Factors influencing the habitat use of owls in a mosaic landscape in Garo Hills, Meghalaya

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CERTIFICATE

This is to certify that **Mr. S. Sangeeth Sailas** of Sálim Ali Centre for Ornithology and Natural History (SACON) has carried out an original research work titled, '***Factors influencing the habitat use of owls in a mosaic landscape in Garo Hills, Meghalaya'*** in partial fulfilment of the M.Sc. (Ornithology & Conservation Biology) degree of Saurashtra University, Rajkot. This investigation was carried out under my supervision from December 2019 to August 2020. I also certify that this research work has not been submitted for any other degree to any university.

Date: 21st August, 2020

Place: Coimbatore

(**Dr. P. PRAMOD**)

Principal Scientist

सालिम अली पक्षिविज्ञान एवं प्रकृति विज्ञान केन्द्र
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(पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय के अधीन उत्कृष्टता का एक केंद्र, भारत सरकार)
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SUMMARY

Habitat use of owls is under-studied in the tropics, and more so in North-eastern India, a part of the Indo-Burma region, one of the biodiversity hotspots of the world. Twenty species of owls have been recorded in North-eastern India, and yet there have not been much studies on any of them from the region. Hence, a study on the habitat use of owls was conceived, selecting the Garo Hills in Meghalaya as the study site, where the landscape is a mosaic made up of plantations, agricultural fields, settlements, disturbed and undisturbed forests. The presence of Community Reserves, a type of Community Conserved Area, adds to the heterogeneity in the landscape.

I used alternate grid sampling in and around Community Reserves to select the survey stations and a combination of listening to spontaneous calls, call playback method and spotlight searches to survey for owls. I also collected relevant sampling and site covariates from the grids where the surveys were done. A total of 33 grids (each 500 x 500 m) were surveyed between January and March, 2020 with three replicates, after which the field work ceased to an end due to the COVID pandemic.

Occupancy and N-mixture models were used to assess the effect of sampling and site covariates on the detection probability, occupancy and abundance of three species of owls that were detected most during the surveys; Brown Wood Owl *Strix leptogrammica*, Mountain Scops Owl *Otus spilocephalus* and Collared Owlet *Glaucidium broidei*.

It was found that overall, wind speed, temperature, relative humidity and time of survey were the sampling covariates that had the most effect on detection probability of owls. Detection probability of the Brown Wood Owl decreased with increase in wind speed, while that of the Mountain Scops Owl increased with temperature and humidity. Probability of detection of the Collared Owlet was higher earlier in the night and as temperature increased.

Among site covariates, it was found that distance to stream, slope, disturbance and tree structural characteristics (Girth at Breast Height (GBH) and heterogeneity in tree height) had the most effect on occupancy and abundance of owls. Occupancy and abundance of the Brown Wood Owl increased in areas closer to streams and those with gentle slopes. In addition to this, there was a substantial positive influence by GBH and heterogeneity in tree height on the abundance of this species, an old-growth forest specialist. In contrast,

occupancy and abundance of the Mountain Scops Owl increased in relatively more disturbed areas, away from streams. Slope was the one covariate that had a substantial influence on the occupancy and abundance of the Collared Owlet and the weak relationships with other habitat covariates are indicative of its generalist nature.

It was also found that there were significant differences observed between detections of the Brown Wood Owl and Mountain Scops Owl inside and outside Community Reserves. Mountain Scops Owl were detected more from outside Community Reserves, where there are greater levels of disturbance. On the other hand, there were higher numbers of Brown Wood Owl detections from inside Community Reserves, the least disturbed and only areas where old-growth forests remain outside the Nokrek National Park in the landscape.

Hence, with these findings that provide baseline information on the habitat use of three under-studied species of owls from India, we highlight the importance of preserving streams, old-growth forests and Community Reserves that seem to be acting as refugia for the Brown Wood Owl and probably also for other mature forest specialists and cavity associated vertebrates in the Garo Hills landscape.

1. INTRODUCTION

1.1. BACKGROUND

Habitat use can be defined as "the relative probability of utilisation or the amount of time that an individual spends in a habitat" (Cassini, 2013). Studies on habitat use of species have revealed important facets of species' life history, including differential use of habitats by different age groups (Rosenberger & Angermeier, 2003; Arthur *et al.*, 2008), sexes (Jonsson, 1989; Ardia & Bildstein, 2001), as well as habitat use during the breeding and non-breeding seasons and during migration (Petit, 2000; Fellers & Kleeman, 2007). Inter-specific relationships have also been seen to influence habitat use through competition (Robertson, 1996; Maitz & Dickman, 2001; Razgour, 2011) and predation (Cowlishaw, 1997; Heithaus & Dill, 2002; Valeix *et al.*, 2009).

Studies on habitat use also provide insight into the correlates of the habitat used, which range from ecological [for example, type of vegetative cover (Overdorff, 1996; Tufto *et al.*, 1996), terrain characteristics (Nellemann, 1996; Nellemann, 2007)] to anthropological [such as presence of human settlements (Harris *et al.*, 2008; Gomez *et al.*, 2014) and even socio-economic factors (Żmihorski *et al.*, 2020)]. Species responses to current and past pressures have also been assessed through their habitat use (Erwin, 1980; Ngoprasert, 2007; Bonnot *et al.*, 2013), including the influence of Protected Areas (Galanti *et al.*, 2006; Honda *et al.*, 2016), making such studies crucial for developing conservation and management plans if required (Bull & Holthausen, 1993; Carvell, 2002; Lopez *et al.*, 2004). Petit *et al.* (1995) puts this message quite simply, "habitat studies form the framework for conservation efforts aimed at preserving species diversity". Thus, studies on habitat use are central to understanding species ecology in relation to their habitats and for conservation.

Owls [Order: Strigiformes], predatory, generally nocturnal and cavity-nesting birds have been the subject of various studies on habitat use, globally (Nicholls & Warner, 1972; Carey *et al.*, 1990; Kavanagh & Bamkin, 1995; Ganey *et al.*, 1999; Hinam & Duncan, 2002; Glenn *et al.*, 2004; Bond *et al.*, 2009; Grzywaczewski, 2009; Roberts *et al.*, 2011; Panzeri *et al.*, 2014). Yet, there are only a handful of studies on this subject from India (Babu, 2011; Pande *et al.*, 2011; Jathar & Rahmani, 2012; Babu *et al.*, 2019), a country where 36 species from this order have been recorded (Praveen et al., 2020). North-east India in particular, a part of the Indo-Burma region, one of the biodiversity hotspots of the world (Myers, 1988; Myers *et al.*, 2000) has records of 20 species of owls (Grimmett *et al.*, 2014). Yet there are not much studies on habitat use of owls from this region, making the lacuna in information obvious.

Keeping this in mind, a study on habitat use of owls in North-east India was envisaged, focussing on the ecological correlates of habitat.

The Garo Hills of Meghalaya in North-east India, where the current study was conducted is a mosaic landscape made up of plantations, agricultural fields, settlements, disturbed and undisturbed forests. This region is also known for traditionally practising *jhum* or shifting cultivation, resulting in patches of vegetated land in various stages of recovery. Adding to this diversity of habitats is the dimension of protected versus non-protected areas. In Meghalaya, majority of the Protected Areas come under the framework of Community Reserves (a type of Community Conserved Area), where indigenous tribes own the land on which reserve is declared and they manage the forest in consultation with the Forest department (The Meghalaya State Biodiversity Strategy and Action Plan Draft, 2017).

To understand habitat use by owls in such a scenario, I came up with two objectives for this study.

1.2. OBJECTIVES

a) Assess the influence of ecological correlates of habitat used by owls on their occupancy and abundance in the study area.
b) Compare habitat use of owls inside and outside Community Reserves.

1.3. LITERATURE REVIEW

1.3.1. Habitat use studies of owls – terminologies and context

Block and Brennan (1993) define habitat use as "the manner in which a species uses a collection of environmental components to meet life requisites". Studies on habitat use patterns describe the distribution of individuals across habitat types and often include relationships of the species abundance or a similar parameter with habitat covariates/ecological correlates. Here, the use of a habitat by an individual could mean "use" in a general sense of the word or for specific activities like foraging, roosting and nesting. Although studies on habitat use *per se* do not involve evolutionary connotations, habitat use patterns are really the consequences of habitat selection processes which influence the fitness and survival of the individuals (Block and Brennan, 1993; Jones, 2001).

Owls are generally nocturnal, predatory birds of the order Strigiformes that have specific habitat requirements for roosting and nesting such as cavities or burrows. There are about 250 species of owls found all over the world except for Antarctica, right from the tiny Elf Owl *Micrathene whitneyi* to the huge Blakiston's Eagle owl *Bubo blakistoni*. Owls are known to occur in a wide variety of habitats across forests, grasslands, human settlements, wetlands, deserts and even in the tundra (König & Weick, 2008). Their specific habitat requirements and secretive nature have made them of interest to ecologists for over a century and hence owls have been subject to many studies that looked into their habitat use.

Block and Brennan (1993) describe bird-habitat studies as occurring in three different eras; the catalogue era, which consisted mainly of collecting specimens and describing the habitats in which they occurred; the qualitative natural history era, where ornithologists started to investigate the factors responsible for the distribution and abundance of birds mainly through qualitative research into natural history through the impetus of Joseph Grinnell; and the quantitative ecology era, which started with Evelyn Hutchinson describing the ecological niche as multi-dimensional and influenced by a variety of abiotic and biotic factors, each adding another dimension to it, and his student MacArthur, who initiated the use of rigorous quantitative methods in describing, testing and predicting habitat use patterns of birds during the 1950s (Block & Brennan, 1993).

Studies on habitat use of owls followed this progression of advancement in research described above, simply because they are really just a subset of studies on habitat use of birds.

1.3.2. Catalogue and qualitative natural history era

The studies on habitat use of owls in the early half of the 20th century clearly belong to the catalogue and qualitative natural history eras of bird-habitat studies. During this period, Swarth (1915) writes of the preference of the Spotted Owl *Strix occidentalis* for heavily timbered regions in canyons and densely wooded hillsides in North America. Marshall Jr. (1942) also writes of the Spotted Owl, describing the transition zones of deep conifer forests with shaded ravines as its preferred forest type in the Sierra-Cascades Province in USA. Studies on habitat use of several species of owls was done by Kenneth A. Wilson (1938) in Ann Arbor, Michigan. He found that Long-eared Owls *Asio otus* were found in hardwoods during the nesting and brooding seasons and in coniferous woods during the rest of the year. Screech owls *Megascops asio* were found in both hardwood and coniferous forests, while the rarer Northern Saw-Whet Owls *Aegolius acadius* were seen to use only the denser stands of coniferous forests. Wilson also found that Barn Owls *Tyto alba* and Barred Owls *Strix varia* also predominantly used coniferous stands (Wilson, 1938). These studies basically catalogued owls occurring in different habitats and indicate their preference for habitats through observed variations in abundance. In the UK, Lack and Venables (1939) described the nesting habitat of Long-eared Owls to be in pine or broadleaved trees. Another study in Livingston County, Michigan, found that Northern Saw-Whet Owls in tamarack bogs were consistently present only in relatively open areas with smaller trees (Mumford & Zusi, 1958). Randle and Austing (1952) found Long-eared Owls only in coniferous plantings in a study in South-Western Ohio and that they preferred to use trees smaller than 15 feet when available, for roosting. In the same study, Saw-Whet Owls were found usually in upland plantings of coniferous trees and never in the ravines and deep valleys (Randle & Austing, 1952). Another New World species, the Great Horned Owl *Bubo virginianus* was described to be widely distributed in many types of habitats with tall trees, with it breeding in groups of tall trees adjacent to open fields (Johnson Jr., 1957).

While these habitat use studies on owls from the earlier half of the 20th century largely deal with dominance of owl species in one habitat over others, they did reveal little snippets of information on ecological correlates/habitat covariates that might be causing these observed preferences through their qualitative descriptions.

1.3.3. Studies and findings during the quantitative ecology era

Advancing from the qualitative descriptions of habitat associations of owls, Getz (1961) studied habitat use of Long-eared Owls using a use versus availability approach. Lowell Getz estimated relative abundance of small mammals in different available habitats and compared it with prey remains from Long-eared Owl pellets. His study quantitatively revealed that Long-eared Owls preferred to use open, grassy areas for hunting, where there was an abundance of meadow voles (Getz, 1961).

The development of digital computers and radio-telemetry were two technological advancements that allowed more in-depth studies on habitat use of owls and reduced the difficulty of actually finding these nocturnal birds. In one of the early studies on habitat use of Barred Owls using radio-telemetry, oak woods were found to be most preferred by the owls, which were characterised by a lack of dense undergrowth which facilitates easy hunting of prey, with many dead and dying trees which act as homes for their rodent prey such as squirrels and mice (Nicholls & Warner, 1972).

Fast and Ambrose (1976) conducted an experimental study on Barn owls (probably one of the few on habitat use of owls) that showed that they chose to hunt more in a field-like habitat than a woods-like habitat when presented with both, even when prey availability was the same.

Habitat use studies of owls only grew with the integration of rigorous quantitative methods in ornithological research. Many studies investigated the habitat use of Spotted Owls in North America, probably the most favoured owl species in terms of the number of habitat-related studies conducted on it. Many of these studies particularly looked into the association of the species with old-growth forests. Spotted Owl densities were discovered to be 12 times higher in old-growth forests (thought to be important as nesting and roosting sites) in Oregon, when compared to young or second-growth forests (Forsman *et al.*, 1977). Another study on the foraging site selection of the Spotted Owl showed that on most occasions, the species used old-growth forests. This study also found that the owl had a seasonal variation in preference for roosting habitat. During hot, summer days, the Spotted Owl roosted in the understorey in small, second growth trees where temperatures were slightly lesser, while on cold days, the owl roosted in large trees in the forest overstorey (Forsman, 1980). Solis Jr. and Gutiérrez (1990) supported the observation of Spotted Owls preference for old-growth coniferous forests with a study using radio-telemetry. They also indicate that there might be a differential use of foraging habitat among the sexes, implied from the males' use of areas with higher density of trees compared to females (Solis Jr. & Gutiérrez, 1990). Spotted Owls showed a preference for old-growth forests in habitat use in a radio-telemetry study in southern Oregon Coast Ranges as well (Carey *et al.*, 1990). Even landscape composition around Northern Spotted Owl nests had larger patches of old-growth coniferous forests than random (Ripple *et al*., 1997). Colonisation of Spotted Owls was also found to be negatively correlated to alteration of mature coniferous forest in territories in the Sierra Nevada (Seamans & Gutierrez, 2007).

Spotted Owls were also found to prefer areas with larger trees, decadence and greater canopy closure (Gould Jr., 1975). Aspect (direction of slope) also had an influence on habitat use of the species, with many studies indicating that it preferred north or east-facing aspects where forests are thought to be denser (Forsman, 1975; Gould Jr., 1975). The relationship with large-girth trees that are important to the species as sites for roosting and nesting was also found by Bias and Gutierrez (1992), Blakesley *et al*. (1992), Call *et al*. (1992) and Ganey and Balda (1994). Greater canopy closure/cover which facilitates thermoregulation, influences shrub cover and hence availability of prey was found to influence habitat use of the species by Gould Jr. (1975), Bias and Gutierrez (1992), Call *et al*. (1992), Ganey and Balda (1994), Martinez and Jaksic (1996), Miller *et al*. (1997) and May *et al*. (2004). The effect of topographic position was explored by Blakesley *et al.* (1992) and Tarango *et al*. (1997). Density of logs and large snags also had an effect on habitat use of these species as they acted as homes for the owls' prey (Ganey & Balda, 1994; Hershey *et al*., 1998; Bond *et al*., 2009) Spotted Owls were also more commonly found on steep slopes and canyons (Gould Jr., 1975; Ganey & Balda, 1989; May *et al*., 2004)

These habitat requirements or covariates such as presence of old-growth forests, canopy closure, tree size, slope, aspect, shrub cover that have been found to influence the habitat use of Spotted Owls also influence many other owl species. The following are some of the findings from many studies from the temperate regions of North America and Europe.

Presence of old-growth forests and mature forest stands has been found to influence habitat use of Barred Owls (Bosakowski *et al.*, 1987; Mazur *et* al., 1998; Olsen, 1999) and Great Horned Owls of North America (McGarigal & Fraser, 1984), Tengmalm's Owls *Aegolius funereus* (Sonerud *et al.*, 1986) and Pygmy Owls *Glaucidium passerinum* in Europe (Strøm & Sonerud, 2001; Shurulinkov *et al*., 2007). As in the case of the Spotted Owl, canopy closure/cover has been known to affect habitat use of Great Gray Owls *Strix nebulosa* in North America (Servos, 1987; Whitfield & Gaffney, 1997). Shrub and understorey cover has been known influence several species of owls such as the Burrowing Owl *Athene cunicularia* (Lantz *et al*., 2007), Flammulated Owl *Psiloscops flammeolus* (McCallum & Gehlbach, 1988), Great Gray Owl (Servos, 1987), Elf Owl (Goad, 1985) and Barred Owl (Takats, 1998). Habitat use has been influenced by aspect (direction of slope) in Burrowing Owls (Rich, 1986), Barred Owls (Hinam & Duncan, 2002) and Great Gray Owls (Bull & Henjum, 1990; Hinam & Duncan, 2002) as well as by angle of slope in Barred Owls (Singleton *et al*., 2010). Anthropological factors have also been found to influence habitat use of owls; road density in Little Owls *Athene noctua* (Zabala *et al*., 2006); proximity to roads in Eurasian Eagle Owls *Bubo bubo* (Martínez *et al*., 2003), higher proportion of arable land, pastures and even presence of old churches in Barn Owls (Żmihorski *et al*., 2020).

In Australia as well, several studies have been done on habitat use of owls, including a study on the habitat use of nocturnal mammals and birds in a logged-unlogged forest mosaic (Kavanagh & Bamkin, 1995), a study on the habitat use of the Masked Owls *Tyto novaehollandiae* (Kavanagh & Murray, 1996) and a study on the habitat use of Tasmanian nocturnal birds by Todd *et al*. (2019). Studies on the habitat use of the Barking Owl *Ninox connivens* in Central and North-eastern Victoria were done by Taylor *et al.* (2002a; 2002b).

While not as abundant as studies from the temperate regions, studies on habitat use of owls from the tropics are not non-existent. A few notable studies include an investigation into the effect of vegetation structure on the owl assemblage in a semi-deciduous forest in southern Brazil (Menq & Anjos, 2015), a study of habitat use of owls in two Amazonian forest types (Borges *et al*., 2004), studies on the influence of old-growth forests and mature forest stands on habitat use of Rufous-legged Owls *Strix rufipes* of southern Chile (Martinez & Jaksic, 1996), and on the habitat preferences of owls in the Springbok flats, South Africa (Mendelsohn, 1989). There are extremely few studies on habitat use of owls from India, and the few that have been conducted include studies on the habitat use of the Forest Owlet *Athene blewitti* (Jathar & Rahmani, 2012; Kulkarni & Mehta, 2020), a study on the factors influencing distribution and habitat use of owls of the Andaman Islands, India (Babu *et al*., 2019) and a study on the habitat use of the owl assemblages of the Western Ghats of India (Jayson & Sivaram, 2009; Babu, 2011).

1.3.4. Criticisms

One of the criticisms that habitat use studies, along with habitat selection studies receive is that there does not seem to be any uniformity on the scale at which different studies are conducted (Jones, 2001). Results and interpretations can change depending on the scale of the study. To address this issue, studies were done at multiple scales (for example, at the nest site level, the home range level and the landscape level) and this could be seen in several studies on habitat use of owls as well. Multi-scale habitat selection studies from which habitat use patterns can be inferred have been conducted on several owl species, including Burrowing Owls (Lantz *et al*., 2007), Little Owls (Šálek *et al*., 2016) and Eurasian Eagle Owls (Ortego & Díaz, 2004).

It is also abundantly clear from the literature that most habitat use studies of owls have been done in the temperate regions in North America and Europe. While the tropics are not completely devoid of such studies, compared to the number of studies done in temperate regions, they are just a handful.

1.3.5. The way forward

There is clearly a rich history of habitat use studies on various species of owls which has revealed much about their ecology, but there are still a great many owls in the world that occur in the tropics that are under studied. One example is that of north-eastern India, a part of the Indo-Burma region and one of the biodiversity hotspots of the world (Myers, 1988; Myers *et al.*, 2000), which has had not much studies done on habitat use of owls, although historically this region has reported 20 species from the order (Grimmett *et al.*, 2014). In the current scenario, there needs to be a greater focus on studies of habitat use and selection of owls in the tropics to better understand their ecology and also to assess the effect of ongoing pressures on these species/populations.

2. STUDY AREA

The study was conducted in the Garo Hills of Meghalaya, which is a part of the Indo-Burma region, one of the biodiversity hotspots of the world (Myers, 1988; Myers et al., 2000). The state of Meghalaya lies between 20.1° N and 26.5° N latitudes and 85.49 °E and 92.52 °E longitudes (Department of Tourism, Government of Meghalaya, 2020). Meghalaya comprises of three hill regions; Garo, Khasi, and Jaintia Hills and the state is divided into 11 districts; South Garo Hills, South West Garo Hills, West Garo Hills, East Garo Hills, North Garo Hills, West Khasi Hills, East Khasi Hills, South Khasi Hills, Ribhoi, West Jaintia Hills and East Jaintia (The Meghalaya State Biodiversity Strategy and Action Plan Draft, 2017).

Meghalaya, which literally translates into "abode of clouds", is one of the wettest regions of the world. Various types of tropical and sub-tropical forests can be found in Meghalaya and the landscape is a matrix of forests, cultivation (*Jhum*, cultivation for cash crops, horticulture) and settlements. Species records from Meghalaya include 3,128 species of flowering plants, 139 species of mammals, 659 species of birds, 55 species of amphibians and 71 species of reptiles (The Meghalaya State Biodiversity Strategy and Action Plan Draft, 2017).

Sixteen species of owls have been recorded from Meghalaya (Ali & Ripley, 1981), however three of them (Barn Owl *Tyto alba,* Eastern Grass Owl *Tyto longimembris* and Short-eared Owl *Asio flammeus*) have not been sighted in the recent past (Grimmett et al., 2014; eBird, 2019a; eBird, 2019b; eBird, 2019c). Therefore the following 13 owl species were initially expected to be encountered in the study area: Oriental Bay Owl *Phodilus badius*, Collared Scops Owl *Otus lettia*, Mountain Scops Owl *Otus spilocephalus*, Oriental Scops Owl *Otus sunia,* Collared Owlet *Glaucidium brodiei,* Asian Barred Owlet *Glaucidium cuculoides,* Spotted Owlet *Athene brama,* Spot-bellied Eagle Owl *Bubo nipalensis,* Dusky Eagle Owl *Bubo coromandus,* Brown Fish Owl *Ketupa zeylonesis,* Tawny Fish Owl *Ketupa flavipes,* Brown Wood Owl *Strix leptogrammica* and Brown Hawk Owl *Ninox scutulata.*

The Protected Area network of Meghalaya consists of two National Parks (Nokrek National Park in the junction between East, West and South Garo Hills districts and Balpakram National Park in South Garo Hills district) (ENVIS Centre on Wildlife & Protected Areas, 2019a; The Meghalaya State Biodiversity Strategy and Action Plan Draft 2017), four Wildlife Sanctuaries (Siju Wildlife Sanctuary, Baghmara Pitcher Plant Sanctuary, Nongkhyllem Wildlife Sanctuary

& Narpuh Wildlife Sanctuary) (ENVIS Centre on Wildlife & Protected Areas, 2019b) and 65 Community Reserves (ENVIS Centre on Wildlife & Protected Areas, 2019c).

The study was conceived to be undertaken in and around ten Community Reserves in East and West Garo Hills districts of Meghalaya. But due to the CAB protest and COVID pandemic, field work had to be stopped after four out of the ten study sites were surveyed. The Community Reserves that were surveyed are listed in Table 1. Figure 1 shows a map of the same along with the surrounding landscape. Two of the Community Reserves surveyed; Daribokgre and Sakalgre fall within the buffer zone of Nokrek Biosphere Reserve, while Baladinggre and Sasatgre are located in the transition zone of the same. This landscape is also a mosaic, like the larger Garo Hills landscape, with *jhum* cultivation, orange plantations and other cultivation for cash crops, settlements, disturbed secondary forests, early secondary growth, along with undisturbed primary and secondary forests.

Table 1: Surveyed Community Reserves, with their area, district in which they are located, altitudinal range, major vegetation type, duration of sampling and number of grids.

Sl. No.	**Name of Community Reserve & District**	**Area (ha)**	**Altitudinal range**	**Major vegetation types**	**Duration of sampling & no. of grids**
1	Daribokgre, East Garo Hills	173	1050-1350 m	Sub-tropical evergreen forest	17-31 January, 2020 (9 grids)
2	Sakalgre, West Garo Hills	122	800-1200 m	Sub-tropical evergreen forest	2-22 February, 2020 (8 grids)
3	Sasatgre, West Garo Hills	60	850-1050 m	Moist deciduous forest	1-22 March, 2020 (8 grids)
4	Baladinggre, West Garo Hills	50	1050-1350 m	Semi-evergreen forest	14-27 March, 2020 (8 grids)

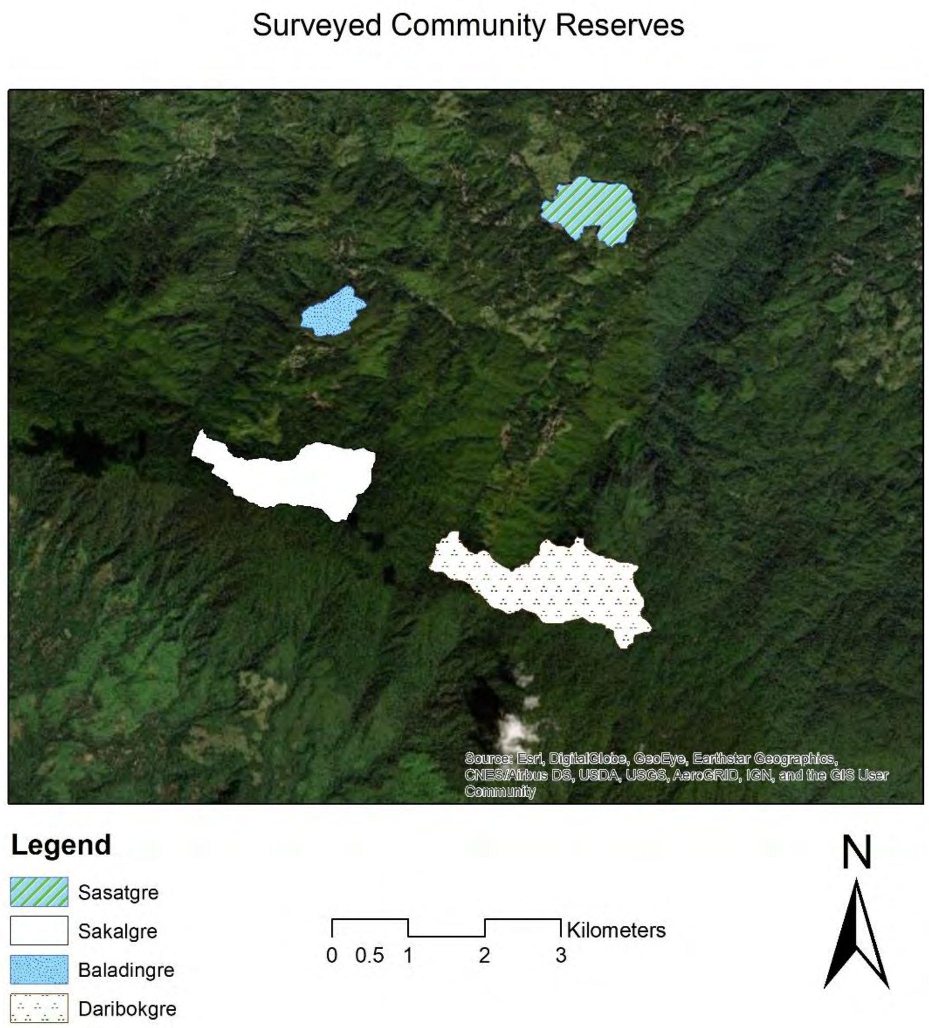

Figure 1: Surveyed Community Reserves of East and West Garo Hills.

3. METHODS

3.1. SAMPLING DESIGN

Plots of 4 km^2 (2x2 km) were overlaid around each Community Reserve using QGIS software (QGIS Development Team, 2019), where the centre of the grid was overlaid on the centroid of the Community Reserve. Each 4 km^2 plot was divided into 16 grids, each 500 m x 500 m (see Figure 2) and these grids were treated as sampling units for estimating the occupancy and abundance of select owl species. I followed "alternate grid sampling method" to select the sampling units. The centre of alternate grids (eight in each grid) were taken as survey stations (wherever accessible) for surveying owls. 500 x 500 m (25 ha) was chosen as the sampling unit because several small and medium-sized owls are reported to have territories with smaller or comparable sizes [22 ± 12.6 ha in Tawny Owls S*trix aluco* in rural areas (Galeotti, 1994); a core area of activity of 10.5 ha and a home range of 30 ha in Eurasian Scops Owls *Otus scops* (Martínez *et al*., 2007); 19.9 ha in Little Owls *Athene noctua* (Grzywaczewski, 2009)]. This allowed the assumption that the sampling units were independent. All the grids were repeated thrice to get the detection histories of presence and absence of owls in the grid.

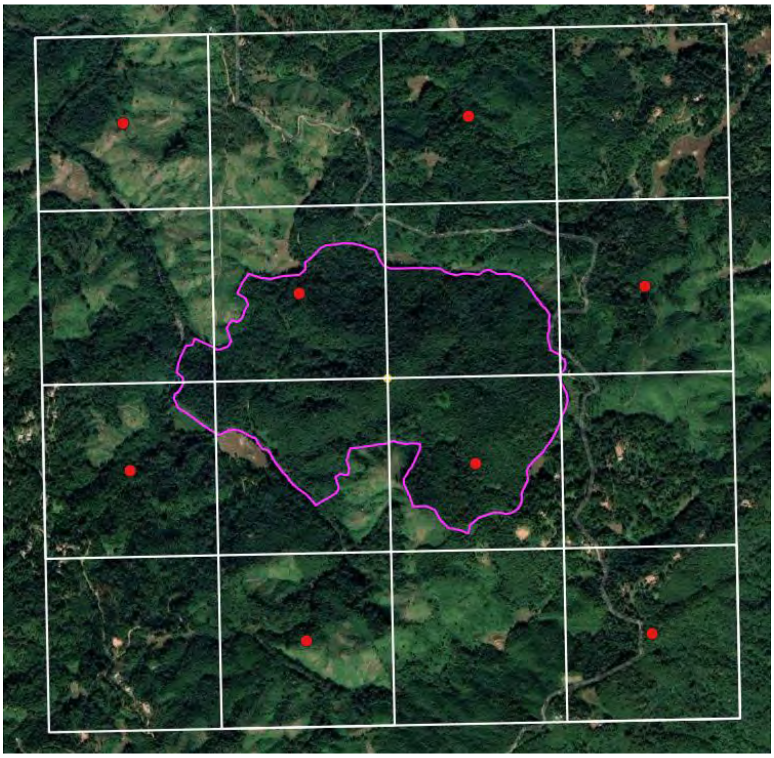

Figure 2: Design for sampling in each 2x2 km plot around the Community Reserves.

3.2. OWL SURVEY METHODS

Surveys were conducted between January and March, 2020. Three survey protocols were followed: (1) listening to spontaneous calls vocalisations, (2) the call playback method using conspecific calls, and (3) spotlight searches. The playback method using conspecific calls to elicit territorial response from owls is commonly used in owl surveys and censuses (Redpath, 1994; Braga & Motta-Junior, 2009; Clewley *et al*., 2016; Vrezec & Bertoncelj, 2018) and is described as most effective for this purpose (Zuberogoitia & Campos, 1998). In each survey point, after an initial settling period of two minutes, five minutes was spent in **listening to spontaneous vocalisations** of owl species and looking for any owl's movement. This was followed by the call **playback method**, where calls were played in the order of increasing size of owls. This is to avoid predatory and/or competitive behaviour among the owls (Zuberogoitia & Campos, 1998). Each owl call was played for 30 seconds, followed by a listening period of one minute. The order of call playback used was Collared Owlet, Oriental Scops Owl, Mountain Scops Owl, Spotted Owlet, Asian Barred Owlet, Collared Scops Owl, Oriental Bay Owl, Brown Hawk Owl, Brown Wood Owl, Brown Fish Owl, Tawny Fish Owl, Dusky Eagle Owl and finally Spot-bellied Eagle Owl. Calls of the owls used in the playback were downloaded from https://www.xeno-canto.org/ (Xeno-canto Foundation, 2020) and https://ebird.org/ (eBird, 2017). Call playback was not conducted during rain or on extremely windy days (Legare et al., 1999) as these conditions can negatively influence the ability of observers to detect owls. **Spotlight searches** were done for two minutes around the point count station at the end of the call playback session to record any visible but non-vocally responsive owls (floaters). During the survey protocols, species, number of individuals, time taken to respond (for call playback) and approximate distance of visible/calling/responding owls were noted. Altogether, each survey lasted approximately 30 minutes and three temporal replicates on different dates were done at each survey station.

3.3. SAMPLING AND SITE COVARIATES

3.3.1. Selection and data collection of sampling covariates

Time of survey (minutes after sunset), temperature, relative humidity, moon phase and wind speed are known to influence detection of owls (Braga & Motta-Junior, 2009; Todd *et al*., 2019; Zuberogoitia *et al*., 2020) and these five variables were considered as the sampling covariates. Temperature (^{0} C) and relative humidity (%) were recorded using a Winner TH 402 thermo hygrometer, while wind speed (m/s) was recorded using a Lutron AM-4202 digital anemometer. All five sampling covariates were recorded at the start of each survey. The hypothesised effects of sampling covariates on detection probability of each owl species are given in Table 2.

Table 2: Hypothesised effects of sampling covariates on detection probability of owls.

Sampling covariates	**Abbreviation**	**Hypothesized effect on detection probability (*p* and *r*) of owls**
Wind speed	Wind	-
Temperature	Temp	+
Relative Humidity	Humid	+
Time of survey (minutes after sunset)	Start time	+ (on BWO and MSO), - (on CO)
Moon phase	Moon	+ (as amount of illuminated portion of moon as seen from Earth increases)

BWO, Brown Wood Owl; MSO, Mountain Scops Owl; CO, Collared Owlet; +, Positive; -, Negative

3.3.2. Selection of site covariates

The following covariates were considered after a review of literature to determine the factors influencing occupancy (ψ) and abundance (λ) of owls in the study area:

- Vegetation parameters:
    - Tree structural characteristics: Tree height (Johnson Jr., 1957), Girth at Breast Height (GBH) (Forsman, 1980), coefficient of variation of tree height (Forsman, 1980), coefficient of variation of GBH, canopy height, canopy cover (Gould Jr., 1975; Ganey & Balda, 1994), number of dead trees (Ganey & Balda, 1994; Hershey *et al*., 1998; Bond *et al*., 2009).

    - Understory structural characteristics: Height, cover (McCallum & Gehlbach, 1988; Lantz *et al*., 2007).
    - Number of dead logs (Ganey & Balda, 1994; Hershey *et al*., 1998; Bond *et al*., 2009).
- Disturbance parameter:
    - Disturbance Index (Doak, 1989).
- Spatial variables:
    - Terrain structure: Elevation, slope (Gould Jr., 1975; Ganey & Balda, 1989; May *et al*., 2004), and terrain ruggedness (Sánchez-Zapata & Calvo, 1999).
    - Distance parameters: Distance to water body (Bosakowski *et al.*, 1987; Rinkevich & Gutiérrez, 1996), human settlement, nearest Community Reserve, and continuous primary forest.

3.3.3. Data collection of vegetation parameters

Vegetation parameters were quantified for each 500 x 500 m grid where owl surveys were done. Tree and understorey structural characteristics were evaluated at five vegetation points established at 20 m distance along the four cardinal directions from each survey station. Point-centred Quarter (PCQ) method (Cottam & Curtis, 1956) was used to measure the tree layer characteristics. At each vegetation point, a PCQ plot was laid and the structural characteristics [height (m), GBH (cm), canopy height (m) and cover(%)] of the nearest tree (girth greater than or equal to 23 cm) in each quarter was measured (Babu *et al.*, 2019). Understorey structural characteristics [height (m) and cover (%)] were measured at the five points of each grid by laying 5 x 5 m plots. Number of logs and dead trees within 10 m radius at each of the PCQ plots were also counted.

Tree, canopy and understorey heights were measured ocularly. GBH was measured using a measuring tape. Canopy cover was measured using a circular mirror at each tree and expressed in percentage based on the gaps in the canopy. Understorey cover was expressed in percentage for each 5 x 5 m plot based on the gaps in the understorey. Figure 3 gives a visual representation of the sampling design for tree and understorey structural characteristics.

A disturbance index with values ranging from 0 to 20 was developed and was calculated by summing the scores given for felling (0-5), lopping (0-5), evidence of recent fire (0-5) and cattle dung (0-5) evaluated within a 10 m radius.

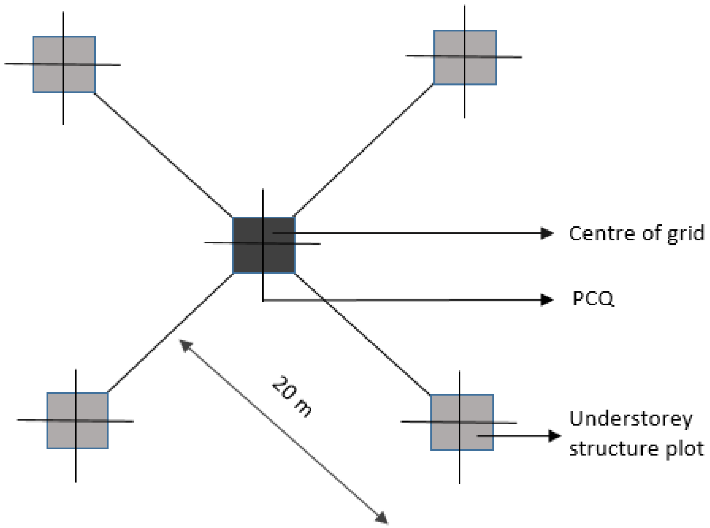

Figure 3: Design for sampling vegetation.

3.3.4. Data collection of spatial variables

Values for elevation, slope, terrain ruggedness, distance to water body, nearest community reserve, settlement, and primary forest were generated for each survey station where owl surveys were done. Elevation was recorded for the centre of each grid using a Garmin eTrex 10 GPS device during the vegetation sampling or owl surveys. Slope for the centre of each grid was extracted from the SRTM 1 Arc-second Global Digital Elevation Models (DEMs) downloaded from https://earthexplorer.usgs.gov/ (United States Geological Survey, 2020).

Terrain ruggedness was calculated similar to Riley et al. (1999) for each grid by taking the difference in elevation values from the centre of the grid and the centres of 16 sub-units into which the grid was further divided, each of 125 x 125 m. The 16 elevation differences were squared to remove the negative signs and averaged. The Terrain Ruggedness Index was determined as the square root of this average value for each grid.

Distance to stream, human settlement, nearest Community Reserve, and primary forest (Nokrek National Park) was measured using GIS software (ESRI, 2011; QGIS Development Team, 2019) from Aster Global Digital Elevation Models (NASA/METI/AIST/Japan

Spacesystems & U.S./Japan ASTER Science Team, 2019), Google Earth imagery (Google Earth, 2020) and Community Reserve shapefiles.

3.4. DATA ANALYSIS

3.4.1. Variable screening

There was high correlation observed among many of the site covariates selected for assessing their influence on owl species' occupancy and abundance (Appendix 1). Removing the correlated variables (Pearson's correlation coefficient > 0.6) resulted in the following list of variables which were subsequently used for the analysis:

- Girth at Breast Height of trees (GBH)
- Coefficient of variation of tree height (a measure of heterogeneity in tree height)
- Shrub cover
- Disturbance Index
- Distance to stream
- Slope
- Terrain Ruggedness Index

The hypothesised relationships of these site covariates on occupancy and abundance of owls are given in Table 3.

3.4.2. Modelling occupancy and abundance

The single-species single-season occupancy model (Mackenzie *et al*., 2002) and the N-Mixture model (Royle, 2004) were used to assess the factors influencing occupancy and abundance, respectively for three owl species; Brown Wood Owl, Mountain Scops Owl and Collared Owlet.

The single-species single-season occupancy model fits zero-inflated binomial models to presence-absence data, while allowing occupancy and detection probability to be modelled as a function of site and detection covariates. This model makes the following assumptions: (1) the occupancy status of sites does not change during the study period, (2) probability of occupancy is constant at all sites or else is modelled with site covariates, (3) probability of detection is constant at all sites or else is modelled with sampling covariates, (4) the detection of species at each site is independent and (5) that there are no misidentifications or false positives (Gerber *et al.,* 2009). N-mixture models enable fitting of Poisson, zero-inflated Poisson and negative binomial models to count data and allow modelling of abundance and detection probability as a function of site and sampling covariates, respectively. This model makes three assumptions that are similar to that of the occupancy model: (1) the population is demographically closed during the study period, (2) individuals are counted only once per survey and (3) detections are independent of each other (Kidwai *et al.,* 2019). These assumptions were decided to have been met since the surveys were conducted during a short time period (January-March, 2020), sampling unit size was decided on to keep detections independent, ecologically relevant site and sampling covariates were included and the observer was proficient in identifying calls of different species of owls recorded in the study area.

Detection histories were created for each species in each surveyed grid with presence-absence data for the occupancy modelling and count data for the abundance modelling. Detection probability (*p* in the case of occupancy modelling and *r* in the case of abundance modelling) was first modelled with the sampling covariates, followed by occupancy (ψ) and abundance (λ) modelling. *p* and *r* in the occupancy and abundance models were modelled as a function of the sampling covariates included in the top model for estimating detection probability.

All possible combinations of site covariates were used in running the occupancy and abundance models. Models with ΔAIC_c values >4 were selected for calculating averaged β co-efficient and summed AIC_c weights to assess the effect of site covariates on occupancy and abundance of the three owl species. It was decided to consider models with ΔAIC_c values >4, as opposed to only the models with ΔAIC_c values >2 which are described as having substantial support by Burnham and Anderson (2002) because there was no overwhelming support for the models with ΔAIC_c values >2. ΔAIC_c values between 2 and 4 also lie in the in-between between models with substantial support and those with considerably less support (Burnham & Anderson, 2002). Symonds and Moussalli (2011) also consider that models with Δ_i values up to 6 should not be discounted. Occupancy and abundance modelling were done using the "unmarked" package (Fiske & Chandler, 2011) in the R statistical software (R Core Team, 2018).

Table 3: Hypothesised effects of final set of site covariates on occupancy and abundance of owls.

Covariate	**BWO**	**MSO**	**CO**
Girth at Breast Height (cm)	+	+	-
Coefficient of variation of tree height	+	+	+
Shrub cover (%)	-	-	+
Disturbance Index	-	-	+
Distance to stream (m)	-	-	-
Slope (^{0})	+	+	-
Terrain Ruggedness Index (m)	+	+	+

BWO, Brown Wood Owl; MSO, Mountain Scops Owl; CO, Collared Owlet; +, Positive; -, Negative

3.4.3. Mann Whitney *U* test

The non-parametric Mann Whitney *U* test was done in SPSS (IBM Corp, 2012) software to test whether there was a statistically significant difference observed between number of detections inside and outside Community Reserves for the three owl species (since the count data was not normally distributed).

4. RESULTS

Thirty three grids were surveyed, each with three temporal replicates during the study period. Out of the 33, at least one owl was detected in 32 grids. A total of five owl species: Collared Owlet, Mountain Scops Owl, Brown Wood Owl, Asian Barred Owlet and Collared Scops Owl were detected with 41, 56, 46, 1 and 2 detections respectively in 99 replications. Absence of detections of other species surveyed for could be due to the smaller area surveyed than initially planned due to the COVID pandemic, seasonal movements of certain species of owls or seasonal variations in vocal activity. Occupancy and abundance modelling, as well as comparing detections inside and outside Community Reserves was done for the Brown Wood Owl, Mountain Scops Owl and Collared Owlet.

4.1. ESTIMATION OF OCCUPANCY OF BROWN WOOD OWL

4.1.1. Factors influencing the detection probability (*p*) of Brown Wood Owl

Brown Wood Owls were detected in 21 out of 33 grids, resulting in a naïve occupancy of 0.64. The most parsimonious model for estimating detection probability of Brown Wood Owl was one that included the effect of wind speed alone (detection probability estimate, p = 0.55 ± 0.082_{SE}, Table 4). In subsequent occupancy models, p was modelled as a function of wind speed, to which it had a negative relationship (Figure 4).

Table 4: Summary of models for factors influencing detection probability of occupancy of Brown Wood Owl with ΔAIC_c less than 4.

Model	***p***	**SE**	**K**	**AIC$_c$**	**Δ AIC$_c$**	**AICc weight**
ψ(.), p(Wind)	0.550036	0.082055	3	125.5	0.00	0.226
ψ(.), p(Wind + Moon)	0.539386	0.098530	4	126.5	1.02	0.136
ψ(.), p(Wind + Start time)	0.559571	0.103901	4	127.4	1.97	0.084
ψ(.), p(Wind + Humid)	0.544427	0.097332	4	127.5	2.05	0.081
ψ(.), p(Wind + Temp)	0.553097	0.102200	4	127.9	2.46	0.066
ψ(.), p(Wind + Moon + Humid)	0.532479	0.111120	5	128.5	3.06	0.049
ψ(.), p(.)	0.569758	0.073874	2	128.5	3.08	0.049
ψ(.), p(Wind + Start time + Moon)	0.547458	0.124140	5	129.1	3.64	0.037

ψ(.), p(Wind + Temp + Moon)	0.541244	0.117209	5	129.2	3.78	0.034
ψ(.), p(Wind + Start time + Humid)	0.554580	0.115574	5	129.3	3.87	0.033

p, the estimated species detection probability; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; ΔAIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;
Wind, wind speed; Moon, moon phase; Start time, time of survey (minutes after sunset); Humid, humidity; Temp, temperature.

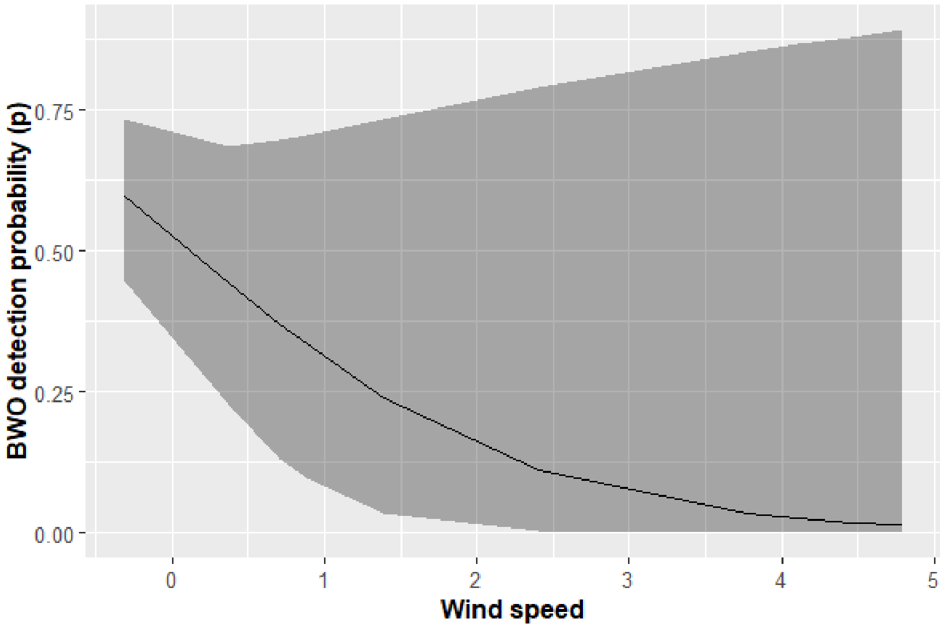

Figure 4: Detection probability of occupancy of Brown Wood Owl in response to wind speed.

4.1.2. Factors influencing the occupancy of Brown Wood Owl

The best-fit model for occupancy of Brown Wood Owl included two site covariates; slope and distance to stream and had an occupancy estimate of 0.66 ± 0.104_{SE}. Slope and distance to stream were also included in all five models reported in Table 5.

Summed AIC_c weights and averaged β-coefficients were calculated for site covariates (Table 6). It was clear from the results that slope, distance to stream and disturbance had a negative effect (Figures 5 and 6) on occupancy of Brown Wood Owl while it was positive for Shrub cover, terrain ruggedness and GBH.

Table 5: Summary of models for occupancy of Brown Wood Owl with ΔAIC_c less than 4.

Model	**psi (ψ)**	**SE**	**K**	**AIC_c**	**Δ AIC_c**	**AIC_c weight**
ψ(Slope + D_Stream), p(Wind)	0.657979	0.104133	5	114.0	0.00	0.355

ψ(Slope + D_Stream + SC), p(Wind)	0.657529	0.118006	6	116.0	2.06	0.127
ψ(Slope + D_Stream + GBH), p(Wind)	0.654529	0.117186	6	116.5	2.49	0.102
ψ(Slope + D_Stream + Disturbance), p(Wind)	0.659788	0.118244	6	116.6	2.62	0.096
ψ(Slope + D_Stream + TRI), p(Wind)	0.656982	0.120059	6	116.9	2.95	0.081

psi(ψ), the estimated species occupancy parameter; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; ΔAIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;
D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index; Wind, wind speed.

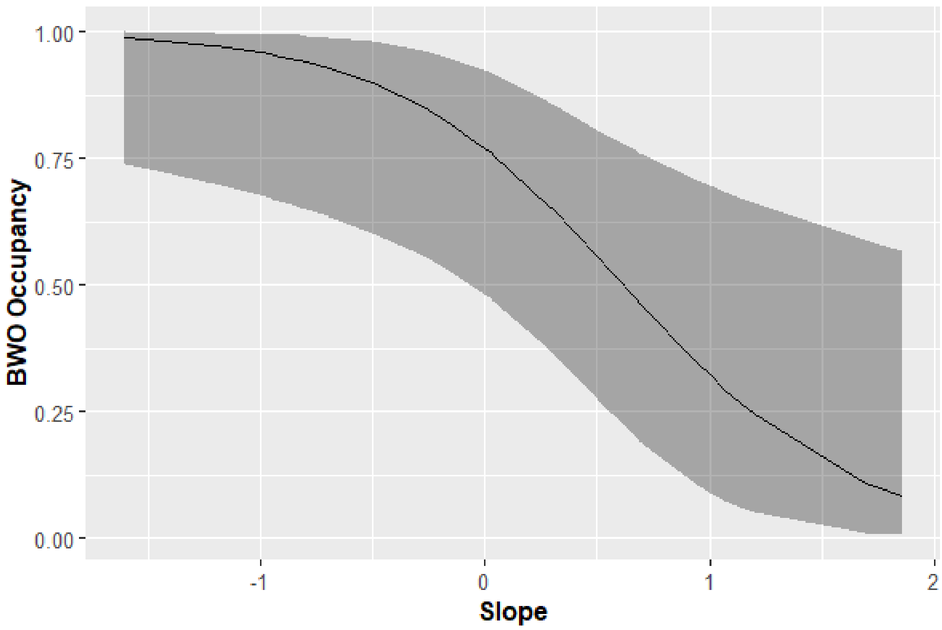

Figure 5: Predicted occupancy of Brown Wood Owl in response to slope.

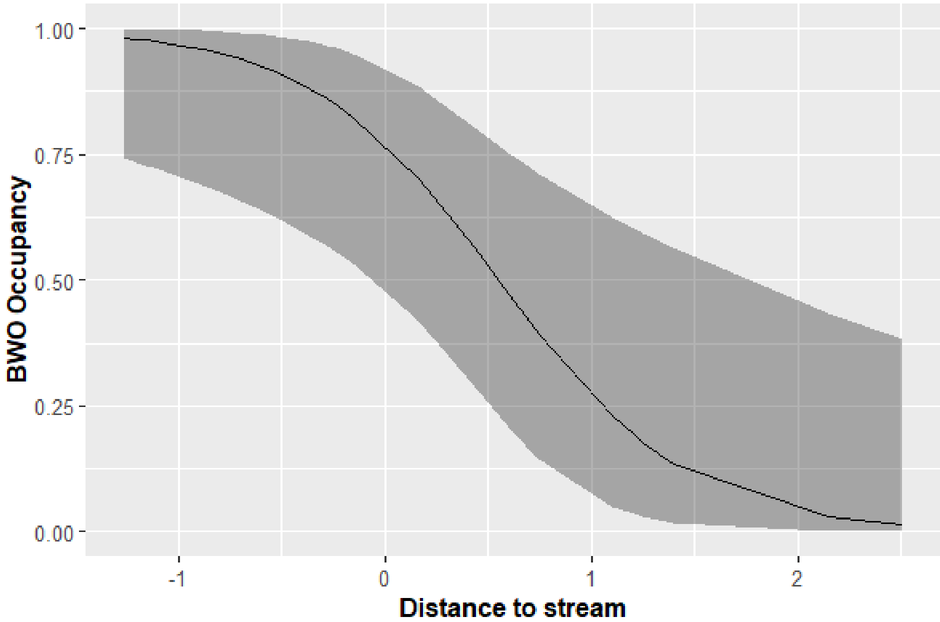

Figure 6: Predicted occupancy of Brown Wood Owl in response to distance to stream.

Table 6: Covariates influencing occupancy of Brown Wood Owl ranked on the basis of averaged β co-efficients, associated standard errors and summed model weights.

Site covariate	**Averaged β co-efficients**	**SE**	**Summed AIC_c weights**
D_Stream	-2.221670	0.845209	0.761
Slope	-1.952020	0.880517	0.761
SC	0.623527	0.663629	0.127
GBH	0.407756	0.585748	0.102
Disturbance	-0.385430	0.585853	0.096
TRI	0.153703	0.666566	0.081

D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index.

4.2. ESTIMATION OF ABUNDANCE OF BROWN WOOD OWL

4.2.1. Factors influencing detection probability of abundance of Brown Wood Owl

While modelling initial abundance, the Poisson distribution was supported more than the Negative binomial and Zero-inflated Poisson distributions since it had a smaller AIC_c value and hence was used for subsequent abundance modelling. Similar to the occupancy modelling, wind speed alone was included in the best-fit model for estimating detection probability (detection probability estimate, r = 0.38 ± 0.106_{SE}; see Table 7), with which it had a negative relationship (Figure 7). In all subsequent abundance models, *r* was modelled as a function of wind speed.

Table 7: Summary of models for factors influencing detection probability of abundance of Brown Wood Owl with ΔAIC_c less than 4.

Model	***r***	**SE**	**K**	**AIC_c**	**Δ AIC_c**	**AIC_c weight**
λ(.), r(Wind)	0.379737	0.106121	3	163.5	0.00	0.250
λ(.), r(Wind + Moon)	0.351402	0.119190	4	165.3	1.82	0.100
λ(.), r(Wind + Humid)	0.376504	0.114593	4	165.4	1.90	0.097
λ(.), r(.)	0.379737	0.106121	2	166.0	2.47	0.073
λ(.), r(Wind + Temp)	0.378795	0.118411	4	166.1	2.55	0.070
λ(.), r(Wind + Start time)	0.381704	0.118895	4	166.1	2.57	0.069
λ(.), r(Wind + Moon + Humid)	0.348325	0.126077	5	167.3	3.81	0.037

r, the estimated species detection probability; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; Δ AIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;
Wind, wind speed; Moon, moon phase; Start time, time of survey (minutes after sunset); Humid, humidity; Temp, temperature.

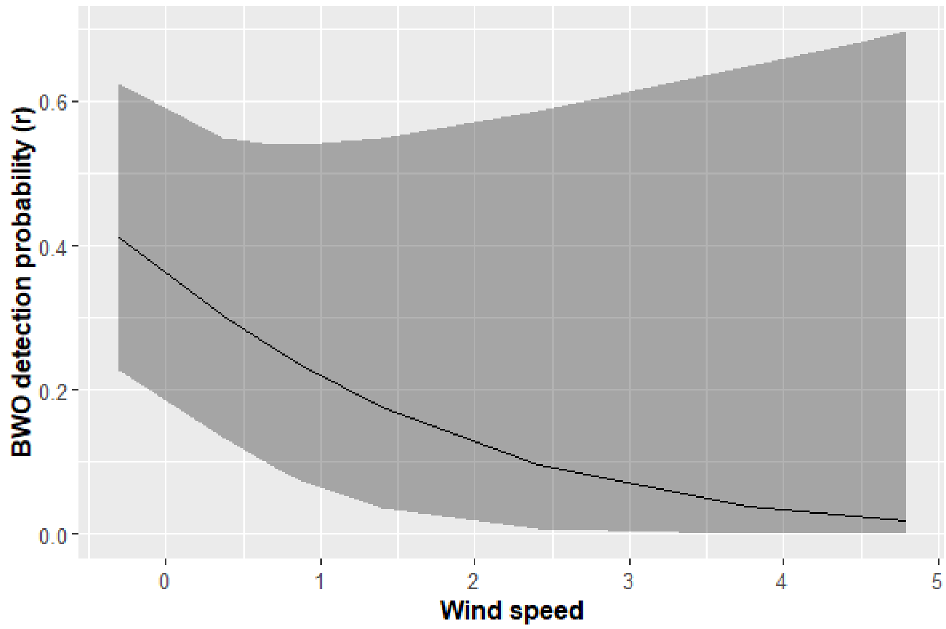

Figure 7: Detection probability of abundance of Brown Wood Owl in response to wind speed.

4.2.2. Factors influencing the abundance of Brown Wood Owl

The best-fit model for Brown Wood Owl's abundance included distance to stream, slope and GBH and had an abundance estimate of 1.4 ± 0.704_{SE} per grid (25 ha) (Table 8). Model averaging was done for these models to get averaged Beta coefficients for site covariates, along with standard errors and summed model weights (Table 9). The results showed that slope and distance to stream had negative effects on abundance of Brown Wood Owl (Figures 9 and 10), while GBH (Figure 8), coefficient of variation of tree height, disturbance, shrub cover and terrain ruggedness had positive effects.

Table 8: Summary of models for abundance of Brown Wood Owl with Δ AIC_c less than 4.

Model	**Lambda (λ)**	**SE**	**K**	**AIC_c**	**Δ AIC_c**	**AIC_c weight**
λ(D_Stream + Slope + GBH), r(Wind)	1.404769	0.704296	6	158.7	0.00	0.078
λ(D_Stream + Slope + THcv), r(Wind)	1.336889	0.633884	6	158.8	0.07	0.075
λ(D_Stream + GBH), r(Wind)	1.361978	0.602862	5	159.2	0.54	0.059
λ(D_Stream + Slope), r(Wind)	1.267990	0.514557	5	159.4	0.73	0.054
λ(D_Stream + THcv + GBH), r(Wind)	1.435939	0.731579	6	159.6	0.95	0.048
λ(D_Stream + Slope + GBH + THcv), r(Wind)	1.472590	0.830166	7	159.9	1.16	0.043
λ(D_Stream + THcv), r(Wind)	1.299615	0.538971	5	160.3	1.66	0.034
λ(THcv), r(Wind)	1.284545	0.474281	4	160.6	1.87	0.030
λ(THcv + Slope), r(Wind)	1.312500	0.559999	5	161.1	2.38	0.024
λ(GBH), r(Wind)	1.311788	0.503807	4	161.1	2.41	0.023
λ(THcv + GBH), r(Wind)	1.368591	0.613275	5	161.1	2.45	0.023
λ(D_Stream + Slope + GBH + Disturbance), r(Wind)	1.380200	0.718957	7	161.5	2.80	0.019
λ(D_Stream + Slope + TRI + THcv), r(Wind)	1.363726	0.706475	7	161.8	3.15	0.016
λ(D_Stream + SC + GBH), r(Wind)	1.384373	0.680654	6	161.9	3.17	0.016
λ(D_Stream + Slope + SC + GBH), r(Wind)	1.405784	0.754899	7	161.9	3.25	0.015
λ(D_Stream + Slope + TRI + GBH), r(Wind)	1.404254	0.751017	7	161.9	3.25	0.015
λ(D_Stream + Slope + THcv + Disturbance), r(Wind)	1.345315	0.691480	7	162.0	3.29	0.015
λ(D_Stream + Slope + THcv + SC), r(Wind)	1.335990	0.681700	7	162.0	3.30	0.015

λ(D_Stream + GBH + Disturbance), r(Wind)	1.345305	0.630788	6	162.0	3.31	0.015
λ(Slope), r(Wind)	1.257153	0.448863	4	162.2	3.47	0.014
λ(Slope + GBH), r(Wind)	1.331859	0.576483	5	162.2	3.53	0.013
λ(D_Stream + TRI + GBH), r(Wind)	1.331859	0.576483	6	162.2	3.55	0.013
λ(D_Stream + Slope + SC), r(Wind)	1.268229	0.567583	6	162.3	3.63	0.013
λ(D_Stream + Slope + Disturbance), r(Wind)	1.270196	0.564710	6	162.4	3.73	0.012
λ(D_Stream + Slope + TRI), r(Wind)	1.268769	0.564512	6	162.4	3.74	0.012
λ(D_Stream + Slope + SC + THcv), r(Wind)	1.335990	0.681700	7	162.5	3.77	0.012

Lambda (λ), the estimated species abundance; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; ΔAIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;
D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index; THcv, Covariance of Tree height; Wind, wind speed.

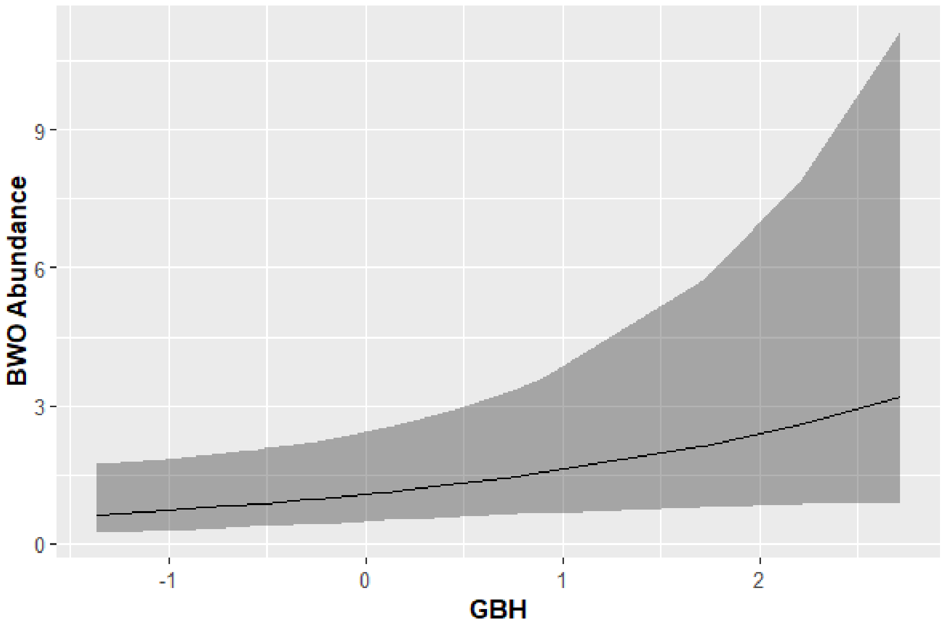

Figure 8: Predicted abundance of Brown Wood Owl in response to GBH.

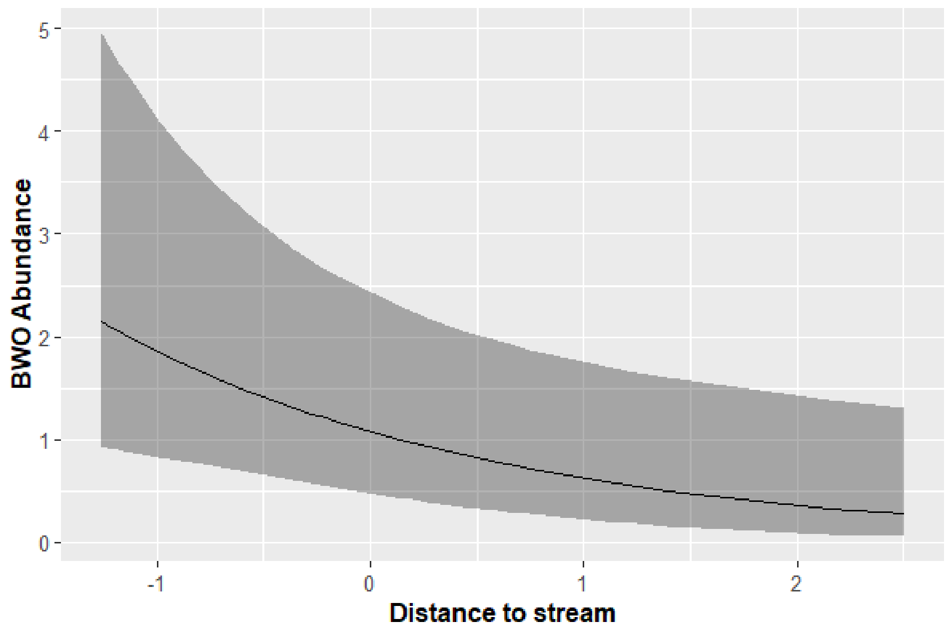

Figure 9: Predicted abundance of Brown Wood Owl in response to distance to stream.

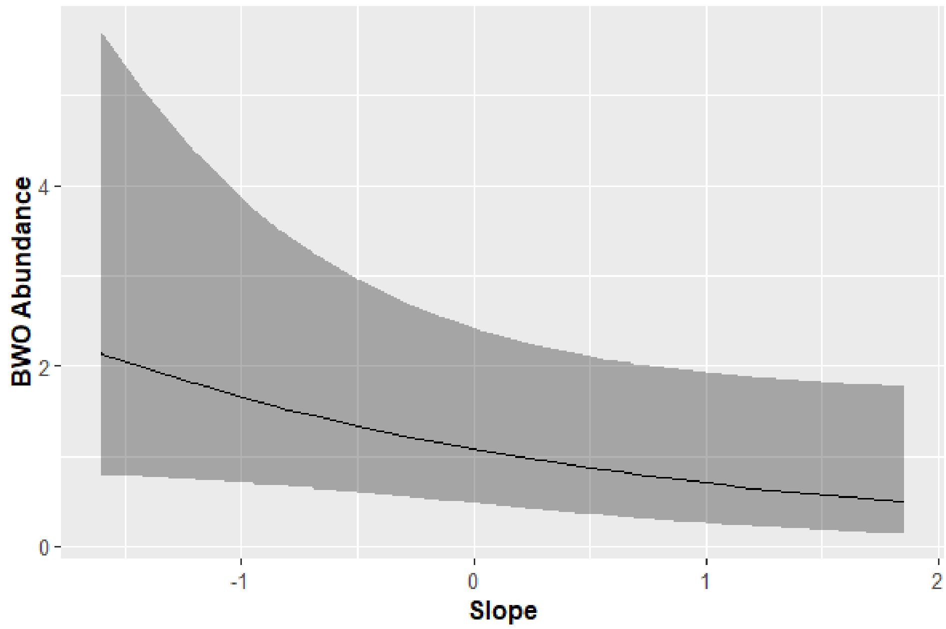

Figure 10: Predicted abundance of Brown Wood Owl in response to slope.

Table 9: Covariates influencing abundance of Brown Wood Owl ranked on the basis of averaged β co-efficients, associated standard errors and summed model weights.

Site covariate	**Average β co-efficients**	**SE**	**Summed AIC_c weights**
D_Stream	-0.49491	0.226423	0.579
Slope	-0.47312	0.242485	0.433
GBH	0.403316	0.189881	0.392
THcv	0.345505	0.175122	0.335

Disturbance	0.066625	0.220017	0.049
TRI	0.026186	0.194211	0.056
SC	0.034514	0.191339	0.059

D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index; THcv, covariance of tree height.

4.3. ESTIMATION OF OCCUPANCY OF MOUNTAIN SCOPS OWL

4.3.1. Factors influencing detection probability of occupancy of Mountain Scops Owl

Mountain Scops Owl had a naïve occupancy of 0.64, as it was also detected in 21 grids out of 33. While estimating detection probability, the model with least AIC_c value was the one that included the effect of temperature alone (positive relationship; Figure 11) and the estimate was $0.604 \pm 0.081_{SE}$ (Table 10). *p* was subsequently modelled as a function of temperature.

Table 10: Summary of models for factors influencing detection probability of occupancy of Mountain Scops Owl with ΔAIC_c less than 4.

Model	***p***	**SE**	**K**	**AIC_c**	**Δ AIC_c**	**AIC_c weight**
ψ(.), p(Temp)	0.603637	0.081320	3	120.9	0.00	0.224
ψ(.), p(Temp + Wind)	0.608967	0.087127	4	121.4	0.47	0.177
ψ(.), p(Temp + Humid)	0.606838	0.098905	4	122.4	1.48	0.107
ψ(.), p(Temp + Humid + Wind)	0.614688	0.102597	5	122.8	1.89	0.087
ψ(.), p(Temp + Start time)	0.596232	0.099781	4	123.3	2.39	0.068
ψ(.), p(Temp + Moon)	0.601791	0.100934	4	123.5	2.59	0.061
ψ(.), p(Temp + Start time + Wind)	0.600892	0.102196	5	123.8	2.9	0.053
ψ(.), p(Temp + Wind + Moon)	0.607224	0.104508	5	124.2	3.25	0.044

p, the estimated species detection probability; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; Δ AIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;
Wind, wind speed; Moon, moon phase; Start time, time of survey (minutes after sunset); Humid, humidity; Temp, temperature.

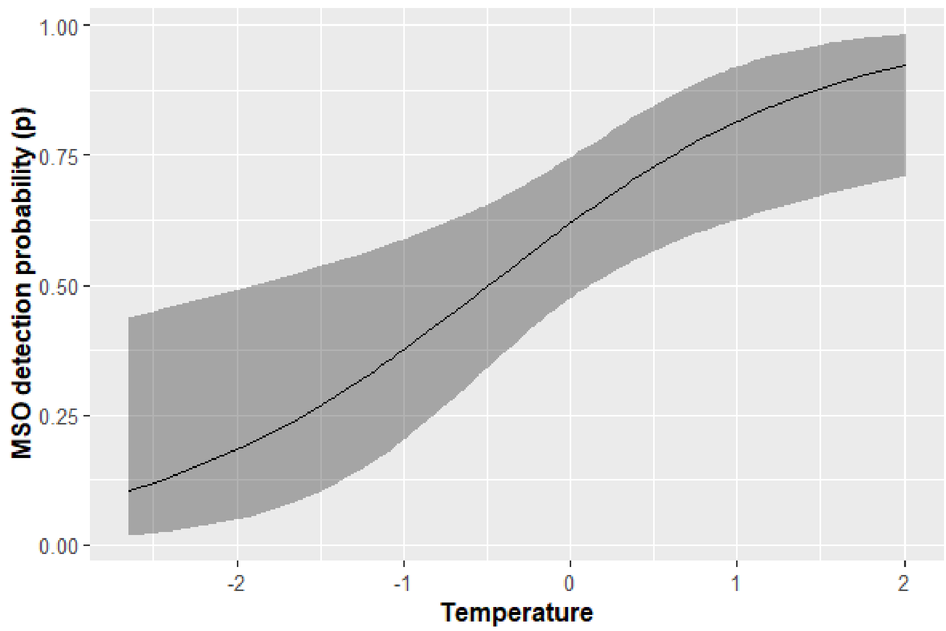

Figure 11: Detection probability of occupancy of Mountain Scops Owl in response to temperature.

4.3.2. Factors influencing the occupancy of Mountain Scops Owl

The occupancy model with least AIC_c value and was determined as best-fit included distance to stream and GBH. This model had an occupancy estimate of $0.69 \pm 0.114_{SE}$ (Table 11).

Summed model weights were calculated to enable comparison of support between site covariates (Table 12). Averaged β-coefficients revealed that disturbance, distance to stream and terrain ruggedness had positive effects on occupancy of Mountain Scops Owl (Figures 12 and 13), while GBH, slope and shrub cover had negative effects (Figure 14).

Table 11: Summary of models for occupancy of Mountain Scops Owl with Δ AIC_c less than 4.

Model	**psi (ψ)**	**SE**	**K**	**AIC_c**	**Δ AIC_c**	**AIC_c weight**
ψ(D_Stream + GBH), p(Temp)	0.691804	0.113959	5	114.3	0	0.112
ψ(D_Stream + Disturbance), p(Temp)	0.678291	0.128157	5	114.4	0.12	0.106
ψ(D_Stream + GBH + Disturbance), p(Temp)	0.681736	0.131624	6	114.9	0.65	0.081
ψ(D_Stream + GBH + Slope), p(Temp)	0.705143	0.123417	6	115.4	1.12	0.064

ψ(D_Stream + TRI + Disturbance), p(Temp)	0.668134	0.138371	6	115.4	1.14	0.063
ψ(D_Stream + GBH + TRI + Disturbance), p(Temp)	0.670046	0.144996	7	115.5	1.27	0.060
ψ(Disturbance), p(Temp)	0.672552	0.103991	4	115.9	1.68	0.048
ψ(D_Stream + GBH + TRI), p(Temp)	0.686327	0.126366	6	116.0	1.69	0.048
ψ(D_Stream + GBH + Slope + Disturbance), p(Temp)	0.693210	0.137163	7	117.1	2.85	0.027
ψ(D_Stream + Slope + Disturbance), p(Temp)	0.684637	0.148339	6	117.2	2.96	0.026
ψ(D_Stream + GBH + SC), p(Temp)	0.692386	0.133099	6	117.3	3.00	0.025
ψ(D_Stream + SC + Disturbance), p(Temp)	0.674978	0.145510	6	117.3	3.00	0.025
ψ(D_Stream + GBH + Slope + TRI), p(Temp)	0.698645	0.132991	7	117.4	3.17	0.023
ψ(Slope + Disturbance), p(Temp)	0.686432	0.130463	5	117.5	3.26	0.022
ψ(D_Stream + GBH + Slope + SC), p(Temp)	0.729781	0.134626	7	117.7	3.40	0.020
ψ(TRI + Disturbance), p(Temp)	0.666050	0.123592	5	117.8	3.55	0.019
ψ(GBH + Disturbance), p(Temp)	0.670894	0.123380	5	118.0	3.74	0.017
ψ(D_Stream + SC + GBH + Disturbance), p(Temp)	0.681074	0.150449	7	118.2	3.90	0.016

psi (ψ); the estimated species occupancy parameter; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; ΔAIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model; D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index; Temp, temperature.

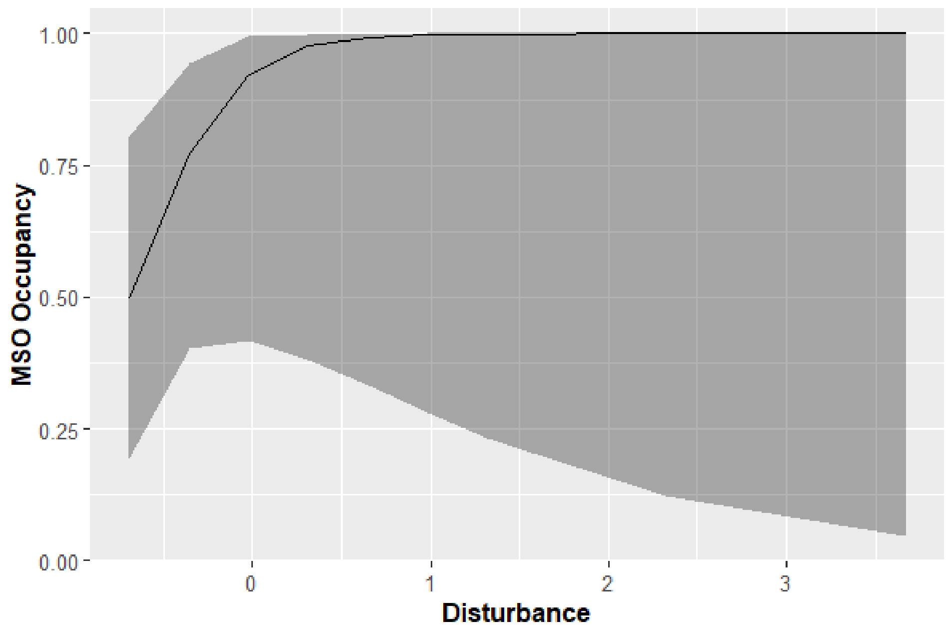

Figure 12: Predicted occupancy of Mountain Scops Owl in response to disturbance.

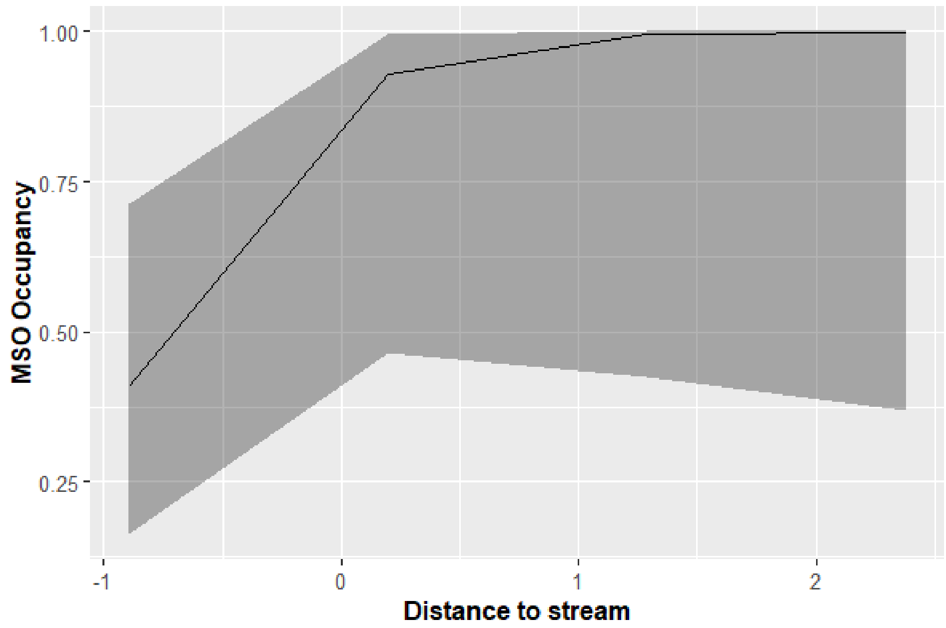

Figure 13: Predicted occupancy of Mountain Scops Owl in response to distance to stream.

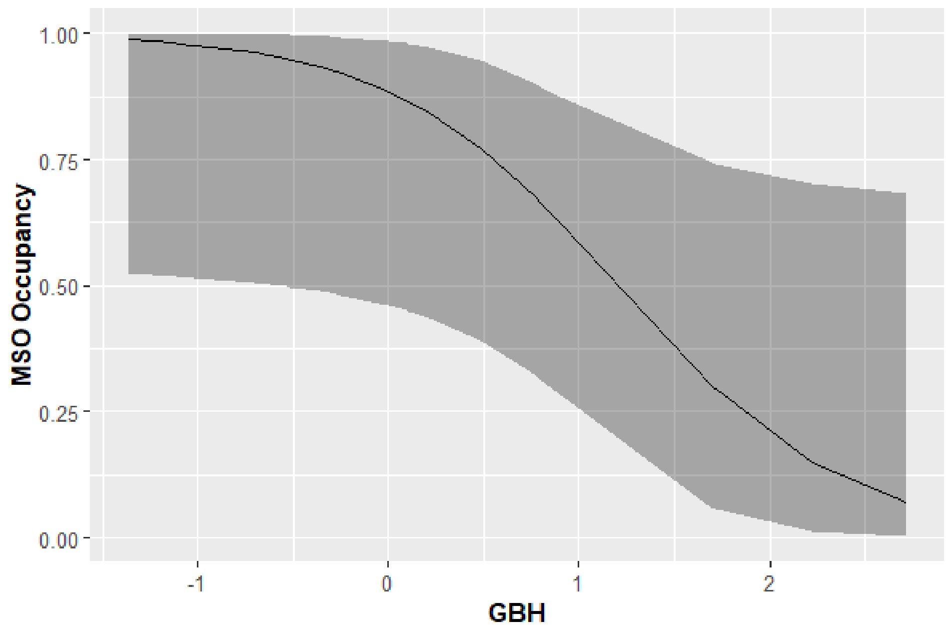

Figure 14: Predicted occupancy of Mountain Scops Owl in response to GBH.

Table 12: Covariates influencing occupancy of Mountain Scops Owl ranked on the basis of averaged β co-efficients, associated standard errors and summed model weights.

Site covariate	**Averaged β co-efficients**	**SE**	**Summed AIC_c weights**
Disturbance	3.275567	2.124232	0.510
D_Stream	2.548471	1.755923	0.696
GBH	-1.807330	1.314307	0.493
Slope	-0.970530	0.948427	0.182
TRI	0.729599	0.586252	0.213
SC	-0.143670	0.633568	0.086

D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index.

4.4. ESTIMATION OF ABUNDANCE OF MOUNTAIN SCOPS OWL

4.4.1. Factors influencing the detection probability of abundance of Mountain Scops Owl

The Poisson distribution was selected over than the Negative binomial and Zero-inflated Poisson distributions as it had a smaller AIC_c value while modelling initial abundance. The best-fit model for estimating detection probability (*r*) for abundance of Mountain Scops Owl deviated from the same for occupancy as it included the effect of humidity, in addition to temperature (detection probability estimate, r = 0.47 ± 0.103_{SE} ; Table 13). Both sampling covariates had positive effects on *r* (Figures 15 and 16). Hence, *r* was subsequently modelled as a function of temperature and humidity.

Table 13: Summary of models for factors influencing detection probability of abundance of Mountain Scops Owl with ΔAIC_c less than 4.

Model	**r**	**SE**	**K**	**AIC_c**	**ΔAIC_c**	**AIC_c weight**
λ(.), r(Temp + Humid)	0.466346	0.103238	4	176.7	0.00	0.231
λ(.), r(Temp)	0.466575	0.089626	3	177.4	0.75	0.158
λ(.), r(Temp + Wind + Humid)	0.475039	0.106054	5	178.4	1.74	0.096
λ(.), r(Temp + Wind)	0.472925	0.091656	4	178.8	2.15	0.079
λ(.), r(Temp + Humid + Moon)	0.458474	0.113562	5	179.2	2.55	0.064
λ(.), r(Temp + Start time)	0.455491	0.101211	4	179.3	2.59	0.063
λ(.), r(Wind + Start time + Humid)	0.458795	0.118113	5	179.3	2.64	0.061
λ(.), r(Wind + Moon + Humid)	0.459965	0.102589	4	179.9	3.22	0.046

r, the estimated species detection probability; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; ΔAIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;
Wind, wind speed; Moon, moon phase; Start time, time of survey (minutes after sunset); Humid, humidity; Temp, temperature.

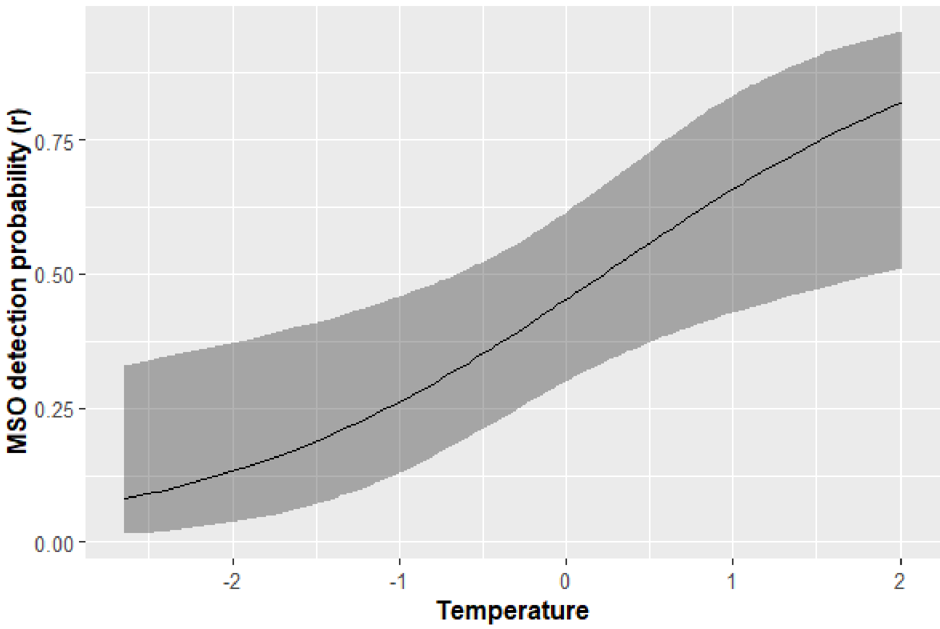

Figure 15: Detection probability of abundance of Mountain Scops Owl in response to temperature.

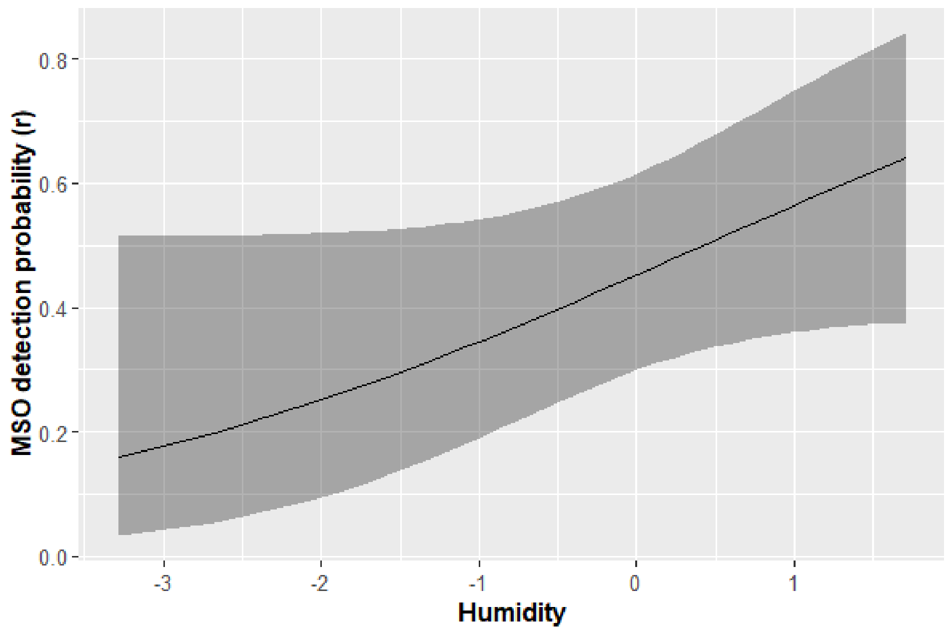

Figure 16: Detection probability of abundance of Mountain Scops Owl in response to relative humidity.

4.4.2. Factors influencing the abundance of Mountain Scops Owl

A single site covariate; disturbance was included in the best-fit model for Mountain Scops Owl's abundance and had an abundance estimate of 1.36 ± 0.396_{SE} per grid (Table 14).

Summated AIC_c weights were calculated for each site covariate (Table 15). Averaged β-coefficients showed that disturbance, distance to stream, shrub cover, coefficient of variation of tree height and terrain ruggedness had a positive relationship with abundance (Figure 17), while the relationships with GBH and slope were negative.

Table 14: Summary of models for abundance of Mountain Scops Owl with Δ AIC_c less than 4.

Model	Lambda (λ)	SE	K	AIC_c	Δ AIC_c	AIC_c weight
λ(Disturbance), r(Temp + Humid)	1.361307	0.396436	5	174.1	0.00	0.133
λ(Disturbance + D_Stream), r(Temp + Humid)	1.348378	0.457318	6	174.9	0.77	0.090
λ(Disturbance + GBH), r(Temp + Humid)	1.386557	0.473316	6	176.4	2.24	0.043
λ(GBH), r(Temp + Humid)	1.303635	0.362158	5	176.4	2.32	0.042
λ(D_Stream), r(Temp + Humid)	1.260122	0.348509	5	176.5	2.36	0.041

λ(Disturbance + SC), r(Temp + Humid)	1.358806	0.462679	6	176.5	2.39	0.040
λ(.), r(Temp + Humid)	1.248158	0.265001	4	176.7	2.58	0.037
λ(GBH + D_Stream), r(Temp + Humid)	1.302294	0.427897	6	176.9	2.79	0.033
λ(Disturbance + Slope), r(Temp + Humid)	1.366821	0.461057	6	177.0	2.90	0.031
λ(Disturbance + TRI), r(Temp + Humid)	1.370935	0.465565	6	177.1	2.95	0.030
λ(Disturbance + THcv), r(Temp + Humid)	1.363010	0.456831	6	177.1	2.99	0.030
λ(Disturbance + GBH + D_Stream), r(Temp + Humid)	1.365005	0.519912	7	177.6	3.45	0.024
λ(Disturbance + SC + D_Stream), r(Temp + Humid)	1.346253	0.513935	7	177.7	3.63	0.022
λ(Disturbance + THcv + D_Stream), r(Temp + Humid)	1.352182	0.514184	7	178.1	3.93	0.019

Lambda (λ); the estimated species abundance; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; Δ AIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;
D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index; THcv, Covariance of Tree height; Temp, temperature; Humid, humidity.

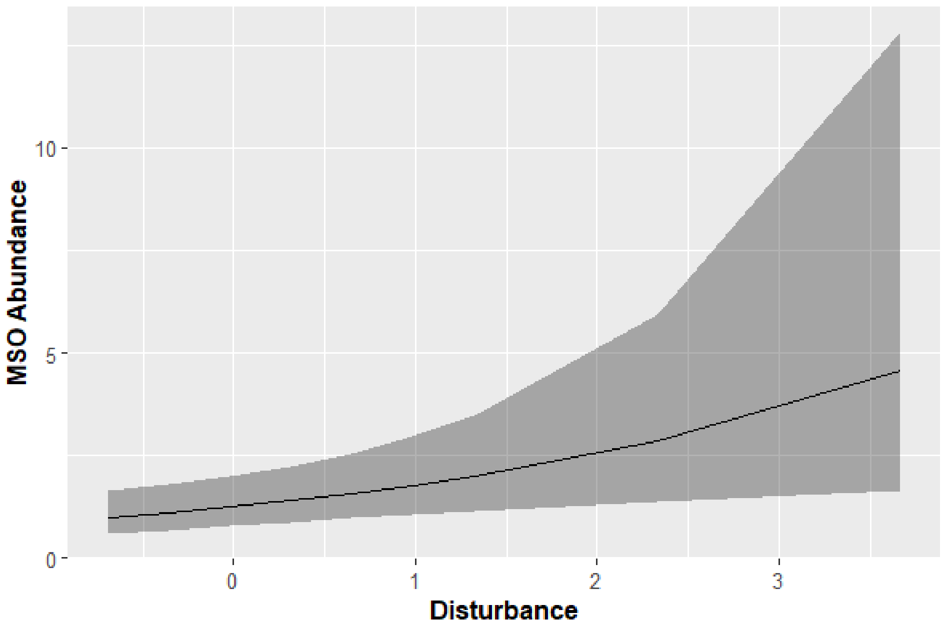

Figure 17: Predicted abundance of Mountain Scops Owl in response to disturbance.

Table 15: Covariates influencing abundance of Mountain Scops Owl ranked on the basis of averaged β co-efficients, associated standard errors and summed model weights.

Site covariate	Average β co-efficients	SE	Summed AIC_c weights
Disturbance	0.347419	0.145367	0.462
D_Stream	0.265366	0.168986	0.229
GBH	-0.253630	0.210096	0.142
SC	0.136868	0.186374	0.062
Slope	-0.060470	0.179934	0.031
TRI	0.026186	0.194211	0.056
THcv	0.034514	0.191339	0.059

D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index; THcv, covariance of tree height.

4.5. ESTIMATION OF OCCUPANCY OF COLLARED OWLET

4.5.1. Factors influencing the detection probability of occupancy of Collared Owlet

A naïve occupancy of 0.61 was calculated for the Collared Owlet as it was detected in 20 out of the 33 surveyed grids. Temperature, which had a positive on detection probability (*p*) (Figure 18), was the only sampling covariate included in the most parsimonious model for estimating *p* ($p = 0.469 \pm 0.083_{SE}$; Table 16). Subsequently, *p* was modelled as a function of temperature.

Table 16: Summary of models for factors influencing detection probability of occupancy of Collared Owlet with ΔAIC_c less than 4.

Model	*p*	SE	K	AIC_c	ΔAIC_c	AIC_c weight
ψ(.), p(Temp)	0.469127	0.082725	3	118.9	0.00	0.182
ψ(.), p(Temp + Start time)	0.462914	0.097360	4	120.0	1.15	0.102
ψ(.), p(Temp + Humid)	0.480409	0.100993	4	120.1	1.25	0.097
ψ(.), p(Temp + Moon)	0.453553	0.099093	4	120.3	1.42	0.089
ψ(.), p(Temp + Wind)	0.455500	0.091738	4	120.4	1.51	0.086
ψ(.), p(Temp + Start time + Humid)	0.475296	0.114391	5	120.9	1.99	0.067
ψ(.), p(Temp + Humid + Wind)	0.467617	0.108239	5	121.6	2.76	0.046

ψ(.), p(Temp + Start time + Moon)	0.445365	0.111298	5	121.7	2.83	0.044
ψ(.), p(Temp + Start time + Wind)	0.450228	0.103881	5	121.7	2.85	0.044
ψ(.), p(Temp + Moon + Humid)	0.463797	0.115573	5	121.8	2.88	0.043
ψ(.), p(Temp + Moon + Wind)	0.437967	0.106090	5	121.8	2.96	0.041
ψ(.), p(Temp + Humid + Start time + Wind)	0.463721	0.119102	6	122.6	3.68	0.029
ψ(.), p(Temp + Humid + Start time + Moon)	0.455231	0.127321	6	122.8	3.95	0.025

p, the estimated species detection probability; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; ΔAIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;
Wind, wind speed; Moon, moon phase; Start time, time of survey (minutes after sunset); Humid, humidity; Temp, temperature.

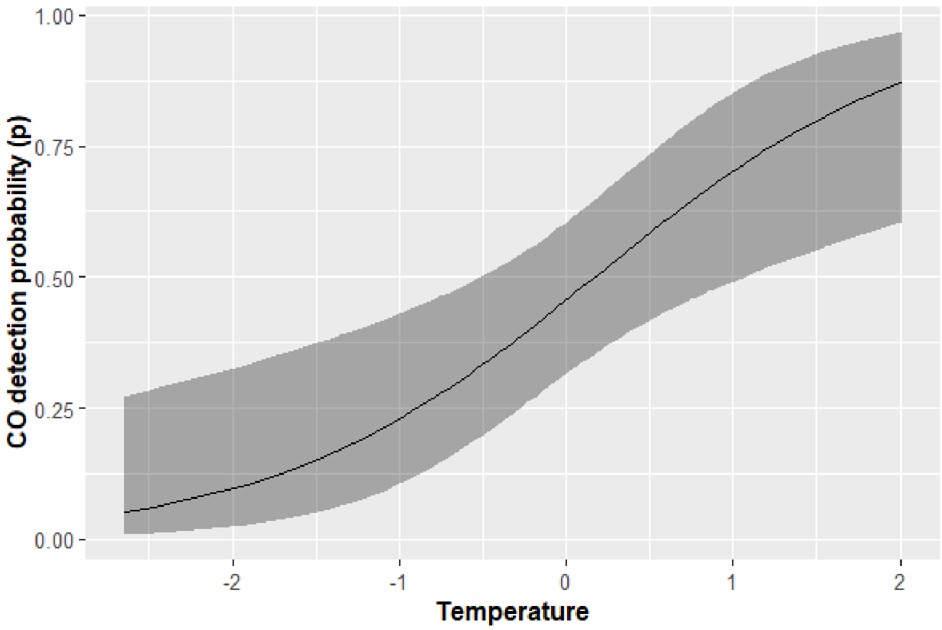

Figure 18: Detection probability of occupancy of Collared Owlet in response to temperature.

4.5.2. Factors influencing the occupancy of Collared Owlet

Slope was the only site covariate included in the best-fit model for occupancy of Collared Owlet, which gave an occupancy estimate of $0.7 \pm 0.139_{SE}$ (Table 17). Averaged β-coefficients (Table 18) indicated that slope, terrain ruggedness and shrub cover had positive effects on occupancy of Collared Owlet (Figure 19), while disturbance and distance to stream had a negative effect.

Table 17: Summary of models for occupancy of Collared Owlet with Δ AIC_c less than 4.

Model	**psi (ψ)**	**SE**	**K**	**AIC_c**	**Δ AIC_c**	**AIC_c weight**
ψ(Slope), p(Temp)	0.698019	0.139194	4	116.8	0.00	0.153
ψ(Slope + Disturbance), p(Temp)	0.690775	0.137518	5	117.1	0.28	0.133
ψ(Slope + TRI), p(Temp)	0.703446	0.147195	5	117.8	0.97	0.094
ψ(D_Stream), p(Temp)	0.721566	0.132881	4	118.4	1.65	0.067
ψ(Slope + D_Stream), p(Temp)	0.690540	0.156413	5	118.7	1.88	0.060
ψ(.), p(Temp)	0.741338	0.102284	3	118.9	2.11	0.053
ψ(Slope + SC), p(Temp)	0.694148	0.162814	5	119.1	2.34	0.047
ψ(Slope + D_Stream + Disturbance), p(Temp)	0.694268	0.160157	6	119.1	2.35	0.047
ψ(Slope + TRI + Disturbance), p(Temp)	0.680523	0.154889	6	119.3	2.51	0.044
ψ(Slope + SC + Disturbance), p(Temp)	0.687695	0.158909	6	120	3.20	0.031
ψ(Disturbance), p(Temp)	0.758263	0.132085	4	120.4	3.59	0.025
ψ(D_Stream + Disturbance), p(Temp)	0.721230	0.147924	5	120.5	3.68	0.024
ψ(D_Stream + TRI), p(Temp)	0.709456	0.147459	5	120.5	3.70	0.024
ψ(Slope + D_Stream + TRI), p(Temp)	0.678631	0.180296	6	120.5	3.71	0.024
ψ(TRI), p(Temp)	0.734299	0.125497	4	120.6	3.87	0.022
ψ(Slope + SC + TRI), p(Temp)	0.701083	0.186149	6	120.8	3.98	0.021

psi (ψ); the estimated species occupancy parameter; SE, associated standard error; AIC_c, the Akaike Information Criterion corrected for small samples; Δ AIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model; D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; Disturbance, disturbance index; TRI, Terrain Ruggedness Index; Temp, temperature.

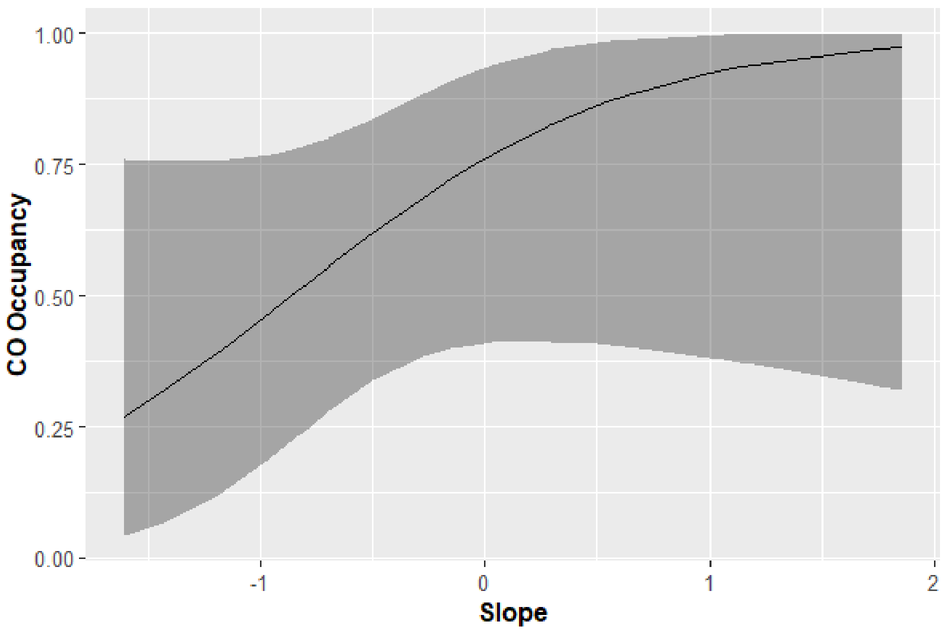

Figure 19: Predicted occupancy of Collared Owlet in response to slope.

Table 18: Covariates influencing occupancy of Collared Owlet ranked on the basis of averaged β co-efficients, associated standard errors and summed model weights.

Site covariate	Averaged β co-efficients	SE	Summed AIC_c weights
Slope	1.457080	0.949774	0.654
Disturbance	-0.839470	0.615765	0.304
TRI	0.700326	0.734013	0.229
D_Stream	-0.827880	0.698355	0.246
SC	0.222951	0.635747	0.099

D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; Disturbance, disturbance index; TRI, Terrain Ruggedness Index.

4.6. ESTIMATION OF ABUNDANCE OF COLLARED OWLET

4.6.1. Factors influencing the detection probability of abundance of Collared Owlet

Among the Poisson, Negative Binomial and Zero-inflated Poisson distributions, the Poisson distribution had the most support as it had the smallest AIC_c value and was hence used for abundance modelling. The best-fit model for detection probability of abundance (*r*) of Collared Owlet also deviated from that of occupancy, as time of survey (start time) was also included, along with temperature (detection probability estimate, $r = 0.27 \pm 0.122_{SE}$; Table 19). Subsequently, *r* was modelled as a function of temperature (positive effect; Figure 21) and start time (negative effect; Figure 20).

Table 19: Summary of models for factors influencing detection probability of abundance of Collared Owlet with ΔAIC_c less than 4.

Model	**r**	**SE**	**K**	**AIC_c**	**Δ AIC_c**	**AIC_c weight**
λ(.), r(Temp + Start time)	0.265042	0.122198	4	160.5	0.00	0.079
λ(.), r(Temp)	0.276325	0.120538	3	160.5	0.00	0.079
λ(.), r(Start time)	0.231149	0.108435	3	160.6	0.09	0.076
λ(.), r(Start time + Humid)	0.266531	0.113624	4	160.9	0.48	0.062
λ(.), r(Temp + Moon)	0.215780	0.129510	4	161.3	0.88	0.051
λ(.), r(Start time + Moon)	0.175038	0.120328	4	161.4	0.92	0.050
λ(.), r(Temp + Start time + Humid)	0.284127	0.125924	5	161.5	0.99	0.048
λ(.), r(Temp + Wind)	0.279548	0.122380	4	161.5	1.08	0.046
λ(.), r(Temp + Humid)	0.298133	0.121964	4	161.8	1.30	0.041
λ(.), r(Temp + Start time + Moon)	0.205175	0.134736	5	161.8	1.34	0.041
λ(.), r(Temp + Start time + Wind)	0.269781	0.124440	5	161.9	1.45	0.038
λ(.), r(Start time + Moon + Humid)	0.210185	0.125159	5	162.2	1.73	0.033
λ(.), r(Temp + Moon + Wind)	0.212926	0.129906	5	162.2	1.76	0.033
λ(.), r(Start time + Wind)	0.223320	0.111541	4	162.2	1.78	0.033
λ(.), r(Start time + Wind + Humid)	0.261550	0.117863	5	162.8	2.33	0.025
λ(.), r(Start time + Moon + Wind)	0.168076	0.117789	5	162.9	2.43	0.023
λ(.), r(Temp + Wind + Humid)	0.300397	0.121352	5	162.9	2.45	0.023
λ(.), r(Temp + Moon + Humid)	0.237799	0.137542	5	163.0	2.55	0.022
λ(.), r(Temp + Start time + Humid + Wind)	0.288937	0.127335	6	163.0	2.57	0.022
λ(.), r(.)	0.238848	0.106041	2	163.1	2.61	0.021
λ(.), r(Temp + Moon + Start time + Humid)	0.224991	0.136597	6	163.1	2.68	0.021
λ(.), r(Temp + Moon + Start time + Wind)	0.207815	0.134010	6	163.2	2.69	0.021

λ(.), r(Moon)	0.192841	0.110901	3	163.3	2.82	0.019
λ(.), r(Moon + Start time + Humid + Wind)	0.200669	0.124575	6	163.9	3.45	0.014
λ(.), r(Moon + Humid + Temp + Wind)	0.235635	0.140299	6	164.1	3.61	0.013
λ(.), r(Humid)	0.276745	0.117586	3	164.1	3.64	0.013
λ(.), r(Moon + Wind)	0.181755	0.109260	4	164.4	3.90	0.011
λ(.), r(Wind)	0.226165	0.109231	3	164.4	3.97	0.011

r, the estimated species detection probability; SE, associated standard error; AIC_c, the Akaike Information Criterion; Δ AIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;

Wind, wind speed; Moon, moon phase; Start time, time of survey (minutes after sunset); Humid, humidity; Temp, temperature.

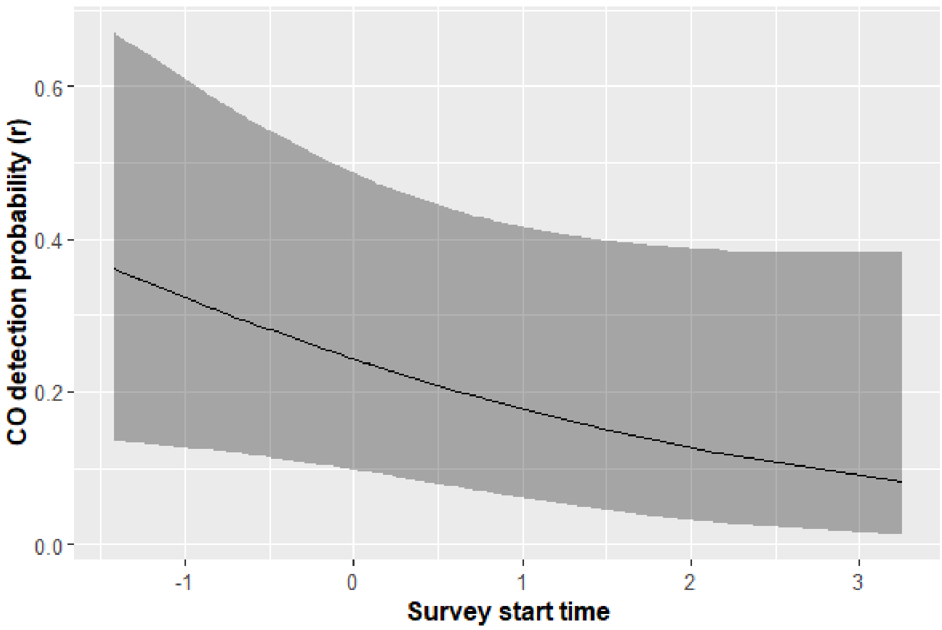

Figure 20: Detection probability of abundance of Collared Owlet in response to time of survey (start time).

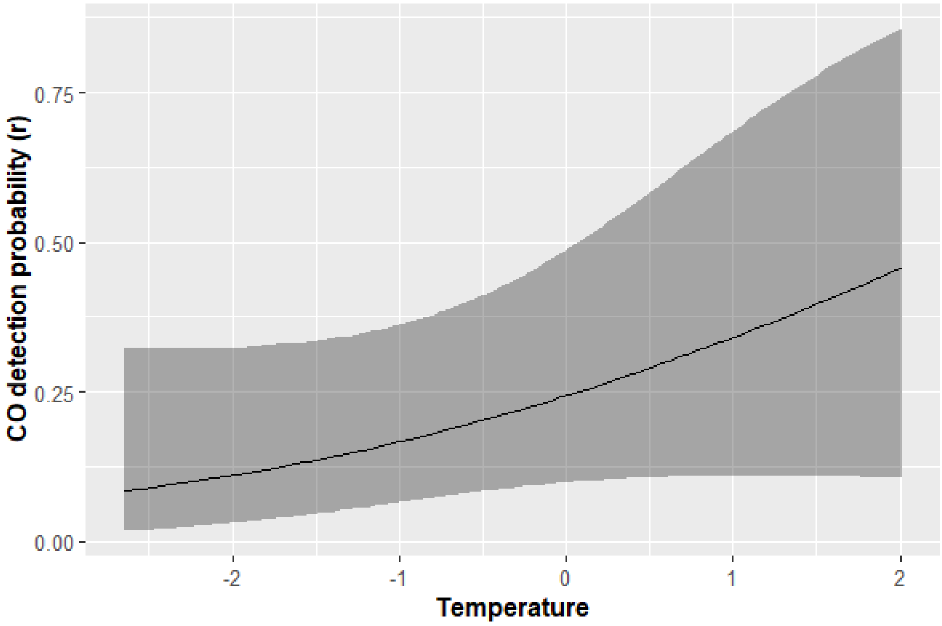

Figure 21: Detection probability of abundance of Collared Owlet in response to temperature.

4.6.2. Factors influencing the abundance of Collared Owlet

As in the results from occupancy modelling, the best-fit model for abundance of Collared Owlet included slope alone. This model gave an abundance estimate of 2.76 ± 2.701_{SE} per grid (Table 20).

Averaged β-coefficients (along with associated standard errors and summed model weights) (Table 21), point out that slope (Figure 22), coefficient of variation of tree height, shrub cover and distance to stream had positive effects on abundance, while disturbance, terrain ruggedness and GBH had negative effects.

Table 20: Summary of models for abundance of Collared Owlet with Δ AIC_c less than 4.

Model	**Lambda (λ)**	**SE**	**K**	**AIC_c**	**Δ AIC_c**	**AIC_c weight**
λ(Slope), r(Temp + Start time)	2.755792	2.708957	5	157.7	0.00	0.172
λ(Slope + THcv), r(Temp + Start time)	2.831275	2.644541	6	158.7	1.00	0.104
λ(Slope + Disturbance), r(Temp + Start time)	2.891269	2.932620	6	160.1	2.40	0.052
λ(Slope + TRI), r(Temp + Start time)	3.397675	4.498547	6	160.1	2.45	0.050
λ(.), r(Temp + Start time)	1.575630	0.626319	4	160.5	2.80	0.042

λ(Slope + SC), r(Temp + Start time)	2.720676	2.672326	6	160.6	2.93	0.040
λ(Slope + D_Stream), r(Temp + Start time)	2.868238	3.075861	6	160.6	2.96	0.039
λ(Slope + GBH), r(Temp + Start time)	2.697357	2.717333	6	160.7	3.00	0.038
λ(Slope + THcv + Disturbance), r(Temp + Start time)	2.929618	2.875853	7	161.5	3.82	0.025
λ(Slope + THcv + GBH), r(Temp + Start time)	2.540885	2.309088	7	161.5	3.82	0.025
λ(Slope + THcv + TRI), r(Temp + Start time)	3.263129	3.696714	7	161.5	3.87	0.025

Lambda (λ), the estimated species abundance; SE, associated standard error; AIC_c, the Akaike Information Criterion; Δ AIC_c, difference in AIC_c values between each model and the model with the lowest AIC_c; w_i, AIC_c model weight; K, number of parameters estimated by the model;
D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index; THcv, Covariance of Tree height; Temp, Temperature; Start time, start time of survey after sunset.

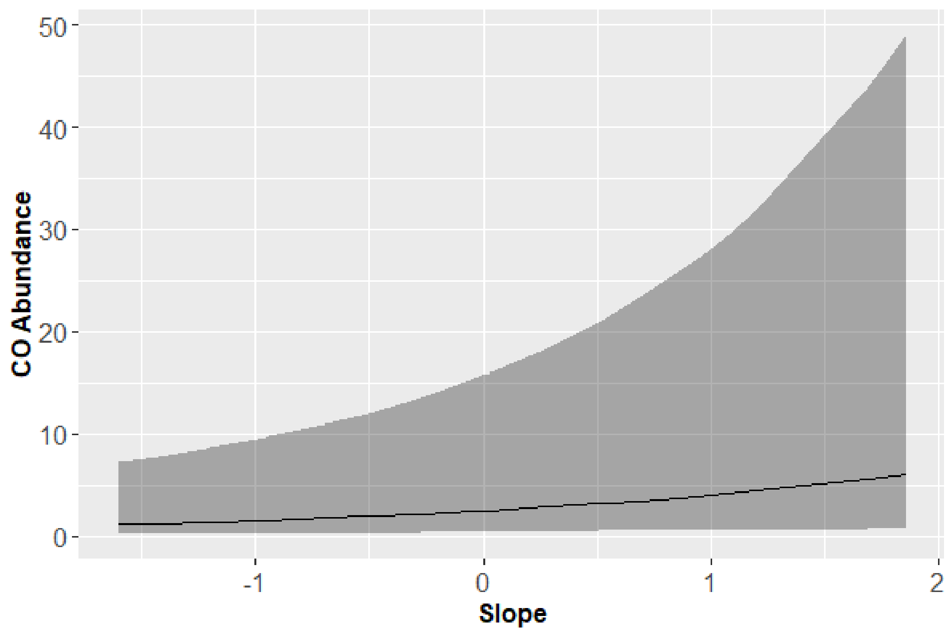

Figure 22: Predicted abundance of Collared Owlet in response to slope.

Table 21: Covariates influencing abundance of Collared Owlet ranked on the basis of averaged β co-efficients, associated standard errors and summed model weights.

Site covariate	**Average β co-efficients**	**SE**	**Summed AIC_c weights**
Slope	0.520929	0.209753	0.570

THcv	0.254022	0.177677	0.179
Disturbance	-0.154150	0.216016	0.077
TRI	-0.136040	0.197196	0.075
GBH	-0.075290	0.22681	0.063
SC	0.056808	0.197591	0.040
D_Stream	0.046848	0.223191	0.039

D_Stream, distance to stream; Slope, slope of terrain; SC, shrub cover; GBH, Girth at Breast Height of trees; Disturbance, disturbance index; TRI, Terrain Ruggedness Index; THcv, covariance of tree height.

4.7. COMPARING DETECTIONS INSIDE AND OUTSIDE COMMUNITY RESERVES

Mann Whitney *U* tests revealed that there was a statistically significant difference observed between number of detections of Brown Wood Owl (p = 0.02) and Mountain Scops Owl (p = 0.007) when comparing sampling points inside and outside Community Reserves (Table 22). Higher number of detections were from inside Community Reserves for the Brown Wood Owl, while the Mountain Scops Owl was detected more outside Community Reserves. The Mann Whitney *U* test failed to detect any significant difference between number of detections of Collared Owlet inside and outside Community Reserves (p = 0.251).

Table 22: Detections of owls inside and outside Community Reserves.

Species	**Inside CR (n = 17)**		**Outside CR (n = 16)**		**M-W *U* test**	***P***
	Mean	**SE**	**Mean**	**SE**		
Brown Wood Owl	2.00	0.39	0.75	0.21	74.0	0.020
Mountain Scops Owl	0.94	0.34	2.50	0.47	64.0	0.007
Collared Owlet	0.94	0.26	1.56	0.39	105.5	0.251

M-W *U* test; Mann Whitney *U* test.

5. DISCUSSION

5.1. ESTIMATES OF OCCUPANCY AND ABUNDANCE

The occupancy estimates of the three species of owls were higher compared to their naïve occupancies, highlighting the advantage of accounting for false absences using occupancy (Mackenzie *et al.*, 2002) and N-mixture models (Royle, 2004). The Brown Wood Owl had an occupancy estimate of 0.66 ± 0.104_{SE} in the top model, compared to a naïve occupancy of 0.64 which increased the proportion of grids occupied by the owl by 3%. The occupancy estimate of the Mountain Scops Owl was 0.69 ± 0.114_{SE} over a naïve occupancy of 0.64, an increase of 8% in the proportion of grids occupied. The Collared Owlet had the greatest increase in proportion of grids occupied among the three at 15% [occupancy estimate, psi (ψ) = of 0.7 ± 0.139_{SE}; naïve occupancy = 0.61]. I also compared the site-specific abundance estimates from the N-mixture models for the three species after converting them into density (individuals per ha), with density estimates of congeneric species from literature. Density estimates of the Brown Wood Owl (0.056 ± 0.028_{SE} individuals/ha) and that of the Collared Owlet (0.11 individuals/ha) were comparable with those of the Black-banded Owl *Strix huhula* (0.04 ± 0.108_{SE} individuals/ha) and Ferruginous Pygmy Owl *Glaucidium brasilianum* (0.13 individuals/ha) in Brazil (Borges *et al.*, 2004).

Table 23: Density of owls from the present study and that of congeneric species in literature.

Country	Species	Density (per hectare)	Source
India	Brown Wood Owl *Strix leptogrammica*	0.056 ± 0.028_{SE}	Present study
Brazil	Black-banded Owl *Strix huhula*	0.04	Borges *et al.*, 2004
Slovenia	Ural Owl *Strix uralensis*	0.002	Vrezec, 2003
Slovenia	Tawny Owl *Strix aluco*	0.004	Vrezec, 2003
USA	Spotted Owl *Strix occidentalis*	0.00235 (95% CI = 0.00214 – 0.00256)	Franklin *et al.,* 1990
Canada	Barred Owl *Strix varia*	0.0004 in 1995 and 0.0005 in 1996	Takats, 1998

India	Mountain Scops Owl *Otus spilocephalus*	0.054 ± 0.016_{SE}	Present study
Brazil	Tropical Screech Owl *Otus choliba*	0.3	Borges *et al.*, 2004
Brazil	Tawny-bellied Owl *Otus watsonii*	0.42	Borges *et al.*, 2004
Various countries in Europe	Eurasian Scops Owl *Otus scops*	0.0005 to 0.015	Vrezec, 2001
India	Collared Owlet *Glaucidium broidei*	0.11 ± 0.108_{SE}	Present study
Brazil	Ferruginous Pygmy Owl *Glaucidium brasilianum*	0.13	Borges *et al.*, 2004
Bulgaria	Pygmy Owl *Glaucidium passerinum*	0.002	Shurulinkov *et al.*, 2007

5.2. COVARIATES INFLUENCING DETECTION PROBABILITY

The detection probabilities for Brown Wood Owl's occupancy and abundance were found to be greatly influenced by wind speed, which was the only sampling covariate in the respective top models. Also, the negative association of wind speed indicates that detection probability of Brown Wood Owl decreases with increase in wind speed. A similar effect has been found on detection probability of Tasmanian Masked Owls *Tyto novaehollandiae castanops* and Tasmanian Boobooks *Ninox leucopsis* (Todd *et al.*, 2018), as well as in Tawny Owls *Strix aluco* and Little Owls *Athene noctua* (Zuberogoitia *et al.*, 2020). Burrowing owls are also known to be less responsive during windy nights (Braga & Motta-Junior, 2009). This has been attributed to the fact that owls have a lower basal metabolic rate compared to diurnal birds (Ligon, 1969; McNab, 1988) and higher wind speeds during the night can negatively affect their ability to retain heat (McCafferty *et al.*, 1997). While surveys were not conducted during very windy nights, higher wind speeds can also affect the observer's ability to detect vocal activity of owls (Babu *et al.*, 2019; Zuberogoitia *et al.*, 2020).

As observed in the present study, the ambient air temperature turned out to have the greatest effect on detection probabilities of both Mountain Scops Owl and Collared Owlet's occupancy and it was also included in their respective top models for estimating detection probabilities of abundance. Temperature had a positive relationship with detection probability, indicating that the probability of the observer detecting these species increased with temperature. Todd *et al.* (2018) also found that ambient air temperature had a positive effect on detection of Tasmanian Masked Owls and Tasmanian Boobooks. Again, it might be the necessity for conserving energy and retaining heat that may be driving this relationship since low temperatures can compromise body heat retention (Todd *et al.,* 2018). Also, both Mountain Scops Owl and Collared Owlet are known to consume insects (Ali & Ripley, 1981) and insect activity increases with ambient air temperature (Mellanby, 1939; Denlinger, 1980). This could also be a possible explanation for the increased activity of the two species at higher temperatures. Another hypothesis is that the owls are more vocally active when temperature is higher since the speed of sound increases with temperature, while its attenuation decreases, enabling the sound wave to travel further (Goerlitz, 2018).

In addition to temperature, the top model for detection probability of Mountain Scops Owl's abundance included relative humidity, with a positive relationship. Similar to the effect of temperature on sound propagation, sound travels faster when relative humidity is higher. This is because the speed of sound is higher in less dense, moist air (higher relative humidity). This again enables the owl calls to travel further (Goerlitz, 2018). Detection of Tropical Screech Owls have also been found to be affected by both temperature and humidity (Braga & Motta-Junior, 2009).

In the case of the Collared Owlet, time of survey or minutes after sunset (start time) was also included in the top model for estimation of detection probability of abundance. The negative slope of this covariate indicates that the Collared Owlet becomes less vocally active as the night progresses. This seems to be in agreement with Ali and Ripley (1981), who write of the species flying and hunting during the daytime and describe it as "very diurnal" and "also crepuscular, but far less nocturnal than many other owls". Owls of the genus *Glaucidium* are also generally thought to be more diurnal or crepuscular (Ritschard & Schweizer, 2007). But it should be noted that the Collared Owlet does not stop vocal activity after dusk as I found it vocalising spontaneously on many occasions even after 2100 hrs.

5.3. COVARIATES INFLUENCING OCCUPANCY AND ABUNDANCE OF BROWN WOOD OWL

Distance to stream and slope were the two site covariates having the greatest effect on both Brown Wood Owl's occupancy and abundance. Occupancy of Brown Wood Owl increased as both angle of slope and distance to stream decreased. Northern Flying Squirrels *Glaucomys sabrinus*, Dusky-footed woodrats *Neotoma fuscipes* and Bushy-tailed woodrats *Neotoma cinerea*, which are important prey species of the Spotted Owl *Strix occidentalis* are known to be more abundant closer to streams (Carey *et al*., 1992; Meyer *et al.*, 2007). Spotted Owls are also known to roost and nest near streams to help them dissipate heat during warm weather (Barrows, 1981). Similarly, Brown Wood Owls, incidentally of the same genus *Strix* might be using areas closer to streams because their prey species such as flying squirrels (Menon, 2014), and other arboreal rodents are also associated with streams, along with this acting as a form of behavioural thermoregulation. The negative relationship with slope indicates that the Brown Wood Owl largely used gentle slopes compared to steep slopes. Barred Owls have also been known to prefer gentle slopes and this has been attributed to their foraging ecology and prey selection (Singleton *et al.*, 2010). For Brown Wood Owl's abundance, apart from angle of slope and distance to stream, GBH and coefficient of variation of tree height had a substantial effect, both with a positive relationship. As predicted, large-girth trees are important for this large-bodied owl, probably as nesting (being a cavity nester) and roosting sites. The positive relationship with GBH is also supported by Ali and Ripley (1981) who describe the owl as a "deep forest" species and Marcot (1995), who describes it to be "closely associated with dense, old forests". These areas are also naturally where such large-girth trees are found. Marcot (1995) also considers the species to likely be in decline due to the loss of old-growth forests in the Indo-Malayan region. Coefficient of variation of tree height also turned out to be an important site covariate influencing abundance as mentioned before, indicating that the species largely used areas with higher heterogeneity in tree height. The congeneric Spotted Owls are known to roost at greater heights during cold weather and at lower heights during warm weather to facilitate thermoregulation (Forsman, 1980). North *et al.* (1999) also found that the Spotted Owl preferred to forage in areas with high diversity of tree heights and hypothesised that it could be because such areas provide low perches as well as enough space for sub-canopy flight and prey capture. These findings might explain the observed relationship of coefficient of tree height with the congeneric Brown Wood Owl as well.

5.4. COVARIATES INFLUENCING OCCUPANCY AND ABUNDANCE OF MOUNTAIN SCOPS OWL

Mountain Scops Owl's occupancy and abundance were influenced the most by disturbance and distance to stream, both having a positive relationship. This indicates that Mountain Scops Owl largely used areas with higher disturbance and away from streams. In the present study, disturbance was a composite index created by summing the scores given for presence of lopping, felling, recent fire and grazing. The observed positive relationship with disturbance is in stark contrast to Ali and Ripley (1981), who describe it as a dense evergreen forest species. While the species was by no means absent from our sampling points in the dense evergreen forests, it seems to have a preference for more disturbed areas, at least in the study area. One explanation could be that such areas will also have more gaps in the canopy and hence, a dense understorey which could support diversity of prey, such as insects and rodents. Flammulated Owls *Psiloscops flammeolus* have been known to nest in open forests with more canopy gaps and dense undergrowth as well (Goggans, 1986). Interestingly, König and Weick (2008) describe the Mountain Scops Owl as a species whose taxonomy needs revision and that some of its subspecies may very well be separate species. Similar to the Brown Wood Owl, the relationship with distance to stream may be driven by the owl's foraging ecology and habitat association of prey. Abundance of the Eurasian Scops Owl *Otus scops* is known to be positively correlated to water bodies for this same reason (Moreno-Mateos *et al.,* 2011). Studies on the Eastern Screech Owl *Megascops asio* have also found a positive association of the species with running water (Ellison, 1980; Smith & Gilbert, 1984). In contrast, Flammulated Owls avoid large areas of water and riparian areas, which has been attributed to its intolerance to higher humidity, which is linked to thermoregulation (McCallum, 1994). Hence, a combination of thermoregulatory strategy and prey distribution might explain the observed positive relationship of Mountain Scops Owl with distance to stream.

5.5. COVARIATES INFLUENCING OCCUPANCY AND ABUNDANCE OF COLLARED OWLET

Angle of slope had the greatest effect on Collared Owlet's occupancy and abundance with a positive relationship, pointing out that the species largely used areas with steeper slopes.

Spotted Owls are also known to have activity centres on steep slopes in old-growth forests (Ganey & Balda, 1989). Slope is also thought to influence foraging ecology and prey selection (Singleton *et al*., 2010). None of the other site covariates had comparable support, which was indicated by their summed AIC_c weights. These weak relationships with other site covariates might be indicative of the Collared Owlet being a habitat generalist. Austral Pygmy Owls *Glaucidium nanum,* a congeneric of the Collared Owlet are also known to a more generalist species in terms of forest structure compared to the Rufous-legged Owl *Strix rufipes* (congeneric of the Brown Wood Owl) (Ibarra *et al*., 2012).

5.6. DETECTIONS INSIDE AND OUTSIDE COMMUNITY RESERVES

There was a statistically significant difference in the number of detections of Brown Wood Owl and Mountain Scops Owl when comparing sampling points inside and outside Community Reserves. Brown Wood Owl detections were twice as high inside Community Reserves, indicating their importance for this species. Community Reserves are the areas with the least amount of human disturbance in the study area (apart from the adjoining Nokrek National Park) and are crucial areas for an old-growth forest species such as the Brown Wood Owl (Marcot, 1995) in this mosaic landscape. Large-girth trees, which are important as roosting and nesting sites for this species were found mostly within Community Reserves among the sampling points. This further highlights the importance of maintaining Community Reserves for the Brown Wood Owl in this landscape.

Contrastingly, Mountain Scops Owl detections were higher outside Community Reserves. This is supported by the results from occupancy and abundance modelling, which indicates that the Mountain Scops Owl largely used relatively disturbed areas.

5.7. CONCLUSION

The current study revealed species-specific differences in sampling covariates that influenced the detection probability, highlighting the need to account for such variables that can cause false absences when surveying for owls.

Distance to stream, slope, disturbance and tree structural characteristics (GBH and heterogeneity in tree height) turned out to be the variables that most influenced the occupancy and abundance of owls. This draws attention to the necessity to protect streams and old-growth forests (where there is higher abundance of large-girth trees and diversity of tree heights) in the entire Garo Hills landscape.

Finally, Community Reserves, the only areas with old-growth forests in the landscape (except for the Nokrek National Park) seem to be acting as refugia for the Brown Wood Owl, an old-growth forest specialist that is considered to be in decline due to habitat loss. Hence, the maintenance and preservation of Community Reserves is important for the conservation of this species in Garo Hills.

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APPENDIX 1

Results of Pearson's correlations between site covariates

Table 24: Results of Pearson's correlations done to check for correlations between site covariates.

		GBH	TH	THcv	GBHcv	CH	CC	SC	Slope	TRI	D_settle	D_Stream	D_CR	D_Pfr
GBH	*r*	1	.730	.421	.425	.644	.446	-.055	-.331	.066	.654	.040	-.427	-.430
	p		.000	.015	.014	.000	.009	.759	.060	.716	.000	.827	.013	.012
TH	*r*	.730	1	.223	.110	.852	.769	-.240	-.081	-.228	.606	-.175	-.602	-.254
	p	.000		.212	.542	.000	.000	.178	.654	.201	.000	.329	.000	.154
THcv	*r*	.421	.223	1	.642	.056	.141	-.052	-.221	-.123	.274	-.085	-.164	-.118
	p	.015	.212		.000	.758	.433	.775	.216	.495	.123	.638	.362	.514
GBHcv	*r*	.425	.110	.642	1	.018	.070	-.069	-.133	-.068	.212	-.008	.048	-.109
	p	.014	.542	.000		.921	.697	.703	.461	.707	.236	.967	.790	.548
CH	*r*	.644	.852	.056	.018	1	.668	-.165	-.027	.026	.633	-.300	-.575	-.458
	p	.000	.000	.758	.921		.000	.358	.882	.887	.000	.089	.000	.007
CC	*r*	.446	.769	.141	.070	.668	1	-.243	-.065	-.126	.440	-.123	-.686	-.101
	p	.009	.000	.433	.697	.000		.172	.719	.486	.010	.497	.000	.574
SC	*r*	-.055	-.240	-.052	-.069	-.165	-.243	1	-.278	-.026	-.176	.015	.173	.086
	p	.759	.178	.775	.703	.358	.172		.117	.885	.329	.935	.337	.634
Slope	*r*	-.331	-.081	-.221	-.133	-.027	-.065	-.278	1	.059	-.278	-.264	.209	.266
	p	.060	.654	.216	.461	.882	.719	.117		.743	.117	.138	.242	.135

TRI	*r*	.066	-.228	-.123	-.068	.026	-.126	-.026	.059	1	.197	.038	-.066	-.412
	p	.716	.201	.495	.707	.887	.486	.885	.743		.272	.833	.716	.017
D_settle	*r*	.654	.606	.274	.212	.633	.440	-.176	-.278	.197	1	-.120	-.641	-.729
	p	.000	.000	.123	.236	.000	.010	.329	.117	.272		.507	.000	.000
D_Stream	*r*	.040	-.175	-.085	-.008	-.300	-.123	.015	-.264	.038	-.120	1	.138	.007
	p	.827	.329	.638	.967	.089	.497	.935	.138	.833	.507		.445	.970
D_CR	*r*	-.427	-.602	-.164	.048	-.575	-.686	.173	.209	-.066	-.641	.138	1	.371
	p	.013	.000	.362	.790	.000	.000	.337	.242	.716	.000	.445		.033
D_Pfr	*r*	-.430	-.254	-.118	-.109	-.458	-.101	.086	.266	-.412	-.729	.007	.371	1
	p	.012	.154	.514	.548	.007	.574	.634	.135	.017	.000	.970	.033	

r, Pearson's correlation coefficient; GBH, Girth at Breast Height of trees; TH, tree height; THcv, coefficient of variation of tree height; GBHcv, coefficient of variation of GBH; CH, Canopy height; CC, canopy cover; SC, shrub cover; TRI, Terrain Ruggedness Index; D_settle, distance to settlement; D_Stream, distance to stream; D_CR, distance to Community Reserve; D_Pfr, distance to primary forest.