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National pine marten population assessment

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National Pine Marten Population Assessment

Declan T. O'Mahony[1], Ciara Powell[2], John Power[2], Ruth Hanniffy[3], Peter Turner[2] and Catherine O'Reilly[2]

[1]Agri-Food and Biosciences Institute, Newforge Lane, Belfast BT9 5PX, Northern Ireland.

[2]Waterford Institute of Technology, Cork Road, Waterford.

[3]The Vincent Wildlife Trust, Galway, Ireland

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The NPWS Project Officer for this report was: Ferdia Marnell; ferdia.marnell@ahg.gov.ie

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Executive Summary

Pine marten (*Martes martes*) are a protected species in Ireland and have recently undergone a natural range expansion after centuries of decline. Estimates of population abundance and of the conservation status of pine marten are required to meet national and international legislative requirements, and to inform effective management of the species.

In this study, variation in pine marten density and abundance was assessed in 19 forested study sites throughout Ireland, using non-invasive research techniques. Pine marten hair samples were collected and analysed using molecular methods to determine individual identity data for each pine marten captured. Density estimates were obtained using spatially explicit capture recapture models. This data was then used as the basis for determining a mean pine marten density across randomly selected study sites, which was combined with data on the current distribution and estimated habitat area occupied by the species, to provide a national pine marten population abundance assessment.

Across all study sites, a total of 134 individual pine marten were identified in 339 hair samples. In most study sites, the number of individual pine marten detected was low (≤ 10 individuals). Estimated pine marten density varied from 0 to 2.60 individuals per km^2 of forested habitat in randomly selected study sites, with all but a single site having an estimated density of ≤ 1 pine marten per km^2 of forest habitat. There was relatively little variation in density across the majority of random study sites. In preselected study sites, estimated pine marten density varied from 0.57 to 4.29 individuals per km^2. Across all randomly selected study sites, 93 individual pine marten were captured 217 times, and a mean density estimate of 0.64 (95% CI 0.49 - 0.81) pine marten per km^2 of forest habitat was determined. Combining this with data on the current distribution and area of forest habitat occupied by the species in Ireland, the total population abundance of pine marten in Ireland was estimated at 3,043 (95% CI 2,330 – 3,852) individuals.

This research involved the largest scale investigation of pine marten density and abundance in Ireland, and has determined that the species exists at low density throughout the majority of study sites investigated, with relatively little variation in density across these sites. A national population estimate of 3,043 individuals confirms, and reinforces, that pine marten are amongst the rarest of all mammalian species in Ireland and require careful conservation management to sustain the population and to meet international obligations for protection.

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1. Introduction

1.1 Pine marten biology, ecology and legal status

The European pine marten (*Martes martes*), also known as the tree cat (Cat crainn), is the only member of the genus *Martes* that is native to Ireland. Pine marten have a Palearctic distribution stretching from Siberia, Iran, across Europe to its most westerly range in Ireland. Other related species that occur in continental Europe include stone marten (*M. foina*) and sable (*M. zibellina*), the latter occurring mainly in Russia. A hybrid between pine marten and sable known as kidus occurs in the Ural Mountains, at the juncture between the continents of Europe and Asia. Pine marten belong to the family Mustelidae and are related to species such as the badger (*Meles meles*), otter (*Lutra lutra*) and stoat (*Mustela erminea*).

In appearance, pine marten have traits typical of other Mustelid species in that they are medium sized, have an elongate body (up to 50cm), short legs, a loping gait, small rounded ears, a long bushy tail (up to 25cm), and chestnut to dark brown fur. Additional distinctive features of the species include a creamy-yellow chest / throat patch, which can extend down its front legs and be of variable pattern, and a yellow or pale fringe to the ears. Pine marten are considered a forest dwelling species and are adept at tree climbing, aided by their bushy tail and strong claws. Where forest habitat is not available, the species can exist in scrub habitats and increasingly it is being acknowledged that pine marten are becoming more adaptable at exploiting open habitat once suitable forest cover exists nearby.

In terms of general ecology, individual pine marten are solitary (except for mating purposes) and have an intra-sexual system of territorial organisation, which at the population level can be very well structured (Powell 1979). Pine marten territories and home range size can vary from 0.5 - 20km^2, which can be influenced by habitat type, forest cover, gender, food abundance, season, habitat fragmentation and age-class of the individual (Zalewski & Jędrzejewski 2006). Within their home range pine marten will utilise a wide variety of refuge sites such as tree cavities, tree canopy and underground burrows that provide cover and protection when the species is at rest. Pine marten are typically nocturnally active and can travel several kilometers during periods of activity, which can be influenced by local ambient temperature (Zalewski 2000). Breeding in the species typically takes place between June and August after which there is delayed implantation for approximately six months. After a gestation period of thirty days, the young (kittens) are born in March or April in a den site that can be located in tree cavities, roots or rock outcrops and occasionally in attics of barns or houses.

Litters usually range in size from one to three individuals and maturity is reached within twelve months. Pine marten are opportunistic omnivores and have a broad and seasonally varied diet that includes small mammals, microtine rodents, invertebrates, amphibians, small birds, carrion and fruits/berries throughout their range (De Marinis & Messeti 1995). Life expectancy is typically 5-8 years for adult pine marten with substantial rates of annual mortality (i.e. 0.38-0.49: Zalewski & Jędrzejewski 2006). The species has a low reproductive output both in terms of its annual output (i.e. the number of young produced) and the age at which reproductive maturity is reached (Buskirk & Ruggiero 1994).

Pine marten receive full legal protection throughout the island of Ireland under the terms of the Wildlife Acts 1976 to 2012 and Wildlife (Northern Ireland) Order, 1985 (as amended). It is an offence to capture or kill a pine marten, or to destroy or disturb its place(s) of rest. The species also receives International protection on Annex V of the EU Habitats Directive [92/43/EEC] and Appendix III of the Bern Convention 1979. These legislative instruments obliges Ireland to ensure that the pine marten population remains in favourable conservation status and prohibits certain management methods that are capable of causing local disappearance of, or serious disturbance to, a population of the species.

1.2 An overview of pine marten research in Ireland

In general terms there have been few direct research studies that have focused on pine marten in Ireland and this is especially true prior to the onset of the new millennium. Previous to the 1970s, data on pine marten in Ireland largely consisted of incidental records of sightings derived from direct observations, trapping and taxidermist returns, as well as a few anecdotes about the status of the species (Stendall 1946; Stendall 1947; Ruttledge 1948; Deane 1952; King 1952; Rogers 1959; Moriarty 1961). Due to concerns about the conservation status of pine marten in Ireland in the 1970s and a complete lack of knowledge on their distribution and ecology, a national survey was undertaken (O'Sullivan 1983). That study surveyed 428 10km grid squares to detect pine marten using scats, direct sightings or other records. O'Sullivan (1983) determined that pine marten range and distribution had undergone major reductions, that the species was absent from areas and regions where it had been historically present and that the population was concentrated in forested areas of the mid-western region of Ireland. It was suggested that the major reduction in the species range was attributable to the continual loss and fragmentation of established woodland habitat, direct persecution of the pine marten and predator control programs that involved the use of poison baits and traps that were occurring throughout Ireland. Fairley (2001) collated existing information of pine marten distribution in Ireland from 1870 to 1975, which showed an increase in the number of counties reporting no records of pine marten. All of this evidence clearly pointed to the fact that during the 19th and 20th

centuries the pine marten population was undergoing major and sustained declines in distribution and abundance throughout Ireland, caused by human mediated factors.

Sustained research on pine marten in Ireland did not occur until the mid 2000s. A key instrument that addressed many of our knowledge gaps on pine marten was a research project referred to as the National Pine Marten Survey (NPMS) of Ireland, which was instigated in 2005. The NPMS conducted a variety of studies on pine marten, on an island of Ireland basis, to investigate the current distribution, conservation status and ecology of the species (O'Mahony *et al*. 2005; O'Mahony *et al.* 2007a; O'Mahony 2007b; O'Mahony *et al.* 2008(a); O'Mahony *et al.* 2008(b); O'Mahony 2009; O'Mahony *et al.* 2012; O'Mahony 2014). Various studies from the NPMS determined a significant pine marten range expansion had occurred in Ireland over the last 30 years (O'Mahony *et al*. 2012), provided the basis for a species conservation assessment to fulfil reporting requirements of the Habitats Directive (O'Mahony 2007b), produced the first national population abundance estimates for pine marten (O'Mahony *et al*. 2012), and completed the first radio-tracking based spatial ecology and habitat utilisation research on pine marten (O'Mahony 2009; O'Mahony 2014).

Further recent studies on pine marten in Ireland have concentrated on dietary analysis using traditional and molecular methods (Lynch & McCann 2007; O'Meara *et al*. 2014; Sheehy *et al*. 2014), questionnaire based distribution surveys (Carey *et al*. 2007), some parasitological investigations (Stuart *et al*. 2010; Stuart *et al.* 2013), studies that have aimed to determine pine marten abundance in different regions (Lynch *et al*. 2006; Mullins *et al*. 2010; O'Mahony 2014; Sheehy *et al.* 2014*)* and species distribution modelling (O'Mahony 2017).

1.3 Pine marten status and conservation in Ireland

Although the origin of the pine marten population in Ireland is subject to debate, whether it was present prior to the last glacial maximum or was introduced by humans, evidence suggests that pine marten have been in Ireland for thousands of years and are considered a native species. Historically pine marten would have been present throughout Ireland and would have inhabited the natural forests that dominated Ireland up until the 16th century. The species was likely to always have been exploited by humans due to its valuable fur. However, it was not until the 16th century that large-scale commercial exploitation of the species as a fur-bearer started, with evidence of tens of thousands of pelts being exported to England during that time period (Hickey 2012). This, coupled with the destruction of native forests from an estimated 95% cover to 1% at the onset of the 1900s (EPA 2006) could only have had a severe negative impact on pine marten population abundance and distribution throughout Ireland. During the rise of game estates in Ireland, pine marten along with a suite of other predators were persecuted through trapping, poisoning and shooting as 'vermin', and throughout that

period and continuing to this day, to a lesser extent, indiscriminate deployment of poison baits that 'target' species such as foxes and corvids also had an impact on the species.

The cumulative effect of these various ad hoc 'campaigns' against pine marten in Ireland was that by the 20th Century, and probably earlier, the population had become extirpated throughout most of the country, with only a few isolated strongholds where the population persisted (O'Sullivan 1983). Full legal protection was enacted under the Wildlife Acts (1976) and subsequent International legislation including the Bern Convention and Habitats Directive. Since that low point for the population, increasing forest cover, less direct persecution, legal protection, the banning of poisons and potential deliberate releases have provided for a natural range expansion of pine marten (O'Mahony *et al*. 2012), such that the species is now probably more common than any time in the last 100 years. However, it must be emphasised that whilst the pine marten population is recovering in Ireland, the species remains one of our rarest terrestrial mammals with a population estimate of *ca*. 2,700 breeding individuals (O'Mahony *et al*. 2012). The recent conservation assessment of the species deemed pine marten to be of favorable status in Ireland (NPWS 2013). However, the re-occupation of the species former historic range and increasing abundance is likely to bring the species into increasing conflict with human interests (O'Mahony *et al*. 2012). If this is not managed properly, through research, education and adequate mitigation measures, increased rates of illegal persecution are likely to occur, which could cause future local population extirpations or even range contraction of pine marten in Ireland (O'Mahony *et al*. 2012). Indeed recent adverse media attention and calls for control attest to the requirement for urgent action in terms of education, mitigation and research to ensure the viability of this species in the long-term in Ireland.

1.4 Aims of current study

The scientific base of our knowledge on pine marten in Ireland is currently not adequate to address key issues that face the population into the future. In this study, pine marten population density estimates were investigated in multiple study sites located across Ireland. This data provided the basis for estimation of the national population abundance of pine marten in Ireland. This study also conducted an assessment of the current conservation status of pine marten in Ireland, which will help inform Article 17 requirements for this species under the Habitats Directive. Recommendations for the future monitoring of this species are also provided

2. Methods

2.1 Background to use survey methods

Hair tubes were first developed for martens in Canada (Foran *et al.* 1997) and by the Vincent Wildlife Trust in the UK (Messenger & Birks 2000), with the former using sticky patches and the latter springs to collect hair. The spring type traps were used in Co. Kerry (Lynch *et al.* 2006). In 2006, a novel hair trap using lightweight PVC tubing and efficient sticky patches was developed (Mullins *et al.* 2010). These were applied in trial surveys in Co. Mayo and Co. Galway and in a long term survey in Co. Waterford. In the most recent surveys, the samples obtained were used for population estimation by microsatellite analysis of DNA extracted from the hair samples (Mullins *et al.* 2010; O'Mahony *et al.* 2015). In all these surveys a similar pattern was observed, a low early success rate and a progressive increase in the number of samples obtained in subsequent trap sessions. In most surveys the success rate increased to over 50% of the tubes yielding samples. In all cases pine marten were detected. These surveys are summarised below (Table 1).

Table 1. Summary of previous hair tube surveys in Ireland.

Site	Year	Type	Tube number	Genotype	Reference
Sheskin, Co. Mayo	2006	Sticky	10	No	Unpublished
Cloosh, Co. Galway	2006	Sticky	10	No	Unpublished
Killarney National Park, Co. Kerry	2006	Spring	50	No	Lynch *et al*. (2006)
Portlaw, Co. Waterford.	2006-16	Sticky	20-25	Yes	Mullins *et al.* (2010)
Mourne, Co. Down	2011	Sticky	126	Yes	O'Mahony *et al*. (2015)
Corbally, Co. Kilkenny	2014	Sticky	12	Yes	Power (2016)
Kilsheelan, Co. Waterford	2015	Sticky	10	Yes	Unpublished
Crom, Co. Fermanagh	2014	Sticky	40	Yes	O'Mahony unpubl
Castleward, Co. Down	2014	Sticky	15	Yes	O'Mahony unpubl
Midlands, Ireland	2014	Spring	28	Yes	Sheehy *et al*. 2014

2.2 Study site selection

A random sampling design was used to sample the pine marten population in Ireland throughout the species known current range. This involved selecting the majority of study sites randomly (n = 14), and surveying a number of additional preselected study sites (n = 5). It may be better described as a

random-hybrid sampling design as most of the sites were randomly selected and a reduced number of sites were selected *a priori*. The term study site in this report refers to the individual 19 x 10km grid squares (Fig 1), within which surveys of suitable habitat formed the basis of density estimation for pine marten. As the target species is considered to require woodland habitat for population persistence, only areas of forest that occurred within the current distribution of pine marten were surveyed. Individual study sites were chosen using pine marten distribution data from O'Mahony *et al*. (2012) and records from the National Biodiversity Data Centre (www.biodiversityireland.ie). Combining this distribution data with various forestry and landuse GIS layers for Ireland (i.e. Forestry 12 and Coillte forest maps) in ArcMap 10.3 (ESRI systems), 14 x 10km grid squares were randomly selected that contained at least 200ha of woodland habitat within known pine marten distributional range. Where an initial randomly selected 10km grid square was not possible to survey (n = 2) for reasons related to the unavailability of landowner permission and site access, a random selection of an adjacent 10km that had at least 200ha of woodland habitat was undertaken. In addition to the randomly selected grid squares, project funders (NPWS) had identified 3 specific sites that were required to be surveyed for pine marten density (Ballycroy, Killarney and Wicklow National Parks). A further 2 pre-selected sites (Cong Forest and Dromore Wood Nature Reserve) were surveyed on the basis of having long-established pine marten populations in some of the last, most pristine remnants of semi-natural native woodland in Ireland, and were sites of potentially high suitability for pine marten.

Each study site was assessed and its total forest cover determined using GIS datasets in ArcMap 10.3. The majority of the forests surveyed in the current study were owned by Coillte (www.coillte.ie), who provided permission to access all of their forest estate. Attempts were also made to obtain similar permission from local private forest landowners and where this was available such sites were surveyed. Coillte are the largest single owner of forestry in Ireland, with over 445,000 hectares of land. Due to logistical constraints including the requirement to complete all of the surveys within a relatively short sampling timeframe (i.e. 5 months), the maximum number of hair tubes that could be surveyed at any one site was 30 tubes. We aimed to have an approximate tube density of 3 hair tubes per 100ha, a similar tube density to other studies that have used this methodology (O'Mahony *et al*. 2015). In each individual study site that had less than 1,000ha of forest cover, all accessible habitat was surveyed. Where more than 1,000ha of forest occurred in an individual study site, then a sub-sampling approach was adopted wherein each separate block or unit of forest was provided with a unique identity, and forest blocks that were surveyed were randomly selected so that the approximately 30 tubes or an equivalent habitat area of approximately 1,000ha was surveyed.

Once forests that were to be surveyed were identified in each study site then experienced field surveyors were provided with GPS positions of potential hair tube deployment locations. Field surveyors then deployed tubes in study sites either at, or close to, the hair tube grid provided and these individual surveyors made field-based decisions on tube locations based on site specific data such as forest management considerations, recent felling and unsuitable or inaccessible habitat. All study sites, apart from the 3 preselected National Park sites, were surveyed by trained field surveyors employed as part of the project. Project field surveyors trained NPWS staff at each National Park site and provided those staff with all necessary equipment to complete their surveys. All study sites were surveyed between January and June 2016.

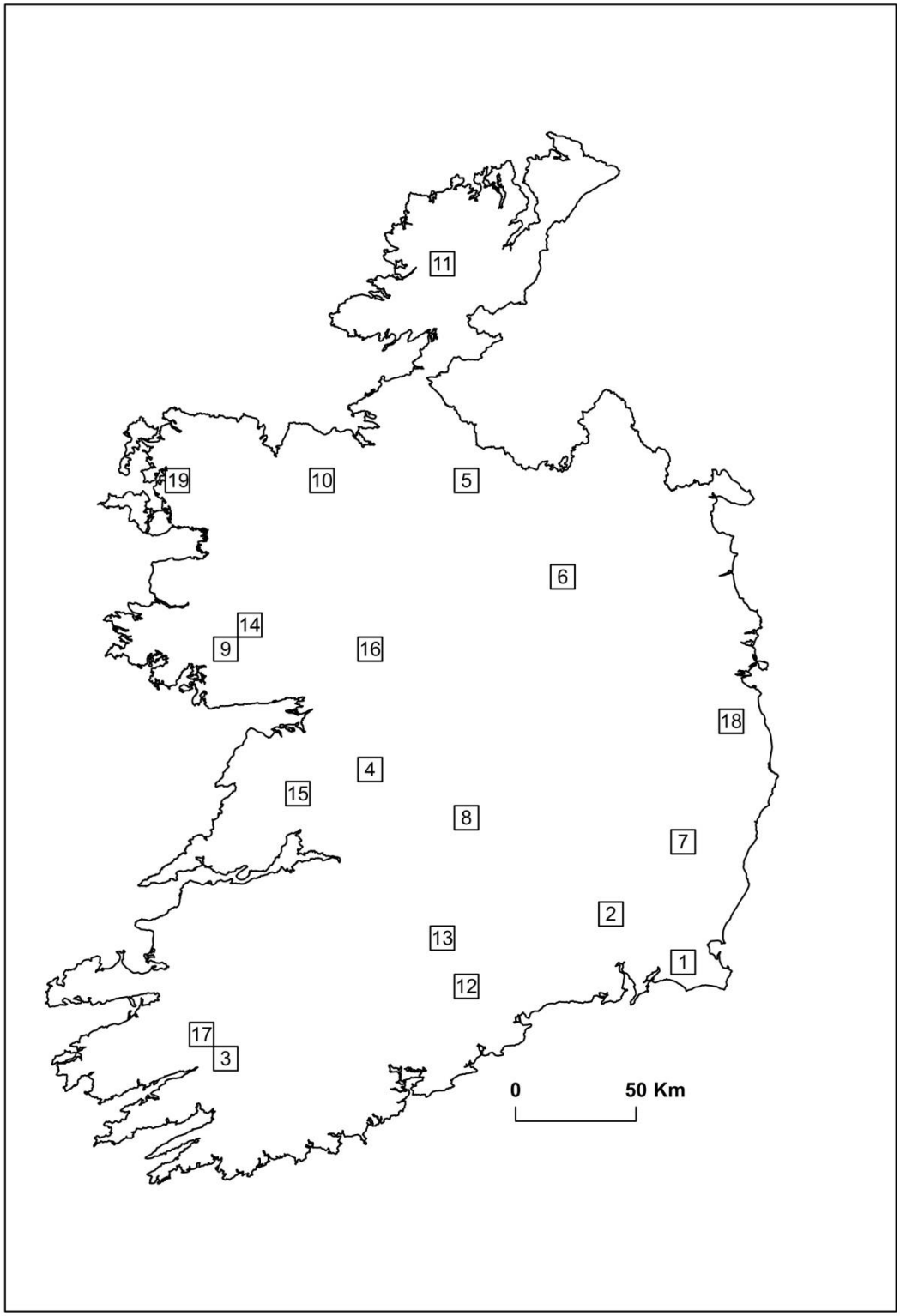

Figure 1. Location of 19 study sites surveyed to estimate pine marten density in Ireland during 2016. Randomly selected study sites are 1-13 and 16; preselected study sites are 14, 15, 17-19.

2.3 Sample collection and genetic analyses

2.3.1 Hair capture

Hair samples were collected by means of hair traps developed at Waterford Institute of Technology (WIT; Mullins *et al*. 2010). These consisted of plastic tubes (250x118mm) fixed vertically to trees and closed at the top. Tubes were baited with raw chicken tightly wired in the top of the tube. Hair was captured as the pine marten pressed against sticky patches at the tube entrance in order to remove the bait. Sticky patches were made from 1.5x2.5x0.3cm squares of hollow plastic board wrapped in double sided tape. Hair capture was on 1cm x 1cm squares cut from mouse glue trap. As the use of such glue traps is illegal in Ireland these were cut into squares before import in order to prevent their use as mouse traps. Tubes were fixed to trees using galvanised wire which allowed adjustment to compensate for tree growth as necessary.

2.3.2 Sample collection

Each study site was surveyed for approximately one month. During the first week in any study site, field surveyors deployed hair tubes and recorded locations with a Garmin 62 handheld GPS unit. At 5-7 day intervals, field surveyors re-visited each tube in each study site and ascertained whether or not hair samples were present. If hair samples were present then the sticky patches were removed from the tube and placed in a labeled sample tube for storage at -20°C. New sticky patches were then placed in the hair tube. If tubes had not been visited, the bait was replaced but clean sticky patches were left in situ. In total, each tube in each study site was visited on three sampling occasions, with tubes removed during the last sampling session. Tubes that were removed were cleaned and reused in other study sites.

2.3.3 DNA Extraction

Hair samples (ideally 10 hairs or more) were recovered from sticky patches using 1-2 drops of xylene to soften the glue and hairs were transferred to 1.5ml microfuge tubes using forceps. Forceps were heated to red heat and cooled between samples to prevent cross contamination. Hair was digested in 1.5ml microfuge tubes containing 90µl HPLC grade water; 90µl 2x digestion buffer (ZR Genomic DNA II Kit™ (ZYMO Research, CA, USA)); 10µl 20mg/ml Proteinase and 10µl 1M-dithiotreitol (Sigma-Aldritch). Digestion was at 56°C for 1-3h using a shaking heating block. DNA was purified using ZR

Genomic DNA II Kit™ (ZYMO Research, CA, USA) according to appropriate manufacturer's method. Final eluates were stored at -20°C.

2.3.4 Genetic analysis

Real-time quantitative PCR (qPCR) assays for species and sex identification were carried out as described in Mullins *et al.* (2010). Two PCR replicates were carried out for molecular sexing (Lynch *et al*. 2006). Females were identified through the amplification of ZFX only, while a signal from both ZFX and ZFY probes indicated male DNA was amplified. The ZFX allele therefore acted as an internal amplification control for the assay.

Microsatellite analysis to identify individual pine marten was carried out using six microsatellite markers. These were: Gg7; Ma2; Mel1; Mvi1341, (Mullins *et al.* 2010) and Mar21 and Mar43 (Natali *et al*. 2010). Each sample was analysed in triplicate and only samples giving identical results in the replicates were scored. Genotype data were analysed for probability of identity (PI and PI*sibs*), observed (H_o) and expected (H_e) heterozygosity and allele frequencies using GENALEX version 6 (Peakall & Smouse 2006).

2.4 Density and abundance estimation modelling at regional and the national scale

2.4.1 Background to density and abundance estimation

We used a study design and statistical analysis framework in the current study that was similar to that of O'Mahony *et al*. (2015), a study which conducted the hitherto largest scale population density research on Irish pine marten. The methods were also consistent with density and abundance studies for related species such as American marten *M. americana* (Mowat & Paetkau 2002) and wolverine *Gulo gulo* (Royle *et al*. 2011) in terms of design and analyses. Non-invasively collected hair samples combined with capture-mark-recapture analysis techniques provided the basis for density estimation in the current study, with collected hair samples being species typed, sexed and genotyped using molecular techniques. For each study site, this data provided the unique individual identity data and capture histories for each individual that could be used in capture recapture statistical approaches.

Following O'Mahony *et al*. (2015), spatially explicit capture recapture (secr), also referred to as spatial capture recapture (scr), analyses were used to determine study site specific, and national population density and abundance of pine marten in Ireland. Spatially explicit capture recapture modeling is a recent advancement on traditional forms of capture recapture analyses in that the technique includes

spatial information on an individual's capture and home range activity centers inferred from provided spatial data, to model population density, overcoming issues associated with non-spatial estimation techniques such as edge effects (Efford 2004a; Efford *et al*. 2004b; Royle *et al*. 2009; Borchers & Fewster 2016). Spatially explicit capture recapture techniques are increasingly being used in density estimation studies of species of conservation and management concern throughout the world (Karanth 1995; Royle *et al*. 2011; Gray & Prum 2012; Head *et al*. 2013; Rouco *et al*. 2013; Anile *et al*. 2014; Borchers *et al*. 2014; Stetz *et al*. 2014; Dumond *et al*. 2015; Morin *et al*. 2016; Sirén *et al*. 2016).

Spatially explicit capture recapture models are primarily used where populations are closed and can estimate density and abundance, whereas non-spatial capture recapture can only determine abundance, which then needs to be divided by an estimated effective sampling area to obtain density estimates for a population of interest, which can lead to biased estimates (Efford 2004a). Spatially explicit capture recapture uses inverse prediction (Efford *et al*. 2004b), maximum likelihood (Borchers and Efford 2008) or Bayesian based estimation methods (Royle *et al*. 2009) to estimate three main parameters: the magnitude of individual capture probability (g0), the spatial scale (σ) over which capture probability declines, and population density (D) (Efford 2004a). Ancillary information provided in secr analyses include configuration of detectors or traps (i.e. hair tubes), the type of spatial point process (i.e. Poisson), models of detection events, habitat mask(s) and the s hape of the spatial detection function (Efford *et al*. 2004b). Spatially explicit capture recapture models can account for biologically relevant forms of heterogeneity in capture probabilities and home range size, avoids assumptions of geographic closure, variance in density is estimated directly from fitted spatial models and reflects all forms of uncertainty and process variation included in the model (Obbard *et al*. 2010). Spatially explicit capture recapture based analyses can also produce more reliable estimates for populations with small sample size of individuals, as compared to more traditional non-spatial capture recapture, particularly when relatively simple models are implemented (Borchers & Efford 2008; Royle *et al*. 2009; Sollman *et al*. 2011). Current knowledge of pine marten densities in Ireland suggests that populations largely consist of relatively small numbers of individuals (Lynch *et al*. 2006; O'Mahony 2014; Sheehy *et al*. 2014, O'Mahony *et al*. 2015) in any single location. The program CAPWIRE (Miller *et al.* 2005) was used for population abundance estimation, this was designed for studies such as this, where individuals are not held but are released after sampling, i.e. recapture is allowed within sessions.

2.4.2 Assumptions of density estimation

Spatially explicit capture recapture analysis, like all statistical models, has several underlying assumptions including: the population is closed; animals are captured with certainty and captures do not affect movement patterns of the animal within a trapping session; hair tubes are located at known locations for a fixed time period; animal tags are not lost and animal capture location(s) are recorded

accurately; hair tube placement is random with respect to the range of an animal, which are orientated randomly; animal home ranges are circular, do not change during a trapping session and follow a Poisson distribution within the sampled area; and that detection occurs independently for each animal (Efford *et al*. 2004b)

In the current study, each study site had 3 sampling occasions that lasted 1 week each (i.e. 3 weeks sampling in each study site), which was a very short sampling period and consistent with population closure at the study site level. By using non-invasive genetics techniques it was ensured that animals were captured with certainty and tags could obviously not be lost. Utilising hair tubes as a trap type did not interfere with animal movement patterns during sampling sessions as animals were not restrained. Hair tube locations were permanently marked with GPS, were placed systematically through the surveyed area and therefore could be considered random with respect to animal ranges. Pine marten home ranges are generally stable over the medium-long term, and certainly over the duration of the sampling occasions in this study (i.e. 3 weeks). Although pine marten home ranges are generally not circular (O'Mahony 2014), violation of this assumption may only effect variance in D and not density estimates directly (Efford *et al*. 2004b; Obbard *et al*. 2010). Pine marten exhibit mutual avoidance of individuals with overlapping home ranges, rather than spacing themselves evenly, therefore, randomly distributed home range centre locations may be a reasonable approximation in the current study (see Obbard *et al*. 2010). Pine marten biology and ecology, combined with the survey design deployed in this study maximised likely fulfilment of key assumptions of secr, and it is suggested that potential violation of assumptions on home range may not have severely biased secr based density estimates in any case (Obbard *et al*. 2010).

2.4.3 Pine marten density estimates in individual study sites

Using the genotyped data for each individual pine marten detected in each specific study site, capture histories were created for each sampling occasion (n = 3 per study site). For secr analysis, the detector type chosen was 'proximity' to allow for multiple individuals to be captured at the same location; a Poisson distribution of home range centers was specified; and probability density functions were modeled using half-normal processes. Half normal spatial capture probability functions are commonly used in secr analyses (Dumond *et al*. 2015) and assume that the probability of pine marten capture increases linearly with proximity of a hair tube to the home range of an individual, which is biologically reasonable. As the sample size of the number of individual pine marten and associated capture rates were generally low for each site (Table 2), it was advisable that relatively simple models of detection and spatial processes would be the most biologically meaningful (Royle *et al*. 2009; O'Brien & Kinnaird 2011).

As it is known that pine marten ecology, behaviour and spacing patterns can vary between males and females (Zalewski & Jedrzejewski 2006; O'Mahony 2014), and that these ecological differences may have affected capture probabilities and spatial scales within the current study, it was important to account for this when estimating pine marten density. A hybrid mixture model was implemented in secr (Efford 2016) to account for variation in capture probability and spatial scale by sex in the current study. The hybrid mixture model uses the hcov command in package *secr* and refers to a flexible combination of latent classes (as in a finite mixture) and known classes (cf groups or sessions) (Efford 2016). In addition to models that accounted for sex, models that specified a behavioural response to capture *b*, whether an animal had been previously detected at a specific site *bk*, and sampling time occasion effect models *t* were also implemented in effecting capture probability (g0). A null model, where detection and movement parameters were assumed to be equal amongst individuals and sexes was also specified. Overall model selection was based on the lowest Akaike Information Criterion value, corrected for small samples sizes (AICc). Where candidate models were closely related to each other, model averaging was undertaken.

A habitat mask that incorporated a map of surveyed forests, tube locations and a specific buffer zone around this surveyed habitat is an important concept in secr based analyses (Efford *et al*. 2004b). The buffer distance should be sufficiently large to ensure that all animals with a negligible probability of encounter are included (Royle & Converse 2014). The size of the buffer distance is a function of the movement parameters of the species of interest and should generally be 3 times sigma (home range size) to minimise bias in density estimation (Efford *et al*. 2004b). In this study a buffer zone distance of 2,000m was specified on the basis of that being approximately 4 home range centers in size for pine marten in Ireland (O'Mahony 2014). This distance is within the range of pine marten daily activity movement in Ireland (O'Mahony unpubl) and accounted for potential movement of individuals in the buffer area around the study sites. A habitat mask was created in ArcMap 10.3, which included the forest area within which hair tubes were deployed, and a 2,000m buffer around that surveyed area that only contained suitable habitat for pine marten (i.e. forests). Density was expressed as number of pine marten per km^2 of forest habitat. All density estimation was undertaken using package *secr* (Efford 2016) in R version 3.3.1 (R Core Development Team 2016), with some preliminary data exploration in Density 5.0 (Efford *et al*. 2004b). In secr analyses, data were simultaneously modeled with each candidate model. The most parsimonious model was then fitted to each individual study sites unique capture data, trap and habitat mask area configurations to derive site specific density estimates. The 14 randomly selected study site dataset and preselected 5 study sites dataset were analysed using the exact same means as described above, but using separate coding in package *secr*. Site specific and across site abundance estimates were obtained using CAPWIRE (Miller *et al*. 2005).

2.4.4 National density and population of pine marten in Ireland

To estimate a national mean density for pine marten across sampling sites, all capture recapture data from each sampling occasion across the 14 randomly selected study sites were pooled into a single database. The habitat area and tube locations from site 7, where no pine marten were detected in this study and density was assumed to be zero, were included in analyses. A pooled habitat mask was created in ArcMap 10.3 that included all the combined habitat area surveyed in each individual site and this was buffered by 2,000m (see section 2.4). The best performing secr model (see section 2.4.3) was then applied to the pooled dataset. CAPWIRE was also applied to the 14 randomly selected sites to obtain an overall abundance estimate for these study sites.

This mean pine marten population density was scaled to a national pine marten population abundance estimate for Ireland by incorporating data from the current distribution of pine marten in Ireland (see Fig. 2) and quantifying all of the available forest habitat within that distribution, as determined from various GIS datasets (see section 2.2). This approach is frequently used when data on regional or national population abundance estimates are required for species of interest (Erb & Sampson 2009; Frary *et al*. 2011; O'Mahony *et al*. 2012; Fechter & Storch, 2014; Humm *et al*. 2015; Gervasi *et al*. 2016). It obviously has underlying assumptions that include current knowledge on pine marten distribution is correct, study sites are randomly selected, all available habitat in the species distribution is occupied by pine marten, GIS layers are accurate and habitat suitability is accounted for. As pine marten are a relative habitat specialist and are dependent on forested habitat, the basis for scaling up density estimates in terms of the availability of suitable habitat in the current study is well founded.

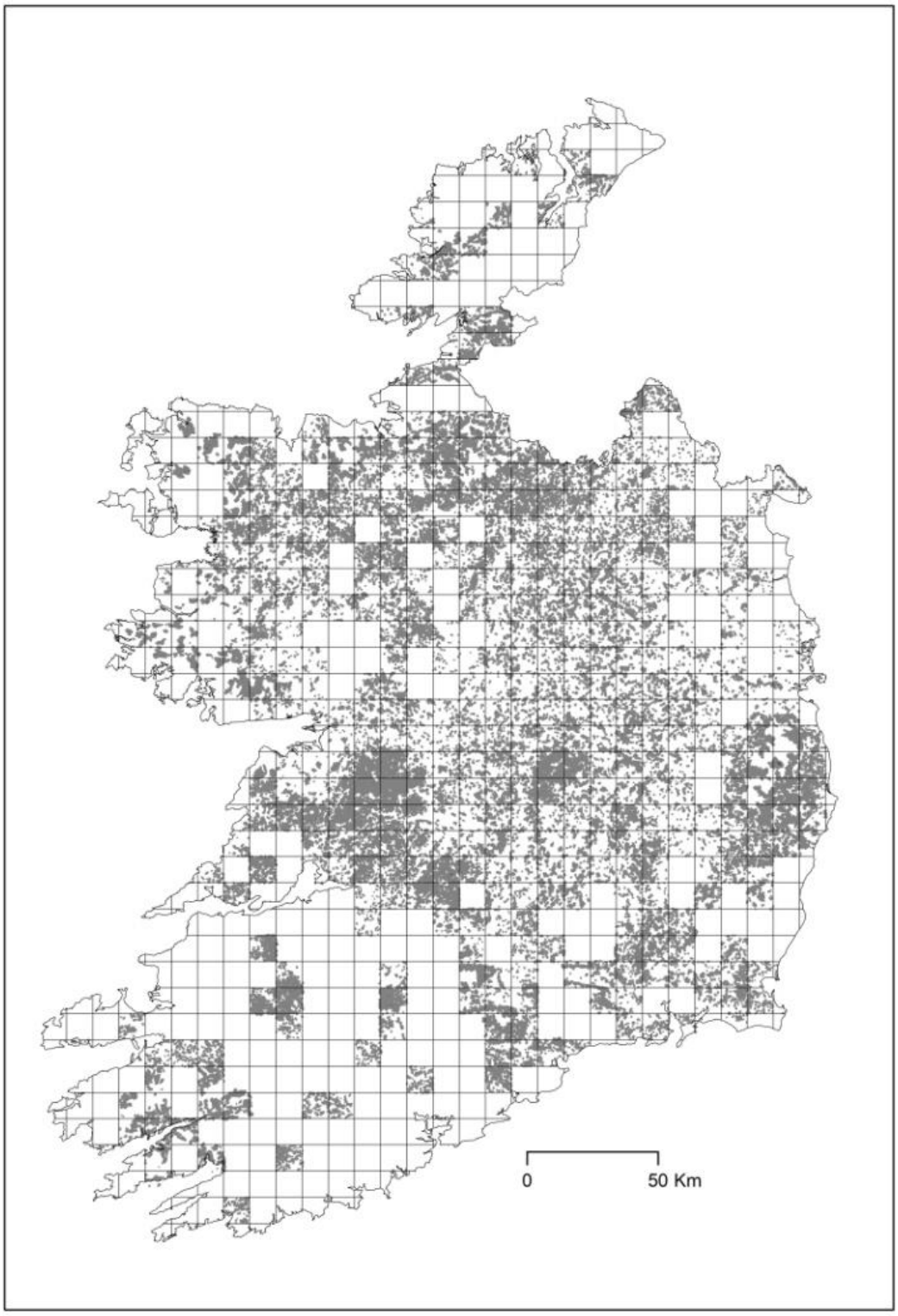

Figure 2. The distribution of forestry within the current pine marten range in Ireland as represented at the 10km square level. Pine marten distribution data provided by the National Biodiversity Data Centre from records of pine marten between 2010 and 2015.

3. Results

3.1 Overview of data presented in the study

In the current study we present the full dataset that included all tubes and study sites surveyed in the current project (Table 2). This data included study sites for which no pine marten were detected (site 7), and hence, density was treated as zero, and site 18, which for data specific reasons could not be included in analyses. Within the data there are effectively 2 datasets, one for the 14 randomly selected study sites (1-13 and 16; see Fig. 1) and one for 5 preselected sites (14, 15-17-19; see Fig. 1; see section 2.2). Density and abundance estimates were derived for all of the 14 random sites, and to determine a mean density across these random study sites, as a basis for national population assessment. Even though surveys in site 7 did not detect pine marten, the habitat area of this site was included in mean density estimation across sites (see section 2.4.4). The preselected data, which included site 18, was targeted at specific sites in the country for *a priori* reasons (see section 2.2) and, apart from site 18, pine marten density and abundance was estimated to assess the magnitude of pine marten density in these sites that included habitat considered to be highly suitable.

3.2 Hair tube surveys

A total of 339 hair samples were collected from 537 hair tubes deployed throughout the 19 study sites (Table 2). The number of hair samples collected per study site varied from 0 to 40. DNA analysis verified that 97% of the hair samples were pine marten and 89% of those yielded genotypes with the six microsatellite loci. All loci were polymorphic with 3-4 alleles per locus. The probability of identity (PI) using all six loci was PI = 0.00042 and PI*sibs* = 0.024. No deviation from Hardy-Weinberg equilibrium was observed.

In total, 134 unique individual pine marten were determined across all study sites, 71 male and 60 female (3 were undetermined), and 0 to 19 individuals were detected per study site. Across the 19 study sites, 37.6% of hair tubes yielded pine marten hair samples (212/537), ranging from 0% to 90% of tubes per study site (Table 2). The total return on tubes was 63% (339 hair samples from 537 tubes). Across sampling sessions the number of unique individual pine marten captured did not significantly differ between sessions $\chi^2 = 1.78$, $df = 2$, $P > 0.40$ (session 1 = 37, session 2 = 46, session 3 = 48), and the levels of animal recaptures increased as sampling sessions progressed (session 1 = 37, session 2 = 68, session 3 = 95). Across all study sites and sampling sessions, on average, individual pine marten had a recapture rate of 2.20 (SE 0.16; range 1-11), with 52.95% of individuals detected once, and 47.05% of pine marten captured more than once (Fig. 3). Few individual pine marten were captured 5 or more

times within the study (Fig. 3). In a similar pattern as observed with pine marten captures rates, on average, pine marten were captured in 1.58 unique hair tubes (SE 0.08; range 1-5), which does not include re-use of the same tube.

Table 2. Summary of pine marten capture data for each study site. Hair samples were defined as pine marten by DNA analysis and as individuals by unique genotypes at the initial six microsatellite loci. Recapture rate is the mean for each sample set. Na, not applicable. "All" represents data pooled for all sites and "Random" shows data pooled from the 14 randomly selected sites (*).

Site Code	Number of Tubes	Hair Samples		Pine marten Hair		Sex Type		Genotyped Samples		Unique Genotypes	
		n	return	n	% of hair	n	%male	n	% marten	n	recapture rate
1*	24	11	0.46	11	100%	10	40%	10	91%	6	1.67
2*	30	34	1.13	34	100%	32	56%	27	79%	9	3.00
3*	29	23	0.79	19	83%	17	82%	18	95%	8	2.25
4*	30	21	0.70	21	100%	20	55%	20	95%	10	2.00
5*	30	16	0.53	16	100%	16	81%	16	100%	5	3.20
6*	23	11	0.48	11	100%	11	45%	11	100%	6	1.83
7*	30	0	0.00	0	na	na	na	0	na	0	na
8*	31	20	0.65	20	100%	20	85%	20	100%	11	1.82
9*	30	16	0.53	16	100%	16	63%	15	94%	6	2.50
10*	30	25	0.83	25	100%	23	70%	22	88%	8	2.75
11*	25	2	0.08	2	100%	2	100%	2	100%	1	2.00
12*	26	4	0.15	3	75%	2	100%	2	67%	2	1.00
13*	30	26	0.87	24	92%	18	67%	16	67%	7	2.29
14	30	40	1.33	39	98%	38	55%	31	79%	19	1.63
15	30	21	0.70	21	100%	21	81%	21	100%	8	2.63
16*	22	38	1.73	38	100%	38	37%	38	100%	14	2.71
17	27	12	0.44	11	92%	11	18%	11	100%	7	1.57
18	30	6	0.20	4	67%	4	50%	4	100%	3	1.33
19	30	13	0.43	13	100%	9	89%	9	69%	4	2.25
All	537	339	63%	329	97%	309	60%	293	89%	134	2.20
Random	390	247	63%	240	97%	225	60%	217	90%	93	2.30

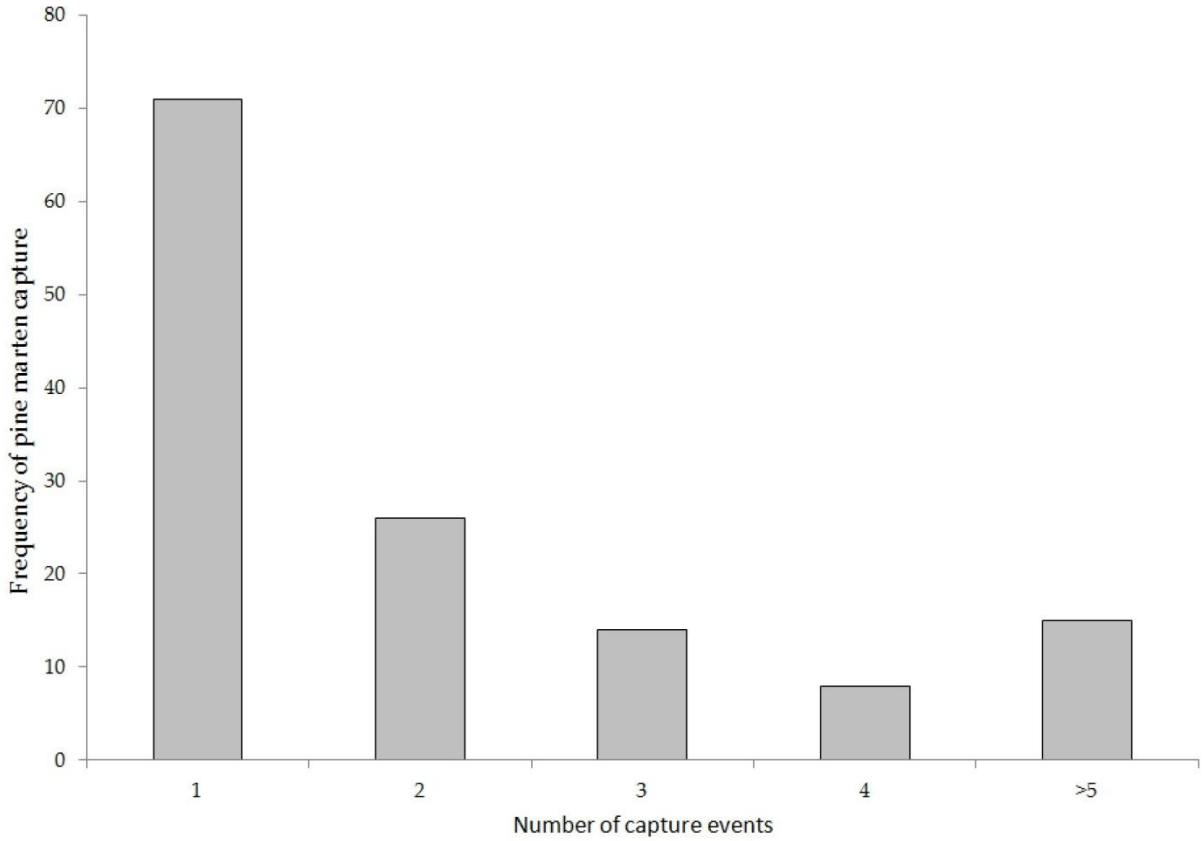

Figure 3. Capture frequencies of individual pine marten across all study sites.

3.3 Study site variation in estimated pine marten density and abundance

Density and abundance estimates were obtained for 18 out of the 19 study sites across Ireland. Based on secr analyses the best performing models were hybrid mixture models that included sex and site specific detection effects on pine marten capture probability and sex effects on spatial scale for both the random, and preselected study sites data (Table 3). The estimated habitat mask area including all forested habitat within a 2,000m buffer of all surveyed sites was 36,041ha (Table 4). Estimated pine marten density varied from 0 to 2.60 pine marten per km^2 of forested habitat in random sites (Table 4; Fig. 4). In all but a single random site, pine marten density estimates were below 1 individual per km^2 of forest habitat. Confidence intervals associated with density estimates from random study sites overlapped for most of the study sites (Fig. 4), with the exception of study site 16, which was significantly greater than other sites. In preselected study sites, estimated pine marten density varied from 0.57 to 4.29 pine marten per km^2 of forest (Table 4, Fig. 5). Abundance estimates of pine marten for each study site, based on using CAPWIRE, are shown in Table 5. For CAPWIRE abundance analyses, the TIRM model was implemented on combined capture data across each sampling session, in each study site. Estimates of pine marten abundance ranged from 6-39 individual pine marten across all study sites (Table 5).

Table 3. Akaike information criterion (AIC) model selection for spatially explicit capture recapture analyses of pine marten density. Model specified capture probability at home range center (g0), and spatial scale (σ), modelled with variation in sex (h2), individual behaviour response to capture (b), whether an animal had been previously detected at a specific site (bk), sampling time occasion effect models (t), and null model (1). Number of parameters (npar), log-likelihood (LogL), AICc is AIC with a correction for finite sample sizes.

Data	Model	npar	LogL	AIC	AICc
Random Sites	g0~bk + h2, σ ~ h2	7	-732.18	1478.36	1479.68
	g0~b + h2, σ ~ h2	7	-768.47	1550.94	1552.26
	g0~t + h2, σ ~ h2	8	-769.34	1554.67	1556.39
	g0~ h2, σ ~ h2	6	-796.61	1605.23	1606.20
	g0~1, σ ~ 1	4	-802.35	1612.69	1613.15
Preselected sites	g0~bk + h2, σ ~ h2	7	-250.21	514.42	518.28
	g0~t + h2, σ ~ h2	8	-263.20	542.41	547.55
	g0~b + h2, σ ~ h2	7	-266.77	547.53	551.39
	g0~ h2, σ ~ h2	6	-272.22	556.43	559.23
	g0~1, σ ~ 1	4	-281.45	570.90	572.15

Table 4. Pine marten density estimates for each study site using secr based analysis of pine marten capture data across 19 study sites in Ireland. No density estimates could be derived for site 18 (see section 3.1). Density estimates were derived using hybrid mixture models in spatially explicit capture recapture analyses. Estimated habitat mask area refers to the surveyed area within which hair tubes were located in each study site, including a 2,000m buffer of suitable habitat. Randomly selected sites are 1-13 and 16; preselected study sites are 14-15 and 17-19. SE is standard error; LCL is lower 95% confidence interval and UCL is upper 95% confidence interval.

Site	Estimated Habitat Mask (ha)	Density	SE	95% LCL	95%UCL
1	1,462	0.75	0.21	0.44	1.29
2	1,908	0.97	0.24	0.60	1.56
3	2,607	0.60	0.15	0.37	0.99
4	4,269	0.52	0.13	0.32	0.83
5	2,399	0.46	0.15	0.24	0.86
6	1,435	0.89	0.27	0.50	1.59
7	1,652	0.00	-	-	-
8	1,792	0.93	0.17	0.64	1.32
9	1,832	0.54	0.14	0.32	0.88
10	2,218	0.72	0.18	0.44	1.16
11	2,099	0.12	0.09	0.03	0.45
12	2,108	0.25	0.14	0.09	0.68
13	3,211	0.50	0.15	0.28	0.87
14	1,141	4.29	1.72	2.01	9.17
15	1,849	2.12	1.06	0.83	5.37
16	1,031	2.60	0.56	1.71	3.95
17	1,564	2.51	1.43	0.88	7.11
18					
19	1,464	0.57	0.28	0.22	1.44
Total	36,041				

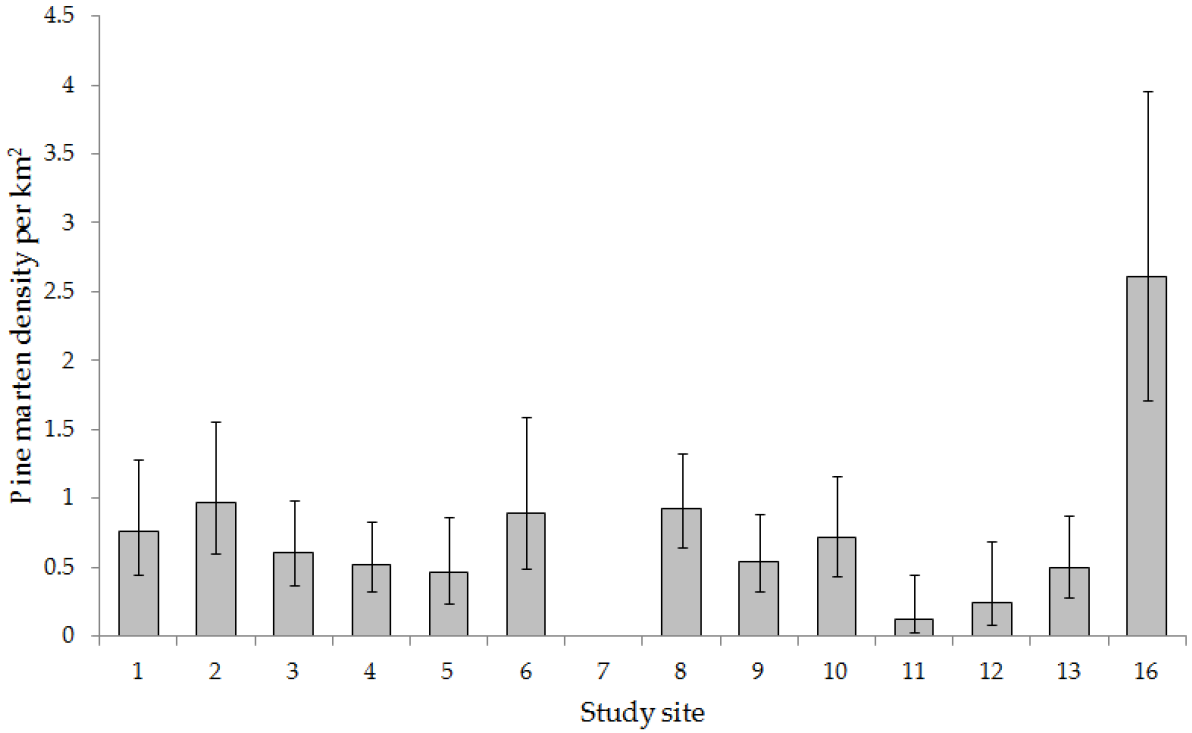

Figure 4. Variation in pine marten density across random study sites in Ireland. 95% CI for each site are indicated by error bars. Densities were estimated with the most parsimonious hybrid mixture models using spatially explicit capture recapture models.

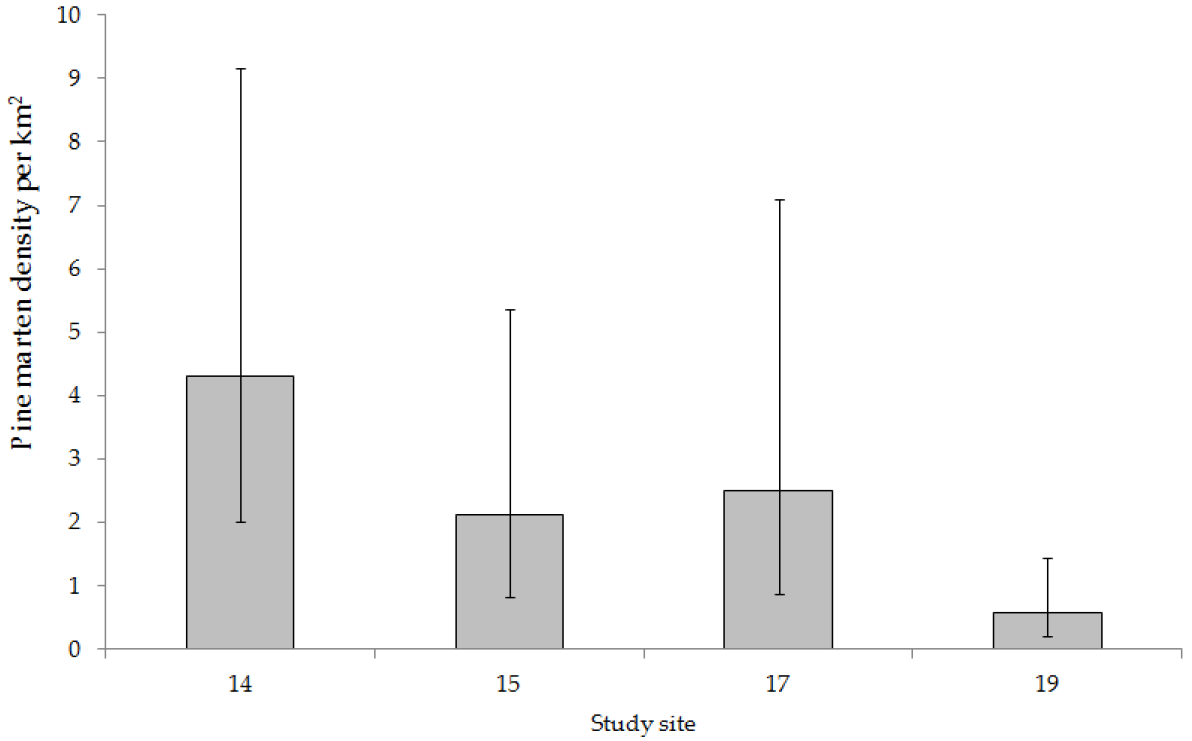

Figure 5. Variation in pine marten density across preselected study sites in Ireland. 95% CI for each site are indicated by error bars. Densities were estimated with the most parsimonious hybrid mixture models using spatially explicit capture recapture models.

Table 5. Estimation of pine marten abundance in each individual study site using CAPWIRE. Data were analysed using a Two Innate Rates Mode (TIRM) as recommended by Miller *et al*. (2005). Site locations given in Figure 1; MNA, Minimum Number Alive, number of unique genotypes detected; N, CAPWIRE population abundance estimate. The percentage of frequently captured individuals is given. (na, CAPWIRE analysis not carried out as sample size too low; *sites where recapture rate ≥2.5, see discussion). "Random" represents pooled data for the 14 randomly selected study sites.

Site code	Sample number	MNA	Recapture rate	N	95% CI		Frequently captured
1	10	6	1.67	12	6	30	17%
2*	27	9	3.00	9	9	9	44%
3	18	8	2.25	12	8	21	25%
4	20	10	2.00	19	10	32	11%
5*	16	5	3.20	6	5	10	17%
6	11	6	1.83	7	6	10	43%
7	0	0	na	na	na	na	na
8	20	11	1.82	27	11	44	7%
9*	15	6	2.50	6	6	6	67%
10*	22	8	2.75	8	8	8	38%
11	2	1	na	na	na	na	na
12	2	2	na	na	na	na	na
13	16	7	2.29	11	7	18	18%
14	31	19	1.63	39	21	61	18%
15*	21	8	2.63	11	8	18	9%
16*	38	14	2.71	19	14	26	32%
17	11	7	1.57	10	7	24	30%
18	4	3	na	na	na	na	na
19	9	4	2.25	5	4	9	20%
Random	217	93	2.33	148	119	165	22%

3.4 A national population abundance of pine marten

To estimate a national population abundance of pine marten based on the survey data in the current study, all capture data from the 14 randomly selected study sites (Sites 1-13 and 16) were pooled to estimate an average pine marten density across these study sites. This dataset consisted of 93 individual pine marten captured 217 times. This resultant mean density estimate was then combined with data on the current distribution of pine marten in Ireland and the amount of forested habitat within that distribution.

Using this approach and running a series of candidate models in secr, it was determined that a model specifying a sex and site specific detection effects on capture probability and sex effects on spatial scale was the best model (AICc 1479.68; Table 3). This provided a mean pine marten density estimate across the randomly selected study sites of 0.64 (95% CI 0.49 - 0.81) pine marten per km^2 of forest habitat. The habitat mask for this analysis was approximately 30,023ha of forest habitat. In CAPWIRE, the estimated total pine marten population abundance across the 14 randomly selected study sites was 148 (95% CI 116-165). Combining the mean density estimate across the 14 randomly selected study sites with current pine marten distribution in Ireland, it was estimated that 475,565ha of forest habitat existed within current pine marten range in Ireland. Combining this data with mean density estimates, the estimated current pine marten population in Ireland was estimated at 3,043 (95% CI 2,330 – 3,852) individuals.

4. Discussion

4.1 Genetic analysis

The overall yield of samples in hair tubes was 63%. Only 11 of the samples (3%) did not yield pine marten DNA, only one of these could not be identified and that was a poor hair sample with only 2 hairs. The remaining 10 samples were dog (4), cat (1) or stoat (5). The dog and cat samples may be assumed to be environmental contamination, a low rate considering the large number of patches manufactured for the survey. It is worth noting that four of the five stoat samples were in site 3 and were collected from two groups of tubes 6.7km apart. Sex testing was slightly less successful (94% of pine marten samples), which reflects the lower concentration of X and Y chromosomal DNA. Individual study sites had a range of sex ratios reflecting the low numbers of individuals concerned, and the overall sex ratio had a small male bias (60% of samples) consistent with larger male territories and less risk averse behaviour. Genotyping was highly successful with 89% of pine marten samples yielding a good genotype at the main 6 loci. This high success rate is the result of considerable method development at WIT.

4.2 Pine marten density in Ireland

This is the first study that has explicitly aimed to determine variation in pine marten density across multiple sites throughout Ireland and produce a national population abundance estimate for pine marten. Such information is critical in terms of the conservation and management of protected and important species such as pine marten, and provides the basis for part fulfillment of national and international conservation obligations with reference to this species. The estimated site specific densities for pine marten ranged from 0 to 2.60 individuals per km^2 of forest habitat in randomly selected sites, however, the majority of study sites had density estimates of less than 1 pine marten per km^2 of forested habitat. In preselected study sites density ranged from 0.57 to 4.29 pine marten per km^2. The majority of current density estimates are within the ranges reported for pine marten in Ireland (Sheehy *et al*. 2014; O'Mahony *et al*. 2015) and for the species across its range (Zalewski *et al*. 1995; Manzo *et al*. 2012; Balestrieri *et al*. 2016). Therefore, although comparisons between studies should be treated cautiously due to differing objectives, methods and analyses, as a general inference, pine marten densities in Ireland are not exceptional in terms of the range that exists for the species in other parts of its global distribution. Pine marten, like other members of the genus *Martes*, and carnivores in general, typically exist in low density populations with the range of densities for pine marten across Europe from 0.03 to 1.75 per km^2 (Zalewski & Jędrzejewski 2006), which correspond

well with the majority of the estimates in the current study. Pine marten ecological and behavioral traits such as their solitary nature, low reproductive output, territorial system of social organisation and variable home range overlap with other individuals, combined with their relative habitat specialism for forests and woodlands, which is a limited resource in Ireland, are indicative factors that generally promote the existence of low densities within this species across their range. Areas of high pine marten density were highly localised and rare in the current study.

Although one of the principal objectives of the current study was to determine variation in pine marten density across sites in Ireland, the sample size of individual pine marten and the number of captures was low in most of the sites surveyed. Only 21% (4/19) of study sites in the full dataset had minimum number alive estimates of 10 or more pine marten, and out of the 14 random site dataset, only 21.42% of sites (3/14) had a minimum of 10 individual pine marten. As each study site was surveyed for one month and included several hundred, if not thousands, of hectares of forest habitat per site, and given that the non-invasive technique used in the study has been proven to work in Ireland (O'Mahony *et al*. 2015; see Table 1), we can be confident that these estimates of low pine marten numbers are robust. Traditionally, in capture recapture studies, sample sizes of individuals of less than 20 may be too small for reliable density estimation (Otis *et al* 1978; White et al. 1982). However, spatially explicit capture recapture techniques can produce more reliable density estimates with small sample sizes of individuals (Borchers & Efford 2008; Gardner *et al*. 2010; O'Brien & Kinnaird 2011; Sollman *et al*. 2011).

Where small numbers of individuals exist within a population, limiting the complexity of implemented secr-based candidate models is advisable (Royle *et al*. 2009; O'Brien & Kinnaird 2011), and was the approach undertaken in this study. Similarly, CAPWIRE that was used to estimate abundance in the current study was originally designed specifically for small populations (Miller *et al*. 2005). Estimated confidence intervals associated with density estimates, in most cases overlapped to such an extent that it was not possible to statistically compare density estimates across sites. High pine marten densities (i.e. >2 per km^2 in the current study) were rare, having occurred in a single random study site, and in 3 study sites within the preselected study sites (i.e. 22.22% of all sites where density could be determined). Potential factors that may have influenced such comparatively high density estimates in preselected sites may include that these sites were in some of most intact remnants of semi-natural forest habitat in Ireland, 3 of the sites were protected either as National Parks or nature reserves and had associated long-term forest cover. Specific research investigating factors influencing the occurrence of high density pine marten populations in Ireland would be required to determine any causal processes influencing variation in pine marten density in Ireland.

This study combined a randomised survey design to estimate site specific and mean density estimates across sites, with current knowledge on pine marten distribution and the extent of habitat occupied, to derive a national population abundance estimate for pine marten. Potential limitations of this methodology have been discussed in section 2.4. Evidence based extrapolation from multi-scale density and abundance studies to produce larger scale regional or national population abundance of species is widely reported in the literature (Erb & Sampson, 2009; Frary *et al*. 2011; O'Mahony *et al*. 2012; Fechter & Storch, 2014; Humm *et al*. 2015; Gervasi *et al*. 2016). Without major funding initiatives to support research studies, these methods are the only realistic means of obtaining such data. The current study was carried out in the range of habitat types within which pine marten occur in Ireland from semi-natural broadleaf forests to non-native coniferous plantations. A relatively large forest area was surveyed to establish density estimates, which were then scaled up to national abundance using current distribution data and estimates of habitat area occupied. This study represents the largest-scale direct assessment of pine marten density in Ireland, and probably across the species global distribution. The combined dataset from the 14 randomly selected sites consisted of 93 individual pine marten, captured 217 times, a recapture rate of 2.33 across the individuals identified in the study. This compares well with studies involving capture recapture estimation for related species such as the American marten and fisher (Mowat & Paetkau 2002; Sweitzer *et al*. 2015) and provided reliable estimation of pine marten density across the study sites surveyed in this project. The current study has produced the most reliable density and abundance estimates hitherto for pine marten in Ireland.

The national pine marten abundance estimate in the current study of 3,043 (95% CI 2,330 – 3,852) individuals, is as far as we are aware, the first directed large-scale pine marten density and abundance research study in any country subject to the reporting requirements of the EC Habitats Directive. In other jurisdictions that have been subject to conservation assessments for pine marten, national abundance estimates for pine marten have been largely achieved using limited data sources and expert opinion (see http://bd.eionet.europa.eu). For example, in the UK the pine marten population has been assessed as similar to that in Ireland at approximately 3,800 individuals, but the majority of that population exists within Scotland where pine marten densities can range from 0.12 to 0.58 per km^2 (Croose *et al*. 2016; and references therein).. The current study may provide a framework for more robust estimates of this species in other jurisdictions. In comparison with other terrestrial mammal populations in Ireland for which data on national population abundance are available such as the Irish hare (up to 1,000,000; Reid *et al*. 2007), badger (84,000; Sleeman *et al*. 2009) and even European otters (up to 10,000 females only; Reid *et al*. 2013), it is clear that pine marten are amongst the rarest of Ireland's wildlife populations, despite any potential increases in the species distribution and abundance over the last 10 years.

4.3 Conservation status of pine marten in Ireland

4.3.1 Range

The most recent distribution and range assessment for pine marten in Ireland is from the period 2005-2007 (O'Mahony *et al*. 2012) and no further national range assessments for pine marten have been undertaken since that survey. Given that a period of 10 years has elapsed since the last national distribution survey for pine marten, a new assessment would be prudent as reliable knowledge on the pine marten distribution in Ireland has been a key component on national abundance estimates for the conservation assessment. In the absence of national-scale directed research studies on pine marten distribution in Ireland, the National Biodiversity Data Centre has used an online Mammal Atlas project that involves compiling existing and historic datasets on pine martens recorded from varied studies in Ireland, together with a proactive citizen science type approach to determine current pine marten distribution (Lysaght & Marnell, 2016). Although comparisons between the field-based distribution study of O'Mahony *et al*. (2012) and that of the Mammal Atlas should be treated with caution, at the very least it is possible to deduce that current pine marten range in Ireland has remained stable, if not marginally increased, in the intervening years since the previous conservation assessment. A field-based distribution survey on current pine marten distribution in Ireland is required to determine the current range of pine marten, particularly in the southwest of Ireland where pine marten distribution is apparently very fragmented.

4.3.2 Population

There have been relatively few ecological studies on pine marten in Ireland and only a single national population abundance assessment for the species. O'Mahony *et al*. (2012) utilised data on the known distribution of pine marten in Ireland (derived from data during the 2005-07 distribution study) and combined that with data on average pine marten home range size (O'Mahony 2014), to estimate the first preliminary national abundance of pine marten in Ireland. That approach explicitly acknowledged the caveats and data limitations that this preliminary estimation method was based on (O'Mahony *et al*. 2012). The national population estimate of pine marten in Ireland between 2005 and 2007 was estimated at 2,740 individuals (95% CI 1,350-4,330) (O'Mahony *et al*. 2012). The current study was designed specifically to estimate site specific pine marten density and abundance estimates, dependent on adequate sample sizes of individuals and capture events within study sites, which then could be used to produce average density estimates across surveyed sites, to reliably estimate the range of pine marten densities that may exist in Ireland.

The current study has produced a mean pine marten density estimate of 0.64 (95% CI 0.49 - 0.81) per km² of forest habitat from 14 study sites in approximately 30,133ha of forest, including a 2,000m habitat buffer. Combining this with current pine marten distribution data and forest habitat availability within that distribution (see methods section) the current national pine marten abundance estimate for Ireland is 3,043 (95% CI 2,330 – 3,852). Acknowledging methodological constraints associated with this estimate, the current population abundance of pine marten in Ireland is in the range of the low thousands of individuals. Determining the significance of any change in estimated population abundance since the previous national population estimate (O'Mahony *et al*. 2012) should be treated cautiously, as the data used for the basis of assessments were not directly comparable. The previous study considered a breeding population assessment (i.e. pine marten with established territories), whereas this current study was likely to include estimates of sub-adults between 6 and 12 months. However, if any such comparisons were made, then it is obvious that estimated mean abundances and confidence intervals overlap, indicating no significant change. It is suggested that this current study reinforces the abundance of that determined from O'Mahony *et al*. (2012) and that the current pine marten population in Ireland exists in the low thousands of individuals. On the basis of the precautionary principle, it is suggested that the population has at least remained relatively stable over the last 10 years.

4.3.3 Habitat

As pine marten rely on forest and woodland cover throughout their range, the availability of this habitat type is critical to the establishment of the species in areas and for range expansion where the species has been historically extirpated. The Irish government is targeting an increase in forest cover in Ireland by 15,000ha per year between 2016 and 2046, to provide an estimated 18% landcover of forestry by 2050 (DAFM 2014). Currently, the forest extent in Ireland is estimated at 653,980ha or 9.5% of landcover, and is one of the least forested countries in Europe. Irrespective of whether or not these targets will be achieved, significant changes have occurred in the type and extent of forest that is being planted in Ireland. Large-scale new plantations are now discouraged to favour small, more diverse and fragmented forestry by private landowners. This is creating an even more highly fragmented habitat for pine marten, but perhaps more connected in terms of forest availability, with unknown consequences for the species' biology and ecology. However, forest cover is likely to increase and not decrease into the future so habitat availability should be sufficient for at least maintaining the current population of pine marten in Ireland, should potential pressures and threats to the population not increase.

4.3.4 Pressures and threats

Conservation strategies and management objectives for pine marten should be developed to take account of any potential increase in illegal persecution and conflicts arising from the re-establishment of pine marten in previously extirpated areas (O'Mahony *et al*. 2012). Apart from a few important initiatives by the VWT and NPWS in informing householders and game owners on reducing potential conflict with pine marten, there has been little done to address these important issues. Over recent years there has been increasing negative and misconstrued media attention on this species, blaming it for poultry attacks and the killing or damaging of lambs and sheep in parts of Ireland, which have culminated in suggested reports that the species may attack children, and that a 'cull' must be undertaken in parts of Ireland where pine marten are 'out of control'. It is likely that the pine marten population in Ireland is currently being subject to illegal persecution in some regions, to an unknown extent. The future prospects of the species may be uncertain in the medium to long term given current levels of negative media attention, calls for control and the lack of a coordinated strategy to address any potential conflict issues. Pine marten are a species with a low reproductive output and high population turnover, similar to other species (Buskirk & Ruggiero, 1994), and are therefore extremely susceptible to population control, whether illegal or legal.

Other factors that may impact on the pine marten population in Ireland include road traffic mortality; shooting, poisoning, trapping, predator control schemes and forest management. With regard to the latter, the main concerns are that the majority of the forest habitat resource in Ireland is managed for commercial gain and that current forest policy favours small-scale, fragmented forest establishment, which may be unsuitable in terms of pine marten socio-spatial ecology (see O'Mahony 2014). Overall, given the current state of knowledge of pine marten population abundance and distribution in Ireland, the future prospects in the short term (i.e. 5 years) are deemed to be adequate. However, if serious efforts are not implemented to address an increasingly vociferous lobby against the species through evidenced based research studies and the development of any associated mitigation measures, this could quickly be reversed.

4.4 Recommendations for pine marten monitoring in Ireland

Based on the results of this study the following recommendations are provided for the future monitoring of pine marten in Ireland:

1. Conduct a field-based distribution and range assessment for pine marten in Ireland as the previous data is now 10 years old. This should be particularly targeted at the edge of known pine marten distribution in Ireland to assess any continued range expansion and focus on the south and southwest of Ireland where pine marten distribution appears to be reduced and fragmented.
2. The results of this study indicated that in the majority of individual study sites pine marten numbers and captures were generally low, with indications that pine martens may still be absent from some sites within their range, even where large areas of suitable habitat occur. Although statistical density estimation techniques such as secr and CAPWIRE used in the study are generally robust to low sample sizes, increased samples sizes in density estimation research are preferred. Future research that focuses on pine marten density estimation in Ireland should consider adopting a landscape scale approach to study area identification such that it is likely to be sufficient to contain at least 15-20 individual pine marten. Based on evidence from the current study on mean pine marten density of 0.64 (95% CI 0.49 - 0.81), a minimum potential study area size of 2,000 to 3,000 ha of forest habitat could be a useful indicator, as used in O'Mahony *et al*. (2015). That is of course unless *a priori* rationale exists for suspecting high pine marten density in smaller sites.
3. This density estimation research project should be repeated at intervals of 5-7 years, particularly in the 14 randomly selected study sites, to ascertain any changes in site specific and mean density and abundance estimates across sites, which may have occurred within the population.
4. As advocated previously and throughout this report, there needs to be a commitment to funding of research studies into the general ecology of pine marten in Ireland. This will increase our knowledge of the species' role and function in the environment, which can specifically help address issues of potential conflict with people and inform relevant mitigation to reduce any such scenarios. An educational and advisory protocol should also be instigated in areas where current conflict has been identified.

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