Habitat Use and Abundance of Mesocarnivores and Deer along Eastern Loch Lomond

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Abstract

Habitats play a crucial role in the lives of every animal, providing the necessary resources for a species to live and reproduce. For mesocarnivores, a diverse group of predatory species with wide variation in diet and social behaviours, habitat requirements for feeding and reproduction may vary. In Scotland, woodlands are often favoured by mesocarnivores, in contrast, Scotland's native deer are more flexible in their habitat use, occurring in woodland and open moorland, which are suitable for grazing. The aim of this study was to investigate habitat use and abundance of mesocarnivores and deer along the Eastern side of Loch Lomond with the goal of identifying favoured habitats and to estimate population density. This was undertaken by the deployment of camera traps in three different locations from April-June 2024. Results showed that mesocarnivores (badger, pine marten, red fox) did not favour any specific habitats, but roe deer were more frequently recorded in broadleaf woodlands and red deer in moorland compared to other habitats. Using random encounter models (REMs), estimated population densities for all species were within the range of previous estimated abundance across other regions of Scotland. In conclusion, this study demonstrates effective methods of examining the habitat use and abundance of mammals within a localized area of Loch Lomond and the Trossachs National Park. These field and analytical methods could be applied in future to a wide geographical area to provide useful information for the conservation and management of these species.

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Author’s declaration

I declare that all information within this dissertation, expect where a reference is provided to explicitly mention the contributions of others, is a result of my own work and has not been submitted to any other degree at the University of Glasgow or any other institution. This research was conducted between October 2023 and August 2025, under the supervision of Dr Stewart White, Dr Dominic McCafferty, and Dr Anna McGregor. All field methods were approved by the SBOHVM Research Ethics Committee (EA14/23).

Krystin O. Damask

1 General Introduction

1.1 History of carnivores in Great Britain

Terrestrial carnivora, as they exist today, first appeared within the British Isles from approximately 6,000 years ago, during the Middle Stone Age (Sainsbury, et al. 2019; Couzens, et al. 2021). This period saw the existence of large predators such as the brown bear (*Ursus arctos*), the Eurasian lynx (*Lynx lynx*) and Eurasian wolf (*Canis lupus lupus*), their range extending amongst the expansive woodlands that were then found across much of the British Isles (Couzens, et al. 2021). However, as the human population continued to grow and agriculture expanded, so did human-carnivore conflict. The primary concern at the centre of this conflict lies in the perspective that carnivores are viewed as competition and thus are a danger to both hunting game and farmed livestock (Treves and Karanth, 2003; Couzens, et al. 2021). This fear ultimately led to overhunting as a means of predator control, which eventually led to the extinction of the larger carnivores in the British Isles and ended with the killing of the last wolf in the early 17th century (Couzens, et al. 2021). The results of this human-carnivore conflict continues to impact the remaining population of smaller, mesocarnivores, many of which saw a significant decline between the 18th and 20th centuries, furthering the predatory vacuum within the natural environment (Langley & Yalden, 1977; Grabham, et al. 2019).

In areas where the top apex predators are removed from the environment, smaller predators often increase in abundance, filling in some of the gaps left behind (Roemer, et al. 2009; Fryxell, et al. 2014); these are known as mesocarnivores. A mesocarnivore is defined as a predator that is medium or small in their size (approx. < = 15 kg), with more diversity in dietary tendencies, social behaviours, and habitat preferences than their larger counterparts (Roemer, et al. 2009). Today, a total of eight terrestrial mesocarnivores exist within the United Kingdom (excluding the invasive American mink (*Neovison vison*)), five of which are legally protected. These protected species are the European badger (*Meles meles*), the Eurasian otter (*Lutra lutra*), the pine marten (*Martes martes*), the polecat (*Mustela putorius*) and the Scottish wildcat (*Felis silvestris*) (Sainsbury, et al. 2019). The Wildlife and Countryside Act of 1981, the Badger Act of 1992, and the Wild Mammals (Protection) Act of 1996 were particularly crucial in assisting mesocarnivore conservation and welfare efforts, as the protections implemented by these laws targeted actions such as hunting predators for sport, fur trade, and excessive predator control by landowners (Grabham, et al. 2019; Sainsbury, et al. 2019; McNicol, et al. 2020a). The remaining mesocarnivores that are not currently classified as protected species in the UK are often described as "pests" species in legislation regarding property protection (e.g. livestock, crops, landscape, etc.) (Agriculture (Scotland) Act, 1948), this definition applies to the red fox (*Vulpes vulpes*), the stoat (*Mustela erminea*) and the weasel (*Mustela nivalis*). Yet, despite the implementation of various legal protections, none of these pieces of legislation have addressed the biggest ongoing issue that continues to affect the conservation of mesocarnivores today, the fragmentation of habitat.

Habitats give researchers insight into a given species beyond the simple knowledge of location. Studying which habitats are used by a particular species can help in the understanding how an animal uses the environment they surround themselves in, while also providing insight into how changes in the environment can influence the behaviours an animal will display (Bright, 1993; Krausman, 1999; Červinka, et al. 2014; Smith, et al. 2018; Church, et al. 2022). When investigating why a mesocarnivore is present or absent within a particular type of habitat in their environment, it is important to understand two specific concepts relating to their behaviour: habitat use and habitat selection. In simplest terms, habitat use can be defined as how an animal uses the available resources within a specific habitat landscape (Krausman, 1999). Mammalian species, including mesocarnivores, may often 'use' multiple habitat types within their home range for different purposes, such as hunting, denning, and protection (Morellet, et al. 2011; Lovell, et al. 2022). A more complex version of this behaviour falls under the terminology of habitat selection, a systematic behavioural process whereby an individual animal will choose a type of habitat based on specific resources they will actively seek out (Lucherini, et al. 1995; Krausman, 1999). In the context of habitats, most terrestrial carnivores have historically been viewed as specialists, rather than generalists; a habitat specialist requires certain characteristics or resources to be present to have their needs met (Moll, et al. 2016). Even for mesocarnivores, who have been forced to adapt to the ever changing world around them, the consequences of a habitat that lacks these important resources can impact prey availability, access to potential mates, and disrupt individual territory boundaries, leading to expansions into atypical environments (i.e. farmland, non-forested, and urban areas) (Rainey, et al. 2009; Caryl, et al. 2012; Červinka, et al. 2014; Moll, et al. 2016; Smith, et al. 2018;

Lovell, et al. 2022). This makes habitats one of the most important indicators of a species' stability, and a key tool in the conservation of Scotland's mesocarnivores.

Habitat fragmentation within the United Kingdom has influenced the presence and absence of many species, as small patches of suitable habitat for wildlife become broken up and surrounded by anthropogenic landscapes and obstacles (e.g. housing, agricultural fields, roads, etc.) (Bright, 1993; Moll, et al. 2016; Rogan & Lacher, 2018). The loss of habitat, particularly ancient woodland, has and continues to impact the home ranges of mesocarnivores, with Scotland now being the only region where all eight mesocarnivores coexist (Langley & Yalden, 1977; Sainsbury, et al. 2019). Fragmentation has also impacted the population abundance and distribution of mesocarnivores in Scotland, with the high concentration of urbanization from the central belt restricting many species to the highlands in the north (Sainsbury, et al. 2019). This chapter will examine the current research and methods of habitat use and selection of three prominent Scottish mesocarnivores: the pine marten, the European badger, and the red fox. The decision to focus on these species was due to their known presence within our study area near Loch Lomond. Additionally, sections of the chapter will cover the impact of deer on Scottish landscapes, as well as the important role mesocarnivores have in predation. All of this is to establish context and reasoning for our study, how it was conducted, and why the conservation and investigation of mesocarnivores is important for Scotland's environment.

1.2 Habitat use and selection of mesocarnivores

1.2.1 Pine Marten (*Martes martes*)

Pine martens have often been the focal species of studies involving habitat selection, either in the context of habitat fragmentation (Caryl, et al. 2012; Manzo, et al. 2011; Moll, et al. 2016) and/or translocation (Croose, et al. 2019; Grabham, et al. 2019; McNicol, et al. 2020a). A member of the mustelid family, pine martens have long been associated with Scotland's ancient woodlands (Caryl, et al. 2012; Couzens, et al. 2021), with their sharp claws and keen senses making them well-equipped predators, both physically and behaviourally adapted to life amongst the trees (Couzens, et al. 2021). However, this notion of habitat specificity has been debated by ecologists in recent studies, in part, due to the recent expansion of their population ranges in Scotland and beyond (Caryl, et al. 2012; Moll, et al. 2016;

Sainsbury, et al. 2019). One example comes from a study investigating the habitat selection of pine martens via radio collar tracking around Morangie Forest, a commercial coniferous tree plantation located in the northeast of the Scottish Highlands (Caryl, et al. 2012). The landscape around Morangie was broken up by small patches of deciduous trees, agricultural fields, scrub, tussock and open moorland. It was hypothesized that pine martens would select a habitat based on prey availability, as small mammals, like the field vole (*Microtus agrestis*), are important dietary pieces for a marten (Caryl, et al. 2012). It was also suggested that pine martens would display sexually dimorphic behaviours, with female martens being more cautious of open areas, preferring habitats that offered protective coverage from predators (i.e. red foxes and golden eagles (*Aquila chrysaetos*)) compared to their male counterparts (Moors, 1980; Caryl, et al. 2012). Upon analysis, the results indicated that pine martens did significantly prefer forest habitats; however, the evidence also suggested both sexes had a lower preference for fragmented matrix environments of scrub and tussock grassland. Furthermore, male pine martens were recorded as being more likely to venture into open environments, while females showed strong avoidance for open moorlands (Caryl, et al. 2012).

When it comes to translocation studies of pine martens, habitat use and selection are important factors used by ecologists to help with successful reintroductions (McNicol, et al. 2020a). In 2015 and 2016, two groups of pine martens were translocated from the Scottish Highlands to Wales, with individuals being subsequently tracked post release to determine home range settlement (McNicol, et al. 2020a). Results from the first translocation showed a lack of strong preference for any habitat type, but when it came to forest type, first-year martens preferred those possessing felled trees. In contrast, pine martens translocated in the second year displayed a noticeable preference for forested habitats but appeared to have no preference for a certain forest type (McNicol, et al. 2020a). It was concluded that the differences in habitat selection between pine martens in year one vs year two came down to the presence of pine martens within a particular habitat range (McNicol, et al. 2020a). While pine martens are highly territorial in their home ranges (Couzens, et al. 2021), this would not have been an issue for year one pine martens, as they had the privilege to establish their own territories without any pre-existing competition. However, during the translocation of year two pine martens, the home ranges previously established by those in year one likely had influence on the spatial ecology of year two (McNicol, et al. 2020a). In the case of native pine marten ranges in Scotland, this could suggest potential reasoning for the shift away from more habitat specialist behaviours.

Another more broad-scale study determined the habitat use of pine martens across 50,000 km^2 of the Scottish Highlands (Moll, et al. 2016). The study sorted habitat types into seven categories, each being assigned an expected occupancy by the researchers. Using camera traps, Moll, et al. (2016) concluded an expected positive association between marten occupancy and woodland landscapes; pine marten occupancy was also noted in agricultural and open habitat categories, such as heather fields or grasslands. The researchers acknowledge how these results differ from those previously obtained by Caryl, et al. (2012), who found pine martens would actively avoid agriculture fields. However, Moll, et al. (2016) explained this may be due to their study being conducted on a much larger scale than that of Caryl, et al. (2012), and that where an individual pine marten falls on the habitat specialist-generalist spectrum may depend on the context and scale of the study. Pine martens are known to have large home ranges yet often exist at low population densities (Paterson & Skipper, 2008; Jordan, et al. 2012). Ultimately, what Moll, et al. (2016) and Caryl, et al. (2012) both concluded that due to the high occupancy in woodland environments, pine martens in Scotland likely require a habitat that can provide a certain amount of wooded coverage within their home range. This baseline amount varies, depending on a pine marten's behavioural patterns, mobility, how risk-adverse they are, the size of their territory, and resources available (Caryl, et al. 2012; Bartolommei, et al. 2016; Moll, et al. 2016).

1.2.2 European Badger (*Meles meles*)

Another member of the mustelid family, European badgers are one of the most common mesocarnivores in all of Europe and are widely found throughout the United Kingdom (Rainey, et al. 2009; Byrne, et al. 2012; Mitchell-Jones, 2020; Couzens, et al. 2021). Since gaining protection under the Badger Act of 1992, the population of badgers in Scotland has risen significantly (Sainsbury, et al. 2019), with an estimated total of 156,000 badgers (Mathews, et al. 2018; Mitchell-Jones, 2020). In England and Wales, populations are said to have further increased, with one estimate being 485,000 badgers (Sainsbury, et al. 2019). Badgers are social carnivores, known for living in communal dens called setts, a series of complex tunnels and burrows, housing an average of 5 badgers per sett (Byrne, et al. 2012), with the total number of main setts in Scotland estimated to be between 10,290 – 15,864 (Rainey, et al. 2025). To understand the habitat, use and selection of badgers is to understand the importance of setts; a badger's sett is not just an area for resting, it is where breeding occurs and where badgers raise their cubs (Rainey, et al. 2009; Byrne, et al. 2012). Badgers will often have multiple setts in a single territory, with one larger 'main' sett that is continuously used, along with smaller outlier setts used less often, sometimes remaining vacant for periods of time (Rainey, et al. 2009; Byrne, et al. 2012).

The most recent survey on badgers in Scotland occurred from 2022-2025; as done in previous surveys, data was collected using physical signs of badger presence, including scat and hair samples, footprints, bedding material, and of course, the presence of a badger sett (Rainey, et al. 2009; Rainey, et al. 2025) To track the density of badgers across the nine different regions of Scotland, the surveyors utilized 1 km^2 girds, which were categorized into one of six broad habitat types based on whichever habitat type was the most prominent in the grid square (Rainey, et al. 2025). When the survey was completed, 155 main setts were reported to be found, with broadleaf woodland being the most prominent habitat, accounting for approximately 43% of badger setts (Rainey, et al. 2025). The prior Scottish badger survey found a total of 169 main badger setts, with intensive grassland being the habitat most often used for badger setts in Scotland, closely followed by arable farmland, and deciduous woodland (Rainey, et al. 2009). Many of the main setts (60%) found in the 2009 survey were located within patches of deciduous or coniferous woodland, compared to only 9% being located directly within open habitat types of arable farmland or grassland (Rainey, et al. 2009), which lines up to the recent results from the Rainey et al. (2025) survey. This is not too surprising, as like other British carnivores, badgers have long been associated with woodland habitats (Bryne, et al. 2012; Couzens, et al. 2021); woodlands can provide badgers with protective coverage outside their setts, allowing for more opportunities for foraging for food sources, namely earthworms which make up most of their diet (Rainey, et al. 2009; Byrne, et al. 2012).

Outside of Scotland, badgers are often observed in similar habitats within fragmented landscapes, such as fragmented woodland remnants, open meadows and agricultural land (Rainey, et al. 2009; Robertson, et al. 2015; Chiatante, et al. 2017; Silva, et al. 2017). In Ireland, for example, where less than 10% of the environment consist of tree cover, badgers can be observed primarily utilizing hedgerows in areas lacking access to traditional woodland habitats, as hedgerows offer badgers protective coverage for their setts as well as close access to areas ideal for foraging (Byrne, et al. 2012). Badgers in Italy have similarly been found to use hedgerows habitats as a site for establishing setts, especially in agricultural heavy areas (Chiatante, et al. 2017). In addition to this, in more recent decades, badgers have been sighted expanding into urban areas (Rainey, et al. 2009; Couzens, et al. 2021; Lovell, et al. 2022). Unlike red foxes, who appear to be more well adapted to urban environments, badgers appear to show more specialist behaviours towards their habitat preferences. One study conducted in London found badgers having an increased preference for patches of woodland in areas where non-natural light levels were increased (Lovell, et al. 2022). These behavioural patterns of searching for some level of overhead protective coverage displayed by badgers may suggest a threshold, in which badgers may require a minimal amount of overhead protection within their territory to establish a sett (Rainey, et al. 2009; Byrne, et al. 2012; Chiatante, et al. 2017; Lovell, et al. 2022). Therefore, when it comes to badgers' habitat use and selection in Scotland, the reason why woodlands remain the primary habitat type used by Scottish badgers is likely due to the notion that woodlands, especially within a fragmented landscape, can offer badgers the most ideal surroundings to establish setts, forage for food, and avoid conflicts with anthropogenic obstacles (Rainey, et al. 2009; Byrne, et al. 2012; Rainey, et al. 2025).

1.2.3 Red Fox (*Vulpes vulpes*)

The red fox, unlike the pine marten and the badger, is an unprotected species of carnivore in the United Kingdom (Sainsbury, et al. 2019; Couzens, et al. 2021). However, they are also perhaps the most adaptable carnivore in all of Britain, being found in a wide range of habitat types in both rural and urban areas (Lucherini, et al. 1995; Leckie, et al. 1998; Scott, et al. 2014; Couzens, et al. 2021). When compared to carnivores like the pine marten or badger, red foxes can be observed as greater risk-takers, in that they are less elusive and more opportunistic, often crossing boundaries between rural and urban environments (Kurki, et al. 1998; Márton, et al. 2016; Lovell, et al. 2022). In urban city areas, foxes have been known to take refuge in residential areas, putting them in close proximity to humans, which in turn, can cause foxes to become more tolerant of human presence and activity. Compare this to what behaviours badgers displayed in urban environments, having a tendency to rely on patches of woodland for cover and distance from human activity (Lovell, et al. 2022). This can have both positive and negative consequences on urban foxes; beneficial aspects can include an increased access to food resources, while in contrast, conflicts with human disturbances (e.g. automobile accidents, disease transmission, biting incidents towards humans, etc.) can have lethal consequences (Scott, et al. 2014).

Based on initial searches, research investigating red fox habitat selection and use in Scotland, especially in recent years, is limited. As fox populations are stable in the UK, regular surveys and monitoring of foxes are not legally required as with protected mesocarnivores (Sainsbury, et al. 2019; Mason, et al. 2022). Those studies that have been done are often in the context of urban environments outside of Scotland, particularly those in southern England, where woodland environments are scarce and due to increasingly fragmented habitats, fox populations have been found to exist at higher densities within urban environments than in the English countryside (Scott, et al. 2014). Highly adaptable, red foxes are considered both habitat and dietary generalists (Leckie, et al. 1998), being able to find all their typical rural resources (e.g. prey, denning spaces, etc.) in urban environments, where they have less competition with other specialist carnivores (Lovell, et al. 2022) and are able to find alternative sources for food (e.g. anthropogenic feedings, food waste, etc. (Scott, et al. 2014)). However, this behavioural adaptation is not without consequences, as often foxes will find themselves more exposed to direct conflicts with humans in areas where more anthropogenic activity is occurring, especially near areas of farmland (Scott, et al. 2014). One of the few studies on red fox habitat use conducted in rural Scotland occurred in 1998, in which researchers investigated the variation of diet and habitat use of red foxes on Scottish moorland near Langholm through the collection of scat samples (Leckie, et al. 1998). Over half of the scat samples were found in heather moorland, with the remaining samples being found in areas of grassland. When comparing the two sample groups, fox scat from moorland were found to be more likely to include larger prey, such as gamebirds and rabbits, while fox scat from grasslands mostly consisted of rodents (Leckie, et al. 1998). While the study mostly focused on foxes' role in predation, the results did provide evidence on how different prey availability can influence the presence of red foxes in nearby habitats.

Outside the British Isles, red fox habitat selection has been more widely studied. In 1995 the habitat use and spatial behaviours of red foxes in central Italy were investigated across eight habitat types, broadly categorized a managed and unmanaged (Lucherini, et al. 1995). Managed habitats included pastures, olive fields, vineyards, cultivated crop fields (primarily wheat) and farmyards (e.g. land within the boundaries of a farmhouse), while the remaining three unmanaged habitats included scrubwood, overgrown and abandoned olive fields, and reed thicket. Over the course of the study, the researchers tracked the home range movements of individual foxes, who were found to often use different habitat types at different times of the day, a clear indication of diel movements. All foxes were most active at night, a behaviour to be expected as foxes (as well as many other carnivores) are primarily nocturnal (Lucherini, et al. 1995; Lovell, et al. 2022); during these nocturnal hours, foxes were more likely to use habitats with less protective coverage, such as farmyards or vineyards. The most prominent habitat used overall was abandoned olive fields, which were also the most common habitat type of diurnal activity, and one of the most common areas preferred for resting, followed by reed thicket and scrubwood, all of which provided more protective coverage for foxes during daylight hours (Lucherini, et al. 1995). What this study highlighted is that red foxes are highly motivated by availability and access to food resources; in this case, the olive fields were multi-functional, providing not only protection during resting hours, but also a variety of prey species, from insects, to rabbits, birds, and even small mammals (Lucherini, et al. 1995). These findings correlate to a previous Italian study from 1991, which also noted foxes selecting habitats based on prey availability, foxes using a variety of habitats at different times, with areas of rest being environments of higher protective coverage (e.g. areas of understorey) (Cavallini & Lovari, 1991).

1.3 Impact of native deer populations

Deer are one of Britian's most numerous groups of herbivores and have existed in the British Isles since the Mesolithic period (The British Deer Society, 2024). The two most prominent species in Scotland are the large red deer (*Cervus elaphus*) and the smaller European roe deer (*Capreolus capreolus*). Similarly to carnivores, deer are also dependent on woodland habitats, which provide them with protective coverage from predators, as well as an abundance of resources for their dietary needs (Morellet, et al. 2011). On a local-scale, deer are inclined to forage in areas that are often not managed (e.g. without mitigation methods like fencing, etc.), including some woodland habitats (Spake, et al. 2020). And just like with mesocarnivores, anthropogenic interference has had an impact on the habitat selection behaviours of both red and roe deer; the loss of Britian's large predators, the expansion of agricultural landscapes and of course, habitat fragmentation, have all contributed in part to the preferences of deer populations (Morellet, et al. 2011; Pérez-Barbería, et al. 2013; Spake, et al. 2020). One important behavioural characteristic deer have in relation to habitat usage is their performance of diel movement patterns which, depending on the species and ecosystem, can mean using different types of habitats depending on the season or time of day (Fattebert, et al. 2019; Klarevas-Irby and Farine, 2024). For some species of deer, this could mean utilizing the protect coverage of woodlands by day, while exploring and grazing in open moorlands at night (Welch, et al. 1990). But because many of Scotland's woodlands are fragmented and under protective management, and therefore designed to be inaccessible to deer, both red and roe deer have had to adapt to search for resources, an adaptation that has been shown to have a significant impact on Scottish ecosystems caused by over-grazing (Spake, et al. 2020).

In the past 200 years, over-grazing by deer and domestic ungulates (e.g. sheep and cattle) has negatively affected the biodiversity and health of habitats within the highlands through prevention of new undergrowth, which can have an impact on the habitats of birds, rodents, and other prey species in the environment (Nilsen, et al. 2007; Buesching, et al. 2011; Pérez-Barbería, et al. 2013). In woodland and moorland environments alike, the presence of a high population of deer can result in the removal of woody vegetation (e.g. seedlings, brambles, ferns, etc.) (Buesching, et al. 2011). Small mammals such as field voles (*Microtus agrestis*), wood mice (*Apodemus sylvaticus*) and rabbits (*Oryctolagus cuniculus*) are all dependent on this undergrowth for their own dietary needs, as well as protective coverage from mesocarnivores (Buesching, et al. 2011; Villar, et al. 2013). The removal of this important plant growth can have a cascading effect, as changes in the habitat structure can lead to small mammals being forced out of their typical habitat, causing mesocarnivores to lose a key prey species in their territory, and thus, venture out into other habitats they would be less inclined to use (Leckie, et al. 1998; Gill & Beardall, 2001; Buesching, et al. 2011; Villar, et al. 2013).

Because of the impact grazing can have on small prey species, investigating the movements and habitat behaviours of large herbivores like red and roe deer is important in the conservation of carnivores in Scotland. In 2013, Pérez-Barbería, et al. studied the habitat preferences of red deer populations across Scotland. At the time, Scotland's red deer population was the largest in all of Europe at approximately 300,000 (Pérez-Barbería, et al. 2013); because of this large population size, competition for resources increased significantly, leading to an overreliance on non-woodland habitats. In their results, Pérez-Barbería, et al. (2013) found red deer had a strong preference for heather moorland, followed by both grassland and Scottish peatland, all environmental types that are vulnerable to damage by over-grazing. Similarly, a study on roe deer conducted in France also found the distribution of resources amongst their populations to influence habitat use (Morellet, et al. 2011). Like the roe deer populations in Scotland, roe deer in France have also grown rapidly, forcing the species to seek resources in non-woodland habitats as a means of supplementation (Morellet, et al. 2011). Roe deer habitat selection was investigated through two different scales, the first being within a deer's home range (measured via radio collars on individuals) and secondly in the context of the landscape found within the study area (~11,000 ha), taking into account the mix of open fields with small patches of woodland between them. Results of the study showed that as the availability of woodland decreased, on both a home range and overall landscape scale, deer displayed a higher preference for hedgerows, meadows, and cultivated fields (Morellet, et al. 2011). What this shows is that roe deer, just like red deer in the Scottish study, display flexibility in their habitat behaviours when environments are lacking in necessary resources, and that a deer's preference for a particular habitat is likely to be dependent on specific attributes region to region (Morellet et al. 2011; Pérez-Barbería, et al. 2013; Spake, et al. 2020; The British Deer Society, 2024b).

1.4 Role of predation

In the context of mesocarnivores and their habitats, understanding how they impact ecosystems is important. The key role of all carnivores is predation (Banks, 2000; Sheehy, et al. 2018; McNicol, et al. 2020b; Twining, et al. 2020a), the effects of which can be best explained by the interactions of trophic cascades. In simple terms, a trophic cascade is an ecological concept that specific species have indirect effects on an ecosystem (McNicol, et al. 2020b); when it comes to carnivores, it has been suggested that the role of predation has an indirect impact on maintaining the balance between herbivores and vegetation, by preventing the overconsumption of plant life (Beschta, et al. 2009). Scotland's lack of large carnivores is a major contributing factor to the rapid increase of deer populations (Kirkland, et al. 2021). Normal grazing behaviours characteristically present in both red and roe deer have become destructive, particularly within areas attempting to recover native trees and shrubbery (Welch and Scott, 2017; Kirkland, et al. 2021). And while mesocarnivores in Scotland are unable to control ungulate populations due to their disproportionate size differences, the impact of their predation may influence ecosystems of the Scottish Highlands (Sheehy, et al. 2018; Twining, et al. 2020b; Twining, et al. 2021).

Pine martens have recently been linked to studies involving the conservation of another protected species, the red squirrel (*Sciurus vulgaris*) (Paterson, et al. 2008; Sheehy, et al. 2018; Grabham, et al. 2019; McNicol, et al. 2020b; Twining, et al. 2020a; Twining, et al. 2020b; Twining, et al. 2021). Interestingly, both species share some striking similarities, both having been impacted by the historical loss of woodland habitats, leading to a majority of their populations being restricted within the boundaries of Scotland (Paterson, et al. 2008; Couzens, et al. 2021). Unlike the pine marten, red squirrel populations have also been significantly affected by disease, the result of a competing invasive species, the grey squirrel (*Sciurus carolinensis*) (Paterson, et al. 2008; Sheehy, et al. 2018; McNicol, et al. 2020b; Couzens, et al. 2021). One example of evidence pointing to the pine marten as an important natural mediator in the conservation of the red squirrel can be found in Sheehy, et al. (2018), in which researchers surveyed for pine martens, red squirrels, and grey squirrels at three sites, one in the Scottish Highlands, one within the central belt, and one near the Scottish borders. Results from the study found the presence of pine martens with each research site had a significantly negative effect on grey squirrel occupancy, while having a strong positive effect on red squirrel occupancy (Sheehy, et al. 2018). One potential explanation for this given by Sheehy, et al. (2018) is that because grey squirrels are an invasive species, they do not share a coevolutionary history with pine martens, therefore, they have not adapted well to avoid martens as predators, exposing them as an easier prey option compared to their native red counterparts.

Other examples of positive mediation through predation by pine martens are exhibited in studies that were conducted in Northern Ireland. One such study from 2020 tested the behavioural responses of both red and grey squirrels at feeding stations by exposing them to the scent of a pine marten (Twining, et al. 2020a). The behaviours displayed by both species of squirrels corroborates with those discovered by Sheehy, et al. (2018), in which researchers observed a reduction in red squirrel appearances to a feeding station, the longer it possessed the scent of a pine marten. Lacking the instinctual need for avoidance, the grey squirrel continued to visit the feeding stations, furthering the suggestion that grey squirrels are an easier prey target for pine martens, as they lack the necessary anti-predator behaviours needed to avoid pine martens (Twining, et al. 2020a). In the same year, a report was published by Twining, et al. (2020b), in which a portion of their study examined 918 samples of pine marten scat collected from multiple sites where red and grey squirrels were known to inhabit in Northern Ireland. In their discussion, the researchers reported a higher mean frequency (12.0%) for remains of grey squirrels in scat compared to the mean frequency of remains belonging to red squirrels (4.2%) (Twining, et al. 2020b).

Another subsequent study from Northern Ireland investigated this ongoing predation dynamic, this time using camera traps as a means of detecting presence at established feeding stations (Twining, et al. 2021). Data compiled from this research project was taken from a variety of habitat types, ranging from urban spaces to more natural woodland areas (Twining, et al. 2021). Just like the results from Sheehy, et al. (2018), Twining, et al. (2021) found pine martens to have a positive effect on red squirrels and a negative effect on grey squirrels; this project also provided evidence calling back to studies discussed in relation to habitat use amongst pine martens (Caryl, et al. 2012; Moll, et al. 2016; McNicol, et al. 2020a), which showed that martens of Northern Ireland favour both coniferous and deciduous, as well as mixed woodland habitats (Twining, et al. 2021). The reason this is brought up by Twining, et al. (2021) is due to the observed preference grey squirrels had towards more urban environments, a habitat type researchers noted was highly avoided by pine martens in Northern Ireland.

The red fox has often been perceived to play a negative role in predation, particularly by those who work with livestock. However, there is an argument that has been made for the potential positive impact red foxes can have in an agricultural landscape. In 2000, Peter Banks publish an article discussing the effect red foxes can have on wild rabbit populations through predator regulation in Australia. Rabbit (*Oryctolagus cuniculus*) populations in the Namadgi National Park boomed after a population of foxes were removed in the early nineties. Rabbits made up approximately 40% of a fox's diet in this area, and by removing them years prior, the population of rabbits continued to increase without any prevention (Banks, 2000). Once foxes were reintroduced to the whole study area, Banks (2000) reported a decrease in rabbit population to numbers like those prior to the foxes' removal. However, population numbers appeared to rise slightly again in one half of the study area after the initial rerelease and maintain around this level till the end of the study's 16-month period (Banks, 2000). The reason for this recovery observed from rabbits in one location in the study area over the other may have to do with the lack of resources; upon examination of rabbit carcases from more heavily impacted population, rabbits appeared to have longer than average caeca, a sign that suggested a poor diet, likely cause by a lack of high-quality forage due to an overpopulation of rabbits in one area (Banks, 2000). What this study shows us is not only how carnivores impact the population levels of their prey but is also a prime example of the potential negative consequences the removal of a predator can have on the health of both the prey species and the environment they forage on.

1.5 Methods of monitoring

Determining where to search for mesocarnivores in Scotland can be a challenge, as many are solitary and tend to exist within large, expansive territories (Croose, et al. 2016; Moll, et al. 2016). Surveys are a common tool used by ecologists to help monitor the status of a species. When conducting surveys, especially those that involve the monitoring of an animal's behaviour, it is important for researchers to consider which method can provide the most accurate data, while also being both time and cost effective (Croose et al. 2019). In many studies, live trapping has been used as a means of assessing a focal species within a study site, either by collecting a direct sample from the animal (e.g. scat, blood, fur), or to attach a tracking device (e.g. radio collar) (Miranda Paez, et al. 2021); but for protected species like the pine marten or badger, live trapping can be an invasive and time-consuming method, one which can cause stress to the captured animal (Miranda Paez, et al. 2021). In Scotland, a researcher requires a survey licence from NatureScot (formerly known as Scottish Natural Heritage) to catch and physically handle any pine marten (Birks, 2013). While this might work for some studies, the more recent trend in ecology is to use non-invasive techniques to observe wildlife (Miranda Paez, et al. 2021). Examples of these non-invasive methods include scat collection, fur samples and camera traps (Croose, et al. 2019; Miranda Paez, et al. 2021).

Camera traps have proven to be a useful tool for ecological studies and wildlife management; they are non-invasive, often cost-effective, can be used in both rural and urban settings, and can produce large quantities of data in the form of either still images or videos (Manzo, et al. 2011; Kilshaw, et al. 2015; Tourani, et al. 2020; Miranda Paez, et al. 2021; Lovell, et al. 2022; Finlay, et al. 2023; Miles, et al. 2024). These qualities can be ideal for studies over long periods of time and have proven to be useful in numerous cases involving carnivores in Scotland. Findlay, et al. (2023) utilized camera traps to study the resting sites of otters around River Tweed catchment located in southeast Scotland. Camera traps were ideal for this study to identify an otter den as a resting site, as researchers would have to correlate field sights with observations of otters displaying resting behaviour (Findlay, et al. 2023). Kilshaw, et al. (2015) also tested the effectiveness of camera traps in their distribution study on the Scottish wildcat in Cairngorms National Park. Camera stations were placed within areas containing field signs of wildcat presence (i.e. tracks, scat, claw markings, etc.); stations were also placed in areas where pine martens were known to coexist. This was done due to pine martens and wildcats sharing prey species and we can see this method similarly conducted in Moll, et al. (2016), who used wildcat camera stations to determine presence of pine martens (Kilshaw, et al. 2015). By using camera traps, researchers were able to determine that camera traps were not only a useful tool to detect the presence of Scottish wildcats but were also helpful to researchers in distinguishing between wildcats and feral hybrids (Kilshaw, et al. 2015).

When monitoring population stability, camera traps can be an excellent tool of collecting data used to estimate abundance (Rowcliffe, et al. 2008; Manzo, et al. 2011; Nakashima, et al. 2018; Palencia, et al. 2021; Mason, et al. 2022). The three most common methods to do this are the Random Encounter Model (REM), Random Encounter and Staying Time (REST), and camera trap distance sampling (CT-DS) (Palencia, et al. 2021; Mason, et al. 2022), all of which utilize similar parameters provided by the camera traps. REM is modelled by a species' random encounters with individual camera traps in combination with variables such as total deployment time, average distance each species travels in a day, and the detection zone of the camera trap itself (Rowcliffe, et al. 2008; Palencia, et al. 2021). REST takes REM a step further, in which the staying time (e.g. the amount of time an animal stays in frame per encounter) of individual animals in video capture is employed to more accurately determine the speed of travel for a specific species (Nakashima, et al. 2018; Palencia, et al. 2021). Both REM and REST rely on the assumption that camera traps are placed randomly, and detection of animals are accurate, occurring within the camera's detection zone (Rowcliffe, et al. 2008; Nakashima, et al. 2018). The final method, CT-DS, calculates density by the probability of animal detection within the camera detection zone at a particular time (Palencia, et al. 2021; Mason, et al. 2022; Miles, et al. 2024). The accuracy of all these methods are study design and species specific, but all are well established and proven to be effective (Palencia, et al. 2021; Mason, et al. 2022). And just as it is when studying habitat use, camera traps are ideal for determining the population abundance of mesocarnivores in Scotland, as they can collect valuable data over long periods of time with very little disturbance to the environment they are deployed in (Manzo, et al. 2011; Moll, et al. 2016; Miles, et al. 2024).

Camera traps have also been used in conjunction with other non-invasive methods. For example, fur and scat samples can be used to inform researchers on the sex of an individual via genetic analysis (Croose, et al. 2016). Baiting is also a common tool used with camera traps to help lure focal species to a camera trap station (Bartolommei, et al. 2012; Moll, et al. 2016; Randler, et al. 2020; Tourani, et al. 2020). When Tourani, et al. (2020) tested the effectiveness of camera traps to detect mesocarnivores in Norway, they used a total of 30 camera traps and tempted carnivores by baiting each camera site using various scent lures. In the end, they were able to collect a total of 1,401 images capturing different mesocarnivores, including 199 images of pine martens (Tourani, et al. 2020). Through the utilization of Bayesian statistical analysis, the researchers were able to conclude it took an average of 4 days for pine martens to first appear at camera trap sites, noted their apparent dislike for fox, skunk, and caster-based scents, which furthered the distance between an individual marten and the lure marker, and finally, that the average amount of time a marten would remain within the field of view of a camera trap was approximately 5 seconds (Tourani, et al. 2020).

Because camera traps can provide a large amount of data, researchers must also give thought into how to best process and analyse their data (Tabak, et al. 2019). In the past, researchers were expected to identify species present in images or videos manually with their own eyes, a very intense and time-consuming task (Tabak, et al. 2019). Today, camera trap data can be automatically organized through artificial intelligence (A.I.) programs (Hiby, et al. 2013; Tabak, et al. 2019; Leorna, et al. 2022; Santangeli, et al. 2022). While a fairly new technology, A.I. is being developed and utilized by ecologists around the world to improve the efficiency of surveys of species within their own regions (Santangeli, et al. 2022). In some cases, we see ecologists create their own machine learning applications (Hiby, et al. 2013; Tabak, et al. 2019). In their study, Tabak, et al. (2019) used the statistical program R to develop a model that would be able to identify and label images of animals existing in North America at an accuracy of 97.6%. While this is impressive, some researchers may find creating their own model to be just as time-consuming as manually identifying and labelling individual images. Another method of processing camera trap data is the use of online databases; Wildlife Insights is an example of these online platforms, designed for ecologists to upload and share their data and knowledge with others on a global scale (Ahumada, et al. 2020).

1.6 Thesis aims & structure

The aim of this research project was to investigate habitat use and abundance of mesocarnivores and deer around the Eastern side of Loch Lomond in the West of Scotland. This location was ideal as it was not only within the bounds of a National Park, but it offered a diverse range of habitats, including natural woodland. This location was also selected as it lacks previous investigations relating to mesocarnivores, their behaviours, and current population status, information that is beneficial towards carnivora conservation efforts. Data was collected via camera traps, which we deployed for 2-week increments amongst 3 locations during the months of April, May, and June. These months were chosen as to align with the most active time of year for our species of interest. To accomplish our goals, we focused on the following primary research questions:

1. Do species of mesocarnivores around Eastern Loch Lomond show preferences for a particular habitat type, and how does this compare to use of habitats by deer?

2. What is the population abundance of mesocarnivores and deer in Eastern Loch Lomond, and how does this compare to previous estimates for the surrounding area?

I hypothesized that mesocarnivores that have been described in previous Scottish studies as "habitat specific" (i.e. pine martens and badgers), would show a preference for native woodland habitat, due to the likelihood of overlapping with common prey species. In contrast, species more known to be flexible in their habitats as well as their diet (i.e. red fox and deer), would use a variety of habitat types. I also expected there to be less overlap between mesocarnivores and deer in habitats they frequently grazed, as research has shown over-grazing can have an impact on smaller prey species consumed by mesocarnivores. In terms of abundance, my expectation was to provide an estimated population count for all mesocarnivores and deer on a local scale within the bounds of the study area using the REM method and comparing our findings to previous reports (Matthews, et al. 2018; McCulloch and Colquhoun, 2020). In the coming chapters, I will go over the details of my project, how we collected and analysed our data before discussing what our results mean for the species we found around the Eastern banks of Loch Lomond. Finally, I will conclude the potential impact our findings have on mesocarnivore and deer conversation in Western Scotland, as well as what implications this could mean for future projects.

2 Habitat use and abundance of mesocarnivores and deer within Eastern Loch Lomond

2.1 Introduction

Habitats play a crucial role in the lives of every animal, in that, they provide all the necessary resources a particular species needs to thrive within their surroundings. Research has shown that fragmentation or loss of habitat has impacted carnivores significantly, sometimes even leading to localized extinction (Crooks, et al. 2011; Sainsbury et al. 2019). How a particular species uses the habitats available to them and is often visualized on a generalist-specialist spectrum (Pereira, et al. 2012; Moll, et al. 2016; Chiatante, et al. 2017). Historically, carnivores are categorized as being habitat specialists, as they require a specific set of characteristics in their environment to have their needs met (Moll, et al. 2016; Sainsbury, et al. 2019). For most carnivores, this is primarily due to their preference for a specific diet, prey availability and large territory ranges (Crooks, et al. 2011; Chiatante, et al. 2017). For protected mesocarnivores in the United Kingdom, like the pine marten (*Martes martes*), Scottish wildcat (*Felis silvestris*), and badger (*Meles meles*), habitat selection has been connected to woodland ecosystems, a habitat type which only covers approximately 13% of the UK, two-thirds of which is found in Scotland (Burton, et al. 2018; Reid, et al. 2021). This dramatic change in Britain's landscape is in direct contrast to the environmental conditions many British carnivores have evolved to exist in (Caryl et al. 2012; Hester, et al. 2019).

Mesocarnivores may favour the edges of habitats, a behaviour that often occurs in areas of high habitat fragmentation (Kurki, et al. 1998; Rainey, et al. 2009; Bateman, et al. 2012; Caryl, et al. 2012; Moll, et al. 2016; Lovell, et al. 2022; Mergey, et al. 2023). It has been suggested that some carnivores are displaying signs of atypical flexibility in habitat selection, and that this behaviour may be due to prey availability and a higher reward for greater risk of exposure (Caryl, et al. 2012; Moll, et al. 2016; Grabham, et al. 2019). This means that a carnivore like the pine marten, badger, or red fox, may be more likely to put themselves at risk by leaving the safety of their typical habitat (e.g. woodlands), if there are greater resources to be gained within nearby open habitats (e.g. grasslands, meadows, gardens, etc.) in fragmented environments (Lurcherini, et al. 1995; Rainey, et al. 2009; Moll, et al. 2016; Lovell, et al. 2022).

Deer, unlike Scotland's mesocarnivores, are often documented habitat generalists (Pérez-Barbería, et al. 2013; Couzens, et al. 2021); Scotland is home to two prominent native species of cervids: red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) (Latham, et al. 1997; Couzens, et al. 2021); unlike the predators they live alongside, both red and roe deer can be found in nearly every corner of Scotland, in part due to a lack of apex predators and conservation efforts in the 17^{th} and 18^{th} centuries (The British Deer Society, 2024a, The British Deer Society, 2024b). Deer have had a major impact on many of Scotland's ecosystems over the decades through overgrazing, preventing the growth of important plant species (e.g. bog plants, native woodland saplings) (Goddard, et al. 2001; Pérez-Barbería, et al. 2013). This action can indirectly have a cascading effect on other species in the environment; in the context of Scotland's mesocarnivores, the presence of large deer populations has been shown to result in a loss of ground coverage in both woodland and open habitat types, meaning a loss of crucial protective cover for both the predators, as well as many of their prey (e.g. red squirrels, voles, wood mice, etc.) (Buesching, et al. 2011; Villar, et al. 2013).

The Western highlands of Scotland have been overlooked in modern investigations of mesocarnivore populations in the United Kingdom, with very little studies monitoring abundance or habitat use. Therefore, investigating the occurrence and abundance of mesocarnivores, like the pine marten, badger, and red fox, in relation to their habitat in the under-researched location of Western regions of Scotland would provide beneficial insights into how different species are using the environment around them, which in turn, can improve our understand of the conservation status of these unique species and help inform methods of ecological management (Macdonald, 2016; Mergey, et al. 2023). For my research, I set out to investigate the abundance and habitat use of mesocarnivores and deer along the Eastern side of Loch Lomond using camera trap detection. I hypothesised the presence of mesocarnivores would be more prominent in both broadleaf and coniferous woodland habitats based on the expectation these environments would provide both suitable protective cover and a higher prey availability. Since many of Scotland's predators are known to use similar habitat types, this data will also help determine if habitat use our overlapped between the species. While the study I am presenting is on a smaller scale, it is the intention for our results is to provide insight into different species' habitat use, with the potential to compare mesocarnivore and deer abundance, using methods that could be expanded to a larger spatial area around Loch Lomond.

2.2 Methods

2.2.1 Study Area

Fieldwork for this study occurred within three locations along the Eastern side of Loch Lomond between April and June 2024. The primary habitats in this area included both broadleaf and coniferous woodlands, open heather moorland, meadows, and livestock farmland. Each fieldwork location was within the bounds of four 1-km^2 grids, a study design based on a previous study conducted by Manzo, et al. 2011. The land in all study locations is within the bounds of Loch Lomond & the Trossachs National Park, and is managed by ecological organizations, including the Scottish Centre for Ecology and the Natural Environment (SCENE), the Cashel Forest Trust, and the National Trust for Scotland (NTS). The only exception to this was the use of private farmland on Blairvockie Farm located next to SCENE, in which permission for camera trap placement was granted to us by the owner.

Fieldwork within SCENE was conducted from 4 April to 25 April 2024, taking place within the grids NS3796, NS3896, NS3996, and NS3995 as a boundary for this location. The duration of some camera traps deployments for this first study location varied outside the planned 14-day deployment due to weather conditions in the area causing delays in both deployment and collection times. The total number for specific habitats within SCENE includes 9 sites classified as broadleaf woodland, 2 in conifer woodland (one of these harvested at the time of deployment), 4 mixed woodland, 4 open moorland, and 1 livestock farm field, with elevation ranging from 20-380 m (mean ~ 150.26 m ± 111.45). Our second location was Cashel Forest Trust within the grids of NS4093, NS4094, NS4194, NS4195. Camera traps were deployed on 1-2 May and lasted the standard 14-day duration, until 15-16 May 2024 respectively. The habitat types in this location include 7 broadleaf woodlands, 5 conifer woodlands, 5 open moorlands, and 3 open meadows, with elevation ranging from 15-340 m (mean = 169.75 m ± 108.48). Finally, our third location took place from 5-19 June 2024 and was conducted around Ben Lomond within the grids of NS3698, NS3699, NS3600, NS3799. This

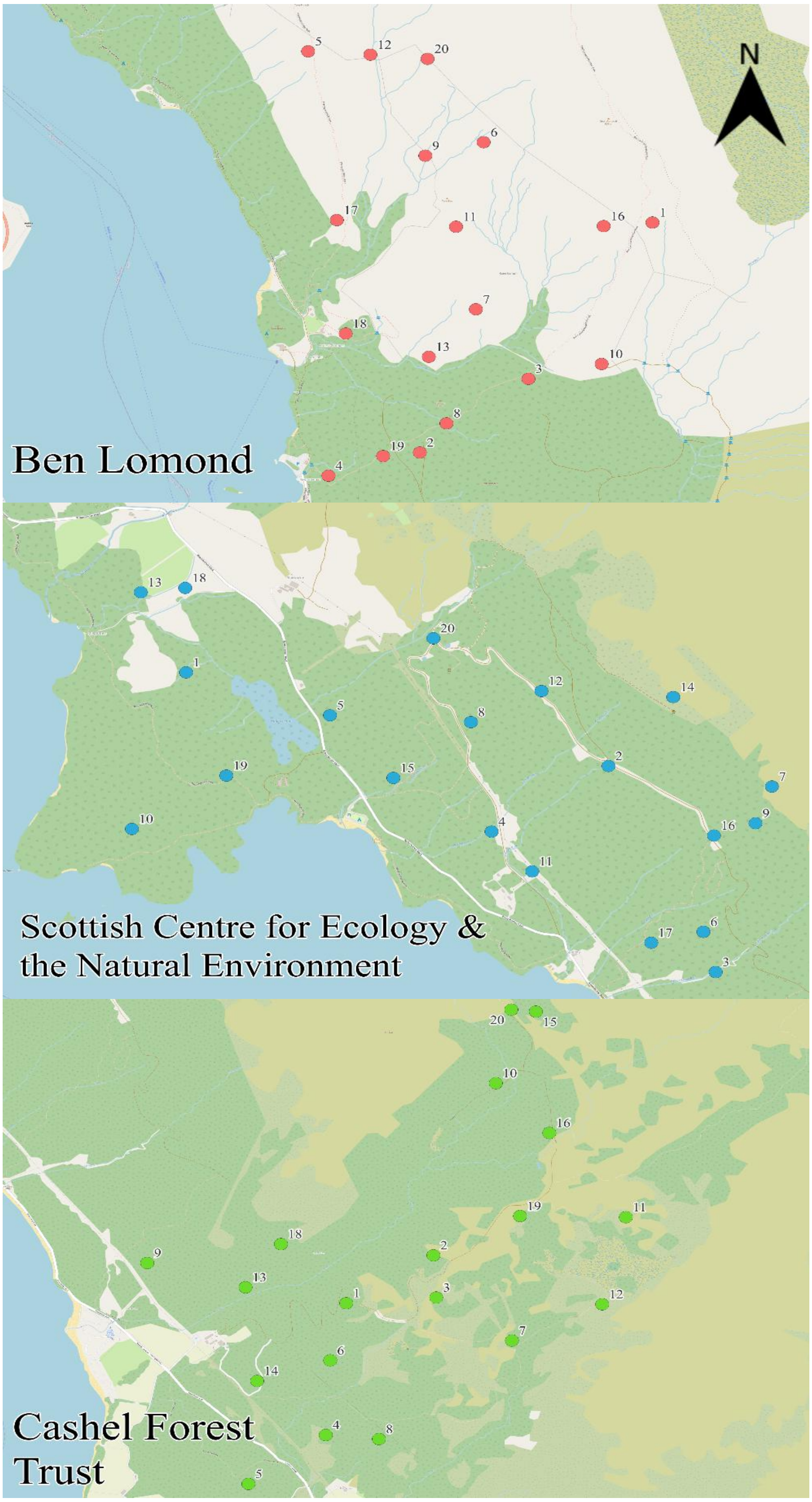


Figure 1: Map of camera traps placements within each study location

land was primarily within the area manged by the National Trust for Scotland (NTS), and included such habitats as 13 open moorlands, 4 broadleaf woodlands, 2 mixed woodland, and 1 conifer woodland. This location had the greatest range in elevation, from 30-450 m (mean = 226 m ± 148.31).

2.2.2 Data Collection

Location coordinates for all camera traps were decided randomly within our chosen grid squares using Quantum Geographic Information System (QGIS). This was done to minimize any bias for certain habitat types and to make sure cameras were within the boundaries of the four 1-km² grids, giving a minimum distance of ~0.44 km between each camera trap. We determined this distance between camera trap placements by calculating the ratio between the number of total camera trap positions within our study locations (60) and the total size of our study area (12 km²); we then inversed the square root of the resulting ratio (5 km²), leaving us with 0.44 km. This distance was used as a standard, but was subject to change if, when out in the field, a camera trap's original location was deemed inaccessible. In this case, the camera trap was placed as close as possible to the original randomized point, with new GPS coordinates noted on site. All habitats in this study can be broadly categorized into two main types: high coverage or low coverage. Habitats of high coverage are those with overhead protective coverage from trees (e.g. broadleaf, coniferous and mixed woodlands); habitats of low coverage can be those with little to no tree coverage (e.g. moorland, meadows, and farmland). The specific type of habitat at each camera trap site was decided during deployment, with additional guidance provided by the Joint Nature Conservation Committee's terrestrial habitat classification scheme (JNCC, 2019), and habitat descriptions as listed by NatureScot, (2023).

Camera trapping

GardePro A3S wildlife cameras (GardePro, Hong Kong) were used at each site; each camera used 8 rechargeable AA batteries and 1 SD-card. In all deployments, camera traps were set to take 3 images and 1 ten-second video clip per motion detection trigger; camera sensitivity was set to "high" to maximize detection of movement by smaller species. Individual camera traps were assigned a number (1-20), which remained the same for every location. At each location, camera traps were strapped securely to either the truck or stump of a tree, a fence post, or a free-standing wooden post if no secure structure was present. Cameras were placed at a height of ~50 cm above the ground (Manzo, et al. 2011; Palencia, et al. 2021), to increase visualization of mesocarnivores and deer. If any vegetation on location was found to be blocking the view of the camera, it was removed. Post-deployment, camera traps were returned to the lab at SCENE where batteries and SD cards were removed. Batteries were set up to recharge and all media data from SD-cards was copied and stored on external storage devices. Baiting was not utilized in this study to avoid interference in typical behaviour (Tourani, et al. 2020). Only one camera trap malfunctioned during the study, SCENE camera trap 19 (S19), which we suspected had battery issues leading to no media being recorded.

Habitat data

Upon initial deployment of camera traps, habitat type was recorded. Details descriptions and data were collected from every camera trap site habitat at the end of each deployment period. This was done to give context to the specific characteristics each habitat had within our study, beyond simple broad categories. At each location, a 10x10 meter square was measured out, with the camera trap at the centre of the bottom side of the square. Inside this perimeter, all species of trees (if present) were recorded, along with the measurement (in centimetres (cm)) of either a circumference or diameter, depending on their size. The maximum number of measurements taken for a single tree species per camera trap site was ten. All species of ground coverage plants were also recorded to give further detail on the location of each camera trap. All habitat data collected was analysed to give context to the difference between the overall landscapes amongst our three study locations.

Figure 2: Examples of habitat data collection during fieldwork

2.2.3 Analysis

Habitat use of mesocarnivores & deer:

Data analysis occurred using multiple programs in multiple stages. The first stage involving sorting and categorizing of media data (e.g. presence of an animal, determining the species), followed by listing the results of the raw data into a Microsoft Excel spreadsheet. Stage two was to take our raw data and plug it into RStudio (R Development Core Team, 2024) and separate the data from species of interest into their own separate comma-separated values files (CSV). Finally, we would then analyse each species in their own set of models in RStudio, exploring the potential relationships between species presence and different habitat types, as well as factors such as time of day and elevation.

Wildlife Insights, an online database that allows users to upload images from camera traps and process them via the program's artificial intelligence (AI), was utilized in our study for the purpose of helping to organize our image data from all camera traps in a time efficient manner. Images were first sorted by the AI and then manually checked by me; this was done in order to ensure that any potential misclassifications made by the AI would be observed, verified and corrected by a real person and make sure all species identification labels were accurate. On Wildlife Insights, most images of species were given labels relating to family group (e.g. Mustelids, cervids, etc.), which when manually checked, would be checked and given a more specific label by myself. On very rare occasions, animals would be missed by the AI; while this was uncommon, it mostly occurred in images with animals at farther (~ > 20 meters) distances from the camera trap; in this case, presence of a species would be manually identified and then labelled accordingly. Additionally, all video data was looked at separately to the image data, as Wildlife Insights is not currently capable of video analysis. Therefore, manual analysis was also utilized for all video data, which was often helpful in determining the potential presence of an animal via visualisation of movement. All images uploaded to Wildlife Insights are under an embargo of two years, at which point all media will be open to the public to help create a collaborative database for other to use.

Statistical analysis was completed using the program R (R v4.4.2), to conduct generalised linear mixed effects models (GLMMs) for each species separately, using the lme4 package (Bate, et al. 2015) in combination with likelihood relationship tests (LRTs) to compare mesocarnivores and other species with habitat characteristics such as the type of habitat, the time of day, and the elevation of the location. Presence (1) /absence (0) of each species was modelled with the explanatory variables of habitat, time of day (morning, afternoon, evening), location (Ben Lomond, Cashel, SCENE) and including interactions between habitat and time of day. The random effect for every model was the specific camera trap name assigned to identify each geographical location. For example, camera traps assigned to locations in SCENE would be labelled with an "S", followed by the corresponding camera number (1-20); this naming method would be repeated with cameras at Cashel (i.e. "C") and at Ben Lomond (i.e. "B").

Different models were tested against each other to examine potential relationships between specific species and their presence in the different habitats, while also looking for any correlations or interactions between habitat and time of day and/or the level of elevation at each site. Model selection would first occur by testing a model with all factors (e.g. habitat, elevation, time of day) and the potential interactions between them. From here, the factor and interaction with the least significant variables in the model would be dropped, and a second model would be made. These models would then be compared to each other using the lrtest() and anova() functions to determine which GLMM model had the best fit and was the most accurate. This process was repeated for all focal species until we had a model with a significant value, and therefore, the best fit. Finally, the best fit was then tested against a null version of the species model, to help further prove the best fit model's validity. When completing the model selection process during statistical analysis in R, it was decided that, for all species habitat models, the elevation factor would be excluded from the final models, as there was a strong correlation between elevation and certain habitats, particularly moorland, a habitat type that within all study locations was exclusively located at higher levels of elevation (range = 100-450 m; median = 340 m; mean = ~303.4 m ± 96.05). For all species, the final model format with the best fit analysed absence/presence count with habitat and time of day, without any interactions between habitat and time of day.

Abundance data analysis:

The population density for all mesocarnivores and deer within our study was estimated using the random encounter model (REM), (Rowcliffe, et al. 2008; Manzo, et al. 2011; Nakashima, et al. 2018). This method was selected as REM has proven to be effective for estimating population densities through camera trap data; specifically when it comes to camera trap images, as other methods such as random encounter and staying time (REST), require long video capture, which can be more time consuming, and take up more storage on a camera trap (Palencia, et al. 2021; Mason, et al. 2022). REM calculates the density of species per square kilometre (km^2) using the following equation:

$$D = \frac{y}{t} * \frac{\pi}{vr(2+\theta)}$$

in which y = the number of recorded animal media (e.g. images/video) and t = total camera deployment time (in days). The combination of r and θ are used to estimate the camera trap sensor's detection zone, with r = maximum distance of detection (in km), θ ('theta') = maximum angle of detection (in radians) which were calculated for each focal species. We determined camera detection zone by taking a video of myself and my supervisors measuring distances (2, 3, 5, 7, 10, 15, and 20 m) from the camera trap, angled to the left, right, and centre. Additionally, a piece of wood, 0.5 m in length, was held at each point of distance, which helped to measure out the lateral distance of detection. We then took those measurement clips and overlayed them with the images of our species of interests to determine their distance and angle of detection from the camera. The estimated day range (speed × activity) is represented by v, in which the levels of activity were calculated using the activity package in R (Rowcliffe, et al. 2014). Calculating activity for our focal species also allowed for observation of diel activity, helping to visualize when species were most active on a 24-hour scale. Like Manzo et al. (2011), who also used REM for their camera trap study on pine martens, we did not track the species in our study, so similarly, we are testing our density model using an average daily distance travelled (km/day) from other studies examining the same focal species present on our study (Kowalcyzk, et al. 2006; Manzo, et al. 2011; McGhee, unpublished data).

2.3 Results

2.3.1 Habitat overview

Habitats within the study consisted of meadow, moorland, farmland, harvested conifer woodland, broadleaf, conifer, and mixed woodland, with moorland (n = 22; ~36.7%) and broadleaf woodland (n = 19; ~31.7%) habitats being the most common within the entire study. SCENE displayed the most diverse group of habitats (n = 6) (S-Table 2), with woodland habitats (65%) making up a majority of

SCENE's environment. Both Cashel and Ben Lomond had a similar number of habitats (n = 4 (Figure 3)), but with Ben Lomond being heavily skewed towards open moorland. Tree diameter also differed significantly between our three study locations (GLM F = 11.59; $p \leq 0.001$). Out of all the locations, Cashel proved to have the greatest tree diameters compared to SCENE and Ben Lomond ($p \leq 0.001$) (Table 1), with no difference in diameters between trees in SCENE and Ben Lomond ($p = 0.99$). This indicates that the age of trees within the Cashel camera traps sites were more mature, on average, compared to the rest of the study.

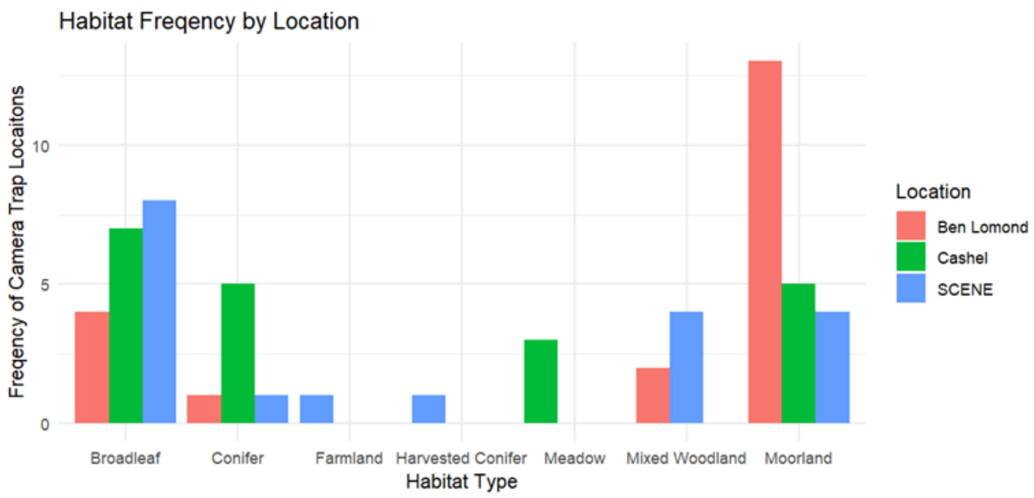


Figure 3: Frequency bar plot of habitats within each study location

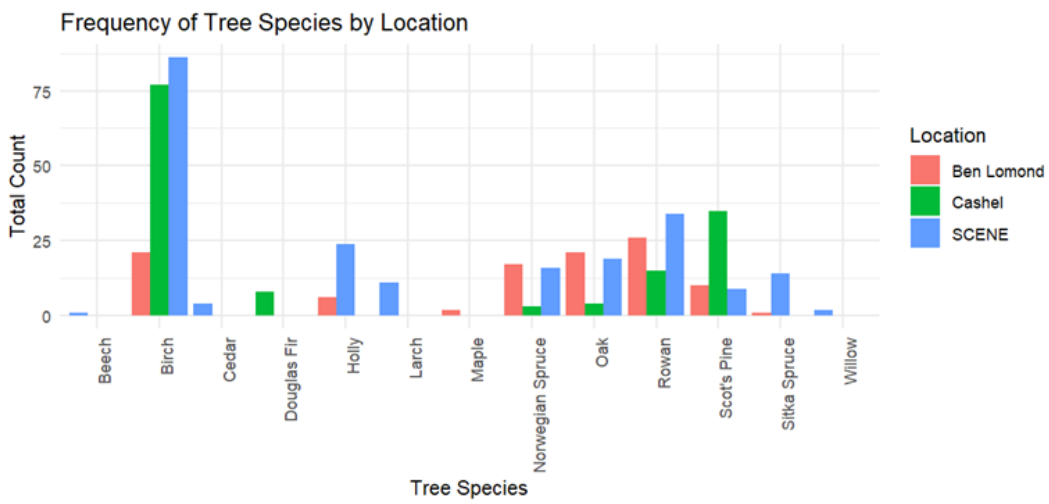


Figure :4 Frequency bar plot of tree species within each study location

Table 1: Average tree diameter (cm) based on study location

Study Location	Mean Tree Diameter (cm)	Estimate	Std. Error	t-value	p-value
SCENE	9.97	0.1017	1.5404	0.066	0.947365
Cashel	16.17	6.3407	1.6707	3.795	**< 0.001**
Ben Lomond	9.81	9.3846	1.2693	7.393	**< 0.001**

*Significant values marked in **bold***

The environmental characteristics of each habitat recorded provided a wide range of both tree species and vegetative coverage, with a total tree count of 477 from 13 different species of trees (Figure 4) and 19 different types of ground coverage plants identified in the entire study (S-Figure 2). The most numerous trees found in the study, making up ~38.6% of the total tree count, was the silver birch (*Betula*

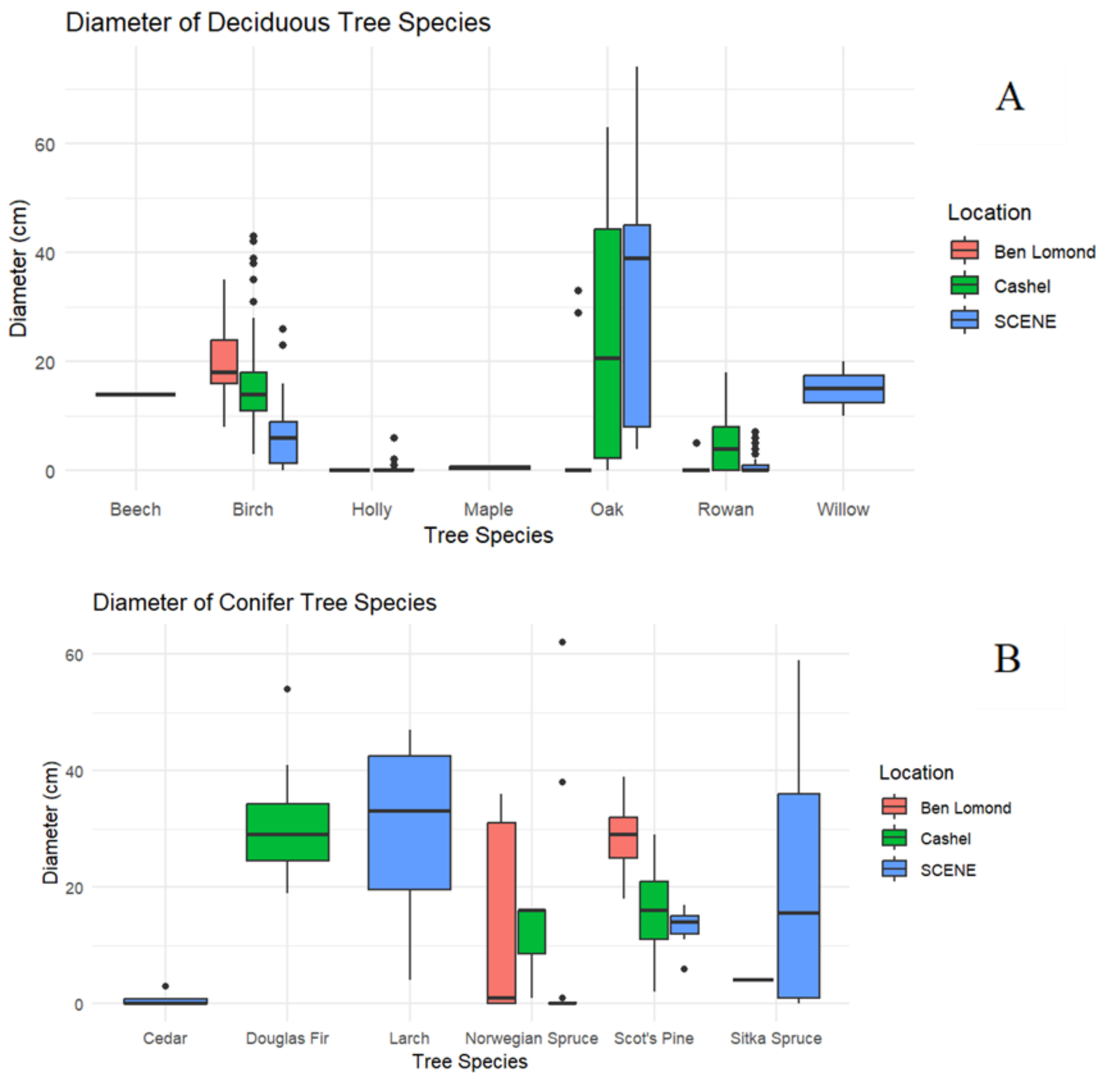


Figure 5: Diameter of deciduous (A) & conifer (B) tree species within each study location

pendula) (n = 184 (Figure 4)) with a mean diameter ~14.34 cm (Figure 5). The only location where silver birch was not the most prominent species of tree was at Ben Lomond, where rowan (*Sorbus aucuparia*) was the most numerous tree species (n = 26 (Figure 4)). Birch was also found to be the most numerous species of tree in both broadleaf (n = 131) and mixed woodland (n = 25) habitats. While broadleaf camera trap locations had the highest total count of trees recorded throughout the study (n = 222), the most diverse habitat with the highest variety of tree species was mixed woodland, with 10 species recorded (S-Figure 1). Conifer woodlands had the least variety of trees out of the woodland habitats, with only 7 species recorded, the most numerous being Scot's pine (*Pinus sylvestris*) (n = 33) (S-Figure-1).

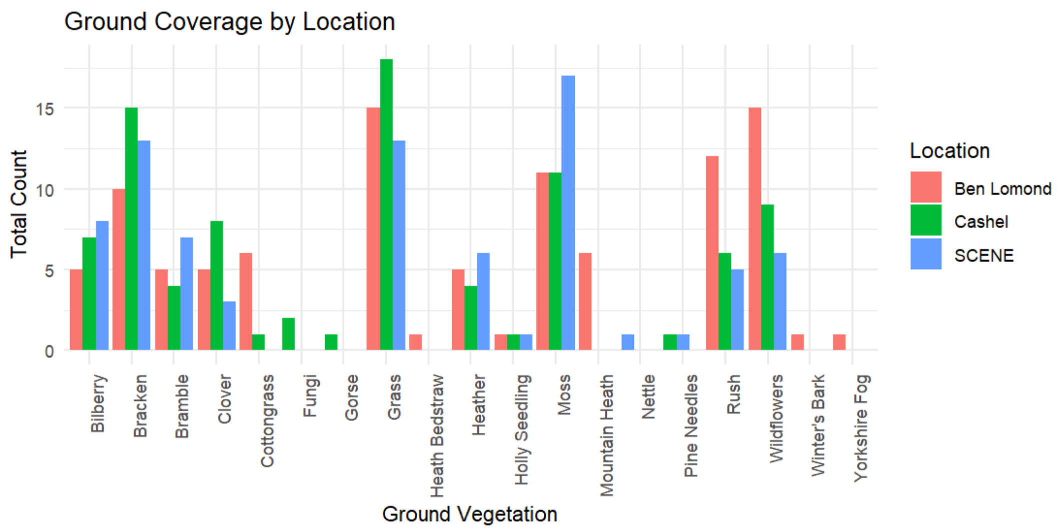


Figure 6: Ground coverage total counts based on study location

When comparing the different species of plant vegetation that made up the ground coverage for each camera trap sites, the top three most prominent types of vegetation present were found to be grass (n = 46), moss (n = 39), and bracken (n = 38). Grass was the most common vegetation present at Cashel (n = 18), it was also tied for the most common at Ben Lomond, along with wildflowers (n = 15). The only exception to this was SCENE, which had moss (n = 17) as it most common vegetation type recorded (Figure 6). In terms of ground coverage amongst the habitats at each camera trap, moorland was the most diverse, with 14 different species of vegetation recorded, followed by broadleaf woodland with 12 species, and mixed woodland with 10 species. In moorland, the most prominent types of vegetation were grass (n = 17), rush (*Juncus inflexus*) (n = 15), and wildflowers (n = 13). For broadleaf, bracken (*Pteridium aquilinum*) was the most common species of ground coverage (n = 17), along with grass (n = 16), and moss (n = 14) (S-Figure 2).

2.3.2 Habitat use based on species detection

During our study, a total of 24 animal species were identified at 40 out of 60 camera trap sites. Species identified included 3 mesocarnivores (e.g. pine marten, badger, red fox), 2 deer species (red deer and roe deer), 2 livestock (domestic cattle (*Bos tarus*) and domestic sheep (*Ovis aries*)), 2 rodents (red squirrel (*Sciurus vulgaris*) and wood-mouse (*Apodemus sylvaticus*)) and 15 species of birds (with an extra category consisting of unidentifiable birds) (S-Table 1). Model selection for all species determined that the model with the best fit examined the effects of habitat plus time of day, without an interaction between them. This was dropped due to a non-significant Anova result ($p > 0.05$) for mesocarnivores and deer alike. As mentioned in section 2.2.3., the effect of elevation was dropped from all models as it was too closely linked with specific habitat types, particularly moorland. All models contained the random effect of location and camera trap.

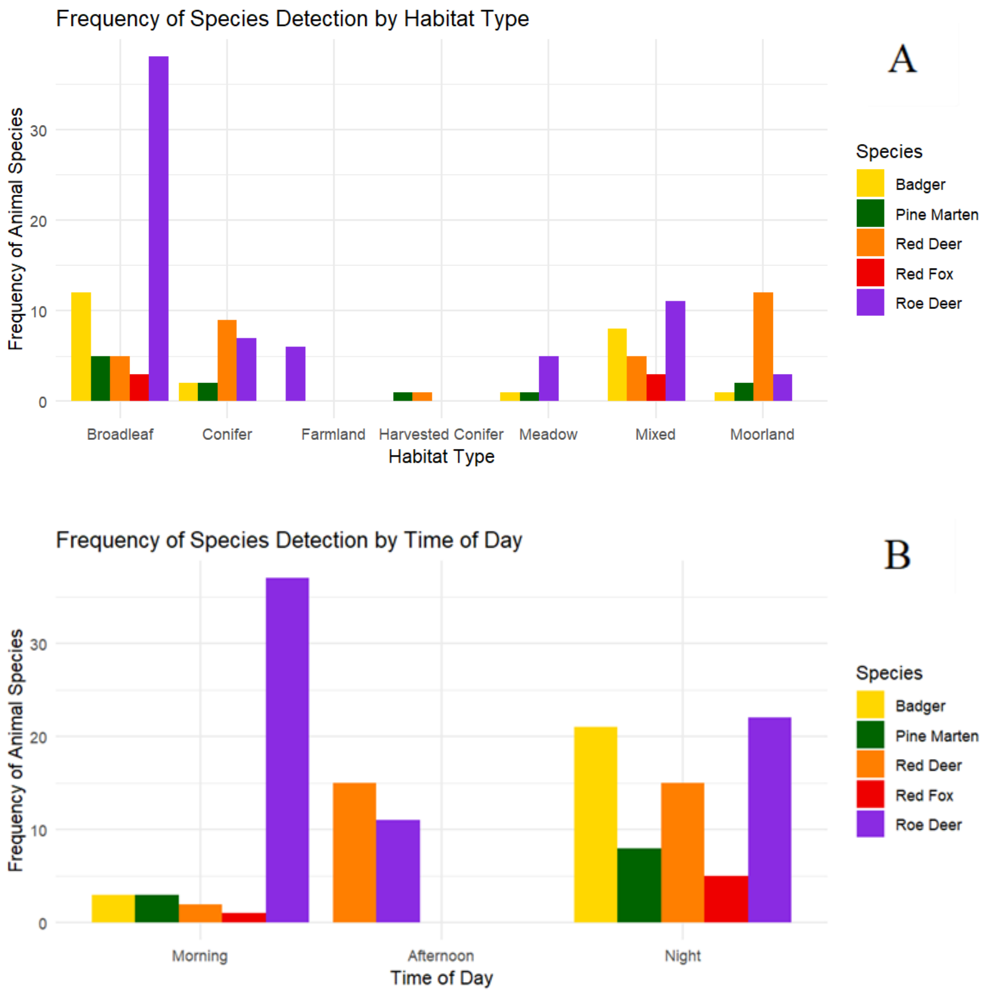
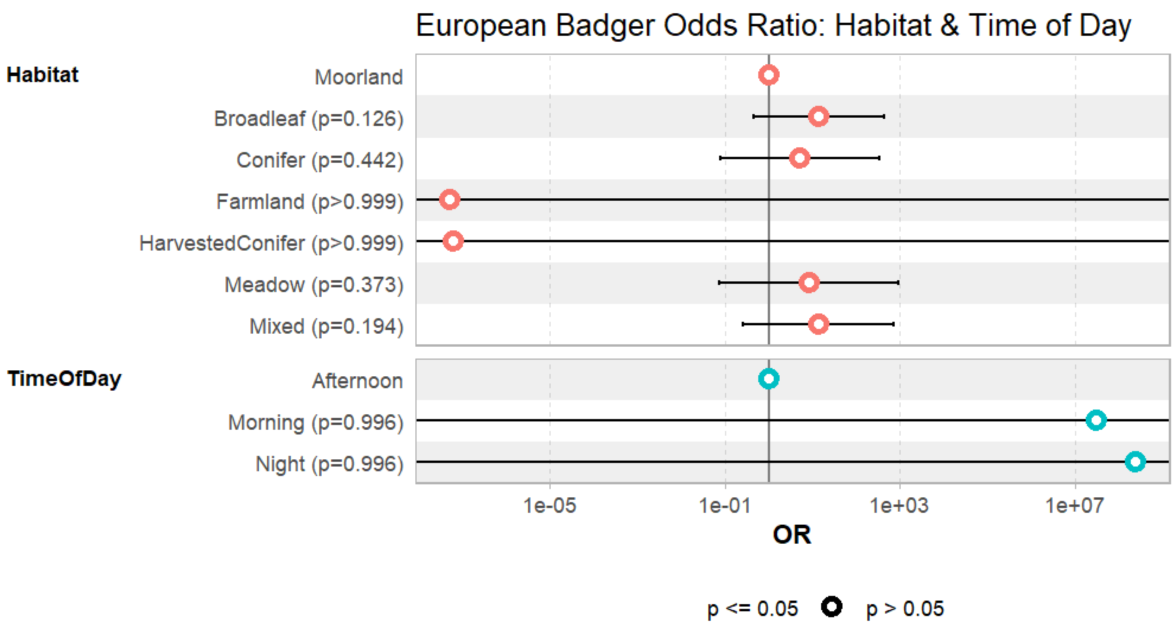


Figure 7: Frequency bar plot of species detected based on habitat (A) & time of day (B)

European badger

Badgers were the most numerous mesocarnivore captured, with a total count of 24 sightings (count of 22 within modified model data), with most sightings occurring within SCENE (n = 11) and Cashel (n = 12) (Figure 9). Badgers appeared in five habitat types, including broadleaf woodland (n = 12), conifer woodland (n = 2), mixed woodland (n = 8), meadow (n = 1), and moorland (n = 1). The range of elevation for camera traps with badger sightings was between 40-300 m (mean = 124.54 m ± 80.05). According to the final best fit model, badger presence could not be explained by any significant habitat values within the study. The model's odds ratio did suggest broadleaf woodlands as having increased odds of being used by badgers within the study (Figure 8). Time of day was also shown to not have significant impact on badgers either (S-Table 5). The explanatory variables in the final badger model improved fit compared with null model included $\chi^2 = 39.254$, *df* = 8, and $p = < 0.001$.



**** Note: intercept reference values for OR = 1***
***** Neither reference vales significant in glmer model***

Figure 8: European badger odds ratio for habitat and time of day

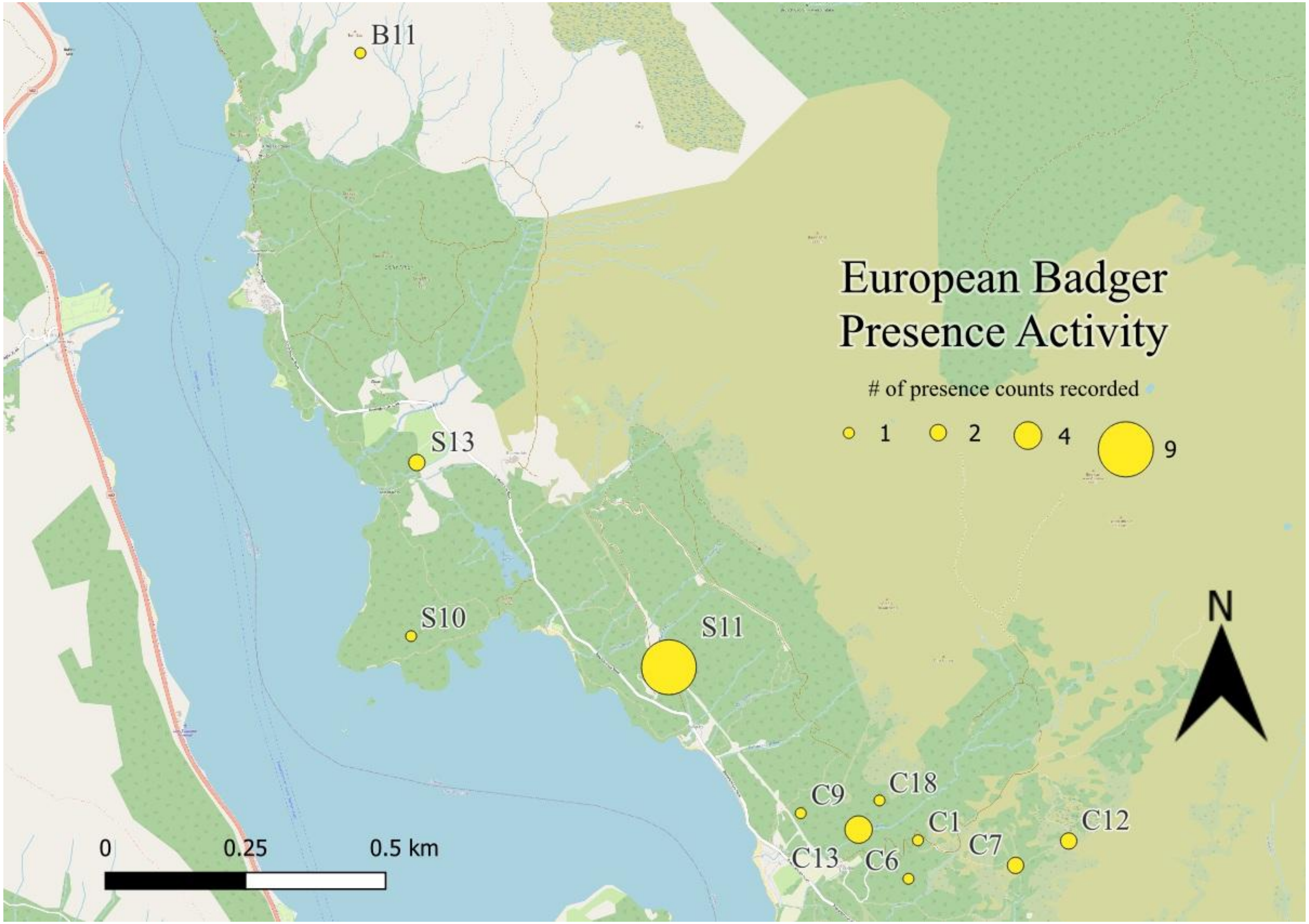
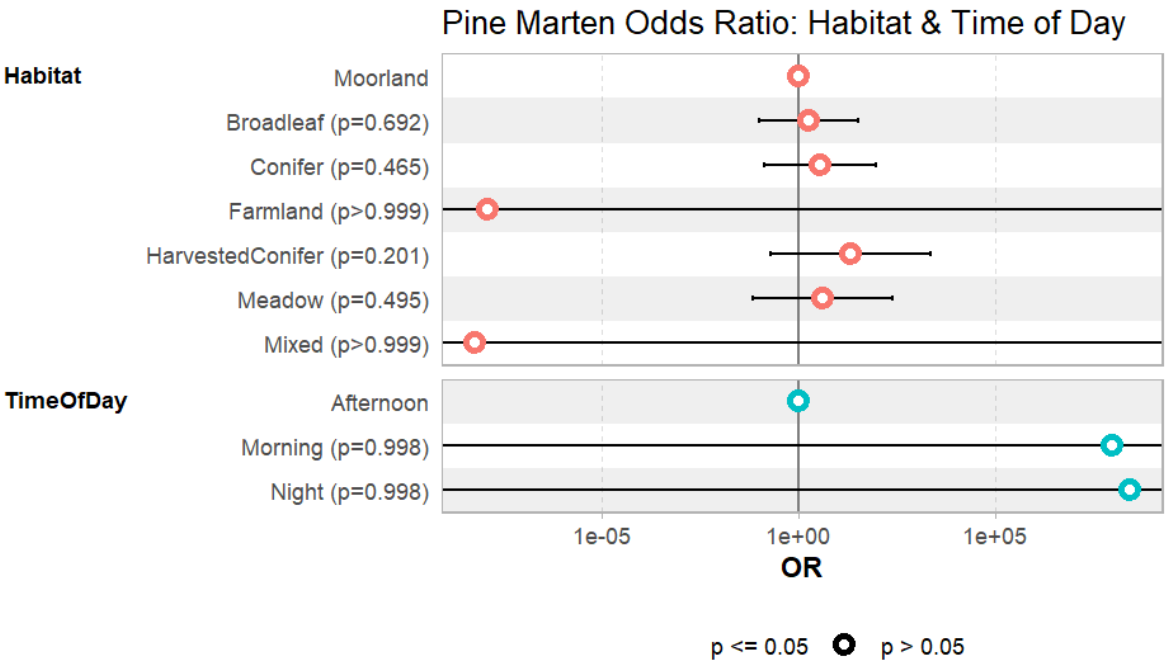


Figure 9: Map of camera trap locations with European badger presence activity

Pine marten

A total count of 11 pine martens were captured within the study in both in the raw and modified model data. Most sightings occurred in at Cashel (n = 9), SCENE had a total of two sightings, while only one pine marten captured at Ben Lomond (Figure 11). Pine martens appeared most often in broadleaf woodland (5), followed by moorland (2), conifer woodland (2), meadow (1), and harvested conifer plantation (1). The range of elevation for pine marten sightings was between 30-300 m (mean = 165 m ± 96.69). According to the final best fit model, pine marten presence was not explained by displayed by habitat type or time of day within the study, with the model's odds ratio displaying a weak increase in odds for broadleaf, conifer and harvest conifer, although the latter is likely skewed due to the habitat type only existing at one camera trap site (Figure 10; S-Table 6). When tested against the null model, the pine marten model possessed explanatory variables of $\chi^2 = 15.339$, $df = 8$, and $p = 0.05288$.



**** Note: intercept reference values for OR = 1***
***** Neither reference value significant in glmer model***

Figure 10: Pine marten odds ratio for habitat and time of day

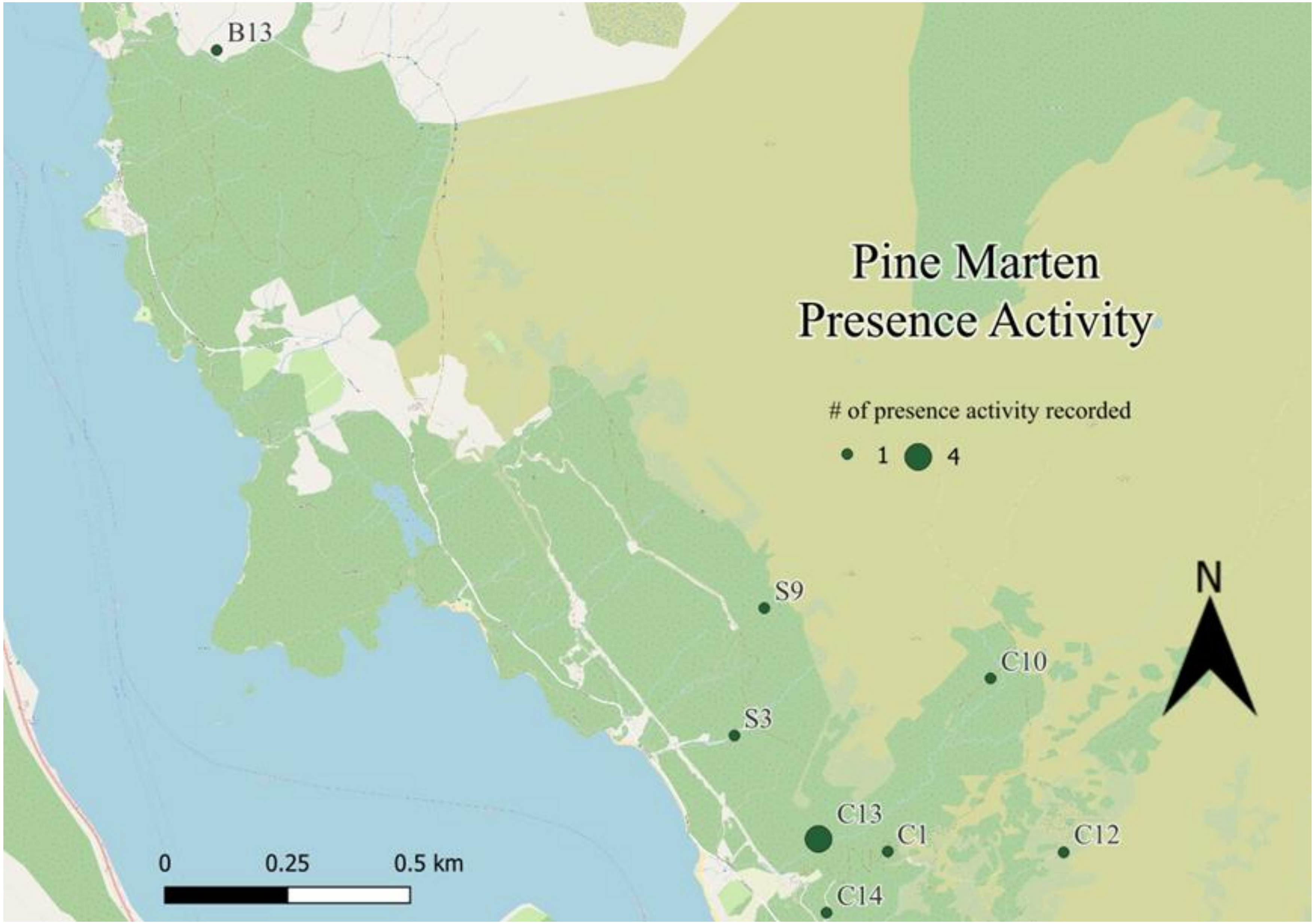
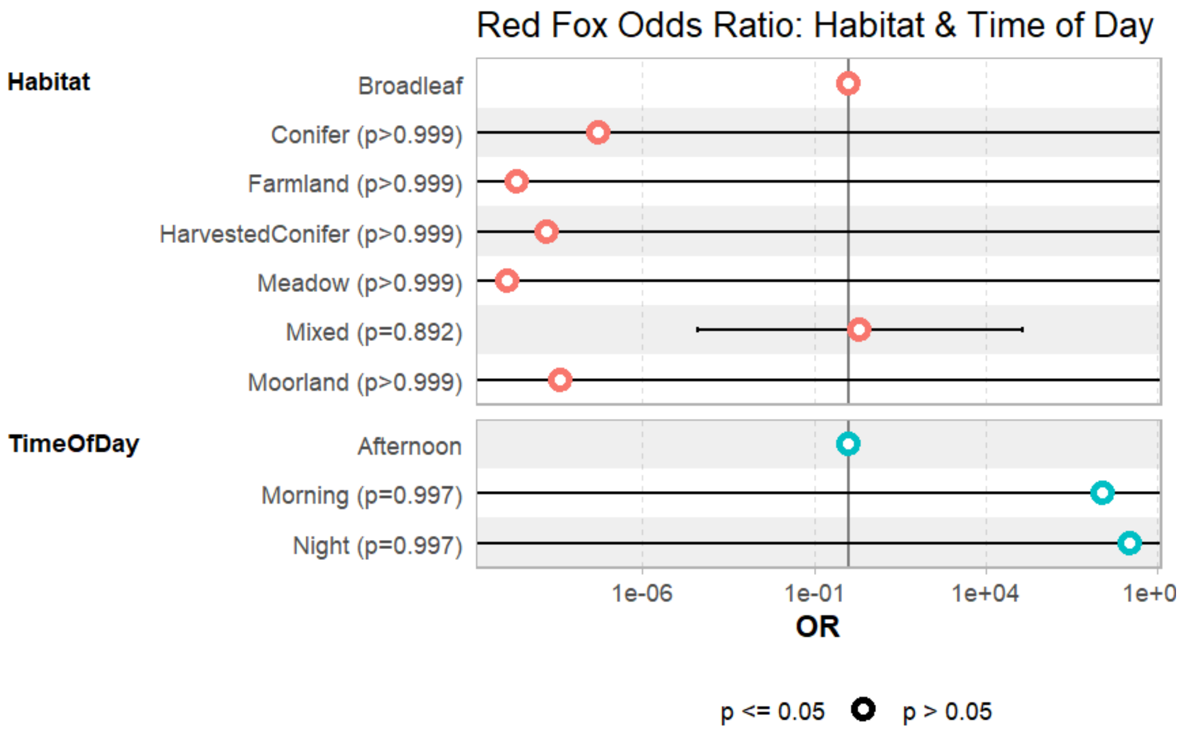


Figure 11: Map of camera trap locations with pine marten presence activity

Red fox

Red fox was the least common species of mesocarnivore, with a total of 6 individuals (same in modified model data) seen within the study; most sightings occurred at SCENE (n = 5) (Figure 13). Habitats red foxes were shown to be present in included broadleaf woodland (3) and mixed woodland (3), occurring at camera trap locations between 60-180 m of elevation (mean = 100 m ± 56.56). In the final model, the presence of red foxes could not be explained by habitat type or time of day, with the odds ratio for the model being highly skewed (Figure 12; S-Table 7); these results are likely due to the low count for foxes throughout the entire study. When tested against the null model, the red fox model with the best fit possessed explanatory variables of $\chi^2 = 9.3805$, $df = 8$, and $p = 0.3112$.



**** Note: intercept reference values for OR = 1***
***** Neither reference value significant in glmer model***

Figure 12: Red fox odds ratio for habitat and time of day

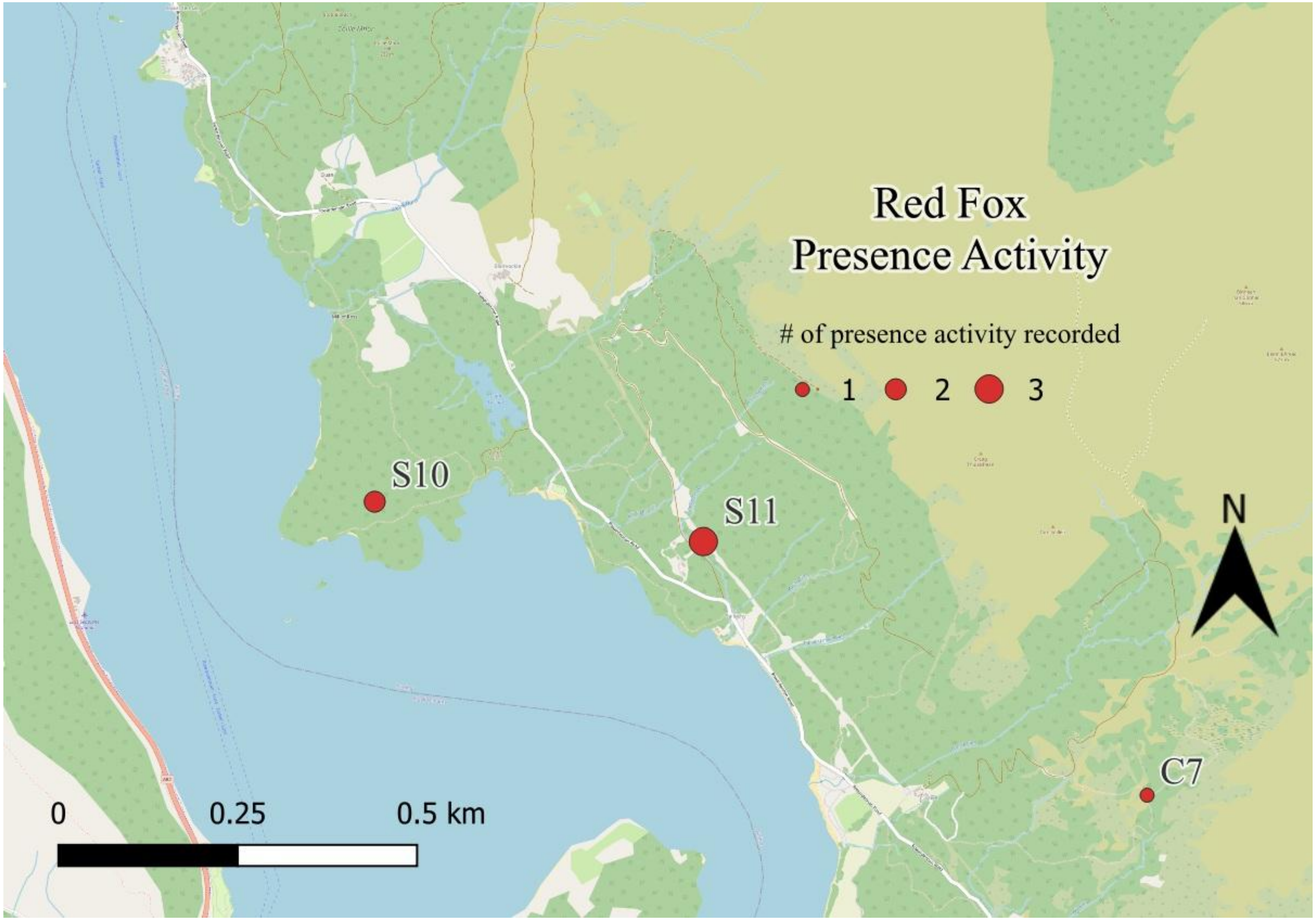
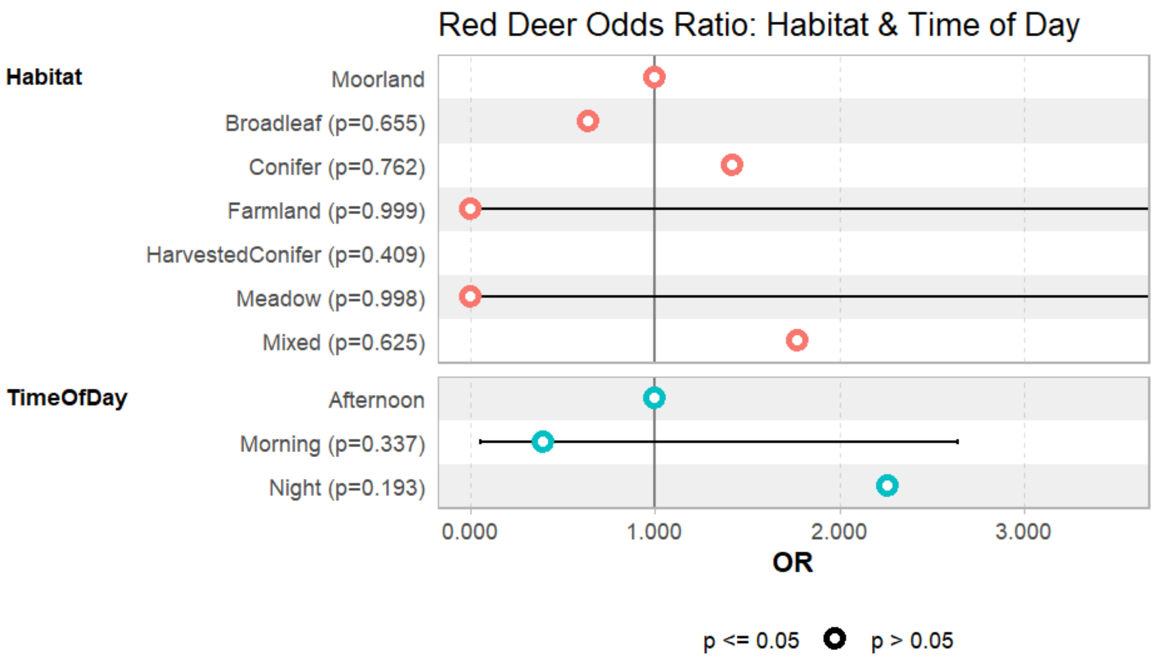


Figure 13: Map of camera trap locations with red fox presence activity

Red deer

The total count of individual red deer within our study was 32 (count of 18 in modified model data), with most sightings occurring at SCENE (n = 15) (Figure 15). Red deer were present in broadleaf woodland (4), conifer woodland (3), moorland (7), mixed woodland (3), harvest conifer plantation (1), with all camera trap locations with red deer sightings occurring at an elevation between 15-300 m (mean ~ 194.58 m ± 118.3). Habitat use model reveal a strong preference for moorland ($p < 0.001$) above all other habitat types present in the study (S-Table 8), which correlates with the observations from the camera traps. The odds ratio for the model displayed a decreased odds for broadleaf, likely due to the lower presence count in relation to the habitat's overall availability. In contrast, conifer woodland had increased odds for red deer presence; this was the highest odds for conifer for all species in the study (Figure 14). There were no significant values shown for time of day within the model (morning, afternoon, evening > 0.1) (S-Table 8). When tested against the null model, the red deer model with the best fit possessed explanatory variables of $\chi^2 = 10.583$*, $df = 8$, and $p = 0.2265$.*



**** Note: intercept reference values for OR = 1***
***** Moorland & Afternoon p < 0.001 in glmer model***

Figure 14: Red deer odds ratio for habitat and time of day

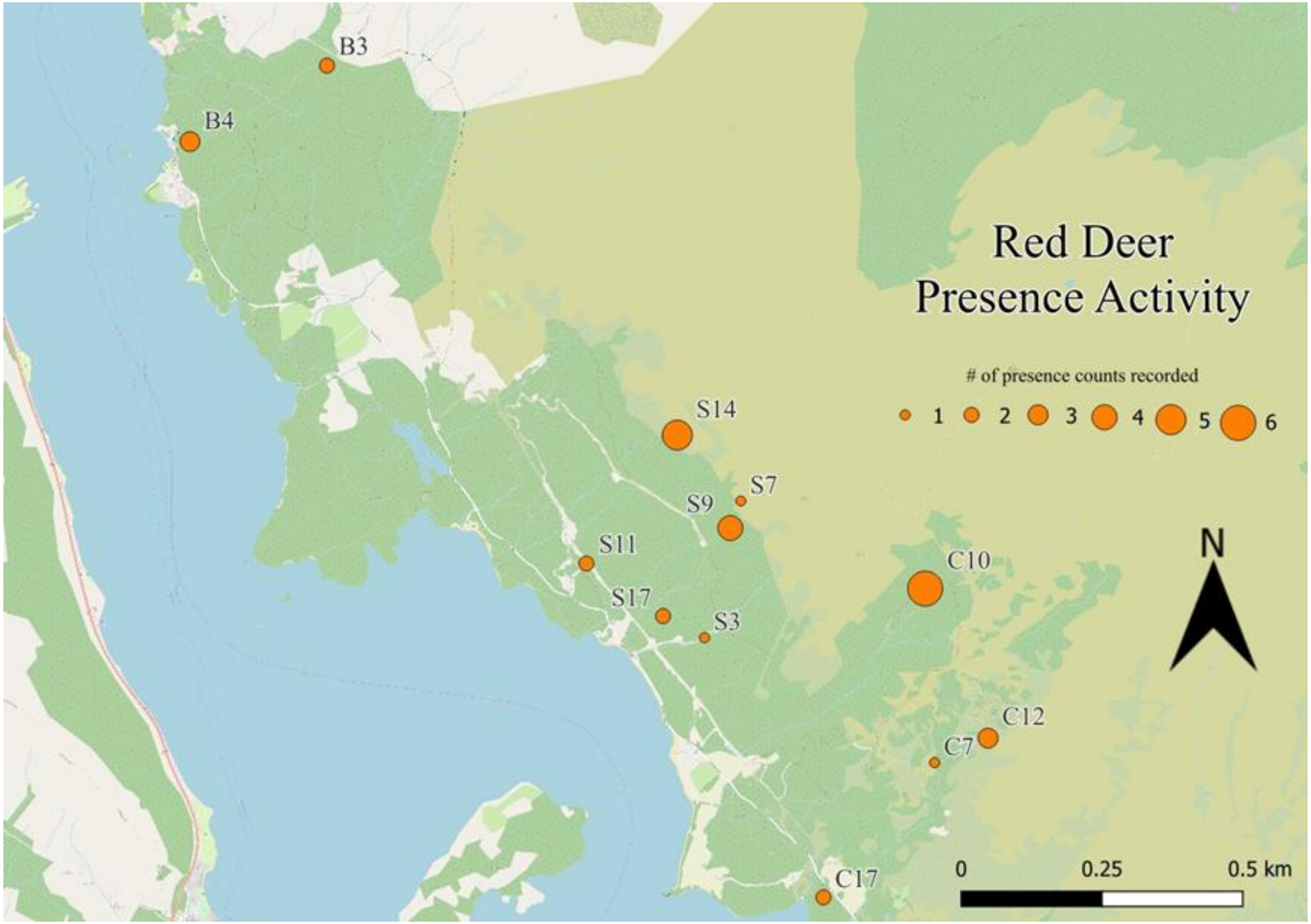
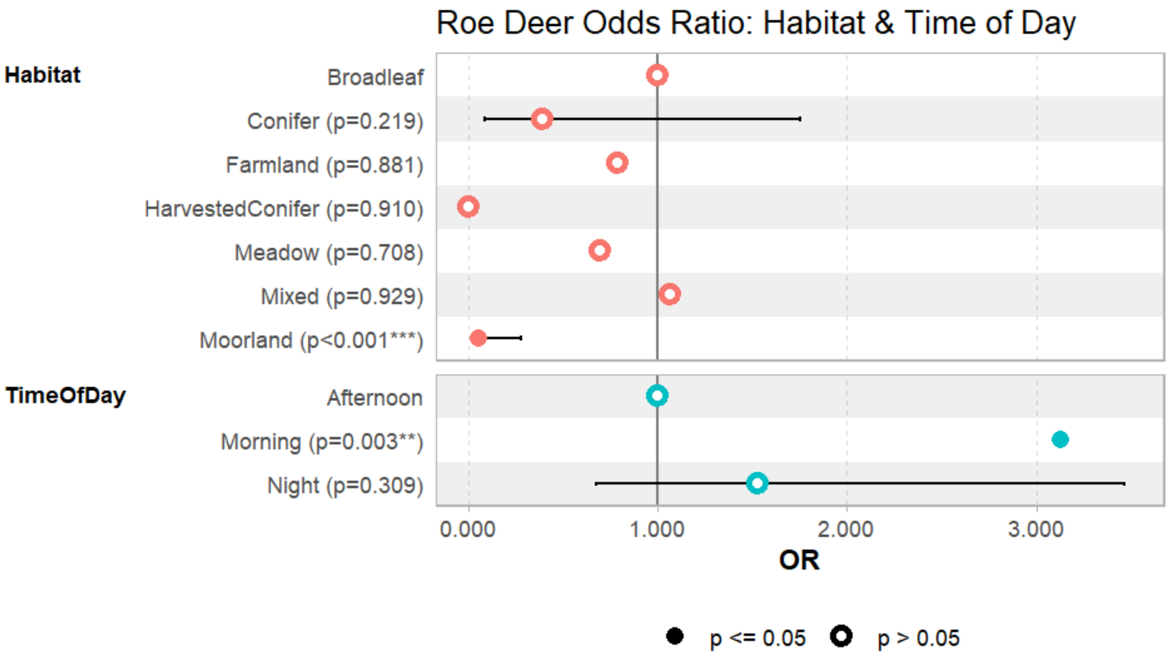


Figure 15: Map of camera trap location with red deer presence activity

Roe deer

A total of 70 individual roe deer (count of 54 in modified model data) were found within our study, with most sightings occurring at SCENE (n = 35) (Figure 17). In our habitat selection model, roe deer showed strong significant results for both broadleaf woodland and open moorland ($p < 0.001$), but not mixed woodland (p = 0.929181) or harvested conifer (p = 0.909780). Based on the model's odds ratio and the actual counts for roe deer presence, interpretation of these results can conclude roe deer displayed a strong preference for broadleaf woodland (n = 32), and a contrasting strong avoidance for moorland (n = 2) (Figure 16). Roe deer were also more likely to be captured during the morning (e.g. between 4:00-11:59 (p = 0.002541)), which is further confirmed by the increased odds displayed by the odds ratio (Figure 16). In terms of elevation, roe deer appeared at a wide range of camera traps, located between 15-380 m (mean = 105.23 m ± 110.56) (S-Table 9). When tested against the null model, the final roe deer model had a better fit then the null, with explanatory variables of $\chi^2 = 30.548$, $df = 8$, and $p = 0.0001691$.



**** Note: intercept reference values for OR = 1***
***** Broadleaf & Afternoon p < 0.001 in glmer model***

Figure 16: Roe deer odds ratio for habitat and time of day

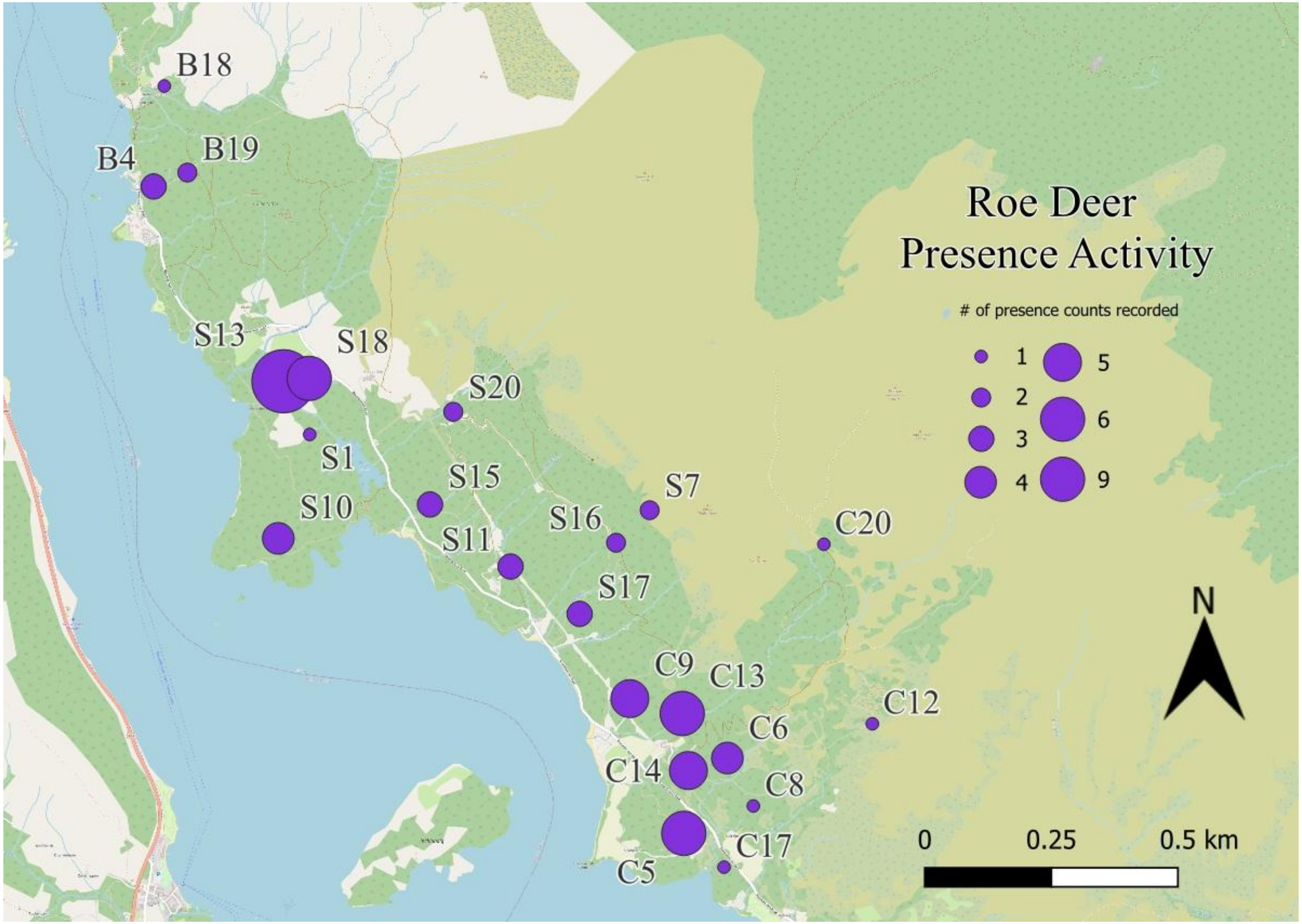


Figure 17: Map of camera trap location with roe deer presence activity

2.3.3 Population abundance of mesocarnivores and deer

Between April and June 2024, our camera traps captured a total count of 11 pine martens, 24 badgers, 6 red foxes, 40 red deer, and 78 roe deer. These individual counts varied amongst the three study locations; for all mesocarnivores and deer, Ben Lomond was the least active location, with Cashel as the most active for pine martens and badgers, and SCENE the most active for both red and roe deer and foxes. Activity levels calculated in R revealed similar hours of nightly activity across all mesocarnivores, while daytime hours of 9:00-18:00 having an activity frequency level of zero (Figure 18), suggesting the mesocarnivores in our study area are primarily nocturnal in their activity behaviour. Red deer also displayed a decline in activity during the morning and mid-day (~5:00-14:00), showing a higher frequency of activity in the evening (~17:00-00:00). Roe deer activity

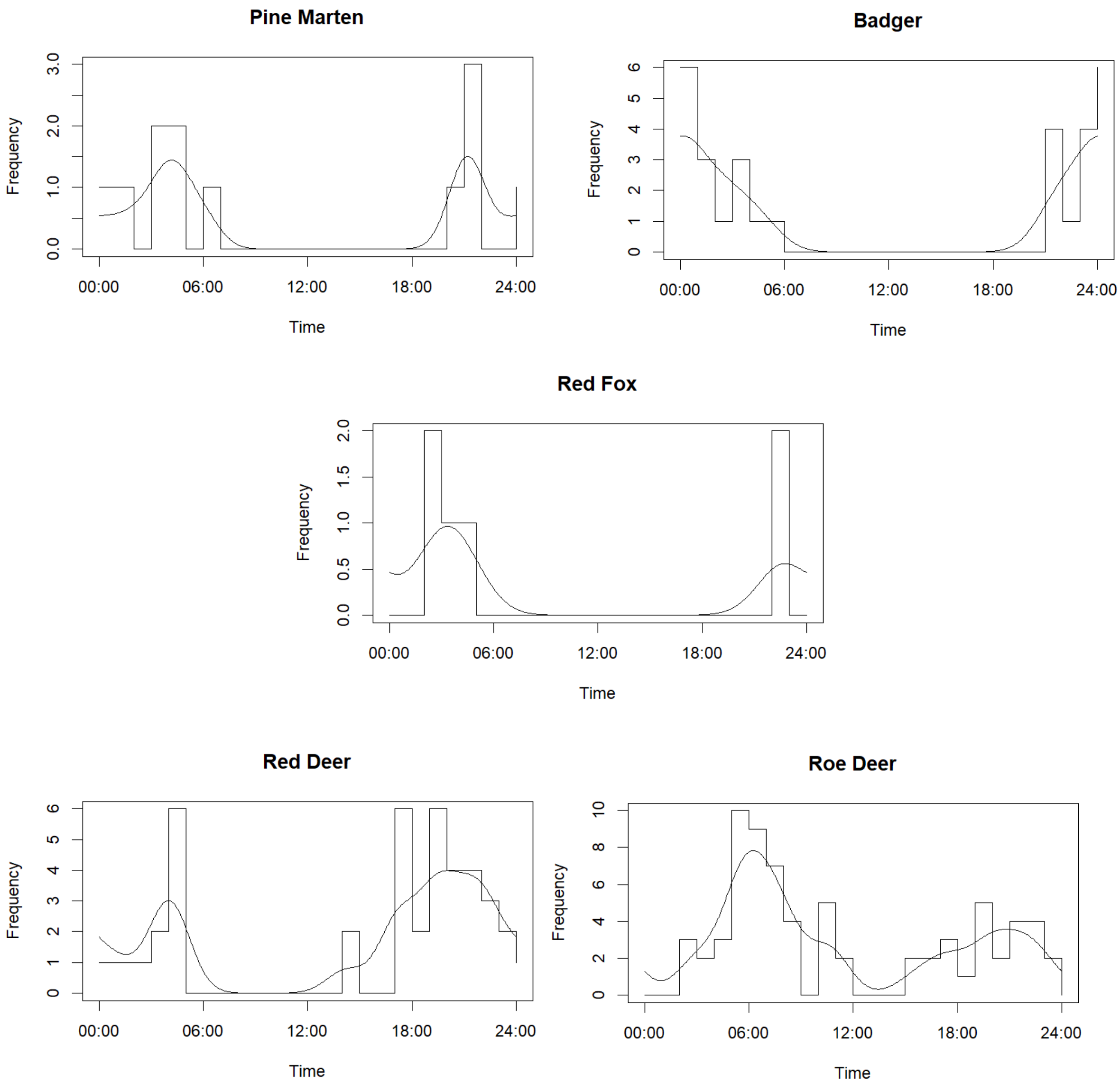


Figure 18: Levels of activity for mesocarnivores and deer recorded in study

peaked in frequency during the early hours of the morning (~5:00-8:00), with consistent levels of activity throughout the day (Figure 18).

Population abundance density calculated for our mesocarnivores was estimated at approximately 2.8 pine martens, 8.9 badgers, and 1.8 red foxes per km^2 at SCENE, 13.9 pine martens, 11.4 badgers, and 0.5 red foxes per km^2 at Cashel, and lastly, 2.7 pine martens, 1.5 badgers, and 0 red foxes per km^2 at Ben Lomond. For the deer, population density at SCENE was 4.9 red deer and 3.2 roe deer per km^2, 2.4 red deer and 5.7 roe deer per km^2 at Cashel, and 1.2 red deer and 1.3 roe deer per km^2 at Ben Lomond. These results combined bring average estimates (95% CI) of 6.47 (-3.32 – 5.32) pine martens, 7.27 (-1.17 – 3.17) badgers, 0.77 (-0.32 – 1.66) red foxes, 2.83 (0.59 – 1.79) red deer and 3.4 (0.61 – 1.6) roe deer for the entire study (Table 2).

Table 2: Average estimates for mesocarnivores and deer

Density (animals/km²)						
Species	**SCENE**	**Cashel**	**Ben Lomond**	**Mean ± SD**	**CI (low)**	**CI (High)**
Badger	8.9	11.4	1.5	7.27 (± 5.15)	-1.17	3.17
Pine Marten	2.8	13.9	2.7	6.47 (± 6.42)	-3.32	5.32
Red Fox	1.8	0.5	0	0.77 (± 0.94)	-0.32	1.66
Red Deer	4.9	2.4	1.2	2.83 (± 1.87)	0.59	1.79
Roe Deer	3.2	5.7	1.3	3.4 (± 2.19)	0.61	1.6

2.4 Discussion

2.4.1 Habitat use

In our original hypothesis, we held the assumption that mesocarnivores observed to be more habitat specific, such as pine martens and badgers, would be more likely to use woodland environments, compared to a more generalist predator, like a red fox, which we assumed would be more flexible, with presence in both woodland and open environments (e.g. moorland and meadows). Based on our data results, all species of mesocarnivores captured during our study displayed no specific preference for any habitat type. This was most likely due to the small sample sizes recorded for our mesocarnivores, which in itself was not a completely unexpected result given the tendency for mesocarnivores in Scotland to exist within large territories and, in the case of pine martens and red foxes, as solitary species (Croose, et al. 2016; Moll, et al. 2016; Matthews, et al. 2018; Sainsbury, et al. 2019). But while our models for habitat use of mesocarnivores resulted in no significant values, the evidence collect from our camera traps did lean in favour of our original hypothesis, with badgers, pine martens, and red foxes captured primarily within habitats with overhead coverage (~89.7%); broadleaf woodland, which accounted for ~31.7% of this study's camera trap sites, was the most common habitat type, making up ~51% of the total combined mesocarnivores habitat data. As discussed previously, mesocarnivores tend to favour woodland habitats as the tree canopy can provide protective coverage to both mesocarnivores and their prey, some of whom in Scotland share many of the same predators (Cavallini & Lovari, 1991; Rainey, et al. 2009; Byrne, et al. 2012; Caryl, et al. 2012; Moll, et al. 2016). Where our study area was located within Loch Lomond and the Trossachs National Park, large birds of prey such as golden eagles (*Aquila chrysaetos*), ospreys (*Pandion haliaetus*), kestrels (*Falco tinnunculus*), and sparrowhawks (*Accipiter nisus*), among others, have previously been recorded in this area (Loch Lomond & the Trossachs National Park, 2025), and while not a common occurrence, young badgers or pine martens may be at potential risk for predation from these species of birds. Woodland habitats also provide a variety of supplementary diet materials outside of traditional prey, including fruiting plants of bilberries and bramble bushes, as well as the opportunity for gathering eggs from nesting birds, in the case of our study locations (Gurnell, et al. 1994).

Additionally, our data results for mesocarnivores leans into those similarly made within other studies, such as Matthews, et al. 2018, which showed the importance of woodland habitats to mesocarnivores, especially in fragmented landscapes similar to the Eastern banks of Loch Lomond. As outside the woodland environments, non-forested site where mesocarnivores were captured most often on the border of or surrounded by patches of woodland. Therefore, based on what we know from previous studies, it can be theorized that, in these locations, pine martens, badgers, or red foxes may feel comfortable being present as the safety of overhead coverage is within an easy to access distance (Lucherini, et al. 1995; Rainey, et al. 2009; Byrne, et al. 2012; Caryl, et al. 2012; Matthews, et al. 2018). As for the more unique sightings, such as the pine marten in a harvested conifer plantation, we hypothesize that this habitat type may appeal to a pine marten for a couple of reasons. It is possible that prior to its harvest, this conifer forest house the former site of pine marten dens, or alternatively, post-harvest, this habitat became an ideal site for prey, particular rodents (e.g. wood mice, field voles, etc.), which were captured on camera or observed on sight during camera trap deployment.

In contrast, we predicted in our hypothesis that deer would be more likely to be present within a variety of habitats, both woodland and open habitats such as moorlands, meadows, and farmland, as these would be ideal for grazing. This expectation for deer habitat usage was partially confirmed, with red or roe deer being captured at least once in all habitat types presented in the study. However, our habitat use models did conclude a difference in presence between red and roe deer, with the former opting for open moorlands, while the latter proved to have a strong link to broadleaf woodland. These results are consistent with some previous studies in Scotland and other European countries, in which red and roe deer here found to have some difference in habitat use (Hinge, 1986; Latham, et al. 1997; Morellet, et al. 2011; Pérez-Barberia, et al. 2013). As with mesocarnivores, one big reason for this contrast in habitat choices comes down to specific dietary differences between the two deer species. Roe deer are known to be more particular in their diets, seeking out low-fibre, woody vegetation, such as bramble, bilberry shrubs, and tree samplings, all of which were commonly noted within our study locations. Meanwhile, red deer are far less selective in their food, preferring to graze on high-fibre grasses (which make up the bulk of their diet) and other readily available plants (Latham, et al. 1997; Couzens, et al. 2021; Čupić, et al. 2023). With all this in mind, it is highly likely that diet, above any other factor, was the greatest influence on cervid habitat use within our study.

2.4.2 Abundance

There are no recent studies or surveys on mesocarnivore populations specific to our study location around Loch Lomond; previous large-scaled population densities given for mesocarnivores in Scotland often provide wide ranging estimates. This is likely due both the elusive behaviours of mesocarnivores and the different varieties of data collect methods (i.e. camera traps, scat collection, sett/den surveys, public reporting, etc.) (Manzo, et al. 2011; Matthews, et al. 2018; Sainsbury, et al. 2019). As for our own abundance estimates for population density of mesocarnivores and cervids, the REM method proved to be effective for our study design. Therefore, we believe our estimates for mesocarnivores are the first of their kind to be reported specifically for Eastern Loch Lomond.

Estimates for pine marten populations within the whole of Great Britian range from 1,600-8,900 with recent studies citing Matthews, et al. (2018) estimate of 3,700 individuals in all of Scotland, with nationwide estimates leave us with a figure of 0.12 – 0.82 pine martens per km² (Scottish Wildlife Trust, 2016). For our study, the average pine marten estimate based on our three REM calculations is ~ 6.5 pine martens per km², which is significantly higher when compared to the average density per km². However, this does not necessarily mean our estimate for pine martens is inaccurate. Pine martens in Scotland have been documented to exist in higher densities locally in areas of moderate forest fragmentation, (Caryl, et al. 2012; Kubasiewicz 2014; Matthews, et al. 2018). As we have discussed in both chapters 1 and 2, habitats are the foundation for a species ability to thrive, whether that be from a dietary, mating, lodging, or risk-avoidance perspective (Červinka, et al. 2014; Smith, et al. 2018; Church, et al. 2022). It is possible that, for our combined study areas, pine marten territorial ranges may be more likely to overlap to incorporate access to necessary resources, and thus, potentially explain our final density average (Caryl, et al. 2012; Matthews, et al. 2018).

Our most abundant carnivore, the badger, had an average population density estimate of ~7.3 badgers per km². Population estimates of badgers for the entirety of Scotland are listed at ~156,000 (Matthews, et al. 2018); this is mostly based on studies calculating estimates using sett surveys as the primary research method (Matthews, et al. 2018; Mitchell-Jones, et al. 2020). Unfortunately, this method can make it difficult to determine group size per badger sett, and therefore, difficult to calculate an accurate population density estimate per km². One recent case study conducted in Durham County in Northern England, an area with similar variety of habitats to our own study area (e.g. heather moorlands, woodlands, grasslands, etc.), estimated a population density of 1.32 badgers per km² (Mason, et al. 2022). If we use this statistic in comparison with our own density estimate, it is obvious that our badger estimate is greater in value than Mason, et al. (2022) or any other broader UK statistics (Rainey, et al. 2009; Matthews, et al. 2018). Unfortunately, we are unable to verify this factor, as we did not include identification of individual animals for any of our species of interests, and therefore, cannot conclude if we were capturing the same individual, multiple times, in areas of high species activity (e.g. badgers at CT S11; Figure 8).

The most difficult population density to evaluate in our study was the red fox, in part to this being our least captured species of interest, but also due to a lack of recent survey data in rural Scotland. Unlike pine martens or badgers, red foxes are not under legal protection in the United Kingdom; this means that, from a governmental perspective, there is no requirement for systematic recording. Therefore, many estimates for population of red foxes we do have (specifically in rural areas) come from game and wildlife organizations or bird surveys due to foxes being the major predator for game birds (Sainsbury, et al. 2019). In our study, the averaged destiny estimate for red foxes was ~0.76 per km², which despite the challenges mentioned above, is similar to that reported by Matthews, et al. (2018) in their review of previous British mammal surveys (~0.79 foxes per km² in rural environment). And what we know about fox behaviour, this low estimation in a rural environment can be explained by larger hunting territories, local-scale differences in prey abundance, and potential conflict with livestock farmers through means of predator control (Matthews, et al. 2018; Sainsbury, et al. 2019).

Meanwhile, population of density surveys for red and roe deer are more frequently conducted, as deer are more heavily managed than mesocarnivores due to the environmental damage often caused by deer overabundance in many areas (Latham, et al. 1997; McCulloch and Colquhoun, 2020). Since our study locations are within the boundaries of Loch Lomond and the Trossachs National Park, we can compare our estimates to those from park authorities as well as national surveys. For our study, the average estimates for density of red deer was ~2.8 and ~3.4 roe deer per km²; based on a 2020 management deer plan for the Eastern Loch Lomond area, deer populations (for both red and roe deer combined) were estimated to be ~6.53 deer per km². This specific estimated comes from an overhead helicopter count from 2019, in which 1,046 total deer were counted within a total area of 160 km (16,000 ha) (McCulloch and Colquhoun 2020). On the surface, if we were to combine our own red and roe deer estimates, we would have an average deer density of ~6.2 deer per km², which is nearly equal to that from the 2019 helicopter survey. It should be noted that, as stated by McCulloch and Colquhoun, this helicopter count only included deer spotted in open areas, and did not account for deer inhabiting woodland environments. As we know from our habitat use data, roe deer have a link to broadleaf woodlands, meaning that this method of counting may be more ideal for red deer than it is roe deer. This is noteworthy, especially when considering the impact deer can have on the growth of young tree samplings in recovering woodlands (Gill & Beardall, 2001; Palmer & Truscott, 2003; Gill & Morgan, 2010); one specific study suggesting a density of 14 deer per km^2 are capable of damaging over half of the necessary seedlings needed to promote sustainable and sufficient forestry recovery (Gill & Morgan, 2010). Due to the nature of our study, the impact of the estimated deer density within our study area is something we cannot conclude on but should be considered in further studies evaluating the habitats around Eastern Loch Lomond.

Overall, the detection of different species of interest varied across all our study locations; mesocarnivore detection in our study was less than anticipated, particularly within the area of SCENE and Ben Lomond. This was unexpected, as pine martens and badgers are often sighted in the area, from discussions with the National Trust for Scotland rangers and previous accounts from staff based at SCENE. Outside our camera trap data, scat samples from mesocarnivores were often notice throughout all study locations, which while not collected for data analysis, did give us signs in the field for potential presence of mesocarnivores. But despite this, Ben Lomond was still our least active study location, with a significant drop in our species of interests. Some of the potential explanations we hypothesize for this may be due to an increase in fragmentation of the landscape around Ben Lomond, including a less diverse tree and ground vegetation, as well as a higher level of anthropogenic activity, both in the form of land management and public foot traffic from hikers. And unlike our sites at SCENE and Cashel, a majority of our camera trap locations around Ben Lomond were deployed along the mountainside, with multiple fences and gates present, dividing the different sections of the hiking trail. These barriers are used both to contain a population of sheep from a local farmer, as well as a control method for deer management to protect new forest growth. It is because of these physical obstacles, as well as a lack of tree cover at higher elevations and a minute variety of ground vegetation (e.g. heavily grazed grass), we believe may have contributed to the decrease in overall species detection.

2.5 Conclusions

The main aim of this study was to investigate the habitat use of mesocarnivores and utilize camera traps to record the population density of our species of interests in comparison to those of the deer co-existing within the Eastern side of Loch Lomond. Based on our results, we were unable to establish any significant values for habitat use among pine martens, badgers, or red foxes via generalized linear models, but were able to provide inclinations towards a potential preference for woodland habitats, particularly broadleaf woodlands. In contrast, we were able to compare these results to that of the native cervid populations, providing a contrasting in preference in habitats between red and roe deer. Finally, we calculated a localized population abundance for mesocarnivores in an area that is underrepresented; and while at first these density estimates may appear to be exaggerated or minimal (likely due to a low count of mesocarnivore species), when the averages are compared to previous studies in other regions of Scotland, there is a reasonable argument to be made that these densities are promising in the localized conservation scale. In the future, we would recommend continuing to monitor mesocarnivores around Loch Lomond via camera traps, with consideration given to some supplementary data collection, such as scat analysis to help identify individuals through DNA profiling, as well as longer durations of camera trap monitoring throughout the year, providing a greater spatial coverage on species patterns within the area.

3 General discussion & final conclusions

3.1 Overview

The aim of this research was to highlight the habitat use and abundance of mesocarnivores and native deer in a fragmented environment, on a localized scale. Using camera traps, we were able to collect data on three prominent mesocarnivores, the pine marten, badger, and red fox along the Eastern side of Loch Lomond, and come to the following conclusions:

1.) Mesocarnivores displayed an inclination towards a potential preference for broadleaf woodland habitat.
2.) Red and roe deer appear to use opposing habitats, with red being recorded most often in open moorland, and roe being at higher frequency in broadleaved woodlands, compared to other habitats.
3.) Although individual counts may have been high in some locations, abundance estimates for all species of mesocarnivores and deer were consistent with previous studies and surveys across Scotland, with some mesocarnivores, such as pine marten, more abundance than the national average.

3.2 Impact & contributions

The findings of this study help contribute to the status and monitoring of mesocarnivores and deer within a localized area in Western Scotland, providing information on habitat use and estimates of population in an under studied location. While on the higher range of abundance for some, these numbers for mesocarnivores are a crucial first step towards monitoring the mesocarnivore population status around the wider area of Loch Lomond and the Trossachs National Park. Additionally, our population estimates for red and roe deer are not only in line with the official deer management plans at Loch Lomond (McCulloch & Colquhoun, 2020) but based on the results of habitat use presented in this work, may help management teams monitor areas at risk for environmental damage from over-grazing.

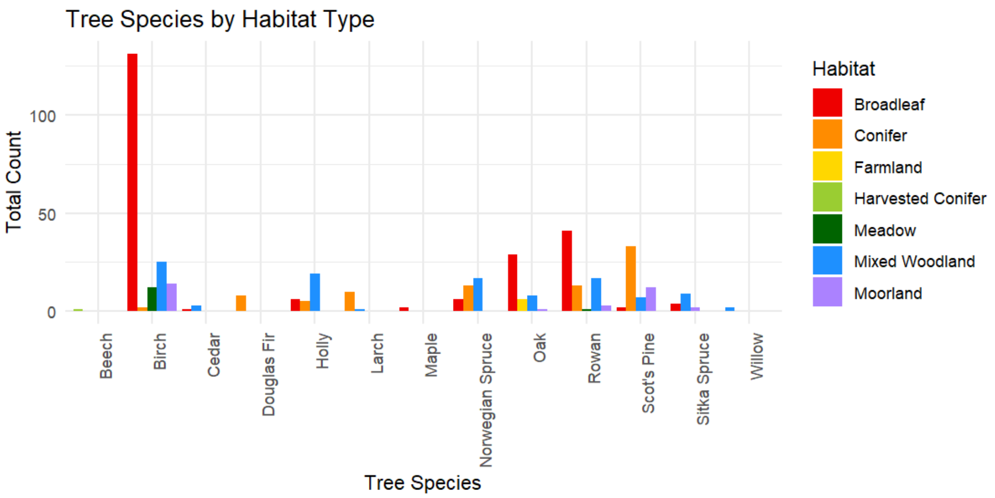
3.3 Remaining knowledge gaps

Due to a combination of low capture numbers for mesocarnivores and inability to identify individual animals, our models were unable to give us a strong correlation between any mesocarnivore and a habitat type. And even though our data does point towards an inclination for broadleaf woodland for all 3 species of mesocarnivore captured, from a technical standpoint this is still something we cannot confirm with absolute certainty. Another knowledge gap we were unable to analyse in our study was the relationship between elevation and species presence. While conducting fieldwork, particularly during data collection at SCENE and Cashel, we noticed pine martens appearing at higher levels of elevation compared to badgers or red foxes. Due to elevation being strongly correlated with habitat type, particularly in the case of moorland, we were unable to analyse this in any of our statistical models. However, considering woodland in the area generally decreases as elevation increases, it may not be easy to distinguish the full effects elevation has on mesocarnivore and deer habitat use.

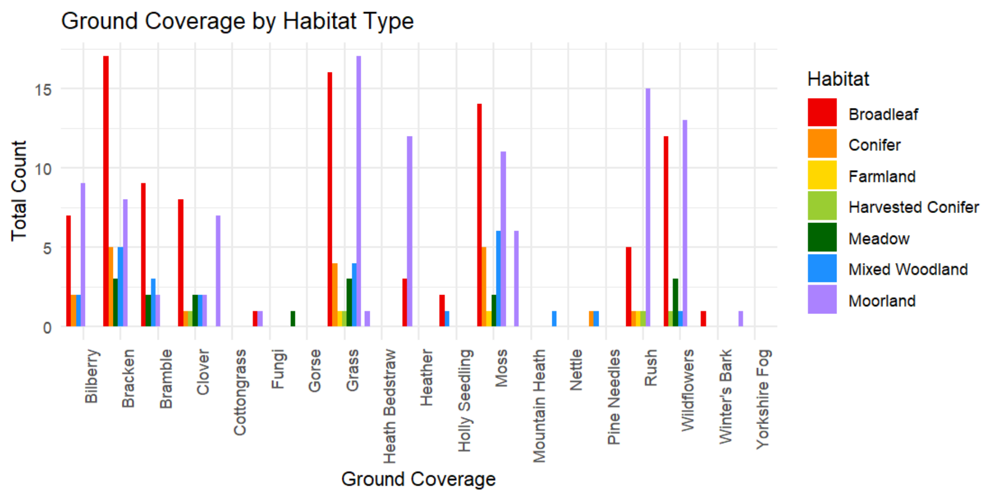
3.4 Recommendations for future research

For future research, we would recommend further studies to focus on monitoring mesocarnivore habitat use and abundance within Loch Lomond and the Trossachs National Park. Expansion of our study practices by increasing spatial and temporal sampling, with additional consideration towards seasonal and diel patterns in relation to habitat use across a wider geographical area to help monitor patterns of species' behaviour. Furthermore, we would recommend camera trap methods could be combined with other methods, such as genetic identification via scat or fur samples to help refine abundance estimates for each species (Leckie, et al. 1998; Croose, et al. 2019; Grabham, et al. 2019; McNicol, et al. 2020a; McNicol, et al. 2020b; Miranda Paez, et al. 2021). The inclusion of these additional methods for data collection would improve the accuracy of a study by identifying individual animals, allowing for more specific differences to be analysed (e.g. male vs female behaviours, individual activity patterns).

4 Supplementary materials



S-Figure 1: Total count bar plot of tree species based on habitat type



S-Figure 2: Total count bar plot of ground coverage based on habitat type

S-Table 1: Total count of species identified within the study, organized by location.

Record of Species by Location		
Location 1: SCENE	Location 2: Cashel	Location 3: Ben Lomond
Mesocarnivores:	**Mesocarnivores:**	**Mesocarnivores:**
Badger (12)	Badger (12)	Badger (1)
Pine Marten (2)	Pine Marten (8)	Pine Marten (1)
Red Fox (5)	Red Fox (1)	**Herbivores:**
Herbivores:	**Herbivores:**	Red Deer (5)
Red Deer (15)	Red Deer (12)	Roe Deer (5)
Roe Deer (35)	Roe Deer (30)	Domestic Sheep (63)
Red Squirrel (2)	Wood Mouse (8)	**Songbirds:**
Wood Mouse (4)	**Songbirds:**	Blackbirds (1)
Domestic Cattle (29)	Blackbirds (8)	Blackcap (1)
Songbirds:	Dunnock (8)	Dunnock (1)
Blackbirds (3)	Eurasian Chaffinch (5)	European Robin (7)
Blackcap (1)	European Robin (1)	Eurasian Skylark (1)
Blue Tit (8)	Song Thrush (8)	Long-tailed Tit (1)
Dunnock (2)	**Birds of Prey:**	Starling (1)
Eurasian Chaffinch (2)	Common Buzzard (2)	Wood Pigeon (2)
European Robin (2)		**Birds of Prey:**
Meadow Pipit (1)		Common Buzzard (1)
Song Thrush (7)		**Corvids:**
Treecreeper (1)		Jay (1)

S-Table 2: SCENE Camera Traps:

Camera Trap	Dates in operation	Habitat
S1	04/04/2024 – 18/04/2024	Broadleaf woodland
S2	09/04/2024 – 19/04/2024	Moorland
S3	09/04/2024 – 25/04/2024	Harvested conifer
S4	05/04/2024 – 18/04/2024	Mixed woodland
S5	04/04/2024 – 18/04/2024	Conifer woodland
S6	09/04/2024 – 25/04/2024	Broadleaf woodland
S7	09/04/2024 – 19/04/2024	Moorland
S8	05/04/2024 – 19/04/2024	Broadleaf woodland
S9	09/04/2024 – 19/04/2024	Moorland
S10	05/04/2024 – 18/04/2024	Broadleaf woodland
S11	05/04/2024 – 18/04/2024	Mixed woodland
S12	05/04/2024 – 19/04/2024	Broadleaf woodland
S13	04/04/2024 – 18/04/2024	Broadleaf woodland
S14	09/04/2024 – 19/04/2024	Moorland
S15	04/04/2024 – 18/04/2024	Mixed woodland
S16	09/04/2024 – 19/04/2024	Broadleaf woodland
S17	09/04/2024 – 25/04/2024	Broadleaf woodland
S18	05/04/2024 – 18/04/2024	Farmland
S20	05/04/2024 – 19/04/2024	Mixed woodland

S-Table 3: Cashel Forest Trust Camera Traps

Camera Trap	Dates in operation	Habitat
C1	02/05/2024-16/05/2024	Broadleaf woodland
C2	02/05/2024-16/05/2024	Moorland
C3	01/05/2024-15/05/2024	Moorland
C4	01/05/2024-15/05/2024	Meadow
C5	01/05/2024-15/05/2024	Conifer woodland
C6	01/05/2024-15/05/2024	Broadleaf woodland
C7	02/05/2024-16/05/2024	Broadleaf woodland
C8	01/05/2024-15/05/2024	Broadleaf woodland
C9	02/05/2024-16/05/2024	Broadleaf woodland
C10	02/05/2024-16/05/2024	Conifer woodland
C11	01/05/2024-15/05/2024	Conifer woodland
C12	01/05/2024-15/05/2024	Conifer Woodland
C13	02/05/2024-16/05/2024	Broadleaf woodland
C14	01/05/2024-15/05/2024	Meadow
C15	02/05/2024-16/05/2024	Moorland
C16	02/05/2024-16/05/2024	Conifer woodland
C17	01/05/2024-15/05/2024	Broadleaf woodland
C18	02/05/2024-16/05/2024	Meadow
C19	01/05/2024-15/05/2024	Moorland
C20	02/05/2024-16/05/2024	Moorland

S-Table 3: Camera traps used at Cashel Forest Trust study location

S-Table 4: Ben Lomond Camera Traps

Camera traps	Dates in operation	Habitat
B1	04/06/2024-18/06/2024	Moorland
B2	04/06/2024-18/06/2024	Mixed woodland
B3	04/06/2024-18/06/2024	Moorland
B4	05/06/2024-19/06/2024	Mixed woodland
B5	05/06/2024-19/06/2024	Moorland
B6	05/06/2024-19/06/2024	Moorland
B7	05/06/2024-19/06/2024	Moorland
B8	04/06/2024-18/06/2024	Broadleaf woodland
B9	05/06/2024-19/06/2024	Moorland
B10	04/06/2024-18/06/2024	Moorland
B11	05/06/2024-19/06/2024	Moorland
B12	05/06/2024-19/06/2024	Moorland
B13	05/06/2024-19/06/2024	Moorland
B14	04/06/2024-18/06/2024	Conifer woodland
B15	05/06/2024-19/06/2024	Broadleaf woodland
B16	04/06/2024-18/06/2024	Moorland
B17	05/06/2024-19/06/2024	Moorland
B18	04/06/2024-18/06/2024	Broadleaf woodland
B19	04/06/2024-18/06/2024	Broadleaf woodland
B20	05/06/2024-19/06/2024	Moorland

S-Table 5: Results of badger (*Meles meles*) GLMM habitat use model

Fixed Effects:	Estimate	Std. Error	Z-value	P-value
Broadleaf	2.672	1.748	1.528	0.126
Conifer	1.644	2.138	0.769	0.442
Farmland	-16.735	37767.110	0.000	1.000
Harvested Conifer	-16.501	30479.158	-0.001	1.000
Meadow	2.140	2.400	0.892	0.373
Mixed	2.623	2.021	1.298	0.194
Moorland*	-26.353	3444.443	-0.008	0.994
Morning	17.225	3444.443	0.005	0.996
Night	19.247	3444.443	0.006	0.996

*Model intercept marked by **

S-Table 6: Results of pine marten (*Martes martes*) GLMM habitat use model

Fixed Effects:	Estimate	Std. Error	Z-value	P-value
Broadleaf	0.5897	1.4910	0.395	0.692
Conifer	1.2185	1.6695	0.730	0.465
Farmland	-18.2000	54315.3873	0.000	1.000
Harvested Conifer	3.0583	2.3902	1.280	0.201
Meadow	1.4217	2.0813	0.683	0.495
Mixed	-18.9977	32281.6955	-0.001	1.000
Moorland*	-25.9181	6467.6625	-0.004	0.997
Morning	18.3421	6467.6624	0.003	0.998
Night	19.3675	6467.6624	0.003	0.998

*Model intercept marked with **

S-Table 7: Results of red fox (*Vulpes vulpes*) GLMM habitat use model

Fixed Effects:	Estimate.	Std. Error	Z-value	P-value
Broadleaf*	-2.800e+01	5.402e+03	-0.005	0.996
Conifer	-1.676e+01	3.849e+04	0.000	1.000
Farmland	-2.224e+01	1.622e+06	0.000	1.000
Harvested Conifer	-2.027e+01	5.521e+05	0.000	1.000
Meadow	-2.290e+01	1.257e+06	0.000	1.00
Mixed	7.559e-01	5.550e+00	0.136	0.892
Moorland	-1.932e+01	7.984+04	0.000	1.000
Morning	1.707e+01	5.402e+03	0.003	0.997
Night	1.883e+01	5.402e+03	0.003	0.997

*Model intercept marked with **

S-Table 8: Results of red deer (*Cervus elaphus*) GLMM habitat use model

Fixed Effects:	Estimate	Std. Error	Z-value	P-value
Broadleaf	-0.4488	1.0031	-0.447	0.655
Conifer	0.3500	1.1551	0.303	0.762
Farmland	-16.4230	10690.3024	-0.002	0.999
Harvested Conifer	1.6098	1.9492	0.826	0.409
Meadow	-16.4763	6124.0011	-0.003	0.998
Mixed	0.5725	1.1707	0.489	0.625
Moorland*	-6.0665	0.7687	-7.982	< **0.001**
Morning	-0.9301	0.9694	-0.960	0.337
Night	0.8158	0.6270	1.301	0.193

*Model intercept mark with *, significant values in **bold***

S-Table 9: Results of roe deer (*Capreolus capreolus*) GLMM habitat use model

Fixed Effects:	Estimate Std.	Error	Z-value	P-value
Broadleaf*	-4.37869	0.48037	-9.115	< **0.001**
Conifer	-0.94245	0.76639	-1.230	0.218799
Farmland	-0.23967	1.59773	-0.150	0.880759
Harvested Conifer	-16.09134	142.00328	-0.113	0.909780
Meadow	-0.36542	0.97584	-0.374	0.708059
Mixed	0.06126	0.68922	0.089	0.929181
Moorland	-2.92163	0.83436	-3.502	< **0.001**
Morning	1.13958	0.37754	3.018	**0.002541**
Night	0.42516	0.41770	1.018	0.308744

*Model intercept marked with *, significant values in **bold***

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