ireland and Northern Ireland) survey that aimed to investigate current pine marten distribution, assess any recent historical change and provide preliminary estimates of population abundance.

A standardised non-invasive survey technique that used scat-based transect surveys and DNA analysis to confirm scat identity was deployed in 258 10 km national grid squares during 2005–2007. In the Republic of Ireland, an occupancy rate of 59.6% was found. Comparisons with historical data indicated that a range expansion of pine marten had occurred over the last 30 years. Indicative core population range extended to over 50% of the land area with population abundance estimates of 2740 individuals.

In Northern Ireland, an occupancy rate of 56.7% was determined with the population largely concentrated in western areas. There was little or no evidence of any recent expansion from core population areas (18% of land area) despite recent increases in forest cover and full legal protection. Population abundance estimates of 320 emphasise the critical requirement for action to conserve this species.

The pine marten is one of the rarest wildlife species in Ireland and, based on our studies, an evidenced based conservation strategy that promotes a sustainable future for the species needs to be developed.

Introduction

Understanding the spatial distribution of wildlife populations is fundamental for the development of management strategies, conservation assessment and identifying species at risk (Austin 2002). Yet reliable determination is often difficult due to a lack of information on species, methodological constraints, logistical issues, funding availability and trans-national boundaries within the biogeographic range of a species (Manley et al. 2005; Field et al. 2005; Plumptre et al. 2007). This can be further exacerbated when the species of interest is rare, difficult to survey or exists in highly fragmented habitat or populations.

Over recent years there has been considerable advancement in wildlife distribution assessment, particularly with the development and application of non-invasive survey methodologies (Kocher et al. 1989; Woods et al. 1999; Mowat and Paetkau 2002), concepts such as detectability (Mackenzie et al. 2003) and spatial modelling (Buckland and Elston 1993; Carroll et al. 1999; Murray et al. 2008). These techniques can provide robust estimation of distribution and predictions on how future change may occur. Yet, their basis is location information, which at its most basic consists of occupancy data that can be derived from many sources (e.g. field surveys, incidental sightings and road kills).

On the island of Ireland, pine martens (*Martes martes* L.) exist at the western edge of their global geographic distribution. Primarily a woodland specialist throughout its range (Buskirk 1992; Proulx et al. 2004), the extant population in Ireland has had to adapt to extensive forest clearance of such an extent that by the 19th century approximately 95% of native forests had been cleared (EPA 2006). Currently, the Republic of Ireland is approaching 10% forest land cover as a result of substantial afforestation programmes. In Northern Ireland, forest land cover estimates are less than 7%. Both jurisdictions are the least forested regions of Europe, with the main type of forest habitat consisting of multi-scale commercial conifer plantation dominated by non-native sitka spruce (*Picea sitchensis*) and lodgepole pine (*Pinus contorta* spp.).

Historically, pine martens were present throughout the island of Ireland. Prior to the late 1970s distribution information consisted largely of anecdotal observations based on incidental sightings (King 1952; Moriarty 1961), returns from taxidermists (Stendall 1946) and animal trapping (Stendall 1947; Ruttledge 1948; Rogers 1959). These were often specific to local areas and there was no

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co-ordination of recording effort at any scale. There has only been one systematic attempt to investigate the distribution of pine martens in the Republic of Ireland through field-based surveys (O'Sullivan 1983), whilst in Northern Ireland data largely consists of anecdotal sources such as questionnaire surveys (Hughes, 1993), direct observations (Deane 1952) or reviews of status (Fairley 2001).

The available evidence suggests that the pine marten population throughout the island of Ireland underwent a major reduction in range, distribution and abundance during the 19th and 20th centuries with widespread extirpation at both a local and regional level. The causative factors influencing these declines included habitat loss and fragmentation; non-targeted predator control programmes that used poisoned baits such as strychnine; direct persecution as a pest species of game/livestock and harvesting as a fur-bearer (O'Sullivan 1983; Fairley 2001).

This decline of pine marten is similar to that which has occurred for the species in other areas (Lockie 1964; Bright and Harris 1994; Webster 2001; Pertoldi et al. 2008) and for related members of the *Martes* group (Buskirk 1992; Ma and Xu 1994; Aubry and Lewis 2003). As a generalisation it appears that a paradigm of initial habitat loss and fragmentation followed by increased persecution as a pest or harvesting as a fur-bearer is useful when describing historical declines of a range of medium sized carnivores such as pine marten. Currently, there is no direct conservation strategy or action for pine marten in either the Republic of Ireland or Northern Ireland. This represents an impediment to sustainable management of the species.

Surveys have been conducted to establish pine marten distribution or abundance for decades throughout Europe (O'Sullivan 1983; Clevenger 1993; Lindström et al. 1995; Balharry et al. 1996; Strachan et al. 1996; Helldin 2000; Barka 2005). They have often relied on locating scats (faeces) with identification from morphological characteristics although this approach has been criticised due to error rates in scat identification (Davison et al. 2002; Birks et al. 2004). Increasingly studies that aim to determine pine marten distribution based on identifying scats are incorporating DNA analysis to confirm species identity (Balestrieri et al. 2008; Ruiz-González et al. 2008). To address these concerns we carried out a scat-based survey of pine marten distribution incorporating DNA testing techniques to confirm species identity. Our study may represent the largest scale application of scat-based surveys that incorporate DNA testing techniques to survey a wildlife species in Europe.

Here, we present the first Irish cross-jurisdictional (Republic of Ireland and Northern Ireland) systematic survey that aimed to determine the current distribution and population range of a terrestrial wildlife species of high conservation importance, namely the pine marten. We also assess any distributional change over the last 30 years by comparisons with historical datasets and provide the first population abundance estimates for the species. Factors influencing current distribution patterns are discussed and the requirements for conservation management considered.

Material and methods

Historical data

Historical data on pine marten distribution were only available for the Republic of Ireland and were digitised directly into a GIS from data presented in O'Sullivan (1983). That study examined pine marten distribution between 1978 and 1980 at the 10 km grid square scale, primarily using scat identification but also incidental sightings and local knowledge such as taxidermist returns to determine occupancy status. Each 10 km grid surveyed was assigned a detection or non-detection status in our GIS, which was then used as the basis for examination of historical change in pine marten distribution.

Survey methodology

The current surveys protocol was developed by reviewing methodologies used in previous surveys and also an initial pilot survey for pine marten in an area where the species was known to be resident. The most commonly used methodology for investigating pine marten distribution have largely relied on using scat-based surveys along various length transects (Clevenger 1993; Balharry et al. 1996; Strachan et al. 1996; Balestrieri et al. 2008; Ruiz-González et al. 2008) in a defined unit area (e.g. 10 km × 10 km grid square). Scat-based transect surveys are useful as they can provide a range of other data on a species of interest (e.g. Kindberg et al. 2011).

An initial pilot survey was carried out in June 2005. This involved surveying 12 transects, each 1.5 km in length, with three transects located within a 10 km national grid square in forest and scrub habitat in a region where resident pine marten were established (Co Fermanagh, Northern Ireland). On each transect, pine marten scats, confirmed via DNA testing were located within 1.5 km (mean distance 745.8 m; range 76–1411 m).

Our current survey relied on the use of transect surveys located in suitable habitat (i.e. forest or scrub) within 10 km national grid squares (i.e. 10 km × 10 km) to locate pine marten scats with DNA testing to confirm species identity. On average, 3 transects each approximately 1.5 km in length were surveyed within 10 km national grid squares to give a total survey effort of approximately 4.5 km per grid square. The number and length of transects were chosen based on other studies that relied on transects 1–2 km in length; to allow at least one 10 km grid square to be surveyed per day; and to enable transects in different locations within a 10 km grid square.

Each transect was surveyed on a single occasion only. Where possible, the location of transects were stratified according to habitat availability such that if different habitat types occurred then these were surveyed in proportion to availability. Vehicle tracks or walking trails constituted the most common transect types (>85%). Where these were not available, paved minor roads or animal trails were used. In total, 762 transects were completed with a combined length of over 1200 km.

The selection of 10 km grid squares was determined by the distribution of historical data and the availability of suitable habitat, primarily forest. On the island of Ireland, the approximate total area of forest land cover is 720,000 ha with the proportion of that habitat included in the current survey estimated at 265,000 ha, the equivalent of 36.8% habitat coverage. In total, 228 10 km grid squares were surveyed in the Republic of Ireland and 30 grid squares in Northern Ireland, approximately 32.6% and 21.4% of each jurisdiction's land area respectively. The senior author surveyed 216 (84%) grid squares and a further 42 (16%) grid squares were surveyed by trained field staff.

The survey was carried out between June and September in 2005–2007, inclusive. These months were the optimal time to carry out surveys as pine marten are more active; scat abundance is greatest (Velander 1983); weather conditions are more suitable to finding scats and daylight hours enable extended field work periods. Surveys were only carried out during optimal weather conditions (i.e. sunny, no rain, little wind) and were postponed during heavy rain or reduced light conditions.

Scats were collected that were consistent with shape characteristics of pine marten although if there was any uncertainty other scats were also collected. Scats were placed in an individual inverted zip-lock bag, which was then reverted and sealed to avoid potential DNA cross-contamination. Sample bags were then

numbered, labelled according to the number of the 10 km grid square, the transect ID and date and stored at −50 °C until DNA testing was undertaken. The total number of scats collected during the survey was 765.

In the current survey, the term occupancy refers to the fraction of sampling units (i.e. 10 km national grid squares) in a landscape where pine marten were present (Mackenzie and Royle 2005).

DNA testing

For DNA analysis, we carried out the methodology described in O'Reilly et al. (2008) and Mullins et al. (2010). The genetic sampling regime did not test all available scats due to funding limitations. Instead a screening system wherein the most likely pine marten scat from each 10 km grid square were analysed and if detection was confirmed then no other scats were tested. If detection was not confirmed from the first scat, then another scat was selected and tested. This protocol continued until either detection was confirmed or no other scats were available for testing. Hence, it was not possible to analyse scat abundance or occupancy at the transect level or how this may have related to habitat availability.

Data analysis

All spatial datasets and databases were stored in Forestry GIS (fGIS, Brian Brown, University of Wisconsin). When DNA testing assigned pine marten species identity to individual scats these were related to the 10 km grid square in which they were located and plotted on maps. Occupancy data and current distribution/range maps were produced and assessed for the Republic of Ireland and Northern Ireland separately and also at a cross-jurisdictional (Island of Ireland) level.

The principal data available from the survey was binomial (i.e. detection or non-detection). It was possible to test for changes in pine marten distribution for the Republic of Ireland only, as reliable historical data were available (O'Sullivan (1983). We compared our 10 km national grid square occupancy data from 2005 to 2006 only (2007 surveys included Northern Ireland and regions of the Republic of Ireland not surveyed historically) with digitised historical 10 km occupancy data from 1978 to 1980, (comparable $n = 183$ grid squares). A McNemar test (Sokal and Rohlf 1995) corrected for continuity, which tested the proportion of grid squares that changed status in one direction against the number that were expected to have changed by chance, was used to test for significant changes in occupancy. Changes in distribution (i.e. detection or non-detection status between surveys) were also assessed visually.

Using the extent of occupancy, survey data was used to provide an indicative assessment of current core population range of pine marten in each jurisdiction and at the island of Ireland scale. This was based on having an arbitrarily defined high threshold (90%) of detection results within a contiguous geographic area, in this case a minimum convex polygon. It was also delineated at is outermost boundary by the absence of directly connected grid squares of detected status, within a 10 km buffer zone.

Prior to the current study, the population abundance of pine marten on the island of Ireland was unknown and represented a significant obstacle in determining the status of the species. We took the opportunity to provide the first estimates of pine marten abundance using methods similar to Harris et al. (1995), Balharry et al. (1996) and Erb (2008). It relied on using current distribution data to establish the occupied area of suitable habitat (km^2) and combining this with average pine marten territory size data in Ireland (O'Mahony 2009) to estimate abundance. Annual pine marten territory size (100% MCP; $n = 7$) ranged from 59.3 ha to 435.3 ha, with males having a mean size of 171.4 ha and females 94.3 ha (O'Mahony 2009). There was also relatively little inter-sexual territorial overlap (mean $12.4 \pm 9.5\%$), which has also been found in previous studies (e.g. Zalewski and Jędrzejewski 2006).

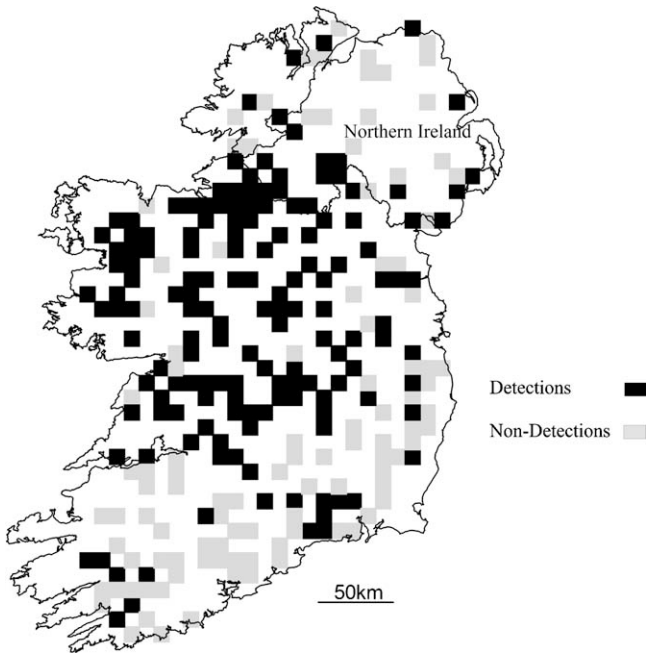

Fig. 1. Distribution of pine marten detection and non-detection results throughout the island of Ireland at the 10 km national grid square scale during 2005–2007.

Pine marten territory data were subjected to 1000 bootstrap re-samples using the accelerated bias corrected percentile method (Manly 1997), which produced an overall mean (154.2 ha) and 90% confidence intervals (97.5 ha and 311.7 ha) of territory size data. This was then divided by the estimated area of habitat occupied in each jurisdiction on the basis of the occupancy results from the current study.

This method has been used to provide population estimates for pine marten in Britain (Balharry et al. 1996) and was useful for comparative purposes. It was also important in establishing the likely magnitude of population abundance in both jurisdictions, which is critical for management purposes. Abundance values are preliminary but represent the only evidenced based approach currently available.

Results

Occupancy status

Of the 258 10 km grid squares that were surveyed, pine marten were detected in 153 (59.3%) and non-detected in 105 (40.7%) (Fig. 1). The proportions of pine marten detections were relatively similar in the Republic of Ireland and Northern Ireland, 59.6% ($n = 136$) and 56.7% ($n = 17$), respectively.

Detections were concentrated in the west and midlands of the Republic of Ireland, with fragmented distributions in the southwest, southeast and east. Non-detections were clustered in the south and southeast of the Republic of Ireland and in the majority of Northern Ireland. Of the non-detection results, no scats were found in 45 10 km squares and scats were not assigned to pine marten in the remaining 60 10 km squares.

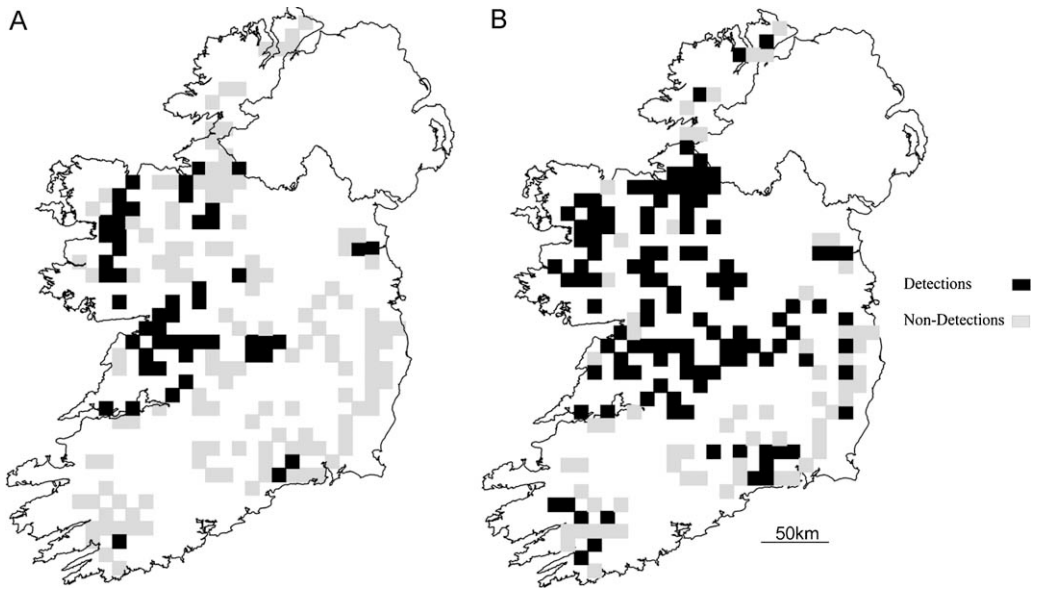

Fig. 2. Distribution of pine marten in 10 km grid squares in the Republic of Ireland during 1978–1980 (O'Sullivan 1983) (a) and from a re-survey in 2005–2006 (b). Total sample size of 10 km national grid squares available for comparison $n = 183$.

Changes in pine marten distribution

The occupancy rate of comparable grid squares in 1978–1980 was 28.4% and in 2005–2006 was 63.9% (Fig. 2), suggesting that a range expansion of pine marten had occurred. Seventy-two 10 km grid squares changed status between surveys with 68 (94%) changing from non-detected to detected status and the remaining 4 (6%) changing from detected to non-detected.

The number of 10 km grid squares where pine marten were detected between surveys had increased by 65, a statistically significant change (McNemar Test: $\chi^2 = 34.3$, df = 1, $P < 0.001$). Changes in occupancy status occurred throughout the Republic of Ireland, but were mainly concentrated in the midlands, southeast, southwest and east (Fig. 2).

Core-range and population abundance

An indicative current core population range for pine marten for each jurisdiction was determined (Table 1). Within this range 135 10 km grid squares were surveyed (approx. survey coverage 35%) and pine marten were detected in 122 (90.4%) and non-detected in 13 (9.6%).

It was estimated that over 50% of the land area of the Republic of Ireland constituted core-range for the species whilst a smaller land area in Northern Ireland (18.3%) was considered pine marten core range (Table 1, Fig. 3). At the island of Ireland scale, 45.9% of the land area was estimated to be core population range for pine marten.

Table 1
Assessment of indicative core population range for pine marten on the island of Ireland.

Jurisdiction	Territorial land area (km^2)	Estimated core range (km^2)	Percentage land-area (%)
Republic of Ireland	69,831	35,975	51.5
Northern Ireland	14,148	2588	18.3
All-Ireland	83,979	38,563	45.9

Using the criteria specified estimated mean pine marten abundance in the Republic of Ireland was 2740 individuals with a population of 320 pine marten estimated for Northern Ireland (Table 2).

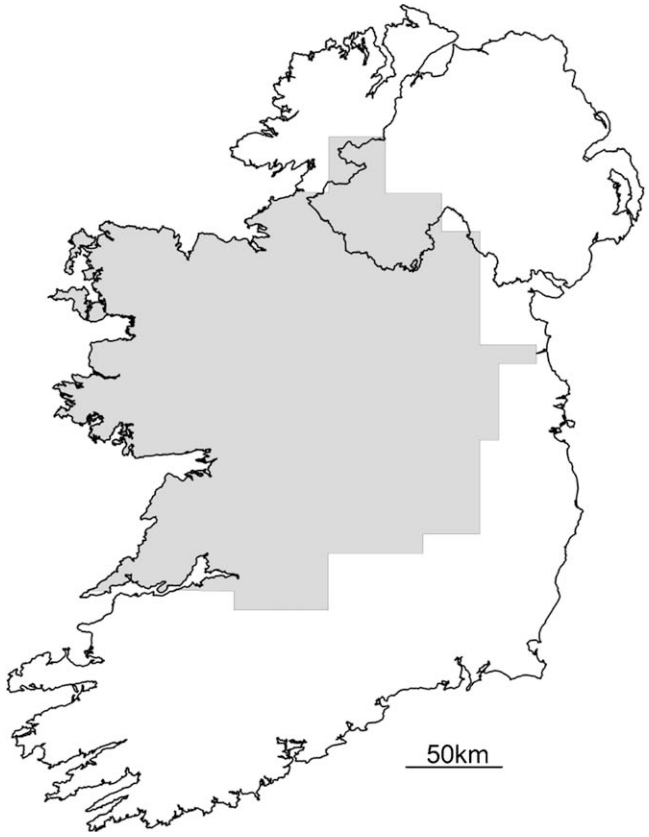

Fig. 3. Estimated pine marten core-population range (90% occupancy) in the Republic of Ireland and Northern Ireland.

Table 2
Estimated population abundance of pine marten at a jurisdictional level on the island of Ireland based on current distribution, occupied habitat and mean territory size. Confidence intervals generated by bootstrapping techniques.

Jurisdiction	Habitat availability (km^2)	Estimated habitat area occupied (km^2)	Abundance estimate	Confidence intervals (90%)
Republic of Ireland	7090	4225	2740	1350–4330
Northern Ireland	880	499	320	160–510

Discussion

Current distribution and change

At the Island of Ireland level, pine marten distribution was concentrated in the west and midlands of the Republic of Ireland, with more fragmented and isolated populations in the southwest, southeast and east. Pine marten were detected in areas where they had been historically absent and their current distribution may represent the most widespread for the species at any point in the last 50 years. However, given that the population had undergone substantial declines in the preceding decades and centuries the importance of this should not be overstated. There remain large regions where the species had historically occurred that contained suitable habitat but pine marten were non-detected. This was particularly the case in the south and southeast of the Republic of Ireland and throughout a large part of Northern Ireland. Therefore, in terms of the historical context, current pine marten distribution remains significantly diminished across the island of Ireland.

In the Republic of Ireland, pine marten range had apparently increased over the last 30 years. This has probably occurred by expansion from refuge areas in the west and other relict populations identified by O'Sullivan (1983). The expansion of population range for *Martes* species have recently been reported in other countries and has been attributed to natural dispersion (Balestrieri et al. 2010), reduced hunting or persecution (Ozolinš and Pilats 1995) and through deliberate re-introductions (Aubry and Lewis 2003).

In the Republic of Ireland there are at least 3 important factors that could have influenced the range expansion found in the current study. Firstly, since the 1980s there has been a large increase in the land area covered by forestry from an estimated 390,000 ha in 1980, to 709,000 ha currently (10% of the country area; DAFF (2008). The increased forest cover provided greater habitat availability and connectivity, which may have assisted in natural range expansion of pine marten.

The second factor that may have contributed to the increase in pine marten distribution in the Republic of Ireland was the legal protection afforded the species under the Wildlife Act (1976). Prior to statutory protection, direct hunting of pine marten for their fur, persecution as a perceived pest species and general predator control programs that utilised poisoned baits and snares contributed to the decline in pine marten distribution (O'Sullivan 1983). Increases in the distribution of pine marten following reduced persecution and/or hunting pressure have been recorded in other parts of their range (Ozolinš and Pilats, 1995).

The third factor that has likely influenced the current distribution of pine marten in the Republic of Ireland is deliberate re-introductions into regions where they were historically present but had become locally extirpated. The best known re-introduction occurred in Killarney National Park (52°02′12N 9°32′04W) during the late 1980s to the mid 1990s when up to 30 individuals were sourced from the west of Ireland and released into the park (P. O'Sullivan, pers. comm.). This release may have accounted for the increased distribution of the species in the southwest of the Republic of Ireland as determined by the current survey. It is uncertain if other re-introductions or deliberate releases of pine marten have occurred or to what extent they may have contributed to range expansion. State conservation agencies do relocate pine marten where they come into conflict with people (e.g. occupy households) but there is little information available on the numbers of individuals involved or the areas from which and to which they are relocated. Potentially this could have been an important mechanism influencing range expansion at a local or regional scale and requires further investigation.

Other possible contributory factors to the range expansion of pine marten in the Republic of Ireland could have included reduced inter-specific competition and intra-guild predation due to changes in the abundance or dynamics of the red fox (*Vulpes vulpes*) the main potential competitor of pine marten in Ireland and even mesopredator release. Data are not available on fox populations or dynamics to this hypothesis. Studies have shown that predation by red foxes has the potential to impact on pine marten populations (Lindström et al. 1995). On the island of Ireland foxes are relatively common and occupy a range of habitats including forestry. Pine marten have had to adapt a highly fragmented forest landscape over recent centuries and the potential impact of species such as red fox is uncertain.

It is important to emphasise that the apparent range expansion of pine martens in the Republic of Ireland has occurred in the absence of any direct or co-ordinated conservation action or intervention for the species. Even though it was known in the 1970s that the population had been substantially reduced and extirpated throughout most of the country, statutory agencies did not act to produce any direct management or policy initiatives to promote the conservation of the species, relying on legal protection only. Afforestation, one of the factors that may have assisted in pine marten range expansion, was enacted primarily for economic and social motives rather than wildlife conservation per se.

In Northern Ireland, there was little or no evidence of any range expansion by pine martens over recent decades. The population remains largely concentrated in western areas where it has been established for decades (Hughes 1993; Fairley 2001). In the remainder of Northern Ireland pine marten are largely extirpated. Where the species does occur, it occurs in fragmented and isolated populations, which are susceptible to stochastic events that may impact on short to medium term population viability (Shaffer 1981). Over the last 30 years legal protection has been afforded pine marten in Northern Ireland (Wildlife Order NI 1986) and there has also been an increase in forest land cover from 6700 ha in 1980 to 8800 ha (6.5% land area) by 2010 (FS 2010). The apparent lack of any or limited range expansion is a cause of concern and suggests that barriers may exist, preventing re-colonisation of former historical range. Potential important factors could include small population size, habitat fragmentation, poor dispersal survival rates and illegal persecution.

Understanding potential barriers to range expansion from western core population range and the extent and viability of fragmented pine marten populations in Northern Ireland is critical to future conservation management of the species. This is particularly urgent given that abundance estimates in the low hundreds

put the population in Northern Ireland a magnitude below that in Scotland (*c.* 3500 individuals) and closer to population status in England and Wales (*c.* 120 individuals) in the wider UK context (Harris et al. 1995). The current absence of a conservation strategy for the species in Northern Ireland needs to be immediately addressed.

Conservation and management

The range expansion of pine marten in the Republic of Ireland is important in terms of species conservation but may increasingly present management dilemmas. Pine marten are highly efficient predators and can impact on other wildlife species, particularly avifauna (Sonerud 1985; Summers et al. 2009; Pöysä et al. 1997; Wegge and Kastdalen 2007). The re-occupation of historic range could bring the species into conflict with management interests of other species. Where this occurs, site specific and integrated management plans should be instigated that explicitly acknowledge that some level of predation is naturally part of a stable predator–prey system, especially where rare, native arboreal predators are concerned. There is also the potential for human–wildlife conflict particularly in relation to game rearing and livestock interests that may lead to increased rates of illegal persecution, which could cause future local extirpations or even range contraction of pine marten.

The largest habitat resource for the species is dynamic, short rotation (e.g. 50–60 years) commercial forestry plantation. There is little understanding of the sustainability of this habitat for pine marten, the impact of forest management practices such as timber harvesting on their ecology or how the population may respond to current and future afforestation policy in both jurisdictions which promotes small-scale private plantations (i.e. extensive habitat fragmentation) as opposed to large-scale forestry development. For a species with a small population size and low reproductive rate that is very susceptible to human interference these factors have the potential to significantly impact on the pine marten population into the future.

Our results may necessitate the re-evaluation of recent jurisdictional conservation assessments for the species that suggest the pine marten is of favourable conservation status and of least concern in terms of red list status, as they were partly based on what appear to be considerable overestimates of population abundance (3000–10,000 individuals, Marnell et al. (2009)), as compared to less than 3000 in the current study. Given the general lack of data on pine marten ecology and the deficient understanding of how important the Irish population may be in the European context a re-assessment appears prudent. The recent finding of a potentially unique "Irish" haplotype with reference to British populations also supports this (Jordan 2011).

In terms of species conservation, statutory agencies in each jurisdiction should develop and implement conservation strategies and management objectives for pine marten. These should ensure the sustainability of any recent range expansion, that possible future expansion is supported and potential conflict scenarios can be identified and mitigated against to limit the potential for increased illegal persecution.

There is also a critical need for studies on the most basic aspects of pine marten ecology, particularly population abundance, socio-spatial ecology, habitat selection, productivity, survival and any impacts of forest management on the species. Regular monitoring and surveillance of pine marten is a fundamental requirement due to international obligations (i.e. Bern Convention and Habitats Directive) and also national commitments in respective jurisdictions with respect to biodiversity conservation but may be limited due to insufficient funding availability.

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