MANIPAL
ACADEMY *of* HIGHER EDUCATION
(Deemed to be University under Section 3 of the UGC Act, 1956)

OCCUPANCY AND DISTRIBUTION PATTERN OF OWLS IN ANDAMAN ISLANDS WITH SPECIAL REFERENCE TO COMMUNITY ASSEMBLY RULES

A THESIS TO BE SUBMITTED TO
MANIPAL ACADEMY OF HIGHER EDUCATION

For Fulfillment of the Requirement for the
AWARD OF THE DEGREE
OF
DOCTOR OF PHILOSOPHY
BY

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UNDER THE GUIDANCE OF

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SÁLIM ALI CENTRE FOR ORNITHOLOGY AND NATURAL HISTORY (SACON)

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MANIPAL
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DECLARATION BY THE CANDIDATE

I declare that this thesis, submitted for the degree of Doctor of Philosophy to Manipal Academy of Higher Education, is my original work, conducted under the supervision of my guide **Dr. S. Babu**. I also wish to inform that no part of the research has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

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CERTIFICATE

This is to certify that the work incorporated in this thesis **"Occupancy and distribution pattern of owls in Andaman Islands with special reference to community assembly rules"** submitted by **Mr. S. Sureshmarimuthu** was carried out under my supervision. No part of this thesis has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

Research Guide

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~ Sureshmarimuthu S.

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Abstract

There is a laxity of knowledge in taxonomically well recognized species, which did not gain adequate attention from conservation biologists and are prone to extinction. Owls are one of such avian nocturnal predators. Due to their nocturnal and conspicuous behaviour many of the avian community studies neglecting owls to incorporate in them. Considering these facts, studies on owl species ecology is prerequisite for the conservation. So, this thesis is an attempt to develop such base line information on owls with two broad objectives: (1) to assess the relative abundance and occupancy of owls in the Andaman Islands and (2) to evaluate various species assembly rules in offshore islands using owls as model organism. To achieve these objectives, I did a survey with an aim to elucidate the environmental gradients (such as land-cover types, logging intensity) that influence the distribution and abundance of owls in the Andaman Islands. In addition, I also assessed the perception of local people about owls and effect of human activities on roosting owls using experimental and evidence-based study. I also employed Hierarchical multi-scale sampling strategy to estimate large-scale (sampling unit level - Ψ) and small-scale (survey station level - θ) occupancy using multi-detection methods (p). I modelled the occurrence of each species of owls as a function of island characteristics using the presence-absence of owls and a set of abiotic and biotic variables of 73 offshore islands. Finally, dispersal-driven assembly rules of the five owl species were tested with the same offshore islands surveyed. EcoSim v. 7.0 was used to test the Diamond's assembly rules (1st, 2nd and 5th rules) using two statistical indices viz., C-score and number of unique species combinations. NeD and Nestedness Temperature Calculator were used to test nestedness. Overall, this study provided first-hand information about the owls' distribution, their threat, ecological requirements, and the dispersal patterns in Andaman archipelago. It also helped to identify the critical island characteristics to ensure the avian population. The continued alteration of evergreen forests, extraction of minor products (for example: cane) and logging associated understory clearings might bring these endemic species' survival to an end.

CHAPTER 1

General Introduction

Middle Button Island

1.1. GENERAL OVERVIEW

Among the environmental problems faced by the humanity, conservation of species from extinction is considered as one of the most challenging tasks (Wilson, 1992). World's species inventory is still considered to be incomplete, and many species are still unknown to science and are going extinct even before they are discovered (Boehm & Cronk, 2021). However, majority of scientific effort, attention, and funds are focused only on species of high economic or emotional value (Amori & Gippoliti, 2000). In addition, there is a laxity of knowledge regarding many of the already described species, which did not gain adequate attention from conservation biologists and are prone to extinction. Considering these facts, extinction can be an unfathomable loss in evolutionary history (Newton, 1998).

Many factors, including lower abundance (Pimm et al., 1993; Newton, 1998), limited geographical range (Manne et al., 1999), trophic level (Manne et al., 1999), life history traits (Pimm, 1991; Purvis et al., 2000), etc., are considered as the natural causes of species vulnerability to extinction. Furthermore, human activities on existing vulnerable species are only hastening the process. In 1984, Diamond summarised the processes of human induced species extinction as habitat loss, over-exploitation, introduced species, and chains of extinction. He named these processes as “Evil Quartet". With the available long body of literature (Leakey et al., 1995; May et al., 1995) based on the prehistoric and historic fossil evidence, it is realized that the natural extinction rate has doubled after human civilization (Ceballos et al., 2015). As a result, it is clear that the primary goal for conservation biologists in the current scenario is to reduce the rate of species extinction (Balmford et al., 2005; Ricketts et al., 2005). In this context, recognising suspectable species and areas is crucial in terms of long-term conservation (Collar et al., 1994; Bennett & Owens, 1997).

Compared to other ecosystems, islands are distinct earthly heaps that require priority for the conservation of its biodiversity. Because, islands are home to about one-fifth of the world's endemic bird species, concurrently 90% of the historic bird extinctions are reported from the islands. (Steadman, 2006). Though islands contribute to a very tiny portion of the earth's massive landmass, they currently hold nearly 10 percent of the world's total number of identified bird species (Collar et al., 1985). Most endemic species found on islands evolved as specialists to suit the limited area availability, geographical location, interactions with other coexisting species, and available environmental conditions. Many such specialist species are generally vulnerable due to their small population with the restricted habitat availability

(Julliard et al., 2004). Apparently greater proportion of currently identified endangered island species are forest-dwellers (Johnson & Stattersfield, 1990). Furthermore, many of the species living on islands may have evolved in isolation from predators and rivals (including humans) rendering them more sensitive to human civilization's actions (Pimm, 1991).

Having carved out a distinct ecological niche for themselves through evolutionary strategy, owls are among these forest-dwelling specialists. There are 268 known species of owls that live on this planet with humans (Mikkola, 2012). Between 1972 and 2014, the actual number of owls species went up from 109 to 268; more than half of the additions are from small islands (Sieradzki & Mikkola, 2020). Out of this, nearly 20% of the owl species are found to be endemic to small islands with severely restricted distributional ranges (König & Weick, 2008), half of those are listed as threatened with a decreasing population (Birdlife international, 2016). Human activities are seen as the major threat for a stable owl population on an island, whilst climate change affects the species associated with islands globally. Climate change causes a total change in the inherited biodiversity of the forest stand through (1) decreasing rainfall; (2) sea-level rise; and (3) increased soil salinity (Blackburn et al., 2004; Didham et al., 2005; Goodman et al., 2012). In addition, the effects of climate change in island ecosystems, are predicted to be higher due to their smaller area in comparison to continents (IPCC, 2019).

1.2. OWLS OF INDIA AND INDIAN ISLANDS

There are 36 owl species in India, belongs to two families: Tytonidae (five species) and Strigidae (31 species) (Praveen et al., 2016). Except for Forest Owlet (*Athene blewitti*) in India, every other owl species, both Tytonidea and Strigidea families, are kept under Schedule IV of the Indian Wildlife (Protection) Act, 1972. The Indian subcontinent has many tiny islands and islets in the Arabian Sea at the West and in the Bay of Bengal in the East. Because of their separation from the mainland, the Andaman and Nicobar Island Group and the Lakshadweep Island Group are considered two distinct island systems in Indian political territory. The Andaman archipelago is better known for its own endemic avifauna. Hence, it is declared as the 126th Endemic Bird Area (EBA) of the world by (BirdLife International, 2021a). Ornithological surveys have been conducted on the islands since the 18th century, beginning with Blyth's contribution (Blyth, 1846) and continuing with subsequent pioneers (Beaven, 1867; Ball, 1873; Walden, 1873; Hume, 1873, 1874 a, b, 1876; Butler, 1899 a, b, c; Richmond, 1902; Osmaston, 1906; Abdulali, 1964, 1965, 1971 a, b, c, 1976 a, b, 1978, 1981 a, b; Abdulali & Grubh, 1970; Tikader, 1984). The addition of new sightings of bird species in the Andaman

Islands is still ongoing (Sivaperuman et al., 2014). Out of 270 species of birds recorded in Andaman and Nicobar Islands, 33.3% (90 species) are endemic to the islands (Rao et al., 2013), which includes five species of owls such as Andaman Barn Owl *Tyto deroepstorffi*, Andaman Scops Owl *Otus balli*, Andaman Hawk Owl *Ninox affinis*, Hume's Hawk Owl *Ninox obscura* and Oriental Scops Owl *Otus sunia* in which first four are endemic to the islands (Vijayan & Sankaran, 1997; Rasmussen & Anderton, 2005; Parveen et al., 2016).

1.3. RESEARCH GAPS IDENTIFIED

1.3.1. Richness, abundance, distribution, and anthropogenic disturbance

Owls play an essential role in ecosystem function as predators and pest controller (e.g., as predators of rodents), and are affected by forest management (e.g., as cavity nesters), and therefore, can serve as valuable indicators of environmental condition (Sundell et al., 2004, Cheveau et al., 2004). Except for a few species of conservation concern, little is known about nocturnal owls in the Andaman Islands. Many ornithological pioneers attempted the critical demographic evaluation of the Andaman owl population. However, due to the species' secretive behaviour and nocturnal habits, vital information such as distribution range and abundance of owls in the Bay Islands is yet to described. Owls are susceptible to environmental change, such as timber harvest (Forsman et al., 1984), road development (Carton & Finch, 2000), and contaminants (Haug et al., 1993, Gervais & Catlin, 2004). Hunting is also reported as another significant threat to owls of Andaman Islands. Despite their ecological importance and the threat, they are facing in the Andaman Islands, the current status, distribution, and vulnerability of each species of owls is still referred from ancient field observations; no scientific approach is made available on these species and the issues they are related with.

The studies on distribution and relative abundance of any species in relation to their habitat and related species is an important component of species ecology (Andrewartha & Birch, 1954; Krebs, 1972). Knowledge of trends in the relative abundance of species helps in knowing the population trends and conservation management of the species. Relative abundance which is the ratio of the number of individuals of one species to that of another species (Preston, 1948) is one such critical information that can be used for the development of appropriate management decisions.

1.3.2. Occupancy

Occupancy is defined as the fraction of sampling units in a landscape where a target species is present (MacKenzie et al., 2006). On the other hand, occupancy is another estimate considered handy when dealing with multiple species within a same taxonomic group and is directly linked to the species abundance (Gaston et al., 2000). Sampling occupancy for a species substantially reduces the effort than estimating abundance and related indices. The basic idea behind occupancy is that the presence of a species in a patch suggests that the patch allows the species to exist (Babu, 2011). Many other estimation methods estimate and adjust for detection probabilities <1 (Reynolds et al., 1980; Marques et al., 2001; Farnsworth et al., 2002) but most of these methods are not practical for nocturnal species with relatively low densities such as small Island inhabited owls. Distance sampling techniques are also unreliable for owls because, nocturnal conditions and the ventriloquial vocalizations of many owl species hinder the accurate estimation of distances of the animal. In Capture-recapture methods, it will be challenging to acquire an adequate sample size relative to the effort. Individuals resight-based models are unreasonable because of the difficulty in resighting marked individuals at night. Hence, it is proved that patch-occupancy models offer the most realistic approach to long-term monitoring of owl populations (Ganey et al., 2004; Olsen, 2005); these models rely on repeated surveys to determine species presence and estimate detection probabilities (MacKenzie et al., 2004).

Designing a study to estimate occupancy that accounts for imperfect detection involves a trade-off between efficiency and robustness. In the case of rare species, the effort needs to be high to increase the detection probability of the species if the site is occupied by them (MacKenzie et al., 2004). Identifying and quantifying factors that affect detection probability will result in improved estimates of detection probabilities and therefore more precise estimates of the parameter of interest (e.g., patch-occupancy, abundance; Hardy & Morrison, 2000; Williams et al., 2002; MacKenzie et al., 2006); future field efficiency also might be improved by focusing survey effort on intervals when detection probability is likely higher. Detection rates of owls are influenced by survey techniques and various environmental, biological, and temporal factors (Hardy & Morrison, 2000, Andersen, 2007). Broadcast recordings of owl vocalizations increase detection rates of most target species and can invoke or discourage responses from non-target species (Fuller & Moser,1981; Hardy & Morrison, 2000). Environmental factors such as wind, precipitation, surrounding landscape, and temperature can affect owl calling rates as well as the ability of surveyors to detect owls (Fuller & Moser, 1981; Andersen, 2007). Time of year and annual variation in phenology can affect calling rates, which at least for some owl species are known to be positively correlated with pairing status (Lundberg, 1978). Similarly, owl call rates are known to vary significantly throughout the night (Palmer, 1987).

Recently, biologists in Canada and the United States developed guidelines for monitoring nocturnal owl species in North America by agreeing on a set of standard components that should be incorporated into surveys for breeding owls (Takats et al., 2001). These guidelines present a standardized approach to survey methods. A survey protocol appropriate for the Andaman Islands still needed to be developed to meet regional objectives and contribute to ongoing continent-wide efforts for monitoring nocturnal owls.

1.3.3. Assemblage

Furthermore, whether communities are made up of random species assemblages or deterministic processes is a hotly discussed topic in animal community ecology (Feeley, 2003). Given the extended duration of isolation of Andaman Islands and of diverse sizes and distances, it is providing better opportunity for testing of various assembly rules. Various assembly rule models have been presented over the last few decades to discover common patterns in community species composition and the underlying mechanisms driving these patterns (Weiher & Keddy, 2001). Diamond's rule (Diamond, 1975), size structure (Hutchinson, 1959; Case et al., 1983), guild proportionality (Wilson, 1989), favoured states (Fox, 1987), and nestedness are five assembly rules that are often used to understand the assemblages in birds (Patterson, 1987). Out of these, diamond's rule and nestedness pattern studied widely in offshore islands (Feeley, 2003). The underlying mechanism behind non-random species co-occurrence patterns in an established community is described as nestedness, which occurs as a result of extinction and colonisation from the source pool (Patterson & Atmar, 1986). Diamond assembly rules are determined by species interactions. He announced a set of criteria based on the species' competitive interactions: what species combinations are allowed to co-occur, and which species combinations are not allowed to co-occur (Diamond, 1975; Collins, 2006). In spite of disproving the non-randomness, many null models have been constructed in order to demonstrate that species communities in fragmented landscapes are just random assemblages or are influenced by other environment conditions (Gotelli & Entsminger, 2001). Since the Andaman archipelago provides a greater opportunity to test these assembly rules, evaluation of these rules on birds have already been conducted (Davidar et al., 2002; Thiollay, 1997), although nocturnal avian predators are not taken into account.

1.3.4. Island Characteristics

The long-term persistence of species in a naturally fragmented landscape like Andaman Island necessitates extensive management efforts and huge financial resources. One of the primary concerns for conservation managers of island is recognising and developing habitat requirements through effective reserve acquisition and management for the localised species' population, which can contribute to colonisation and extinction. To simplify the efforts, birds have been used as a cost-effective indicator of island environmental conditions since they are easy to sample and have a strong affinity with habitat health (Böhning-Gaese & Oberrath, 2003). As a result, formulating conservation plans for habitat fragments based on the presence of specific bird species has gained popularity in recent decades.

In this reliance, Thiollay (1997) analysed the island characteristics using the occurrence and abundance of five diurnal-raptors and reported that the island area was the most deterministic factor for the existence of uncommon and endemic species (*Spilornis elgini*). A comparable study on the island features in response to richness of the 78 bird species found that islands with wet forests were more crucial to maintaining the high number of species (Devy et al., 1998; Yoganand & Davidar, 2000). Island prioritization in the Andaman archipelago was carried out even with the butterfly distribution (Devy et al., 1998). However, it did not include the owls in the analysis, though they are easy to survey by well-designed acoustic methods in the breeding season (Johnson et al., 2009). As high trophic-level consumers that are often relatively long-lived, owls also represent convenient indicators of several ecological processes better than other species. Moreover, the aftermath of the 2004 tsunami followed by the Sumatran earthquake, bird distribution in different offshore island groups has never been investigated.

Hence, the present study was carried out with the following objectives to address above mentioned research gaps on the nocturnal owl species of Andaman Islands.

1.4. OBJECTIVES

The preceding considerations highlight the importance of Andaman Island owl and their conservation. Given the significance of the research, the following objectives were framed:

1. **To assess the relative abundance and occupancy of owls in the Andaman Islands**

   Question 1.1: Relative abundance of owls in response to vegetation types, and anthropogenic disturbance.

   Question 1.2: Factors influencing the occupancy of owls in north Andaman.

2. **To evaluate various species assembly rules in offshore islands using owls as model organism**

   Question 2.1: To test the role of island characteristics in determining the occurrence of owls.

   Question 2.2: To test nestedness, Diamond’s assembly rule, guild proportionality and favored state rules on owls of offshore islands in Andaman.

1.5. STUDY SPECIES

1.5.1. Andaman Barn Owl - *Tyto deroepstorffi*

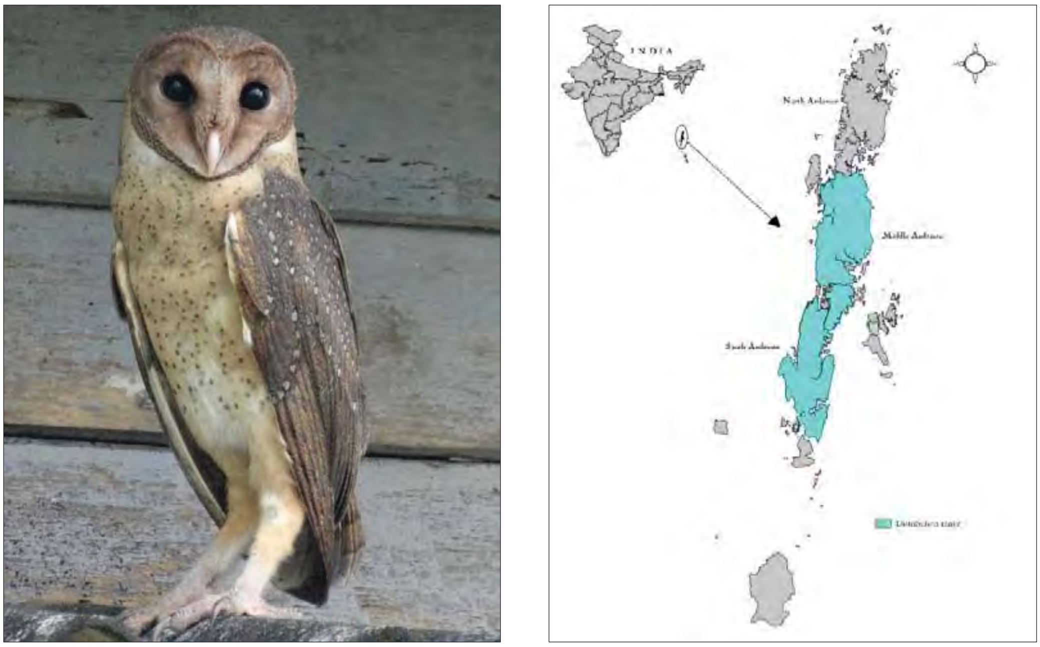


Figure 1.1. Andaman Barn Owl (*Tyto deroepstorffi*) and its distribution in Andaman Islands. Distribution map reproduced as depicted by König & Weick, 2008.

The Andaman Barn owl is the sole member of the Tytonidea family found in the Andaman Islands. Hume (1875) first named this species from the Andaman Islands as *Strix De-roepstorffi* in 1875; he believed that this species was related to the genus *Strix*, which is found in mainland India due to its brighter colour and comparable size. He names this species after a Danish linguist named Frederik Adolph de Roepstorff (1842–1896), who worked as an Indian civil servant in the Andaman Islands. In addition, Hume assumed that it was exclusively found in the South Andamans. Baker (1927) identified this species as a subspecies of the mainland Barn Owl *Tyto alba* after many decades of Hume’s note on this species. Rasmussen & Anderton (2005) elevated the species to the full separate species based on its unique morphology from the mainland species (*Tyto deroepstorffi*). *Tyto deroepstorffi* differs from *T. alba* in that it lacks the greyish veil with white-and-black dots that characterises all races of the latter. BirdLife International (2021b) still considers this species to be the island population of the Common Barn Owl (*Tyto alba*) in the absence of species research, vocalisation, and DNA evidence. As a result, its status still remains as least concern. The distributional range was thought to be restricted to south Andaman Island and its neighbouring islets Unless, but Manchi (2013) recorded some individuals from the Offshore islands of Northern Andaman. However, there is still uncertainty about their ecology, geographical area, and classification. According to anecdotal evidence, this species feeds on Edible-nest Swiftlet *Aerodramus fuciphagus* at its breeding cave entrance (Manchi, 2013). Also, like the Common Barn Owl, it is expected to live in coastal areas and villages (König & Weick, 2008).

1.5.2. Andaman Scops Owl - *Otus balli*

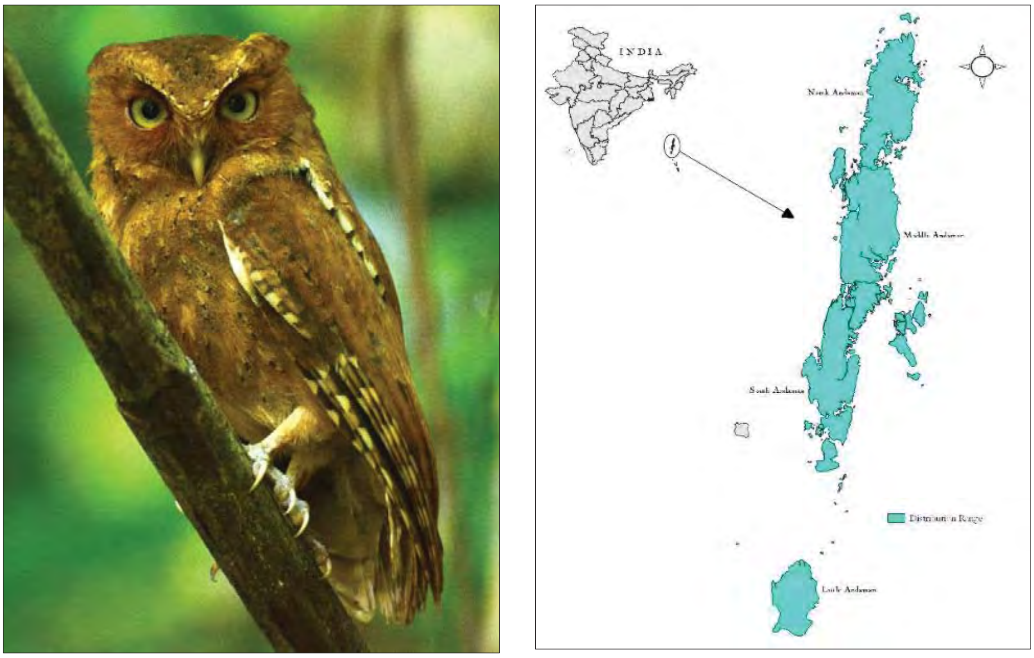


Figure 1.2. Andaman Scops Owl (*Otus balli*) and its distribution in the Andaman Islands. Distribution map reproduced as depicted by König & Weick, 2008

In 1873, Hume described this species as *Ephialtes balli*, a small (16–18cm) brown or rufous scops owl with short ear-tufts. Valentine Ball, an Irish naturalist and collector, was the inspiration for the name of this species. *Otus balli* is an endemic species found only in the Andaman Islands. However, one questionable record was set in 2007 on the Great Nicobar Island (Pande et al., 2007). There are no fine records of their breeding available. Osmaston (1906) documented this species nesting in a single padauk tree hole with three eggs in his “notes on Andaman birds”. Giving the reason for accelerating forest loss in Andaman Islands, authors regarded this species to be uncommon in comparison to others (König et al., 1999; Jathar & Rahmani, 2006). However, its current ecological status in the Andaman Islands is still unknown. Concurrently, conservationists wanted to perform a comprehensive survey of their population size, habitat preferences, and disturbance tolerance (Davidar et al., 1997). In response, the Indian Department of Environment, Forests, and Climate Change, in collaboration with the Zoological Survey of India, began monitoring the bird population in the archipelago (Sivaperuman, 2018).

1.5.3. Oriental Scops Owl - *Otus sunia*

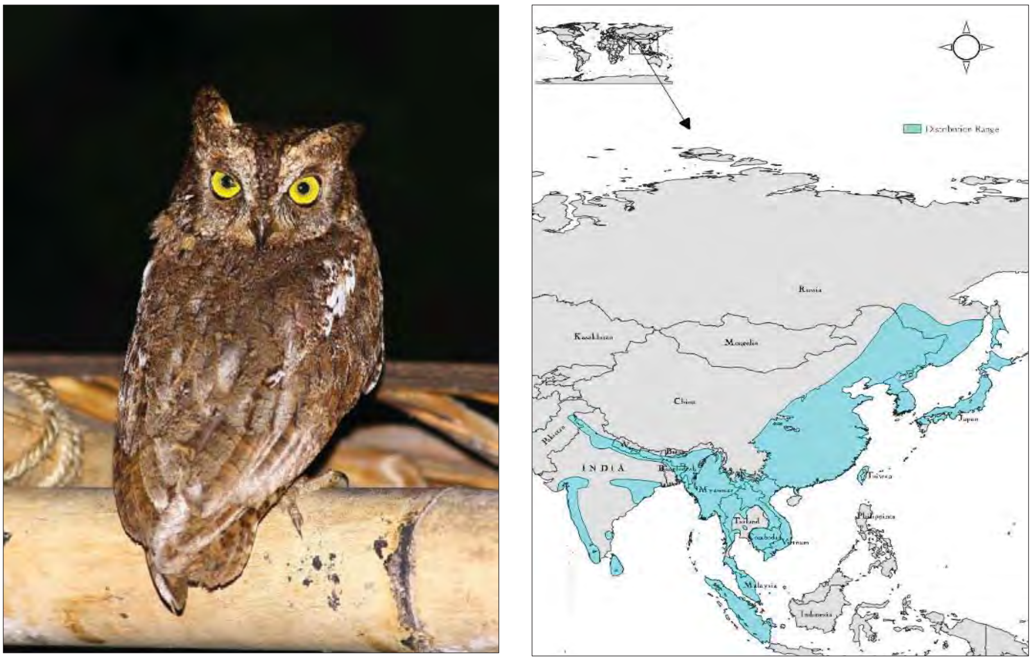


Figure 1.3. Oriental Scops Owl (*Otus sunia*) and their global distribution range. Distribution map reproduced as depicted by König & Weick, 2008.

Hodgson (1836) first described this species from Nepal as *Scops sunia*, which is similar in size to the Eurasian Scops Owl (*Otus scops*) (16–19cm) but has more boldly striped underparts and less bark-like pattern and slightly larger ear-tufts. Its distribution is in North Pakistan (Punjab), India and Nepal east to Bangladesh, Sri Lanka, E Asia from Japan (Hokkaido and Kyushu), E Siberia, Manchuria, Taiwan, and E China to Malay Peninsula (Malacca); also, resident in Andaman and Nicobar Islands, where it is thought to be a winter visitor. It is a vagrant species in Hong Kong and the Aleutian Islands (König & Weick, 2008). Unlike other species of owls in Andaman Islands there are studies available in the ecology of Oriental Scops Owl elsewhere. They are moderately forest dependent since they inhabit farmlands and plantations, and rural gardens. They prefer to live at an altitude between 0 to 1500 above sea level. They consume a wide spectrum of food items ranging from small mammals, small birds to large insects like grasshoppers, locusts, and cicadas. They nest in tree holes from February to May in India and Pakistan, from April to June in Siberia and China, and from May to June in Japan. Due to the wide distributional range, the species is categorized as least concern by BirdLife International (2021b). Despite its large range occurrence, environmental pollution, forest fire, hunting, and trading are considered as an immediate threat to their population (Chen et al., 2007; Liang et al., 2013).

1.5.4. Hume's Hawk Owl - *Ninox obscura*

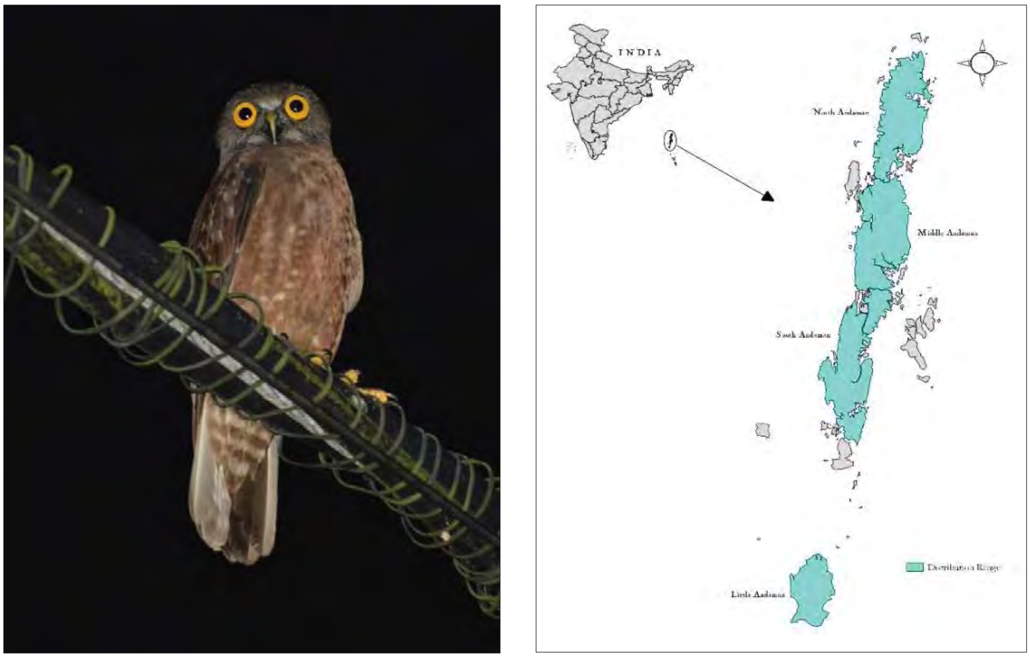


Figure 1.4. Hume's Hawk Owl (*Ninox obscura*) and its distribution in the Andaman Islands. Distribution map reproduced as depicted by König &Weick, 2008.

Raffles (1822) described this species as *Strix scutulata* from Sumatra. The specimen found by Hume (1872) in Andaman was near " Camorta," an Island belonging to the Nicobar Archipelago, but the locality is thought to be incorrect based on evidence that following specimens were taken only from the Andaman Islands. It was originally kept as the subspecies of *Ninox scutulata* known as *Ninox scutulata obscura*, where it is known as an endemic and locally common to the islands. However, it obtains its full species status by its dark Chocolate-brown color, and paler and rufous on belly; whitish spot-on forehead which differs from other races. They found to occupy the moderate forests edged with agricultural land, habitation, and plantations. Diet consists of insects, amphibians, lizards, small birds, and mammals. The monogamous *Ninox obscura* lays three to five eggs during the breeding season in the tree holes. However, breeding season and breeding habits are still unknown.

1.5.5. Andaman Hawk Owl - *Ninox affinis*

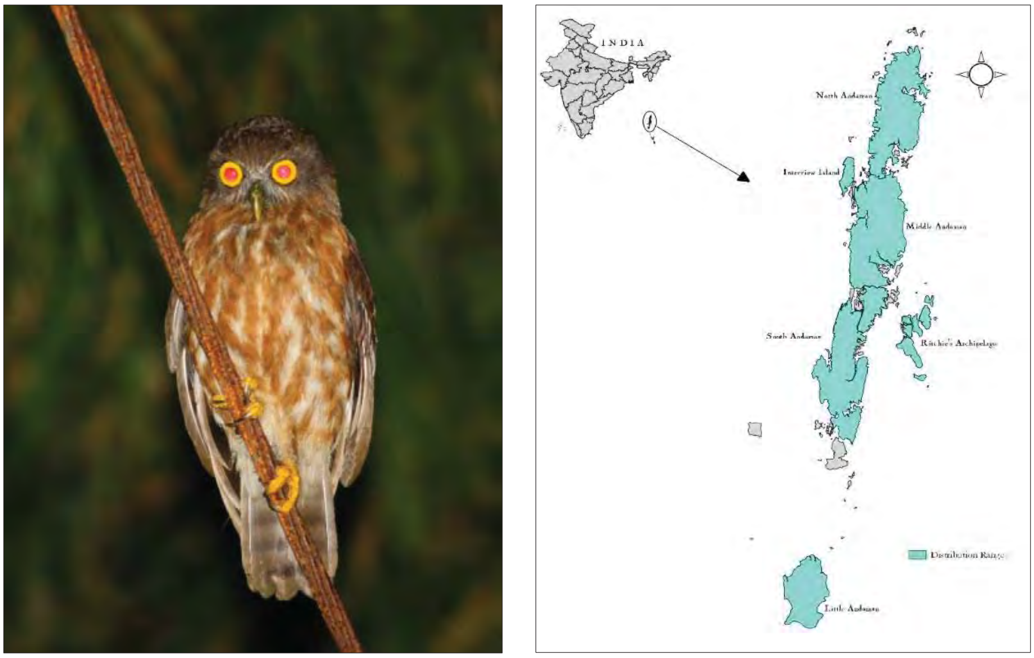


Figure 1.5. Andaman Hawk Owl (*Ninox affinis*) and its distribution in the Andaman Islands. Distribution map reproduced as depicted by König & Weick, 2008.

Beavan (1867) first described this species as *Ninox affinis*. The species name means "allied," as it is very similar to the Brown Hawk Owl, but it is smaller (25–28cm) and browner, with characteristic brilliant rufous striping on brownish-white underparts and different vocalisation, giving it distinctive species status. Longitudinal brown streaks appeared from the breast to the belly gives an appearance of hawks. Hodgson (1836) described this appearance as "It is an owl, undoubtedly, but the most accipitrine of owls". It is endemic to the Andaman Islands and inhabits mainly lowland wet forests, including mangroves (Davidar et al., 1997). Due to their range and observation in human-modified environments, this species is listed as Least Concern by BirdLife International (BirdLife International, 2021b). However, the species ecology on behaviour, reproductive biology and the habitat preference are yet to be studied (König & Weick, 2008). Ministry of Environment Forests and Climate Change, India, along with the Zoological Survey of India is monitoring the species population in these islands (Sivaperuman, 2018).

Table 1.1. Body size and foraging guild of each species studied

Species	Scientific name	Body size (cm)	Foraging guild
Andaman Barn Owl	*Tyto deroepstorffi*	36	Carnivore
Andaman Scops Owl	*Otus balli*	19	Foliage gleaning Insectivore
Oriental Scops Owl	*Otus sunia*	19	Foliage gleaning Insectivore
Andaman Hawk Owl	*Ninox affinis*	25	Hawking Insectivore
Hume's Hawk Owl	*Ninox obscura*	32	Hawking Insectivore

1.6. STUDY AREA

Andaman and Nicobar Islands are a narrow-broken series of elevated oceanic lands located in the Bay of Bengal between 6°5'– 13°30' N and 92°20'– 93°56' E. The Andaman fore-arc is a north-south linear structure generated by the sinking motion of the Indian tectonic plate beneath the Eurasian plate, featuring a steep trench on the western side and a shallow Andaman spread area on the eastern side (Cochran, 2010). The shape spanned 912 kilometres between Arakan Yomas in the north and Sumatran islands in the south (Ripley & Beehler, 1989; Das, 1999). A total of 572 magnificent rocks, islets, and islands cover an area of 8259 km^2, comprising two different archipelagos: the Andaman Archipelago and the Nicobar Archipelago (Jayaraj & Andrews, 2005).

1.6.1. Andaman Archipelago

The contiguous Andaman archipelago is stretched over (06°45'N-13°30'N & 92°20'E-93°56'E) and divided from the Nicobar archipelago by the tumultuous "Ten-degree channel," which is 150 km wide and 731.52 m deep, while the Duncan Passage separates little Andaman from the great Andaman group (Srinivasan, 1986). The Andaman archipelago is spread over 6408 km^2 composed of 325 offshore islands and islets, which are administratively divided into South (3990 km^2), North and middle Andaman district (2118 km^2). Biologically Andamans are considered as having the Indo-China biogeographic affinity (Ripley & Beehler, 1989) rather Indian. Andaman archipelago composed of 80 island wildlife sanctuaries excluding islands within the national parks. About 88.2% of the protected areas of Andaman is constituted by three national parks (Saddle peak, Jhansi rani (3 islands), Mahatma Gandhi (14 islands) (Rajan, 2014). It is administered by two wildlife divisions namely North and middle Andaman Wildlife division and the South Andaman Wildlife division. Two volcanic islands are also found in the

Andaman Archipelago 1. Narcondam (dormant volcano) and 2. Barren Island (Only active volcano of India). North Sentinel is a remarkable island that has an indigenous tribal group called Sentinelese. They ever come into contact with civilized humans, who safeguard their territories from the remaining world with their skilful archery.

1.6.2. Climate

The tropical monsoonal regime shapes and regulates the biotic and abiotic components of the Andaman Islands. The location was strategically located to receive both South-West and North-East monsoonal rains. Following the dry months of February and March, the islands have persistent heavy rainfall surpassing 300 cm between May and October during the southwest monsoon. It will continue to get rainwater from the northeast monsoon for the next three months, between November and January (Rao, 2010). The climate in the Andaman Islands is typically humid, with temperatures ranging from 23℃ to 31℃ and humidity levels exceeding 80 percent (Raghunathan et al., 2012). Because of their proximity to the sea, these regions are thought to be sensitive to future climate change forecasts. Within the next 50 years, an average temperature increases of 2 to 3℃ is projected (IPCC, 2007).

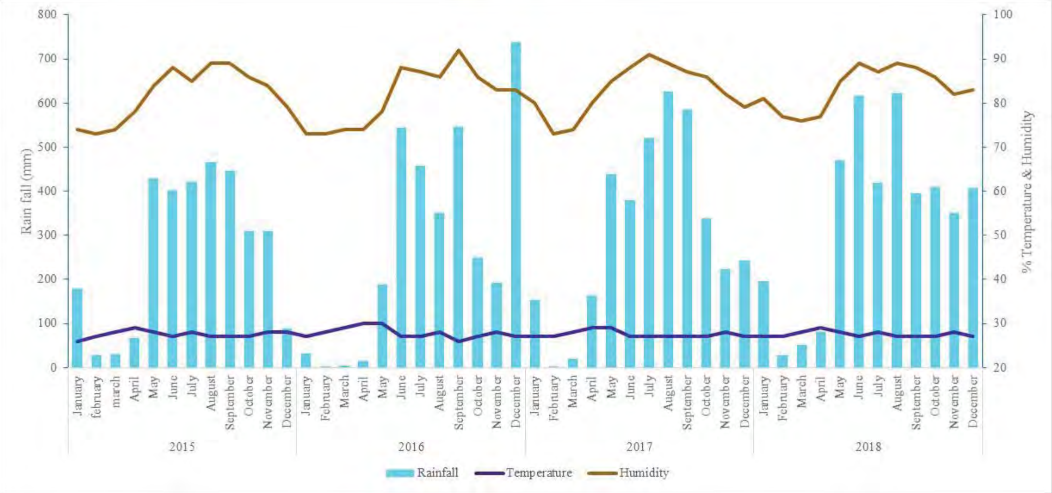


Figure 1.6. Mean monthly temperature, humidity, and rainfall levels of the Andaman Islands observed during the study period (2015 – 2018).

1.6.3. Biological diversity

Biogeography of these islands is distinct floral composition, which is more similar to that of nearby mainland Burma, and it shows a subset of "Indo-Myanmar-Thai" flora (Balakrishnan & Ellis, 1996). Andaman Island Forest types are divided into ten categories: 1) Andaman Giant Evergreen Forest, 2) Andaman Tropical Evergreen Forest, 3) Cane Brakes, 4) Wet Bamboo Brakes, 5) Andaman Semi-evergreen Forest, 6) Andaman Moist Deciduous Forest, 7) Andaman Secondary Moist Deciduous Forest, 8) Littoral Forest, 9) Tidal Swamp Forest (Mangrove Forest), and 10) Hilltop Evergreen Forest (Champion & Seth, 1968). These forests are made up of 2649 plant taxa (Murugan et al., 2016). Including endemic Andaman wild pig, the land provides habitat for 50 mammal species, marine mammal Dugong (*Dugong dugong*) represents Andaman Island as its state animal. Apart from mammals, the rich diversity of Andaman Islands holds 270 species of birds, 40 and 8 species of reptiles and amphibians, respectively, and about 225 species of butterflies and moths, among which ten species are endemic to these islands (Husain, 2009; Sankaran & Vijayan, 1993; Harikrishnan et al., 2010). In addition, the pristine seawater harbours the largest saltwater crocodile, dolphins, dugong, whales, marine turtles, fishes, prawns, lobsters, corals, seashells, including endangered Trochus species and vide variety of coelenterates and echinoderms. In total, 1117 species and subspecies of both vertebrate and invertebrate fauna can be found in the Andaman Islands, both on land and in the sea (Rao et al., 2013). Some of the species were economically important as well, like sea cucumbers, seashells, sharks, turtles, edible-nest swiftlet (Sankaran, 1995).

1.6.4. Natural Disasters

The India's high-powered disaster management committee (HPC) declared and identified the possibility of 31 different types of catastrophes that could affect the country (Das, 2012). However, due to the strategic location of the Andaman and Nicobar Islands and the lack of large-scale industrial operations, the majority of disasters are not relevant to these islands, and some are not documented in history. Still, 14 different types of catastrophes are linked to these islands, out of which natural disasters such as cyclones and earthquakes being the most common.

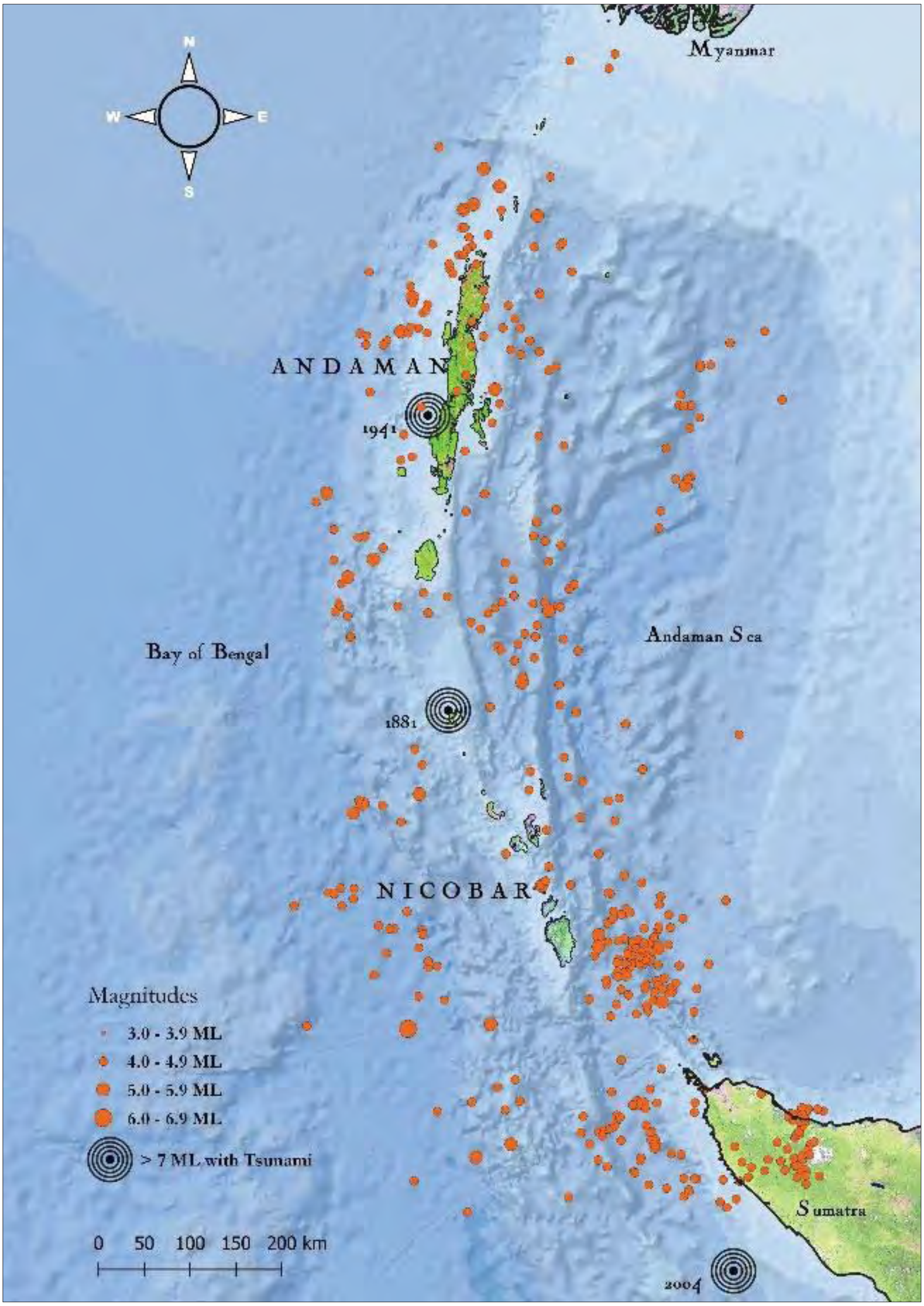


Figure 1.7. Map shows the epicentres of earthquake events that occurred in Andaman and Nicobar archipelago during the study period and the historical mega-earthquake locations.

Natural disasters such as earthquakes and tsunamis are common in the Andaman Islands due to their origin and position in extremely complicated regional tectonic settings. To prioritize the islands' susceptibility, the Geological Survey of India classified Andaman Island as seismic Zone V, which refers to a very high-risk zone (Mohapatra & Mohanty, 2010). The stress created by oblique subduction motion and strike-slip faulting between the Indian and Eurasian plates causes several earthquakes in the Andaman Islands (Eguchi et al., 1979). In the past, Andaman experienced three high magnitudes (> 7 Richter scale) earthquakes in the years of 1847 (Nicobar earthquake), 1881 (Car Nicobar earthquake), and 1941 (The Andaman earthquake) (Figure 1.7). These last two earthquakes resulted in Tsunami, while no information is available on the impact of the Tsunami in 1881. The 1941 earthquake-tsunami caused severe damage in the west-facing forests of the Andaman Islands (Bilham et al., 2005). Finally, on 2004 December 26th, a devastating earthquake (Sumatra Earthquake) with a magnitude of 9.3 Richter scale centres the offshore of northern Sumatra followed by the Tsunami did heavy damage to the Island's biological diversity. It causes the subsidence of South Andaman 1 to 1.5 m at high tide and uplift of North Andaman by 0.5-0.8 m (Malik & Murty, 2005). It leads to the loss of approximately 37.3 km^2 Coastal Forest cover. Other than the forest floral destruction, some of the unique endangered fauna (for example: Nicobar megapode and macaque) also reported being lost their population in Andaman and Nicobar archipelago (Sivakumar, 2010; Ramachandran et al., 2005).

Tripathi (2018) described the Bay of Bengal, and the Andaman Sea are the "birth grounds of the cyclones". Giftedly being a very narrow stretch of Andaman and Nicobar Islands, cyclones seldom impact or make landfall on these lands; instead, they crossover the lands. However, the heavy wind, along with the dense precipitation, causes severe damage to the forests and human well-being (Figure 1.8). Statistically, out of 175 past cyclone occurrences, 66% of the cyclones have occurred in October, November, and December, followed by 27% in April and May. The convergence of the trade winds of both hemispheres is the primary cause of cyclones' birth in these regions in the inter monsoonal seasons. There are two cyclone incidences that had caused notable damage in the Andaman Islands after independence, 1) 1988 November cyclone caused flooding in North Andaman Island. 2) In November 1989, cyclone "Gay" did another severe damage in the Mayabundar region of Middle Andaman.

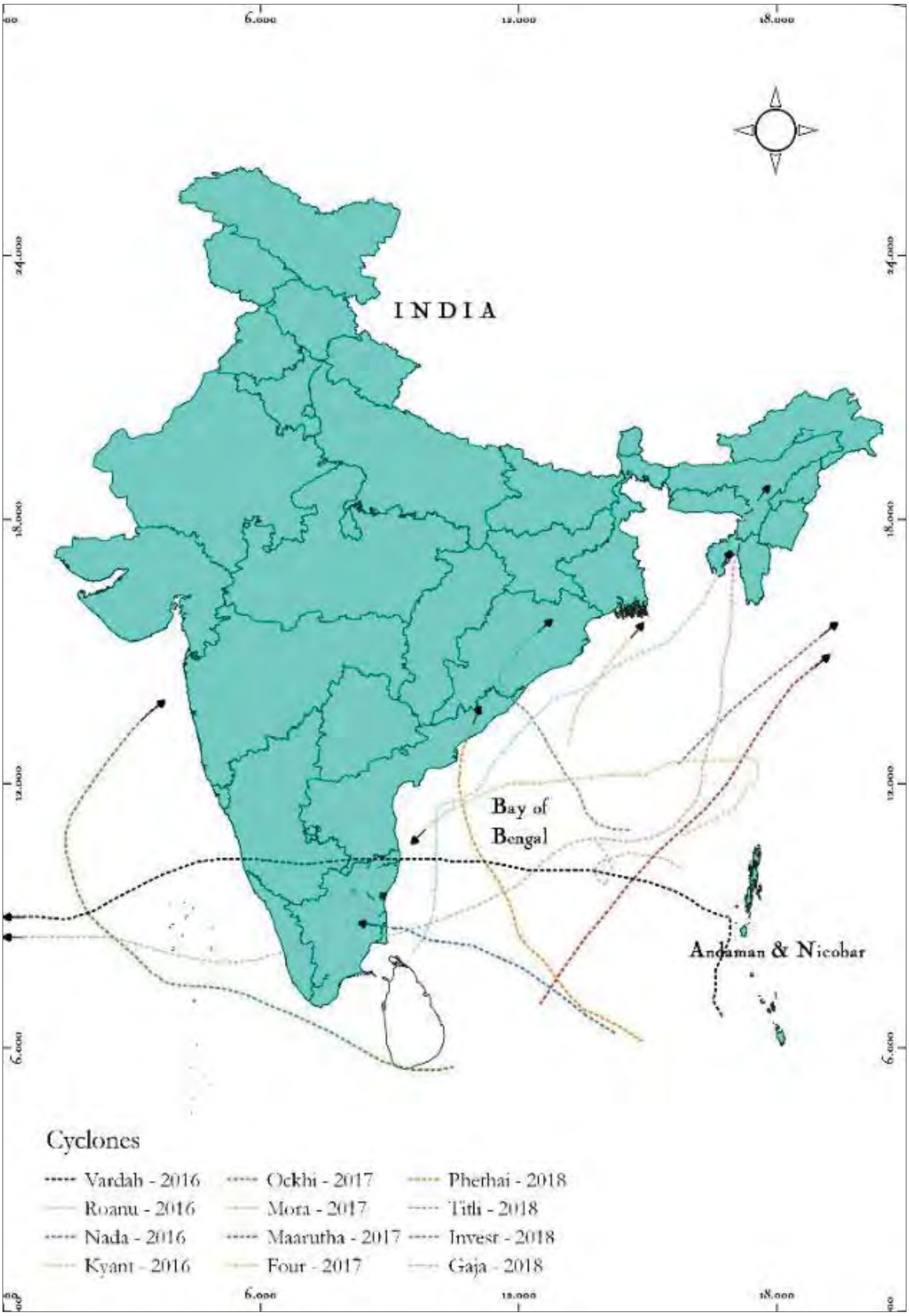


Figure 1.8. Image shows the vulnerable position of Andaman Islands to tropical cyclone paths which occurred in the study period.

1.6.5. Anthropogenic pressure

Coupled with natural calamities, increasing population from both the mainland and the island itself costs forests in the process known as agriculture and habitation. Unfenced forests nearer to the villages are found to lose their diversity through the collection of woods and other needs by the inhabitants of the villages. A study showed that a 3.6% of interior forests between 1976 and 1999 has been lost (Prasad et al., 2009). Due to the lack of river sand and ingredients for the brick production, the Andaman islanders have a distinctive local tradition of buildings with the use of natural resources as non-engineered structures (Rajesh & Prasad, 2005). Those constructions are proved to be performed well under the level VII earthquake (Murty et al., 2006); however, it costs the degradation of fragile forests. The hike in the density of the population from 5 persons per Km^2 to 48 persons per Km^2 between 1961 and 2001 (Census, 2001). During the field studies, I observed that many small hamlets in an inaccessible area of the North Andaman are encroached recently by the mainlanders.

After the establishment of settlements in 1857, the forests of Andaman went through various exploitation-oriented management plans. In 1906, first working plan (Todd's working plan) which had considered the care for the selection of trees to fell without eating away the capital. After this, various working schemes were employed in Andaman forests to improve the forests to ensure the continuous supply of Padauk both for export and for local consumption. Again, during the Japanese occupation (1942 to 1945), the forest went through a serious exploitation to meet the military needs. After independence, proper executive plans were made by a conservator of forests through a working plan for Andaman with actions to avoid the uncontrolled selective felling. However, all the features of the Chengappa working plan were not followed due to the post-independence refugee's settlement program till 1957. In 2002, hon'ble supreme court of India banned all the extraction of forest resources for industry-based activities, which protected the remaining fragile lands from exploitation.

But in the name of tourism development, Andaman forests are still facing severe threat of habitat loss. National Institution of Transforming India (NITI-Aayog) entrusted four islands from the Andaman group for the holistic development for the first phase (https://www.theleaflet.in/niti-aayogs-development-plan-for-little-andaman-generates-concern/). Eleven more locations will be included in the development schemes in the sake of success. This proposed plan alarms the conservation of biodiversity of the islands. By promoting private investments to various tourism-based projects like the construction of island resorts, water villas, and treehouses. Conservationists thought this could be a disaster to the Island's endemic fauna, flora, and the indigenous aboriginal tribal group called "*Onges*".

Andaman and Nicobar had only two opportunities *viz*., fisheries and tourism to hold their economy and island development. In the process, aggressive proposals for tourism promotion in the islands have been considered. A canopy walkway project is one of the finalized projects worth rupees 58 million (Reddy, 2018). It was proposed in two reserve forests *viz*., Chidiyatapu and Mount Harriet. And it was estimated that 364.44 cum of padauk timber for the completion of the projects. However, currently, the project is on hold for various reasons, and the State finance committee requested the forest department to utilize the procured materials for the project to use in different ongoing projects in the islands.

The expansion of the Andaman trunk road is another way of threat to the wildlife in the Andaman Islands. The actual length of the Andaman Trunk Road (NH4) was lengthened from 330.70 km to 422 km and six new National highways were added in the Andaman archipelago between 1. Diglipur and Hathilevel 2. Kalra junction and Ramnagar 3. Govindnagar and Kala patthar 4. Havelock jetty and Radhanagar beach 5. Neil jetty and Sitapur and 6. Hutbay jetty and BK pur. Linear infrastructures such as roads featured to the human activity in the tropical forests have serious impacts on their natural habitats worldwide (Trombulak & Frissel, 2000; Forman et al., 2002). First and most importantly, tropical forest species are specialized for unfragmented interior forests but the linear structures going through such forests create forest edges that are strongly avoided by those species (Murcia, 1995; Goosem, 1997; Laurance, 2004). Secondly, the expansion of roads creates the longer duration to cross the road by birds and animals, consequently leading to greater roadkill, or it may act as a barrier to the animal movement (Goosem, 1997).

Hunting is yet another anthropogenic problem in these islands, either legally by the indigenous communities under the Indian Wildlife (Protection) Act, 1972 or illegally by other culturally diverse communities in the name of sport hunting (Aul et al., 2014). Many endemic species in Andaman and Nicobar were threatened as a primary reason for hunting. Poaching of birds and bird materials like nests of Edible nest swiftlet even occurred in the protected areas as well. Along with the locals' foreign peoples were involved aggressively in poaching of natural resources (Sankaran 1997, Das, 1996, Chandra & Rajan, 1998).

1.6.6. Introduced species

Exotic introduced species have caused significant destruction to the island ecosystems all over the world. Andaman is not immune to this ever-present biological menace. Many birds and mammals were either purposely or accidently introduced to these islands. Herbivore mammals imported to these islands include chital, hog deer, muntjac, and Asian elephants. They were shown to represent a significant impediment to forest regeneration. Birds such as the Common Myna, Grey Partridge, House sparrow, and Peafowl have been introduced to these islands. While peafowl and grey partridge are only found in a small section of the island, the other two species are found throughout the archipelago (Kumara et al., 2012; Tikader & Das, 1985; Wildvistas, 2020).

1.7. ORGANIZATION OF THESIS

My dissertation is composed of four technical chapters with an overall introduction and synthesis of the study as two additional chapters. **Chapter 1: “General Introduction”** describe the motivation of this study with a review of literature about Andaman owls, features of the study area, and various threats. This part also discusses the research gaps identified and the importance of the study. **Chapter 2: "Richness, Abundance, Distribution and Anthropogenic disturbance"** is the first technical chapter that generates the baseline information of the status and threat of owls in the Andaman Islands and peoples' perception about owls. **Chapter 3: "Owl occupancy in North Andaman"** assesses the ecological and environmental factors, which determine the occupancy of owl species in both smaller and larger landscape scales. **Chapter 4: "Island characteristics species occurrence"** evaluates the critical island parameters, which secure the owl’s persistence and identifies the critical islands to be focused on for the conservation. **Chapter 5: "Owl assemblage in Andaman archipelago"** examines the nested and co-occurrence distributional patterns and suggests the possible mechanisms of owl distribution in the fragmented islands. Finally, the conclusions were made in **Chapter 6: "Summary and conclusions"**.

CHAPTER 2

Relative abundance of owls in response to vegetation types, and anthropogenic disturbance.

- Oriental Scops Owl

2.1. INTRODUCTION

The distribution and abundance of a bird species is, in part, a measure of collective outcomes of the response to habitat (Orians & Wittenberger, 1991; Sergio et al., 2004; McCain, 2009), hence an occurrence of a bird may signify the habitat and its physical structure (*i.e.*, physiognomy) that facilitates the species to settle (Babu, 2011). Birds may not occur in all available habitats in a given region: they select specific habitat patches more frequently than others (Crowell, 1962). Stenotopic species (Knopf et al., 1988) may develop adaptations to particular habitats, and in those habitats their abundance should be higher. Similarly, habitat and its structure may directly (through foraging and nesting) or indirectly (e.g., predator avoidance, Martin, 1995) determine the life history characteristics of birds. The structure and configuration of habitat may be altered to fulfil the escalating human demands on natural resources: in the form of timber extraction, conversion of natural forests for commercial plantations (e.g., of teak, eucalyptus and softwood trees), or agriculture, and this may drastically affect the birds that are endemic to unique ecosystems (Vijayan & Sankaran, 2001). Increasing anthropogenic pressure in certain ecologically important eco-regions, like islands, causes tremendous effects on the habitats and associated endemic species (Sankaran, 2001). It is, therefore, important to elucidate the interaction of species with their habitat and its physical structure that facilitate identification of the key factors involved in habitat use (Martínez & Zuberogoitia, 2004).

The ecosystems of the Andaman Islands are experiencing a high degree of anthropogenic pressure despite their conservation importance to endemic birds (Vijayan & Sankaran, 2001). The timber harvest practices (Saldanha, 1989; Vijayan et al., 2006), human-induced land cover changes (Sankaran, 1997; Sankaran, 2001), expansion of agricultural fields (Daniels, 1996) and grazing have contributed to habitat degradation in the islands (Whitakar, 1985; Curson, 1989). These anthropogenic factors may lead to the fragmentation and diminution of suitable habitats for endemic owls and generally to all avifauna thus may result in their population decline (Vijayan & Sankaran, 2001). Delimitation of species geographical distribution is the fundamental objective to understand the biodiversity and for conservation decision-making. However, the exact distribution of all five species of owls in the Andaman Islands are largely hypothetical throughout available literature and field guides on these species (Table 2.1).

Table 2.1. Distribution range of five species of owls in Andaman Islands as depicted in available literatures

Species	König, C., & Weick, F. (2008)	Del Hoyo et al., (1996)	Grimmett et al., 2016	Ali, S., & Ripley, S. D. (1983)
T. deroepstorffi	South Andaman	South Andaman	South Andaman	Andaman
O. balli	Andaman & Interview Island.	Andaman	South Andaman	Andaman
O. sunia	Andaman winter visitor	Andaman & Nicobar	Andaman	Andaman
N. obscura	South Andaman	Andaman & Nicobar	Andaman	Andaman & Nicobar
N. affinis	Andaman	South Andaman & Nicobar	South Andaman	Unknown

In addition to that, it is believed that owls are hunted for meat due to the dearth of large mammals in the Islands (Vijayan, 2009) as well as being persecuted on account of lingering cultural superstitions (Rahmani, 2011). Throughout India, owls are considered as birds of ill omen, messengers of bad luck or servants of death (Santhanakrishnan et al., 2012). In some parts of India, pale-coloured owls are considered the vehicle of goddess Laxmi and hence, people welcome owls into their homes in the belief that these birds will bring wealth and prosperity (Srivastava, 1987). The same believers tend to kill owls within their homes to force goddess Laxmi to remain. On full moon nights and nights of the festival Diwali, believers would sacrifice owls under the assumption that it will improve the family's wealth (Padhy, 2016). The Andaman Islands are culturally and biologically rich. So, the interaction of residents here with forests and local wildlife is often unavoidable and complex. Considering the diverse cultural beliefs among people in the area and the high degree of endemism in owls, understanding the knowledge and perceptions of local communities is a prerequisite for the future conservation of owl species in the Andaman Islands.

Andaman Islands (and in turn, birds found on the islands) have been facing severe anthropogenic pressures including the impacts of selective logging, extraction of climbers (canes), invasive species, photography and tourism, and collection of non-timber forest products. While the effects of these threats on birds have been documented to a certain extent, research on the effect of human activities on endemic birds, especially nocturnal animals, are limited. Owls are experiencing these threats in their the day-time roost site and hence they need to identify a suitable roost location to avoid predation from diurnal avian and mammalian predators. Even mere human presence in the environmental space of an owl is considered as predators and respond accordingly (Frid & Dill, 2002). Then they react to the predator either directly (Flight) or indirectly (vigilance), both reduces the reduces the probability of survival or protection through displacement (Kruuk, 1964). So, researchers worldwide measure the tolerance level of a bird by the measuring of flight initiation distance (FID) and flush response (FR) in response to approaching human threat. These anti-predatory behaviours of birds have been tested in breeding (Collins et al., 2019), roosting (Swarthout & Steidl, 2001) and even foraging sites (Sproat et al., 2019) of many vulnerable species to secure safe and eco-friendly recreational activities (Livezey et al., 2016; Spaul & Heath 2017). The ability of Andaman to attract worldwide tourists with the endemic flora, fauna and pristine beaches providing opportunity for both government and private sectors to develop ecotourism in the fragile ecosystem. However, the assessment of behavioural impact caused to wild animals more specifically to owls by tourists are still lacking.

Given the conservation importance of the islands and the above mentioned threats, this chapter aimed to 1) assess the species richness, abundance and distribution of owl species in relation to different land use land cover types and logging intensity, 2) document people's perception and existing knowledge of local residents about owls and 3) evaluate the anti-predatory behavioural responses (FIR and FR) of three owl species (*O. sunia*, *O. balli* and *N. obscura*) in response to a human stimuli.

2.2. METHODS

2.2.1. Intensive study area

To address abundance, richness and their relationship of owls, and anti-predatory behavioural responses (FIR and FR) of three owl species, the Great Andaman Islands (south, Baratang, middle and north Andaman Islands) were selected. To understand the perception of residents about the owls, questionnaire surveys were conducted in and around six marketplaces (Aerial Bay, Pachimsagar, Ram Nagar, Kalighat, Kishori Nagar, and Radha Nagar; Figure 2.1).

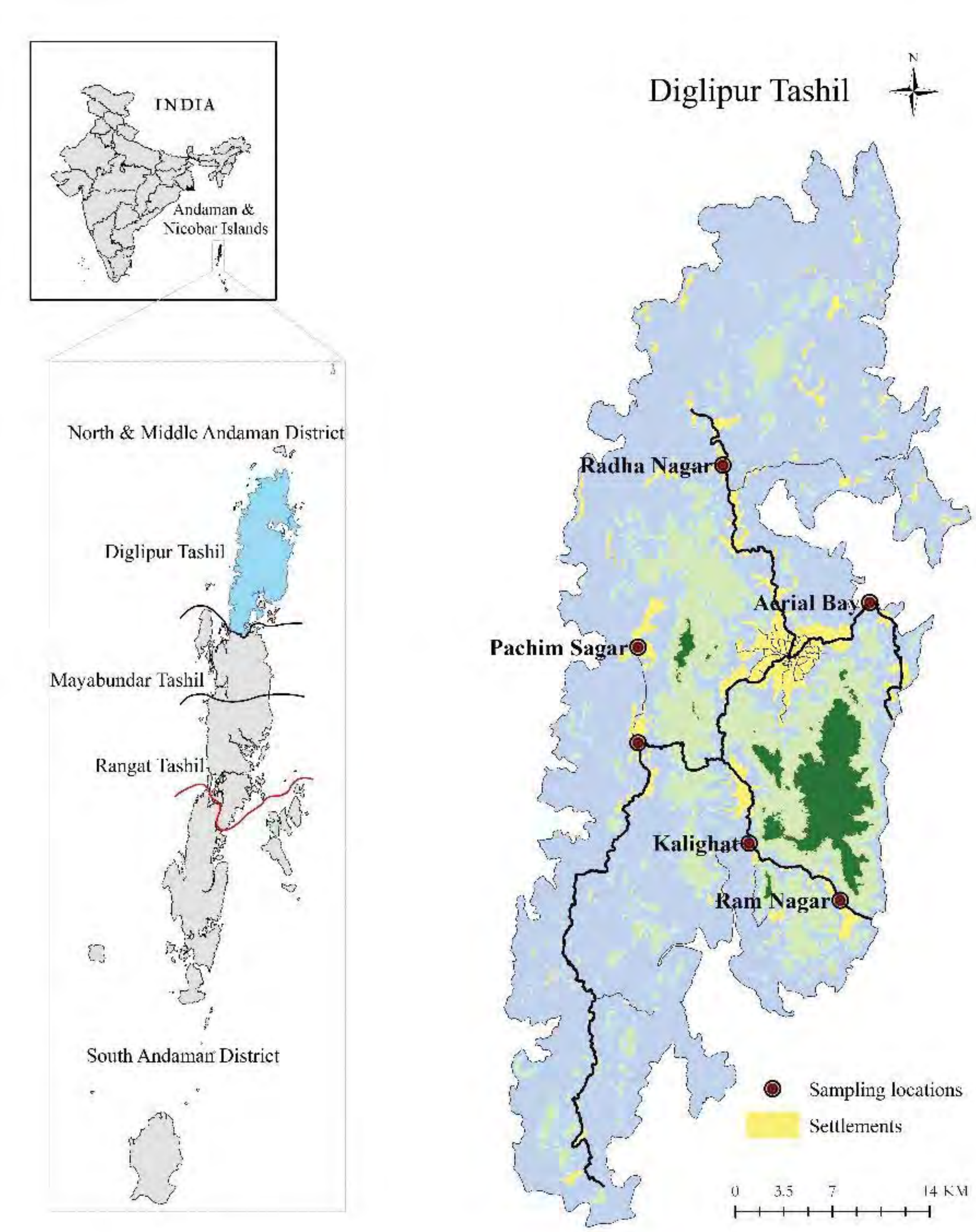


Figure 2.1. Map showing the marketplaces where questionnaire survey was conducted.

2.2.2. Field methods

2.2.2.1. Richness, abundance, and distribution of owls

Sampling across the entire Andaman archipelago was not possible due to large parts being restricted (Jarwa) reserve lands. So, the Andaman trunk road (NH-4) was selected as sampling track since it covers all major land cover types (*i.e.*, deciduous, evergreen, littoral, and mangrove), land use forms (*i.e.*, plantations, paddy, orchards, and human habitations), varied altitudinal gradients, major islands (*i.e.*, South, Middle and North Andaman, which accounted for ~80% of the land mass available), and varied degrees of anthropogenic disturbance (Figure 2.2). Owl sampling was conducted during December 2015 to January 2016 on North Andaman, and during March and April 2016 in South and Middle Andaman using the point count survey method with 100-m radius plots (Bibby et al., 1992).

Spatial distance of 2 km was maintained between points to avoid repeated counting of individual owls and was based on the estimated home range size of similar small, bodied owls which ranged between 1.8 - 2.4 km^2 (Strøm & Sonerud, 2001). Altogether, 143 points were sampled comprised of 35 in south, 49 in middle and 59 in North Andaman Islands. Number of points per island was decided based on the availability of approachable road network within each island. Sampling was done between 17:00 hr and 23:00 hr during clear and calm nights because heavy wind and rain reduces the effectiveness of the method. Geographic locations of the sampling stations were marked using handheld global position system (Garmin LTD, Kansas City, USA).

Owl sampling protocol

Owl sampling along the Andaman trunk road was conducted on selected sampling points with three sampling protocols. 1) ***Initial quiet listening method:*** Upon accessing each sampling point, first 10 minutes spent at each point silently listening for owl calls and looking for movement of owls. All calls and sightings of owls were recorded. 2) ***Broadcasting of conspecific calls:*** This audio lure method was used to attract conspecific individuals and potentially congeneric species as well. A single car-stereo (SONY) with two loudspeakers were used to playback the owl calls that has been recorded from the Andaman Islands. All calls were played in a pre-determined sequence starting with small to large, bodied owl as follows *O. balli, O. sunia, N. affinis, N. obscura* and *T. deroepstorffi* (Refer Table 1.1, page-14). Two minutes response time was given to owls to respond. 3) ***Spotlight searches:*** If no owls were heard, I searched for perched individuals or their eye reflection using head mounted spotlights. Floaters were identified as silent individuals detected during spotlight searches. Results obtained from all survey methods were compiled to develop a comprehensive set of detections and non-detections across all species of owls across all surveyed points. In addition, number of individuals detected at a point was determined by pooling results across all survey methods.

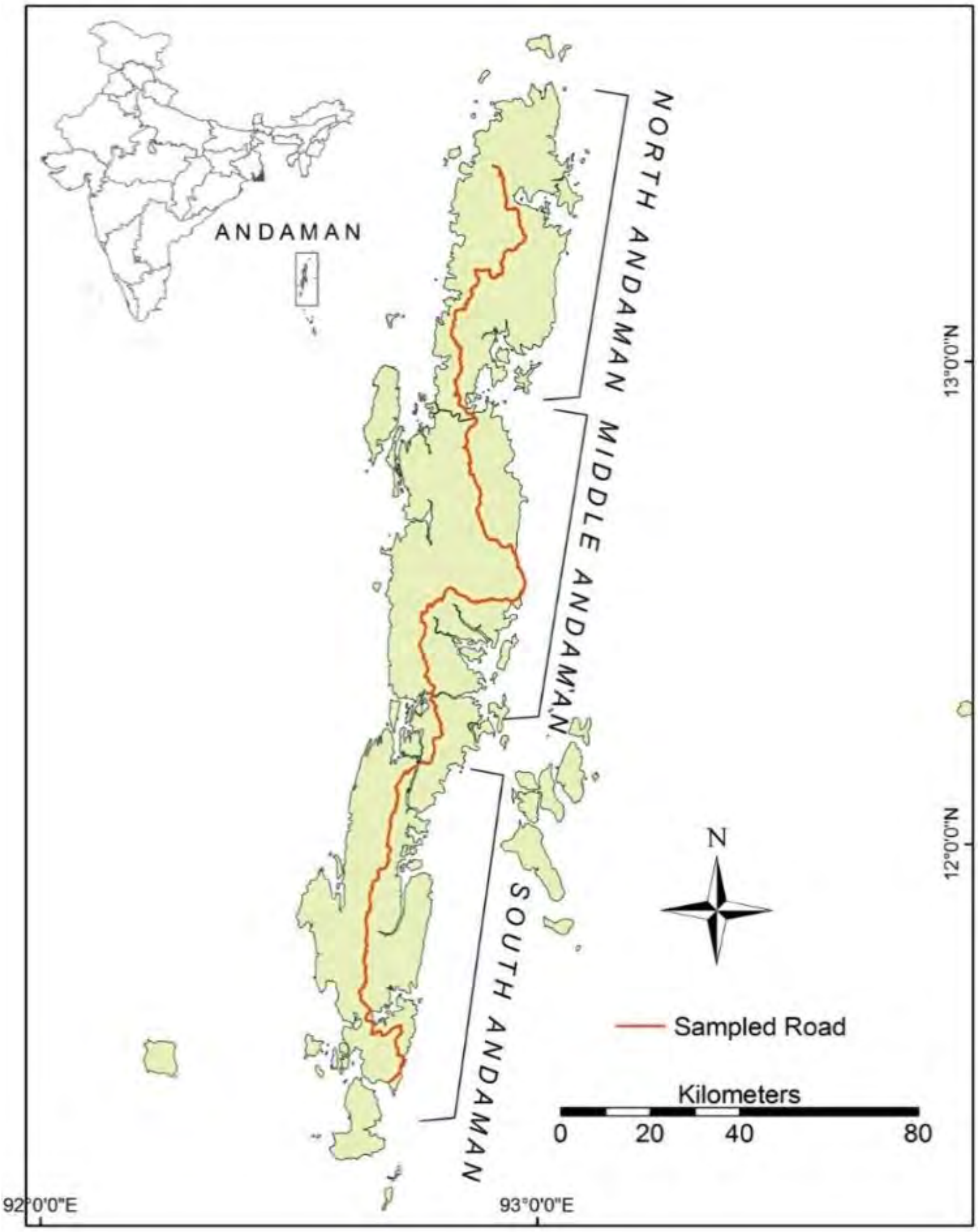


Figure 2.2. Map showing the Sampled Andaman Trunk Road (NH-4)

Explanatory variables

Land use and land-cover types (Evergreen, deciduous, mangroves, plantations, paddy and human habitation) and selective logging (Plantations, selectively logged and unlogged) were coded for each sampling point (Table 2.2). Timber trees are selectively logged in the Andaman Islands, and important timber trees included: Padauk (*Pterocarpus dalbergioides*), Silvergrey (*Terminalia bialata*), Pyinma (*Lagerstroemia hypoleuca*), and Koko (*Albizzia lebbek*). Selective logging is permitted in the island through government owned mills to meet the domestic needs (for instance: house and jetty construction) (Singh, 2005). Point Centered Quarter method (PCQ; Müller-Dombois & Ellenberg, 1974) was employed at all sampling points for assessing the habitat covariates that might influence the distribution of owls. At each owl survey point, four PCQ points were identified in four cardinal directions at 20 m interval. Identified points were then divided into four equal quads and in each quad one closest tree with girth size more than 15cm was selected for quantifying the habitat covariates. The detailed description of the variables and method of measuring and coding are given in Table 2.2.

Table 2.2. Explanatory variables used to assess the owl abundance and richness in owl point count stations

	Descriptions of factors	**Abbr.**
Landcover Types		
Evergreen	Forests are dominated with large trees of evergreen with dense understory vegetation, mostly climbers.	EG
Deciduous	Having irregular canopy, the moist deciduous forest stands are distinguishable by large deciduous trees with the understory stratum dominated by cane and other climbers.	DF
Mangroves	Mangroves are swamp forests in the coastal areas	MNG
Plantation	Yards of commercial trees and plants	PL
Paddy	Agricultural lands of seasonal cultivation	PD
Human habitation	Home gardens	HH
Logging intensity		
Plantations	Paddy fields, plantations, and human habitations	-
Logged	Sites were selectively logged	-
Unlogged	Unworked forest areas	-
Habitat covariates		
Tree distance (m)	Average distance of four nearest trees from the sampling point	MTD
Girth at breast Height (cm)	Average girth of four nearest trees	MGBH
Total tree height (m)	Average height of four nearest trees	MTH
Canopy cover (%)	Average canopy cover of four nearest trees	MCC
Understory plant Cover (%)	Average understory cover of 5 m plot	MUSC
understory height (m)	Average understory height of 5 m plot	MUSH

2.2.2.2. Flight initiation distance and Flush response

All the experiments were conducted on owl roosts of the three species during summer season (February–May) for three consecutive years from 2015 to 2017 (Figure 2.3). Since this period is coinciding with the breeding season of these owl, more care was taken not to experiment breeding owls. In general, Andaman owls are known to utilize tree holes during breeding season, so, owls roosted in holes were omitted. Prior to the experiments, the roosting owls were located by tracing their last vocalization locations during the early morning hours. After marking roost location, the same site was visited around noon (1100–1200 h) and conducted experiments. Roosting owls, which were detectable from around 10m distance were considered for the experiment. In the selected sites, the experiment was conducted with the same dress by walking directly towards roosting owls with a minimum speed of one step per second and recorded the response behaviour of the owls. If the owl was flushed from the roost site, immediately seized the experiment, and moved away then measured the distance from the roost site with the digital range finder. In case of a pair, even one bird being flushed from the roost was considered as FR. If the owl did not flee at all even at 1 m distance, it was categorized as not flushed. While conducting the experiment, all camouflage behaviours of owls were recorded such as elongating its body, erecting their ear tufts, and sliding to an angle. All habitat and climatic variables at the roost sites regardless of if birds were flushed or otherwise were noted down for analysis. The detailed description of the variables and method of measuring and coding are given in Table 2.3.

Table 2.3. Factors hypothesized to influence the flight initiation distance and flush responses in owls from the day-time roost sites in Andaman Islands.

Descriptions of factors	Code used in analysis	Abbr.	Unit
Roosted as pair	1	PAIR	Binary
Solitary	2		
Displaying camouflage action (elongating body)	1	CAMFG	Binary
Without any physical changes	2		
Presence of spines at the roosting branch	1	SPINE	Binary
Absence of spines at the roosting branch	2		
Number of climbers on the roosted plant	-	CLIMB	Count
Status of the roosting branch - alive	1	STATUS	Binary
Status of the roosting branch - dead	2		
Roost height of owls (from the ground)	-	HEIGHT	Meters (m)
Distance at which the observer started	-	BENNG	Meters (m)
Temperature at the roost site	-	TEMP	Degree Celsius (°C)
Relative humidity at the roost site	-	HUMI	Percentage (%)

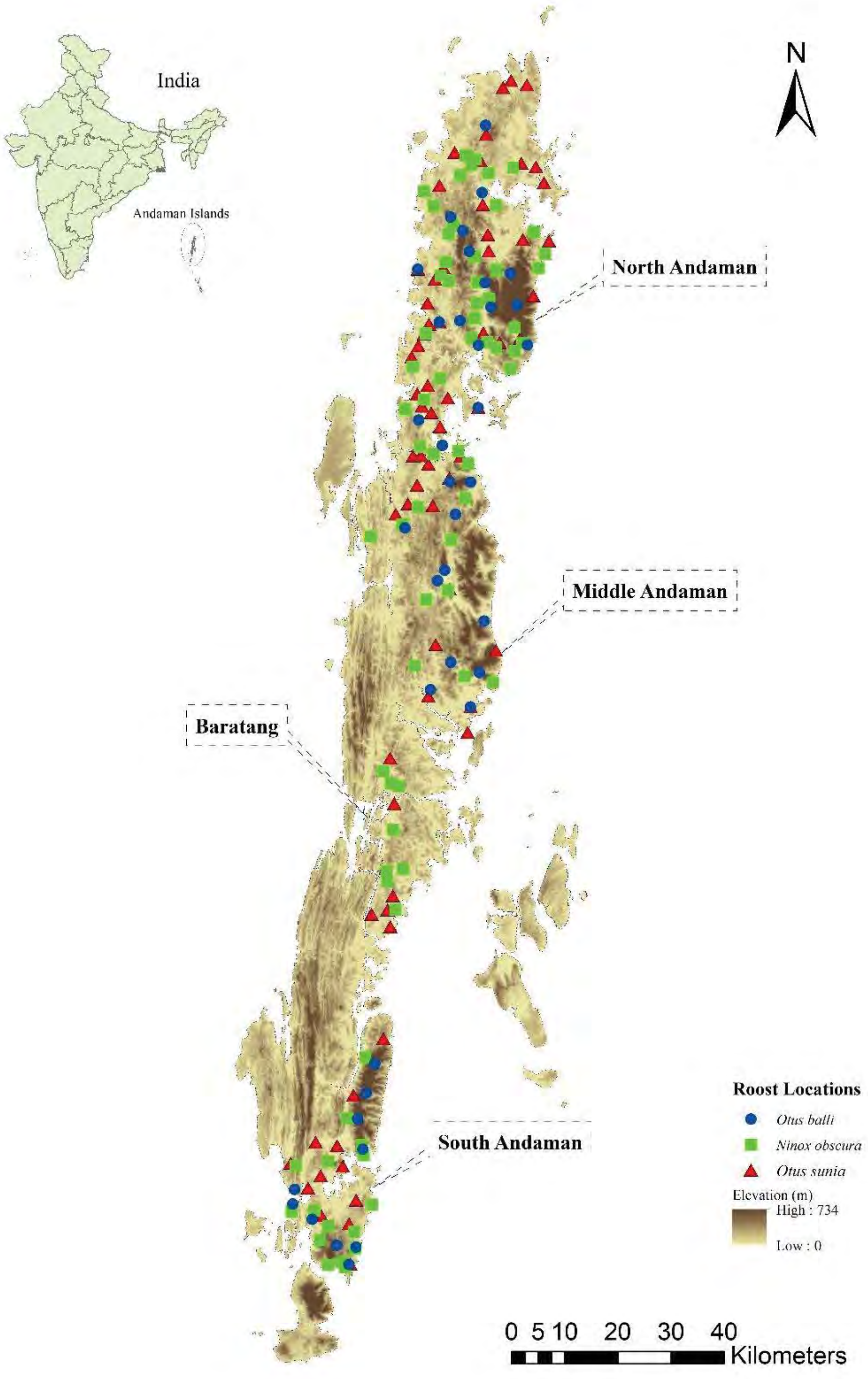


Figure 2.3. Roost locations of *O. balli, O. sunia* and *N. obscura* in Andaman Islands.

2.2.2.3. People's perception about owls

An open-ended questionnaire survey (Appendix 2.4.) was conducted with same set of questions but without any specific order because the objective was to create baseline information on what people know about owls and to record the beliefs surrounding these birds. On selecting a participant for the survey, first the intention of the work was described and inquired about his/her willingness to participate in the interview. Then, I considered them as respondents and asked their socio-economic background (gender, age, occupation, village type, house type, and literacy level) followed by questions related to owls. Questions such as respondents' familiarity with owls (yes or no), knowledge of owl species in the area (one to five), identification technique used (e.g., morphology, calls, behaviour) and their beliefs about owls (positive and negative beliefs; descriptive) were asked. Pictures of owls were showed and mimicked or played the calls of owls to confirm species identity. Since most of the respondents knew language Hindi, all questions were asked in this language. Occupations of respondents were classified into three categories: regular workers (people with employment opportunities for the entire year), irregular workers (people who work for half the year), and unemployed (people without a job). Housewives were considered unemployed for this study. The literacy level of respondents was grouped into two categories: literate (if the person could either read or write) and illiterate (if the person could neither read nor write). Settlements were categorised into two namely revenue land and forest encroachment land. Finally, the houses of respondents were categorised as permanent (concrete house), semi-permanent (walls are concrete and roof as thatched), temporary house (thatched and mud construction) and rented house.

2.2.3. Statistical analyses

2.2.3.1. Richness, abundance, and distribution of owls

Number of individuals detected at a point determined by pooling results across all survey methods. Mean species richness (termed as "species richness") was calculated as the number of species detected divided by the number of point count stations in each habitat. Mean number of owls/habitat (termed as "abundance") = n/S, and relative number of owls (termed as "relative abundance") = $n/N \times 100$, where n = number of individuals of a species; S = total number of points in each habitat; N = total number of individuals of a species. The species' count data did not meet the assumptions of the analysis of variance, so Kruskal-Wallis test was adopted to evaluate the difference in both abundance and species richness of owls across the LULC and logging intensity types. The standard deviation and mean for every variable from each point was used in the analyses.

I used a multi-model inference procedure to analyse the potential effect of habitat covariates on the species richness and abundance of owls in the Andaman Islands (Burnham & Anderson, 2002), applying a Generalized Linear Model (Poisson distribution) and a model averaging process (Barton, 2016). Among the habitats surveyed in the Andaman Islands, the maximum species richness and abundance of owls were recorded from the deciduous forests, and hence *apriori* hypotheses were developed that explain the characteristics of deciduous forests. The deciduous forests in the Andaman Islands have spaced tall trees with low canopy cover and higher and taller understorey cover. Thus, a global model constructed by including all the habitat variables for comparison and alternative models that explain my observed patterns.

A global model was generated, and it was followed by several competitive models using *apriori* hypothesis and model simplification procedure explaining the factors that influence the species richness and abundance of owls in the Andaman Islands. Models were compared by their AIC values (Burnham & Anderson, 2002). A small difference in ΔAIC values was observed between the top four models for species richness and the top two models for abundance. Thus, model weight that has < 2 ΔAIC were summed, for each covariate to explain the importance of these covariates. All analysis were carried out using R *ver. 4.0.0* and the “MuMIn” package was used for model averaging (Barton, 2016).

2.2.3.2. Flight initiation distance (FID) and Flush response (FR)

In total, 180 roost locations were found in Great Andaman Islands including all three species (Figure 2.3). Since the habitat structural characteristics may differ across different habitat types. To maintain the uniformity in the experiments, studies were conducted only on the roost sites located in evergreen forests and moist deciduous forests for *O. balli* and *O. sunia*, respectively. However, roosts of *N. obscura* were mostly found along the edges of the evergreen and moist deciduous forests. To know whether the FID and FR of *N. obscura* vary between habitat types, a univariate *t* tests for FID and chi-square test for FR of *N. obscura* was employed and found no significant difference in the FID ($t = -0.959$, $df = 51$, $P > 0.05$) and FR ($x^2 = 0.02$, $df = 1$, $P > 0.05$) between the habitat types and hence the data collected on both habitat types were pooled for *N. obscura*. The data was arranged with respect to species and checked for normality by Shapiro-Wilk statistic for continuous variables and examined the histogram and boxplots to identify outliers and residuals (Miles, 2014). Since the starting distance was not normally distributed, it was $\log_{10}$ transformed to meet the normality assumption beforehand. One-way ANOVA was applied to find out the difference in FID and FR between species. Variables were logistically regressed for each species separately to predict the most important variable(s) that influence FR in owls. A multiple linear regression analysis carried out to assess the importance of variables' contribution to FID. For both analyses, A global model by including all predictor variables (temperature, humidity, starting distance, number of climbers, branch, presence of spines, species camouflage behaviour, roost height and pair) built. Later, removed variables that were not statistically significant ($P \geq 0.05$) from the model using backward selection. I used R^2 values for linear regressions and drop-in-deviance test for the logistic regression to assess goodness-of-fit of each resulted model (Swarthout & Steidl, 2001).

2.2.3.3. People's perception about owls

To identify the demographic factors that influence the perception of people, generalized linear model with logit link for three species of owls (*O. sunia*, *N. obscura*, and *T. deroepstorffi*) were performed using R *ver. 4.0.0* programme.

2.3. RESULTS

2.3.1. Richness and abundance of owls in relation to land use and land cover (LULC) types and logging intensity

A total of 299 owls of five species were counted from 143-point count stations. Species richness and abundance of owls was 1.48 ± 1.06 species/point and 2.09 ± 1.69 owls/point, respectively. Species richness and abundance did not vary across LULC types (richness $H = 11.319$; $df = 8$; $P > 0.05$; abundance $H = 13.296$; $df = 8$; $P > 0.05$) and logging intensity (richness $H = 0.781$; $df = 2$; $P > 0.05$; abundance $H = 0.724$; $df = 2$; $P > 0.05$). Nevertheless, deciduous forests had the highest species richness and abundance while plantations had the lowest (Table 2.4).

Table 2.4. Species richness and abundance (individuals/point) of owls across different major Land Use and Land Cover types in Andaman Islands.

LULC	Point counts	Species richness/point (Mean ± SD)	Abundance/point (Mean ± SD)
Deciduous Forests	42	2.026 (±1.127)	3.053 (±1.931)
Evergreen Forests	25	1.560 (±1.044)	2.120 (±1.590)
Human Habitation	16	1.063 (±0.998)	1.375 (±1.408)
Human Habitation + Paddy	10	1.500 (±0.850)	1.900 (±0.876)
Human Habitation + Plantation	27	1.333 (±0.832)	1.852 (±1.262)
Mangroves	3	1.667 (±1.155)	2.333 (±1.528)
Paddy	4	1.250 (±0.957)	1.500 (±1.291)
Paddy + Plantation	11	1.273 (±1.104)	2.091 (±2.023)
Plantation	5	0.600 (±0.548)	0.600 (±0.548)

Similarly, unlogged forests (Richness = 0 – 4 species; abundance = 0 – 7 owls) had the highest species richness and abundance while human habitation (Richness = 0 – 3 species; abundance = 0 – 6 owls) had the lowest (Table 2.5).

Table 2.5. Species richness and abundance (individuals) of owls with various degrees of logging intensity in Andaman Islands.

Logging intensity	Point counts	Species richness/ point (Mean ± SD)	Abundance/point (Mean ± SD)
Unlogged	52	1.58 (±1.24)	2.35 (±1.99)
Logged	39	1.51 (±1.02)	2.03 (±1.61)
Paddy + Human	52	1.35 (±0.88)	1.88 (±1.38)

The relative abundance of *O. sunia* (35.45%) and *N. obscura* (35.12%) was higher than *N. affinis* (12.71%) and *O. balli* (16.05%; Table 2.6). *O. sunia* (H = 10.328; *df* = 8; P > 0.05) and *N. obscura* (H = 4.431; *df* = 8; P > 0.05) occurred in all LULC types with no significant difference in abundance. *N. affinis* (H = 33.625; *df* = 8; P < 0.0001) occurred in five LULC types and *O. balli* (H = 22.951; *df* = 8; P < 0.01) occurred in eight LULC types, both with significant variation in abundance. The relative abundance was higher in deciduous forests for four species, and in evergreen forests for one species (Table 2.6). *O. balli* (H = 10.426; *df* = 2; P < 0.01) and *N. affinis* (H = 4.125; *df* = 2; P > 0.05) were more abundant in unlogged sites, but abundance of *O. sunia* (H = 0.225; *df* = 2; P > 0.05) and *N. obscura* (H = 0.387; *df* = 2; P > 0.05) were similar among different logging intensity (Table 2.7). *T. deroepstorffi* was scarcely encountered during the survey.

Table 2.6. Relative abundance (%) of owls in various Land Use and Land Cover types of the Andaman Islands: Values in bold indicate highest relative abundances.

	Land use and land cover types										
Species	**DF**	**EG**	**MNG**	**HH**	**PD**	**PL**	**HH+PD**	**HH+PL**	**PD+PL**	**Count**	**Relative Abundance**
O. sunia	**37.74**	10.38	3.77	9.43	2.83	0.94	6.60	19.81	8.49	106	**35.45**
N. obscura	**29.52**	19.05	1.90	9.52	1.90	0.95	7.62	20.00	9.52	105	**35.12**
O. balli	33.33	**39.58**	2.08	2.08	2.08	2.08	0.00	10.42	8.33	48	**16.05**
N. affinis	**71.05**	7.89	0.00	2.63	0.00	0.00	10.53	7.89	0.00	38	**12.71**
T. deroepstorffi	**100.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**2**	**0.67**

Deciduous Forest = DF, Evergreen Forest = EF, Mangroves = MNG, Human Habitation = HH, Plantations = PL, Paddyfields = PD, Mosaic of Human Habitation and Paddy Fields = HH + PD, Mosaic of Human Habitation and Plantation = HH + PL, Mosaic of Paddy and Plantation = PD + PL.

Table 2.7. Relative abundance (%) of owls in relation to logging intensity in the Andaman Islands. Values in bold indicate highest relative abundances.

Species	**Unlogged**	**Logged**	**Paddy + Human**
Otus sunia	36.79	25.47	**37.74**
Ninox obscura	35.24	25.71	**39.05**
Otus balli	**58.33**	20.83	20.83
Ninox affinis	**44.74**	36.84	18.42
Tyto deroepstroffi	**50.00**	**50.00**	00.00

The species richness and abundance of owls were positively influenced by three covariates: mean understorey height, mean grass cover and mean tree height. The species richness and abundance of owls in understorey cover, tree height and grass cover. Mean understorey height and mean tree height have contributed higher model weight for abundance, whereas mean understorey height, mean grass cover and mean tree height were important for species richness (Table 2.8). The top six and four models are presented in Appendix 2.1 & 2.2 for species richness and abundance respectively.

Table 2.8. Summed model weight for relative importance of each predictor variable for species richness and abundance of owls in Andaman Islands

Covariate	**Summed model weight**	
	Species richness	Abundance
Mean Understory Height	0.961	0.956
Mean Tree Height	0.470	0.285
Mean Grass Cover	0.460	0.594
Mean Understory Cover	-	0.022

2.3.2. Flight initiation distance and Flush response

In total, 180 experiments with an average starting distance of 11.99 ± 3.18 m for *O. balli*, 21.52 ± 2.47 m for *N. obscura*, and 13.94 ± 4.57 m for *O. sunia* were used for analysis. Of these, owls were flushed from their roost during 133 attempts (63 %) (Table 2.9). Significant difference was found in FR ($F_{2,\,177}$ = 7.472, P < 0.001) among the three species. *N. obscura* (x^2 = 12.262, *df* = 1, P < 0.001) and *O. sunia* (x^2 = 9.779, *df* = 1, P < 0.05) were more likely to be flushed than did *O. balli*. However, *N. obscura* and *O. sunia* were not significantly different in terms of FR (x^2 = 0.163, *df* = 1, P > 0.05).

Table 2.9. Mean flight initiation distances and percent of flush responses of three owl species to approaching human in Andaman Islands.

Species	***n***	**Number of owls flushed (%)**	**Flight Initiation Distance (m)**		
			$\bar{x}$	**SE**	**Range**
O. balli	38	14 (37)	4.23	0.42	1.36 – 07.30
O. sunia	69	47 (68)	5.48	0.30	1.42 – 11.25
N. obscura	73	52 (71)	6.78	0.22	3.05 – 10.36
Total	180	113 (62)	5.93	0.19	1.36 – 11.25

When looking into the variable that influence the FR of all three species, the negative influence of pairing (β = -2.248 ± 1.0725, $P < 0.05$), and camouflage behaviour (β = -2.723 ± 1.3687, $P < 0.05$) of *O. balli* were found to be the reason for their tolerance to approaching human, compared to the other two species (Table 2.10). However, the FR of *N. obscura* was largely influenced by the roost tree characteristics *i.e.*, presence of climbers (β = -0.787 ± 0.6963, $P < 0.05$), spines (β = -1.623 ± 0.7583, $P <0.05$) and status of the branch (β = -1.660 ± 0.7413, $P < 0.05$). The FR of *O. sunia* was influenced by species pairing (β = -1.884 ± 0.8611, $P < 0.05$), roost height (β = 0.604 ± 0.2585, $P < 0.05$) and camouflage behaviour (β = 1.283 ± 0.6393, $P < 0.05$) (Table 2.10).

Table 2.10. Factors influencing the flush response of three owl species to approaching human in Andaman Islands.

Species	*n*	Factors[a]	β	SE	Wald's X^2	*p*	Odds ratio
O. sunia	69	PAIR	-1.884	0.8611	-2.188	0.028	0.123
		HEIGHT	0.604	0.2585	2.339	0.019	0.448
		CAMFG	1.283	0.6393	2.008	0.044	5.761
O. balli	38	PAIR	-2.248	1.0725	-2.096	0.036	0.106
		CAMFG	-2.723	1.3687	-1.990	0.046	0.066
N. obscura	73	CLIMB	-0.787	0.6963	-1.130	0.037	0.455
		SPINE	-1.623	0.7583	-2.141	0.032	5.071
		STATUS	-1.660	0.7413	-2.239	0.025	0.190

[a] Refer Table 2.3 for description of variables.

Relatively higher FID was recorded for *N. obscura* (6.78 ± 0.22 m) than the other two sympatric owls (*O. sunia* = 5.48 ± 0.3 m and *O. balli* = 4.23 ± 0.42 m). The FID among three species of owls was significantly different ($F_{2, 110}$= 13.066, $P < 0.05$) and post-hoc test showed significant differences in FID between *O. balli* and *N. obscura* ($P < 0.001$), and *O. sunia* and *N. obscura* ($P < 0.001$). But there was no significant difference in FID between *O. balli* and *O. sunia* ($P > 0.05$). Ninety-five percent of *O. balli* flew at a distance of 8 m in response to approaching human while the distance was around 11 m for both *O. sunia* and *N. obscura* (Figure 2.4). The maximum FR was observed at a distance of 3 to 6 m for *O. balli* and *O. sunia* while it was 6 to 9 m distance for *N. obscura* (Figure 2.5). Roost height, pairing and presence of spine were the important predictors for the FID of *O. balli* while it was roost height, temperature and count of climbers for *N. obscura* (Table 2.11). None of the quantified variables contributed significantly to the FID of *O. sunia*.

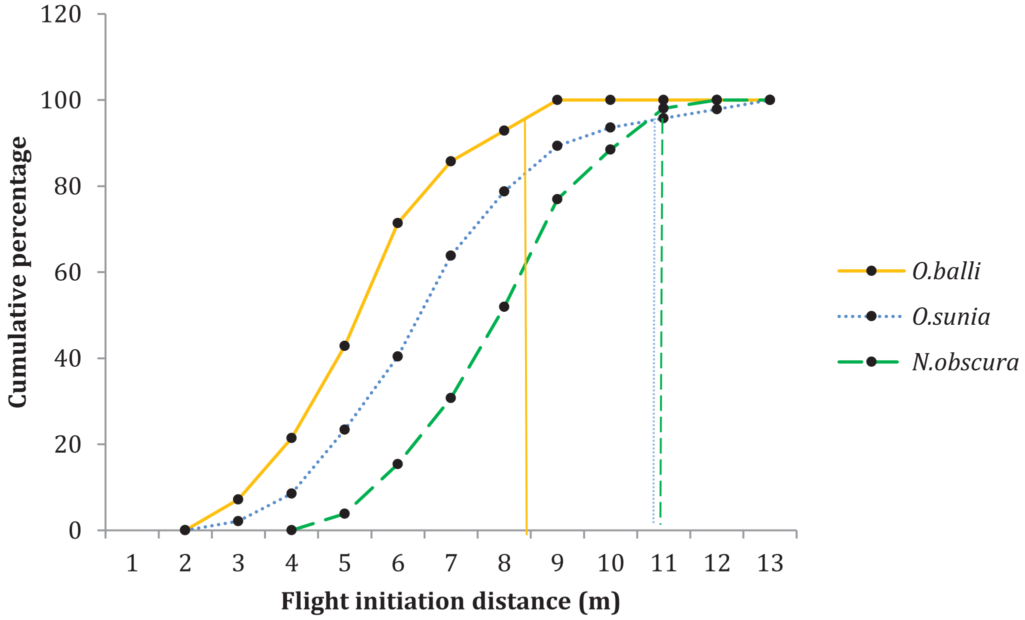


Figure 2.4. Flight initiation distance of flushed owls in response to approaching human and the straight line indicates the 95 % of sampled flushes occurred at the distance from the human.

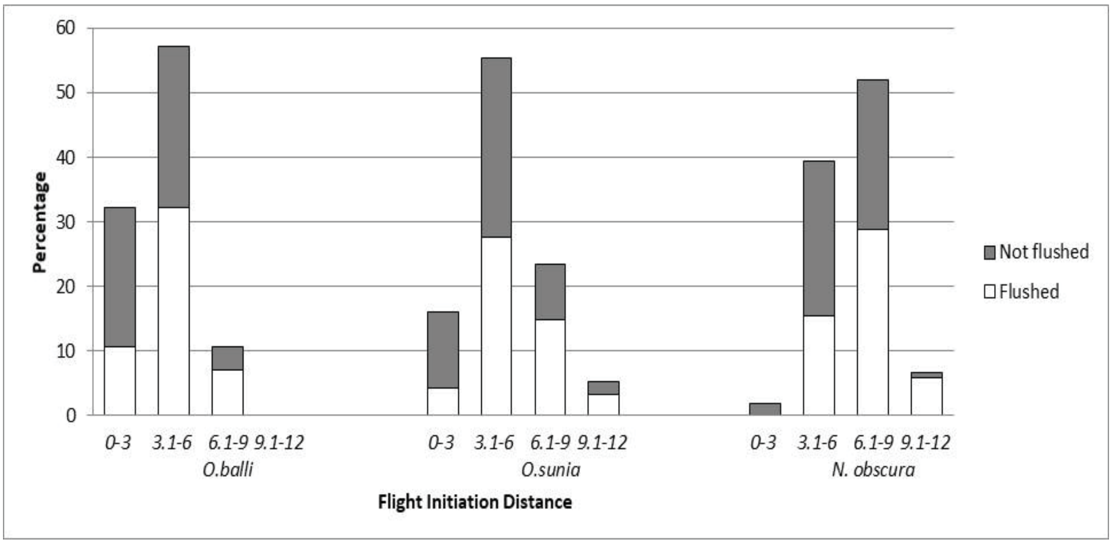


Figure 2.5. Closest distance (in m) an observer approached three owl species at their roost sites and the percentage of the responses.

Table 2.11. Factors influencing flight initiation distance of *O. balli* and *N. obscura* to approaching human in Andaman Islands.

Species	*n*	Factors [a]	Estimate	SE	*t*	*P*
O. balli	14	Intercept	19.40	9.25	2.098	0.081
		HEIGHT	-1.312	0.43	-3.031	0.023
		PAIR	2.305	0.89	2.588	0.041
		SPINE	-3.526	0.96	-3.642	0.011
N. obscura	52	Intercept	-17.65	9.45	-1.867	0.068
		HEIGHT	-0.413	0.13	-2.984	0.004
		TEMP	0.898	0.32	2.779	0.007
		CLIMB	-1.697	0.78	-2.158	0.036

[a] Refer Table 2.3 for description of variables.

2.3.3. People's perception about owls

Altogether, out of 203 respondents, 57% of whom were men and 43% women, across six survey sites: Kalighat (26 people), Kishori Nagar (42 people), Pachim sagar (27 people), Radha Nagar (30 people), Aerial Bay (37 people), and Ram Nagar (41 people). The average age of female and male respondents were 36 years (ranging 21–57) and 46 years (ranging between 21–65) respectively. Out of 203 people, 54% and 46% were considered literate and illiterate, respectively. Nearly 22% of the respondents were regular workers, 45% were irregular workers, and 33% were unemployed. Twenty-two per cent of respondents had permanent houses while 50% had semi-permanent houses. Around 20% and 8% of the respondents lived in temporary and rented houses respectively. Nearly 61% of people lived in revenue villages and 39% lived on encroached forest land.

Only 9% of people could differentiate between the five species of owls and their calls. Nearly 44% (90 people) said that they have seen or heard four different species, 34% (70 people) of people recognized three species, 11% (22 people) knew only two species and only two respondents said they can recognize only one species in Andaman. People often got confused between two species of Hawk Owls (Ninox genus) and scops-owls (Otus genus) and this lead to wrong identification of owls. Interestingly, 7% of people identified *O. balli* calls as "jungle murgi" (Watercock *Gallicrex cinerea*) and one respondent identified *O. sunia* calls as that of a frog. A large proportion of people could identify the *T. deroepstorffi* (Figure 2.6).

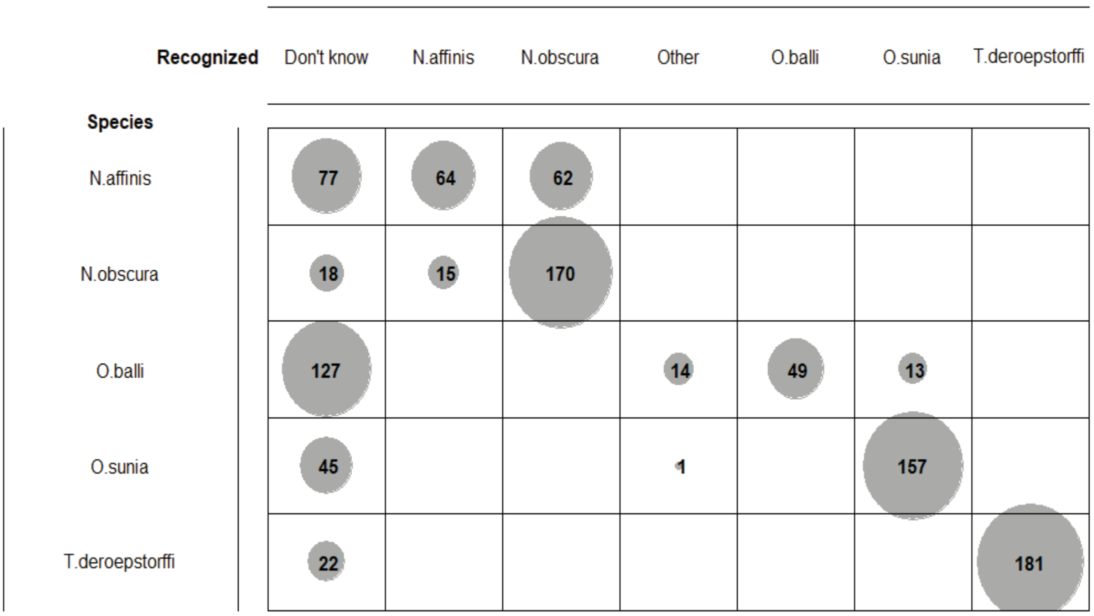


Figure 2.6. Familiarity of respondents in the identification of different owl species. Larger the size of circle indicates more responses.

Nearly 80, 77, and 55 per cent people reported negative beliefs about *O. sunia*, *N. obscura* and *N. affinis*, respectively. Seventy-one per cent of respondents mentioned that *T. deroepstorffi* would bring good luck (positive beliefs) and nearly 59% of people were neutral about *O. balli* (Table 2.12). Illiterate and young persons had more negative attitudes about *O. sunia*, whereas those resides in temporary houses in revenue villages were more positive about *N. obscura*, and *T. deroepstorffi* (Table 2.13).

Table 2.12. Summary of respondent's beliefs about different species of owls in the Andaman Islands.

Beliefs of respondents	Number of responses (%)				
	O. balli (N = 49)	*O. sunia* (N = 157)	*N. affinis* (N = 64)	*N. obscura* (N = 170)	*T. deroepstorffi* (N = 181)
Positive beliefs					
Brings luck	1 (2 %)	0 (0 %)	3 (5 %)	1 (1 %)	128 (71 %)
Beneficial	8 (16 %)	2 (1 %)	6 (9 %)	12 (7 %)	7 (4 %)
Negative beliefs					
Loud vocalisations	0 (0 %)	83 (53 %)	6 (9 %)	27 (16 %)	2 (1 %)
Brings bad luck	9 (18 %)	36 (23 %)	21 (33 %)	32 (19 %)	3 (2 %)
Weird & threatening	2 (5 %)	6 (4 %)	8 (13 %)	71 (42 %)	26 (14 %)
Neutral beliefs					
Does not disturb me	12 (24 %)	20 (13 %)	2 (3 %)	11 (6 %)	6 (3 %)
Not aware of folklore	17 (35 %)	10 (6 %)	18 (28 %)	16 (9 %)	9 (5 %)

Table 2.13. Demographic factors influencing the perception of people about owls in Andaman Islands.

Genus	Predictors	Estimate	S.E	z-Value	p-value
Otus (N=175)	Intercept	-24.36	13.330	-0.018	0.9854
	Literate	1.736	0.5045	3.442	0.0005
	Age	0.1257	0.06074	2.069	0.0385
Ninox (N=153)	Intercept	0.81476	1.60346	0.508	0.6114
	Temporary houses	1.57301	0.7569	2.078	0.0377
Tyto (N=181)	Intercept	1.46234	2.188925	0.668	0.5040
	Revenue village	1.904166	0.498304	3.821	0.0001

2.4. DISCUSSION

Richness, abundance, and distribution of owls

This is the first-ever study exploring the influence of environmental variables on the distribution and abundance of owls on the Andaman Islands, and it has provided baseline data on five owl species. The distribution of the five species varied across the survey area. *O. sunia* and *N. obscura* showed the highest relative abundance, and the endemic species, including *O. balli*, *N. affinis*, and *T. deroepstorffi*, were relatively uncommon to rare. The abundance of *O. sunia* and *N. obscura* did not show any strong patterns in response to land use and land cover types and logging intensity, whereas *O. balli* and *N. affinis* were relatively abundant in evergreen forests, deciduous forests and relatively unlogged habitat. Mean understorey height, mean grass cover and mean tree height positively influenced the species richness and abundance of owls.

The distribution of *O. sunia*, *N. affinis*, *O. balli*, *T. deroepstorffi*, and *N. obscura* was known from south Andaman (Rasmussen & Anderton, 2005; Grimmett et al., 2013) but the present records of all five species are from a much wider range of these islands. The owls persist in remnant patches of native forest despite ongoing conversion of natural forests through natural calamities (tsunami) and anthropogenic activities. The overall abundance of owls in the Andamans was relatively lower (2.09 ± 1.69 owls/point) than in the Western Ghats (2.48 owls/point) (Babu, 2011). In contrast in terms of species abundance, the abundance of *O. sunia* and *N. obscura* in the Andamans was higher than that found in other ecoregions of India and other countries for other Scops Owls and Hawk Owls (Appendix 2.3). This can possibly be attributed to the low species richness of owls, relatively homogeneous habitat configuration and narrow microclimatic and altitudinal (0-700m) gradients in the Andamans.

Differential species richness and abundance of owls across land use and land cover types in the Andamans could be due to interspecific competition (Peterson & Robins, 2003; Wiens et al., 2014), variation in micro-climatic conditions (North et al., 2017), availability and accessibility to prey (Šálek & Lovy, 2012; Apolloni et al., 2017), and availability of potential nesting and roosting substratum (Martínez & Zuberogoitia, 2004). Although the Andaman deciduous forests are only 1,131.2 km^2 in extent (Reddy et al., 2016), these are most likely providing refuge for the endemic and threatened owls, as suggested by the higher species richness and abundance of owls there. The spaced tree assemblage (tree density = 946 trees/ha; basal area = 28.60 m/ha in deciduous; tree density = 1,137 trees/ha and basal area = 44.28 m/ha in evergreen forests, Padalia et al., 2004), dense understorey cover including bamboo groves, thick mid-storey of canes and the high abundance of primary cavity nesters (woodpeckers) in deciduous forests (Santharam, 2003) all offered the greatest opportunities for owls to settle and breed (though not significantly higher than other habitats). Species such as hawk-owls require canopy gaps to hunt actively whereas scops-owls exploit dense bamboo and cane cover in the Andamans, as also reported in the Western Ghats (Babu, 2011). Avoidance by owls of plantations, especially of Coconut *Cocus nucifera*, Areca *Areca catechu*, and Banana *Musa* spp., could be due to the lack of suitable nest sites, as seen with other cavity-nesting birds in the Himalayas (Kumar et al., 2014).

The impact of timber extraction, both in natural forests and forestry plantation, on cavity-nesting birds has been evaluated globally (Forsman et al., 1984; Zarnowitz & Manuwal, 1985; Sallabanks et al., 2000; Lee et al., 2013). Principally, such studies support the fact that logging in natural forests has a negative impact on habitat selection by owls (Doak, 1989; Kavanagh & Bamkin, 1995) and other cavity-nesting birds (Kumar et al., 2014). The greater abundance and diversity of owls in unlogged sites indicate that all species either partly or fully exploit relatively undisturbed and unlogged patches in the Andaman Islands. In contrast, two eurytopic species, the *O. sunia* and *N. obscura*, were relatively abundant in paddy dominated fields. Although the *N. affinis* is a stenotopic owl, it made partial use of logged sites: its association with logged sites may be transitory and requires further survey. My findings emphasise the necessity of strategies and planning to conserve unlogged natural forest patches within the Andaman Islands, to protect and retain the threatened and endemic owl species.

I identified three habitat covariates (understorey height, tree height and grass cover) related with vegetation cover and height that are most likely to determine the species richness and abundance of owls in the Andaman Islands. Species richness and abundance were probably higher in sites where understorey cover is dominated by bamboo groves. My findings support an earlier study that has been conducted on other owls in temperate forests (e.g., the Rufous-legged Owl *Strix rufipes* Martinez & Jaksic, 1996; Ibarra et al., 2014). The bamboo cover provides shelter for roosting and foraging ground for two species of scops-owls and the canopy gaps created by bamboo provides a foraging niche for two hawk-owls (Babu, 2011). Furthermore, the bamboo groves in deciduous habitats are again a critical habitat for most owl species in Andaman. Understorey height, tree height and grass cover constitute key structural characteristics that are probably associated with the roosting and foraging requirements of owls.

Flight initiation distance and Flush response

In 63% of the observations, owls were flushed out from their roost sites when humans approached. Several factors such as the predator's approaching direction, speed and mode have been reported to influence flush response in birds (Spaul & Heath, 2017). Though I did not test the effect of different approaching methods on the FR of owls, Grubb & King, (1991) reported that birds perceive a higher threat from humans on foot than any other mode of approach. This observation also corroborated with Holmes et al., (1993) where grassland raptors in Colorado were reported to be flushed out more frequently in response to human on foot (97%) than vehicular ones (38%).

The average FID of all three species in the Andamans (Table 2.9) was very low compared to the Mexican Spotted Owl (≥24 m) (*Strix occidentalis lucida*; Swarthout & Steidl, 2001), and this might be due to the availability of potential refuge sites and the size of the owl. The FID of Mexican spotted owls was studied in open canyons that have limited refuge sites in the vicinity of roosts. In contrast, the availability of refuge sites in Andaman around the roosting sites of three owls were higher. The Mexican spotted owls are relatively larger (wing span 302–328 mm) compared with the study species *O. balli* (wing span 133–143 mm), *O. sunia* (wing span 137–145 mm) and *N. obscura* (wing span 197–220 mm) (König et al., 1999).

The FID and FR was found to be species specific, which corroborated with other studies (Burger & Gochfeld, 1998; Blumstein et al., 2003; Braimoh et al., 2018). Previous studies demonstrated species-specific responses that are driven by several factors such as previous exposure to humans (Sproat et al., 2020), individual experiences (Martín & López, 2015), hunting pressure (Stankowich, 2008; Sproat et al., 2020) and life history strategies (Bennett & Owens, 2002). In this study, *N. obscura* showed a higher FR and FID compared to the other two species. Possible explanations for a higher FR and FID in *N. obscura* could be its larger body size and dark plumage, as well as the poaching pressure due to the negative attitude of people on the islands. Among the three species, the body size of *N. obscura* is relatively larger. It has been widely recognized that body size is an important factor to elicit higher FRs in many organisms (Gotanda et al., 2009). The darker plumage of *N. obscura* also attracts more attention from humans as it is more visible against the green surroundings of its habitat, which could result in a higher FR. Similarly, Holmes et al., (1993) observed higher FRs and FIDs in the dark morphs of Rough-legged Hawks *Buteo lagopus* and Ferruginous Hawks *Buteo regalis* than in light morph birds. My data on perceptions about owls among the residents of the Andamans revealed that *N. obscura* and *O. sunia* are highly susceptible to being poached on the basis of various myths and superstitious beliefs that surround these species (Sureshmarimuthu et al., 2021). On the islands, *O. balli* occupies undisturbed evergreen forest stands leading to minimal interactions with human and hence it showed a lower FID in this study. This observation corroborated with the results of a study on the FID of *Capercaillie Tetrao urogallus* in central Europe (Thiel et al., 2007), where a low hunting pressure and the occupancy of an undisturbed habitat by the species had been found to reduce its FID.

The count of climbers, presence of thorny vegetation and status of the branch (whether they were dead or live) influenced the FR of *N. obscura* (Table 2.10) while the count of climbers, roost height and temperature influenced its FID (Table 2.11). Higher number of climbers in a roost tree could influence the FR & FID in two ways; first, climbers on the roost tree may provide better concealment by increasing vegetative complexity around the roosting substratum, thus providing good hiding spots from predators. Secondly, dense climbers around the roost site may provide a more favourable microclimate by breaking down hot gusts of wind and providing insulation against the diurnal heat (Walsberg, 1985). The presence of spines in the roost branch decreased the FR nearly fivefold (Table 2.10) because spines could physically impede predators from reaching the roosting owl. The positive association of atmospheric temperature with species' FIDs implies that an increase in temperature increases the FID and it is also evident that *N. obscura* initiated flight quickly in response to the approaching predator when the temperature of roost site was unbearable (Table 2.11). An experimental study on the captive Mexican Spotted Owls found that the birds-initiated flight swiftly when temperature was higher (Ganey et al., 1993). At higher temperatures, an owl could be in heat-related stress.

Unlike *N. obscura*, the FR and FIDs of the two sympatric Otus species were largely determined by the species' behavioural mechanisms rather than their selection of roosting microhabitats. The pairing and camouflage behaviour influenced the FR of both species. Pair status negatively influenced the FR of both Otus species. Owls roosting solitarily were flushed out faster in response to an approaching human than those roosted in pair. The reason for a lower FR while in pair is to increase their reproductive fitness. In such cases, such birds use camouflage as a defensive behaviour to avoid detection and secure breeding opportunities.

In this study, the camouflage mechanisms of species were identified as a possible influencing factor in the FR of *O. balli* and *O. sunia* but their relationship was opposite. Camouflage behaviour might work in two different ways for the two owl species. When a predator approaches, usually prey species would move immediately to a safer place, whereas a cryptic species like owls is flushed out slowly (Hemmingsen, 1951). Their late department is an unusual response that is expected to scare and startle the predator, which is termed close-quadrat effect (Nishiumi & Mori, 2015). Another advantage of using camouflage behaviour prior to a FR is to maximize energy by freezing before initiating an energy-intensive escape flight (Samia et al., 2016). In *O. sunia*, individuals showing camouflage behaviour are likely to be flushed out more than individuals not showing any response to the approaching human. In this study, habituation might be an important reason for the observed responses from *O. sunia*.

Roost height influenced the FID of *O. balli* and *N. obscura*. In both species, roost height was negatively associated with their FID, which could be due to the decrease in predation risk at a higher roost (Tables 2.10 & 2.11). A similar relationship has also been reported in other raptors (Holmes et al., 1993; Steidl & Anthony, 1996). Higher perches afford greater visibility of approaching disturbances, which has been shown to increase the FR rate and FID of Bald Eagles *Haliaeetus leucocephalus* (Steidl & Antony, 1996). In Utah and Arizona, the female Mexican Spotted Owls that nested at higher locations changed their activity budgets in response to hikers more so than females that nested at lower locations (Swarthout, 1999). Higher perches are considered safer and are also likely to facilitate the display of aggression to other group members (Portugal et al., 2017).

Both the FID and FR of *N. obscura* are negatively influenced by the count of climbers, and in particular, canes. Therefore, the extraction of canes on the islands may affect the roosting habitat and behaviour of this species compared to other two Otus species.

People's perception about owls

Residents of North Andaman are familiar with owls but most of them could not identify all species in the area. This may be due to the nocturnal habits and skulking nature of owls. Owls common in and around human habitation were correctly identified by most respondents using size and calls of these owls, in particular the *Tyto deroepstroffi* (Figure 2.6). Most of them are aware of the ecological role played by owls, *i.e.*, control of rodents and insects in agriculture fields. A majority of respondents worship the *T. deroepstorffi*, in the belief that it brings wealth to the family. However, owls in other genus (Otus and Ninox) are being killed or chased away by locals under the superstition that they bring illness/bad luck.

In general, people show more interest towards a bird species that has high aesthetic values (colourful plumage), large body size and unique behaviours (including calls) and hence, they give more attention to those species and show keener interest to classify them using specific local names (Berlin, 1992; Johannes, 1993). Although all respondents knew of the presence of owls on their lands by referring to them using the common name 'ullu', they were not able to correctly distinguish all the five species. It is well known that the local community may use a single name to refer a group of animals if they are not attractive to them (Fleck et al., 2002). However, a majority of people could identify at least three genera present on the Andaman Islands (Figure 2.6) by their sizes. Since there are more than one species in two genera (Otus and Ninox), islanders found it difficult to distinguish species of similar size. This is because most respondents are from mainland India and Burma. Hence, they could better identify widespread species such as the Barn Owl (*Tyto alba*), Oriental Scops Owl (*Otus sunia*), and Brown Hawk Owl (*Ninox scutulata*) (whose call resembles that of the *N. obscura*) than endemic species such as the *O. balli* and *N. affinis*.

Birds are better appreciated than reptiles and amphibians (Czech & Krausman, 2001) but my results indicate that this statement cannot used as a thumb rule for owls. The perceptions of people regarding the importance and conservation of owls in the Andaman Islands are likely to depend on their cultural beliefs. People rank species based on the cultural knowledge about the species (Moral & Camacaro, 2011). This could be the reason for the higher appreciation of the *T. deroepstorffi* by locals when compared to other species in the vicinity, because Barn Owls are culturally believed to be the vehicle of goddess Laxmi, as per Hindu mythology (Srivastava, 1987). Studies suggest that unpopular and wild species receive negative attitudes from people (Bjerke et al., 2003; Røskaft et al., 2003; Lindemann-Matthies, 2005; Ceriaco, 2012; Almeida, 2014; Alves et al., 2014). Our study on population assessment of owls in Andaman (Babu et al., 2019) revealed that *O. sunia* and *N. obscura* are highly abundant and found in wide array of habitats whereas *N. affinis* and *O. balli* were uncommon and found in specific habitats. Even though the people had higher exposure to two generalist and abundant species, they were more negative towards them. This is clear that whether the species is either popular or wild, folklore and superstitious belief play a major role in their acceptance. Barn Owls are celebrated in the ‘Laxmi Puja’ festival while other species are considered as bad omen and have lower conservation values. By contrast, a study in mainland India (Santhanakrishnan et al., 2012) found that 69% of respondents have negative beliefs about Barn Owls *Tyto alba*. Higher neutral values for *O. balli* and *N. affinis* are due to their fewer interactions with humans since both species are found to be habitat specialists and forest dwellers (Babu et al., 2019).

Though differential responses were received from the people of North Andaman Island about different species of owls, three predictors were found to contribute more to their perception. Literate and older people living in temporary houses showed positive response towards these species. It is not surprising that literacy level influenced the perception positively (Heinen, 1993; Fiallo & Jacobson, 1995; Infield, 1988). The people who have the ability to read and write are exposed to the species profiles from media and other sources so they could understand better than those that are illiterate. Older people due their higher level of experience, knowledge and exposure to owls tend to have less belief in the folklore about species (Ceríaco, 2012). Highly appreciated *T. deroepstorffi* have positive perception from the residents of revenue villages.

APPENDIX

Appendix 2.1. Information-theoretical model selection results of the analysis of generalized linear models to explore the possible effect of habitat covariates on richness of owls in Andaman Islands.

Models rank	Intercept	Coefficient				*df*	LL	AIC	Δ AIC	w_i
		MGC	MTH	MUSC	MUSH					
1	0.3367	-	0.1258	-	0.1982	3	-176.21	358.4	0.00	0.253
2	0.3436	-	-	-	0.2453	2	-177.23	358.5	0.04	0.248
3	0.3398	0.1017	-	-	0.2497	3	-176.25	358.5	0.09	0.243
4	0.3331	0.0951	0.117	-	0.2078	4	-175.37	358.7	0.31	0.217
5	0.3534	-	0.2162	-	-	2	-179.58	363.2	4.75	0.024

Habitat descriptors are mean grass cover (MGC), mean tree height (MTH), mean understory height (MUSH). It is given the intercept and coefficients for the descriptors of the (Poisson) models, the degrees of freedom (*df*), the log-likelihoods (LL), the Akaike information criterion (AIC), the difference in AIC values from the lower value (Δ AIC), and the model weights (w_i). Only models within 5 ΔAIC are shown.

Appendix 2.2. Information-theoretical model selection results of the analysis of generalized linear models to explore the possible effect of habitat covariates on abundance of owls in Andaman Islands.

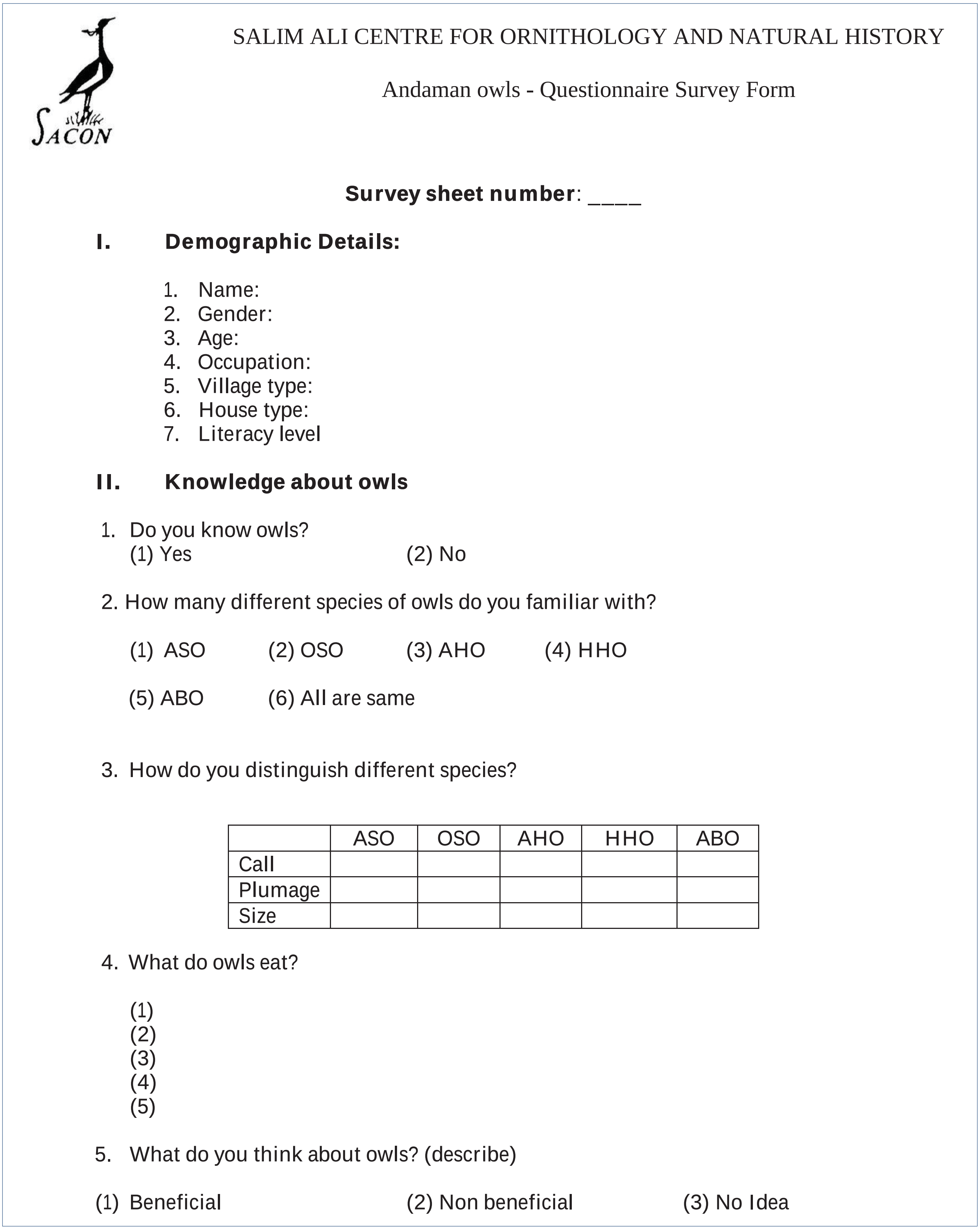
Models rank	Intercept	Coefficient				*df*	LL	AIC	ΔAIC	w_i
		MGC	MTH	MUSC	MUSH					
1	0.6562	0.1505	-	-	0.2774	3	-217.00	440.0	0.00	0.594
2	0.6536	-	0.1625	-	0.2137	3	-217.73	441.5	1.46	0.285
3	0.6651	-	-	-	0.2731	2	-220.04	444.1	4.09	0.077

Habitat descriptors are mean grass cover (MGC), mean tree height (MTH), mean understory cover (MUSC), mean understory height (MUSH). It is given the intercept and coefficients for the descriptors of the (Poisson) models, the degrees of freedom (*df*), the log-likelihoods (LL), the Akaike information criterion (AIC), the difference in AIC values from the lower value (ΔAIC), and the model weights (w_i). Only models within 5 ΔAIC are shown.

Appendix 2.3. Abundance of some owls studied in different countries.

Species	Country	Abundance	Effort	Source
Rufous-legged Owl	Chile	0.127-0.220	86kms	Martinez & Jaksic (1996)
Philippines Scops-owl	Philippines	0.83	128 points	Sanchez (2012).
Eastern Screech Owl	Iowa	0.1 0.2	106-119 sites	Geus & Bowles (1991).
Indian Scops-owl	Western Ghats, India	0.47	276 points	Babu, 2011
Oriental Scops-owl	Western Ghats, India	0.27	276 points	Babu, 2011
Brown Boobook	Western Ghats, India	0.565	276 points	Babu, 2011
Oriental Scops-owl	Andaman Islands, India	0.74	143 points	Present study
Andaman Scops-owl	Andaman Islands, India	0.34	143 points	Present study
Andaman Boobook	Andaman Islands, India	0.27	143 points	Present study
Hume’s Boobook	Andaman Islands, India	0.73	143 points	Present study

Appendix 2.4. Questionnaire Survey Form used to assess the knowledge of owls among Andaman islanders



SALIM ALI CENTRE FOR ORNITHOLOGY AND NATURAL HISTORY

Andaman owls - Questionnaire Survey Form

SACON

Survey sheet number: ____

I. Demographic Details:

1. Name:
2. Gender:
3. Age:
4. Occupation:
5. Village type:
6. House type:
7. Literacy level

II. Knowledge about owls

1. Do you know owls?
   (1) Yes (2) No

2. How many different species of owls do you familiar with?

   (1) ASO (2) OSO (3) AHO (4) HHO

   (5) ABO (6) All are same

3. How do you distinguish different species?

	ASO	OSO	AHO	HHO	ABO
Call					
Plumage					
Size					

4. What do owls eat?

   (1)
   (2)
   (3)
   (4)
   (5)

5. What do you think about owls? (describe)

(1) Beneficial (2) Non beneficial (3) No Idea

CHAPTER 3

Owl occupancy in North Andaman

Andaman Barn Owl

3.1. INTRODUCTION

We are living in an era that poses a serious challenge in reducing biodiversity loss and rate of extinction (Butchart et al., 2010) and it has been attributed to the conversion of natural resources (Dunn, 2004; Feddema et al., 2005; Geist & Lambin, 2002). Conversion of multi-faceted tropical forests into monoculture agriculture fields creates numerous patches of fragmented forests (Pickett & Thompson, 1978; Foley et al., 2005) and such patches endure tremendous anthropogenic pressures through extraction of timbers, cattle grazing, and non-wood forest products. Degraded forests are the consequences of extraction in fragmented patches and the biodiversity values in those patches are much lower than primary forests (Lawton et al., 1998). Therefore, it is important to understand the biodiversity values of remaining natural fragments/patches in highly converted primary forests. This prerequisite data from remaining patches of natural forests is much needed, for better managing patches, in biologically important eco-regions. Furthermore, understanding the effect of agriculture practices on native biodiversity is relevant today to manage the agricultural landscapes and to develop into biodiversity friendly areas (Ranganathan et al., 2008). Such assessments should be conducted at multiple scales, covering macro and micro level habitat requirement of a species, to effectively implement the conservation measures (Lawton et al., 1998).

Andaman archipelago is in the Bay of Bengal, consists of 325 islands of varied sizes and degree of isolation. It has been recognized as Endemic Bird Area by BirdLife International (2021a) for holding high percent of endemic avifauna (39 of 246 bird species). Despite its high conservation value for protecting the several endemic and threatened avifauna, a large proportion of natural forests had already been converted into agriculture fields to meet the growing food requirement of the human population (Singh, 2005). Besides agriculture activities, timber extraction had been carried out for several years and an average of 1.17 lakh cubic meter of timber per year was extracted from different forests of Andaman between 1980 and 2001 (Singh, 2005). Increasing tourism and influx of mainlander (http://www.andamanbeacon.com/andaman_tourist_inflow_yearwise.html) resulting in increase in the demand for agricultural products that might lead switching over to large-scale cropping (for example paddy fields). These processes reflected in the land use and land cover pattern between 1974 and 2014, about 134 km^2 of Moist deciduous forests are lost and about 21% forest cover of Andaman is under man-modified landscapes (includes settlement, plantations, agriculture and developments) and water bodies (Singh, 2005; Table 3.1). The deforestation rate between 2000 and 2006 was 0.78 and the annual rate of deforestation between 2006 and 2014 was 0.4 (Reddy et al., 2016). In 2002, Honourable Supreme Court of India banned the commercial extraction of timber from Andaman forests, but it permitted to extract the timber for local consumption through government owned mills. Selective logging is still practiced in the Andaman Islands to meet the local requirement.

Table 3.1. Land Use and Land Cover change in Andaman Islands between 1976 and 2014.

LULC	1976	2014	Difference
Evergreen	1710.5	1707.1	- 3.4
Semi-evergreen	1553.5	1531.6	- 21.9
Moist-deciduous	**1443.5**	**1131.2**	**- 312.3**
Mangroves	763.7	674.5	- 89.2
Plantations	68.6	102.8	34.2
Scrub	6.7	54.7	48
Grasslands	6.7	27.8	21.1
Agriculture	**163.9**	**402.5**	**238.6**
Barren land	83.5	125.9	42.4
Water	598.2	634.4	36.2
Settlement	9.2	15.5	6.3

Source: Reddy et al., 2016

Primary hole-nesters (for example woodpeckers) and obligatory hole-nesters (for example owls) are the prime victims for logging and conversion of natural forests. The distribution and habitat selection of owls would reflect the effect of agriculture practices, logging activities, and anthropogenic pressure because these species require multi-faceted habitat to attain various life history and behavioural characteristics (nesting, roosting and foraging substratum). Globally, owls are recognized as a coarse filter, indicator species and umbrella species of the ecosystem for their strong association with mature forest for nesting and foraging. Five species of owls are distributed in the Andaman Islands, four of them are endemic to this archipelago. Among four endemics, two are recognized as Near threatened by BirdLife International (2016) considering their low population size and distribution range. Being an avian top predator of the nocturnal food web, they occupy habitat that satisfies the multitude requirements and hence any assessment of their occurrence and habitat use should look at multiple spatial scales.

To meet this challenge, long-term monitoring programs are being initiated globally in the context of understanding and protecting threatened species and ecosystem. Such long-term program often practices site occupancy framework to elucidate the degree of change occurred over spatial and temporal scales (Manley et al., 2005). This paradigm works well as it considers imperfect detection of focal organisms or communities within the sampling unit (MacKenzie et al., 2006). Naïve occupancy estimates (number of sample unit occupied by the species against a total number of units covered) results in biased estimates of occupancy when the species detection probability is less than one. Corrected occupancy values are estimated by incorporating the detection probability into account (MacKenzie et al., 2006). To estimate the detection probability within the sampling unit, several repeated surveys of the species need to be conducted and it can be either spatial (several subunits, points, transects and devices within sampling unit) or temporal (repeated surveys at periodic intervals) (Nichols et al., 2008; Rota et al., 2009; Hines et al., 2010; Pavlacky et al., 2012). Temporal sampling is a challenging and impractical task when the study covers large landmass with the limited budget and manpower. Thus, spatially replicated surveys are advantageous and easy to cover the sampling units in the above circumstances. However, one issue with spatially replicated surveys is that it may violate the closure assumption of occupancy framework under some sampling design. And it is thought to occur when sampling unit is occupied but the chance of detecting species in other subsets of the units is low and it estimates low biased detection probability and high biased occupancy estimates (Kendall & White, 2009). To overcome this bias, design, and model-based methodologies such as subunits with replacement (Kendall & White, 2009), robust design parameterization (Rota et al., 2009) and detection and availability probabilities (Hines et al., 2010) are applied to reduce the bias in detection probability and occupancy.

To increase accuracy over true absences or non-detection in the presence-absence sampling design, multi-detection methods are widely used for large-scale monitoring (Nichols et al., 2008). For example, chance of detecting floaters using call playback method is negligible because they hardly respond to the call playback of conspecific calls that result in biased estimates of detection probability. Similarly, non-breeding individuals/adults hardly respond to call playback calls and spotlight searches. For these species, listening to spontaneous calls may increase the detectability of the species. Hence, it warrants multi-detection methods to chart out the presence and absence of owls in a survey station or sampling unit during the sampling.

In this context, the factors influencing the occupancy of owls at multiple scales (large and small scales) using multi-scale occupancy model was assessed here. Within the broad aim, also assessed: 1) the effect of covariates (both site and spatial covariates) in detecting (p), small-scale occupancy and large-scale occupancy of owls in Andaman, and 2) effect of agriculture fields on stenotopic and eurytopic species of owls in North Andaman.

3.2. METHODS

3.2.1. Intensive study area

North Andaman Island (*i.e.*, north of Austin strait) was selected for the intensive study (Figure 3.1). The topography of North Andaman is slightly undulating terrain with a maximum elevation of 760 m ASL at Saddle Peak, the highest peak for entire Andaman and Nicobar archipelago. It receives both south-west and north-east monsoon and mean annual rainfall is 3100 mm. The weather of these islands is tropical, and the maximum temperature reaches (32.0°C) during March-April and minimum (21.0°C) during December-January. Habitat primarily consists of evergreen and deciduous forests interspersed with altered agriculture fields and human settlements (Table 3.2; Figure 3.1). Narrow strips of littoral forests along the coasts and mangroves within creeks and river estuaries are formed. Nearly 60-70 km^2 area is under the agriculture mostly paddy cultivated and hence North Andaman is locally coined as the granary of Andaman Islands. In addition to habitat alteration for agriculture, selective logging was in practice till 2002 but now trees have selectively been logged for local consumption through government owned mills.

Table 3.2. Extent of LULC types in North Andaman Island

Sl. No.	Land use and Landcover types	Area (km^2)
1.	Evergreen forests	349.58
2.	Moist Deciduous Forests	485.07
3.	Dry Deciduous Forests	134.64
4.	Mangrove (Live)	168.82
5.	Mangrove (Degraded)	45.14
6.	Barren Land	60.33
7.	Agriculture fields+ Human settlement	62.76
8.	Water Body	21.23

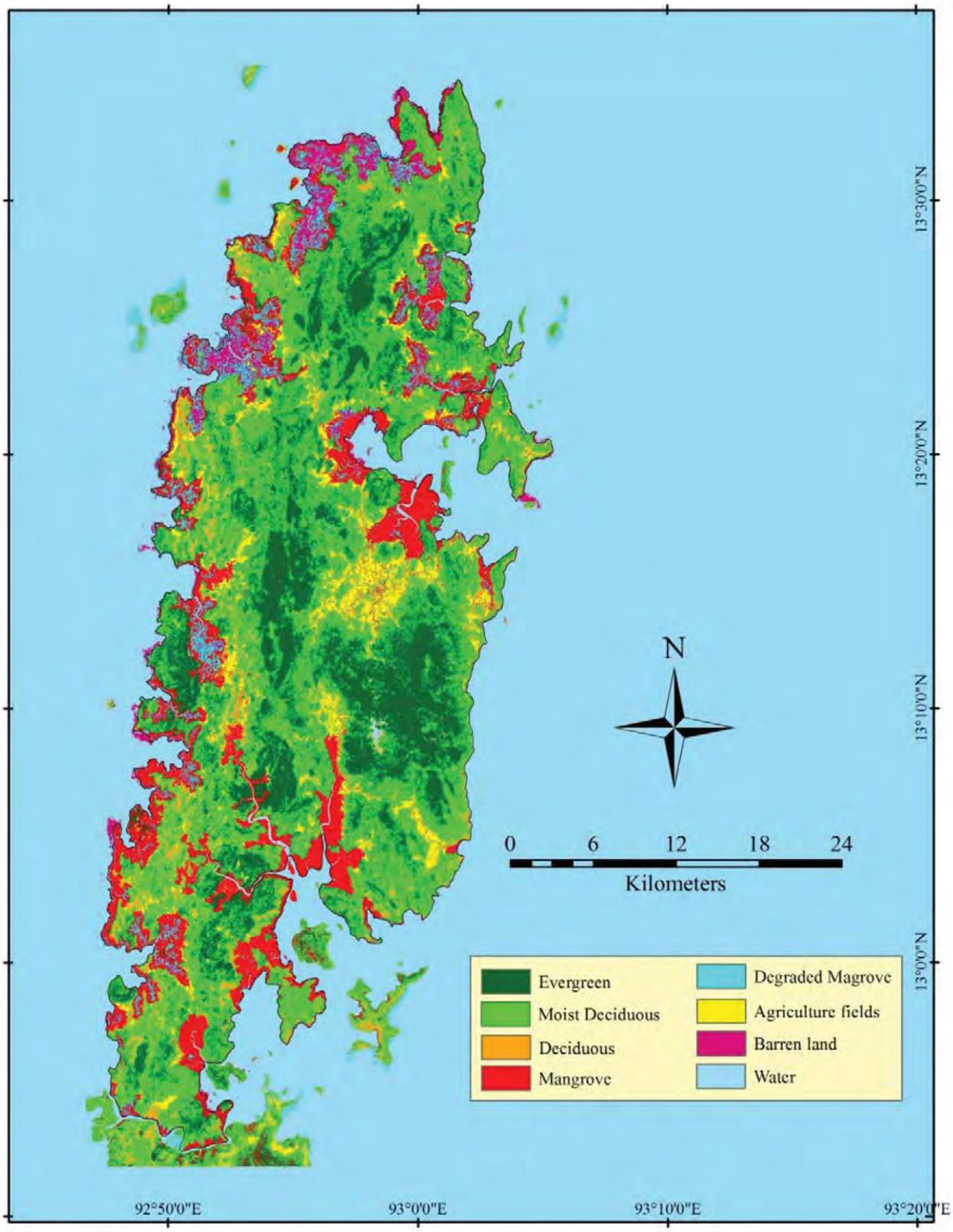


Figure 3.1. Landcover map of North Andaman

3.2.2. Sampling design

Owls are nocturnal in nature and hence, traditional point count surveys (Bibby et al.,1992) may bias the detection and so the occupancy. Owls may go undetected for numerous reasons (for example: Conspicuous, moon status, rain, heavy wind, the presence of river, noise from human habitation and breeding season), which are seldom accounted in owl population estimation (MacKenzie et al., 2006; Zuberogoitia et al., 2011). The bias in the detection may affect the occupancy estimation (otherwise “naïve occupancy”) when it is less than one. Therefore, an estimate of detection probability (p) is included as a function of the occupancy and to derive unbiased estimates of occupancy (MacKenzie et al., 2006).

Hierarchical multi-scale sampling strategy (Rota et al., 2009; Pavlacky et al., 2012; Baumgardt et al., 2014) was adopted to estimate large-scale (sampling unit level) and small-scale (survey station level) occupancy. Spatial grids were considered as sampling unit because it is better represented than other physical features such as ponds and vegetation patches (MacKenzie et al., 2006; Pavlacky et al., 2012). In this context, spatial grid cells of 4 km^2 (2 km × 2 km) were demarcated as basic sampling unit and it was generated over the North Andaman Island using spatial analysis tools (Hawkths Tool and Spatial Ecologist). The grids that fall more than 60% within North Andaman boundary were alone considered for sampling and remaining grids were excluded from sampling design (Figure 3.2). In a short time, it was impractical to cover all the grids in North Andaman and thus, systematic random sampling design was followed to select N sample units over all grids. Following the framework of systematic random sampling, an alternate grid was selected and thereby 50% of North Andaman Islands were chosen to elucidate the habitat use pattern of owls. The N sample units were subsampled by four equal sub-units (R) of 1 km^2 to determine the detection and non-detection of owls. In each sub-unit, one owl point count was conducted following three census protocols (K sessions)– Initial Quiet Listening, call playback of conspecific calls and spotlight searches (for details please see the chapter 2 in *Owl sampling protocol*; page-28) - and thereby three sessions (K) in each sub-units and four survey stations (R) for a sampling unit (N). Twelve detection histories (K × R) for each sub-unit were generated. In addition to this, sampling and site covariates were measured which may influence the detection probability and occupancy at large and small-scale.

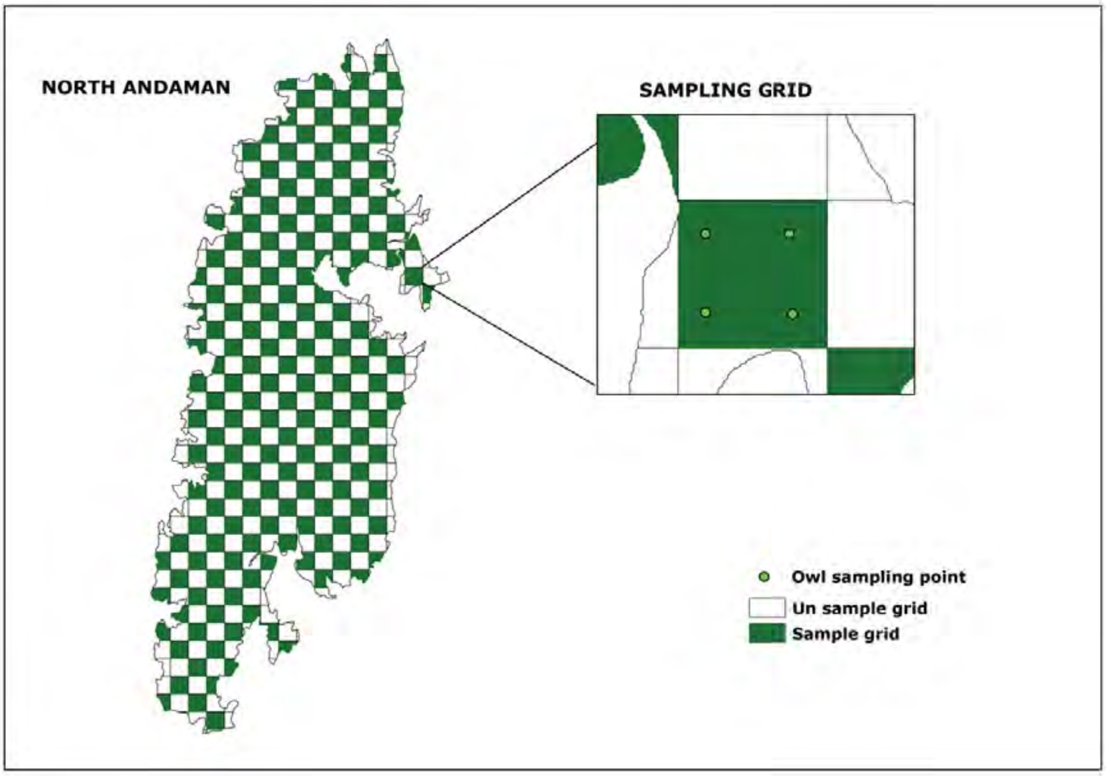


Figure 3.2. Sampling design for multi-scale occupancy estimation of owls in North Andaman

3.2.3. Habitat covariates

3.2.3.1. Sampling covariates

Covariates that can influence the owl activity (such as atmospheric temperature and humidity) and vocal communication (such as wind speed and atmospheric noise) of owls during the sampling (K sessions) were quantified to estimated corrected estimates of detection probability. The hygro-thermometer (HTC 288-CTH) was used to measure the temperature and humidity. Anemometer (Lutron AM-4201) and sound level meter (Lutron SL-4001) were used to measure the wind speed and noise respectively. Since sampling was done only during the non-rainy days, rainfall was not included in the model.

3.2.3.2. Small-scale covariates

Habitat covariates are physical variables (for example tree stand structural characteristics), which might influence the life history characteristics of owls and hence it is expected to affect the occupancy of a species at sampling unit level (Ψ) or at survey station level (θ) as well. Site covariates were measured at two scales: micro and macro scale. Prior to owl survey, nearly two hours before dusk, habitat covariates at micro scale were measured in all survey station (θ) using Point Centered Quarter method (Mueller-Dombois & Ellenberg, 1979). PCQ is the most used distance sampling method for the estimation of plant communities, in particular, the forest plant communities (Mueller-Dombois & Ellenberg, 1974). At each survey station, four PCQ points were fixed in four cardinal directions (90°) at 20 m from the point. Each PCQ point was divided into four equal quarters. Within each quarter, the nearest tree with more than 20 cm Girth at Breast Height (GBH) was selected and distance to survey station was measured (Figure 3.3). Subsequently, in other three quarters, distance to nearest trees was measured to calculate inter-tree distances (Surrogate of tree density). A minimum of four PCQ points per survey station and thus, 16 PCQ points per sampling unit were taken. In this way, 64 trees were sampled to measure habitat covariates at sampling unit level and 16 trees at survey station level.

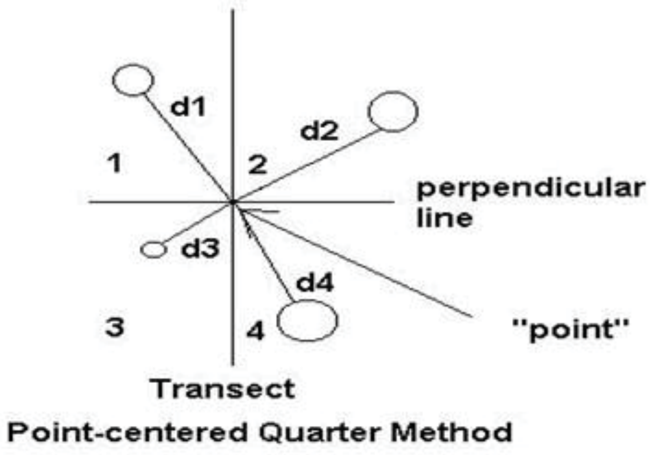


Figure 3.3. Representation of Point Centered Quarter (PCQ) method

3.2.3.3. large-scale

While filed visits adequate ground truth points were collected for each Landuse and Landcover (LULC) types using GARMIN GPS 10 in North Andaman and the same was used to classify the LULC types. Cloud free NRSC-LISS IV satellite images (Scene path and row no. 114-064 B & D and date of imaging: 08th April 2015) was used for LULC map preparation. Supervised classification method was applied to extract LULC types and thereby eight LULC types were classified *viz.*, evergreen, dry deciduous, moist deciduous, mangrove (live and degraded mangroves separately), barren land, agriculture fields + human habitation and water body, which may influence the occupancy of owls at sampling unit scale. The composition and configuration of each LULC types within the sampling unit were extracted. In addition to LULC types, Normalized Difference Vegetation Index (NDVI) maps from the same image for each sampling unit was calculated. The mean NDVI and Coefficient of variation of NDVI for each sampled grid was also calculated as an index of heterogeneity in canopy cover. NDVI maps were extracted following standard protocols used for LISS IV images of NRSC. Mean and coefficient of variation of elevation within the grid (a surrogate of the ruggedness of the terrain) was extracted from the SRTM-DEM images.

Table 3.3. Summary of hypothesized relationship of owls with covariates in detection probability, small-scale (θ) and large-scale occupancy (Ψ). Positive (+) and negative (-) sign shows positive and negative influence on habitat use of owls and "0" indicates no influence

HABITAT COVARIATES	**ABBR.**	**ABO**	**ASO**	**AHO**	**HHO**	**METHOD OF QUANTIFICATION**
DETECTION PROBABILITY (*P*)						
Atmospheric temperature	Temp	0	+	+	+	Hygro-thermometer
Atmospheric humidity	Humi	0	+	+	+	
Wind speed	Wind	0	-	-	-	Anemometer
Noise level	Noise	0	-	-	-	Sound level meter
SMALL-SCALE OCCUPANCY (θ)						
Mean inter-tree distance (m)	Md	-	-	-	-	Point centred quarter method (pcq)
Mean tree height (m)	Th	+	+	+	+	
Mean gbh (cm)	Gbh	+	+	-	-	
Mean canopy cover (%)	Cc	0	+	-	-	
Number dead stumps (count)	Ds	+	+	0	0	
Mean understory height (m)	Ush	-	+	-	-	
Mean understory cover (%)	Usc	-	+	-	-	
Cv_understory height (%)	Cvush	0	-	+	+	PCQ - measure of heterogeneity
Cv_understory cover (%)	Cvusc	0	-	+	+	
Cv_gbh (%)	Cvgbh	+	-	+	+	
Cv_tree height (%)	Cvth	+	-	+	+	
Cv_canopy cover (%)	Cvcc	0	-	+	+	
LARGE-SCALE OCCUPANCY (ψ) (sq.km)						
ELEVATION (M)	Ele	0	+	+	0	GPS - garmin
Proportion of agriculture fields	Ag	+	-	-	+	Data obtained from NRSC, hyderabad
Proportion of dry deciduous	Ddf	+	-	+	+	
Proportion of moist deciduous	Mdf	-	+	+	+	
Proportion of evergreen	Eg	+	+	-	+	
Proportion of mangrove	Man	0	-	-	-	
Proportion of degraded mangrove	Dm	+	-	+	+	
Proportion of barren	Bar	+	-	-	-	
Proportion of water	Wat	0	-	-	-	

CV=Coefficient of variation (mean/standard deviation*100); ABO – Andaman Barn owl, ASO – Andaman Scops Owl, AHO – Andaman Hawk Owl, HHO – Hume's Hawk Owl

3.2.4. Statistical Analysis

3.2.4.1. Hypothesis on owls

Among five owl species, four are small bodied – Oriental Scops Owl (*O. sunia*), Andaman Scops Owl (*O. balli*), Andaman Hawk Owl (*N. affinis*) and Hume's Hawk Owl (*N. obscura*) (Table 1.1) and one is moderate bodied owl – Andaman Barn Owl (*T. deroepstorffi*). Owe to high detection and it is present in almost all sampling unit, *O. sunia* excluded from the analysis. *O. sunia* and *N. obscura* exploited all available habitats including human habitation in North Andaman (as discussed in chapter 2) and thus, they were categorized as eurytopic species. *N. affinis* and *O. balli* were recorded frequently from deciduous and evergreen forests of North Andaman so these two species were categorized as stenotopic species.

Based on the field observation and preliminary analysis, it is hypothesized that *O. balli* is expected to use sampling unit, which is having a greater proportion of evergreen forests/moist deciduous forests. At survey station level, it is expected to occupy station that has mature tree stands (expressed in terms of higher tree height, GBH, and canopy cover and low inter-tree distance) with high understory cover and away from anthropogenic pressures (Human settlement and agriculture fields). *N. affinis* is expected to occupy sampling unit that has a greater proportion of deciduous forests, away from human habitation and agriculture fields. At survey station level, it is likely to occupy the stations that are characterized by high inter-tree distance, CV_tree height and GBH, and low canopy cover and understory coverage. Furthermore, it is also expected to avoid human habitation and agriculture fields. The hawking nature of the species might require clear mid-stratum, which might be reflected in CV_tree height and Understory Height.

N. obscura is expected to occupy sampling units that have a large extent of agricultural fields with a small proportion of natural forests. At survey station level, it may occupy sites with low stand characteristics and close to human habitations. *N. obscura* is probably occupying sampling units, which have a higher proportion of agriculture fields and a lower proportion of evergreen forests, and close to human habitation. At sampling station level, it is likely to occupy stations that have higher tree height and canopy cover.

3.2.4.2. Multi-scale occupancy estimation

It allows estimating the occupancy at two scales: gird (large-scales Ψ) and sub-unit (small-scales θ). Three parameters are estimated in multi-scale occupancy *viz.*, detection probability (estimated based on three survey methods - initial quiet listening, call playback and spotlight searches- within each sub-unit), small-scale occupancy (estimated at survey station or sub-unit level- here 1 km^2); large-scale occupancy (estimated at grid or sampling unit level- 4 km^2 grid). the multi-scale occupancy models generated using program *Mark v. 8.2*.

The following are the assumptions of multi-scale occupancy model (Nichols et al., 2008; Pavlacky et al., 2012; Hagen et al., 2016)

1) “No un-modelled heterogeneity in the probabilities of detection and occupancy”

2) “Each survey station is closed to changes in occupancy over the sampling period”

3) “The detection of species at each survey station is independent and”

4) “The target species are never falsely detected”

Firstly, created a detection history from three survey methods for a survey station and here each method was considered as a replicate. In this way, three replicates in a survey station and 12 replicates (3 methods × 4 survey stations) for a grid. The present design may not fulfil one of the assumptions of occupancy estimation that detections at a station are independent of each other and it is independent of first detection. To overcome this issue, I used removal design for estimating the detection probability (Pavlacky et al., 2012). In this design, the first detection of an owl at a station was considered to construct detection history and rest of the methods was constructed as missing value when the species was detected in the first method. So, the detection probability was maintained constant among the occasions and included sampling covariates for all occasions instead of for unique detection probabilities.

3.2.4.3. Model selection and parameter estimation

The information-theoretic method was used to select the most parsimonious models among a set of candidate models, and it measures the relative loss of information from the parsimonious model and subsequent candidate models (Burnham & Anderson, 2002). Akaike’s Information Criterion adjusted for small sample size (AICc) was used to rank the model. Model weight (*wi* = AICc model weight of ith model) was measured to evaluate the strength of evidence. The evidence ratio (*wi*/*wj*) was assessed for the predictive power of models (*wi* = parsimonious model; *wj* = any candidate model other than the parsimonious model).

Out of resulted models selected models contains less than 2 ΔAICc were selected to estimate the regression coefficient and it is believed that those models might support substantially. Model averaging and parameter estimation was carried out with models less than 2 ΔAICc (Burnham & Anderson, 2002).

3.3. RESULTS

A total of 137 sampling units surveyed to estimate large-scale and small-scale occupancy of owls in North Andaman Island. Multi-scale occupancy was estimated for four species of owls including two stenotopic endemic species (*O. balli* and *N. affinis*) and two eurytopic endemic species (*T. deroepstorffi* and *N. obscura*).

3.3.1. Andaman Scops Owl (*O. balli*)

Effect of atmospheric humidity was included in the best approximating model for estimating the detection probability (p) of *O. balli* (Table 3.4). The differences in Δ AICc values of the most parsimonious model with next two modest models were negligible. However, all these models had greater model weight (*wi*) than the constant model (or null model). This indicates that the detection of *O. balli* was affected by either weather or disturbance factors (such as atmospheric noise and wind speed) during the sampling. Thus, all subsequent models to estimate small-scale and large-scale occupancy were carried out with humidity as a function of detection probability. Humidity positively influenced the detection of *O. balli* (β = 0.5515491; SE = 0.1467; 90% CI: 0.2639715 to 0.83912).

Eleven competitive models were constructed based on a set of a priori hypothesis explaining the small-scale occupancy of *O. balli*. The best parsimonious model included the effect of USC (%), MD (m) and CVCC (%). Three models subsequent (less than 2 Δ AICc) to the top model included the effects of USC and MD to estimate the θ. Along with USC and MD, the effect of GBH, CC and TH has also included the top four models, which had less than 2 ΔAICc. The evidence ratio indicated that the top model (*wi* = 0.21305) was ~1 time more reasonable than the second top model (*wi* = 0.17759) and ~52 times better than the constant model (Table 3.4). USC (β=0.345088; SE=0.17015; CI=0.0115915 to 0.6785857) positively influenced small-scale occupancy while CVCC (β= -0.0216349; SE= 0.1715436; CI= -0.3578602 to 0.3145905) and MD (β= -0.2833601; SE=0.1845242; CI= -0.6450275 to 0.0783073) negatively influenced.

None of the high ranked model (ΔAIC ≥2) showed high AIC model weight, thus model averaging of small-scale occupancy and standard error was calculated. Summed model weights showed that both USC and MD had a higher effect on the small-scale occupancy of *O. balli*.

Table 3.4. Summary of models developed to understand the factors influencing the detection probability (a), small-scale (b) and large-scale occupancy (c) of *O. balli* and each model's AICc values, delta AICc and AICc model weight

Model	AICc	ΔAICc	AICc *wi*	Model likelihood	K
(a) Detection probability (p)					
Ψ (.) θ (.) *p* (Humi)	781.8105	0.0000	0.33335	1.0000	4
Ψ (.) θ (.) *p* (Noise)	781.8118	0.0013	0.33314	0.9994	4
Ψ (.) θ (.) *p* (Wind)	781.8145	0.0040	0.33269	0.9980	4
Ψ (.) θ (.) *p* (.)	793.8156	12.0051	0.00082	0.0025	3
(b) Small-scale occupancy (θ)					
Ψ (.) θ (USC+MD+CVCC) *p* (Humi)	781.3134	0.0000	0.21305	1.0000	7
Ψ (.) θ (USC+MD+GBH) *p* (Humi)	781.6775	0.3641	0.17759	0.8336	7
Ψ (.) θ (USC+MD+CC+CVCC) *p* (Humi)	782.5222	1.2088	0.11641	0.5464	8
Ψ (.) θ (USC+MD+HT) *p* (Humi)	782.7925	1.4791	0.10169	0.4773	7
Ψ (.) θ (CLIM+MD+GBH) *p* (Humi)	783.3619	2.0485	0.07650	0.3591	7
Ψ (.) θ (USC+MD) *p* (Humi)	783.4629	2.1495	0.07273	0.3414	6
Ψ (.) θ (USC+MD+CC+GBH) *p* (Humi)	783.6302	2.3168	0.06689	0.3140	8
Ψ (.) θ (USC+MD+CVGBH) *p* (Humi)	783.6389	2.3255	0.06660	0.3126	7
Ψ (.) θ (USC+MD+CC) *p* (Humi)	784.4045	3.0911	0.04542	0.2132	7
Ψ (.) θ (USC+MD+CC+TH) *p* (Humi)	784.8293	3.5159	0.03673	0.1724	8
Ψ (.) θ (USC+MD+GBH) *p* (Humi)	785.5219	4.2085	0.02519	0.1219	7
Ψ (.) θ (.) *p* (Humi)	793.8153	12.5022	0.0041	0.0019	3
(c) Large-scale occupancy (Ψ)					
Ψ (AG) θ (USC+MD+CVCC) *p* (Humi)	759.9109	0.0000	0.70272	1.0000	8
Ψ (AG+EG) θ (USC+MD+CVCC.) *p* (Humi)	761.6345	1.7236	0.29683	0.4224	9
Ψ (EG+DM) θ (USC+MD+CVCC.) *p* (Humi)	775.0076	15.0967	0.00037	0.0005	9
Ψ (EG) θ (USC+MD+CVCC.) *p* (Humi)	780.3421	20.4312	0.00003	0.0000	8
Ψ (.) θ (USC+MD+CVCC.) *p* (Humi)	781.3134	21.4025	0.00002	0.0000	7

Variables that influenced small-scale occupancy were included in all models developed for large-scale occupancy. I built five competitive models exploring large-scale occupancy of *O. balli*. Among the macrolevel covariates, AG within the sampling unit has negatively influenced the occupancy of *O. balli* with high AICc weight. The second model contained EG and AG. The evidence ratio indicated that the most approximating model was ~2.3 times more plausible than the subsequent model (Table 3.4). AG (β= -1.9148169; SE=0.6316394; CI= -3.1528302 to -0.6768037) in sampling unit was negatively influenced the occupancy.

Table 3.5. Summary of parameter estimates, standard error, lower and upper confidence levels (95%) of top models with less than 2 delta AICc for *O. balli*

Model rank	Parameter	Estimate	SE	LCL	UCL
	Naïve occupancy	0.90511			
1	**Ψ (AG) θ (USC+MD+CVCC) *p* (Humi)**				
	$\hat{\Psi}$ (AG)	0.99069	0.01207	0.89126	0.99928
	$\hat{\theta}$ (USC+MD+CVCC)	0.57737	0.0288	0.52015	0.63259
	$\hat{p}$ (Humi)	0.93394	0.01591	0.89507	0.95908
2	**Ψ (AG+EG) θ (USC+MD+CVCC) *p* (Humi)**				
	$\hat{\Psi}$ (AG+EG)	0.98848	0.01321	0.89828	0.9988
	$\hat{\theta}$ (USC+MD+CVCC)	0.58026	0.02906	0.52248	0.63592
	$\hat{p}$ (Humi)	0.93394	0.01591	0.89506	0.95908

3.3.2. Andaman Hawk Owl (*N. affinis*)

I evaluated the effect of weather (atmospheric temperature and humidity) and disturbance parameters (wind speed and noise level) in detecting *N. affinis* during sampling. Among the sampling covariates, none of them influenced detection probability (p) of *N. affinis*, which is evident from low AICc values and high model weight of constant model (Table 3.6). The constant model was ~ 2.6 times better detected the occurrence of *N. affinis* than the subsequent models with covariates. Hence, occupancy estimation was carried out with constant detection probability (Table 3.6).

Without sampling covariate 10 competitive models constructed based on *apriori* hypothesis for small-scale occupancy of *N. affinis*. The most parsimonious model was a constant model with low AICc values and high model weight (Table 3.6). The second modest model included the effect of USH. The constant model was ~1.5 times better predicted than the second top model. Besides constant model, next three models had less than 2 ΔAICc values and thus, summed model weight was calculated for all three models. It included three variables *viz.*, CC (β= -0.0627711; SE=0.1697302; CI= -0.3954424 to 0.269900), USH (β= -0.1781884;

SE=0.1592849; CI= -0.4903868 to 0.1340099) and CVGBH (β= -0.0677558; SE=0.1673566; CI= -0.3957748 to 0.2602633), and all variables negatively influenced the small-scale occupancy of *N. affinis*.

Table 3.6. Summary of models developed to understand the factors influencing the detection probability (a), small-scale (b) and large-scale occupancy (c) of *N. affinis* and each models AICc values, delta AICc and AICc model weight

Model	AICc	ΔAICc	AICc *wi*	Model likelihood	K
(a) Detection probability (p)					
Ψ (.) θ (.) *p* (.)	1124.0319	0.0000	0.23332	1.0000	3
Ψ (.) θ (.) *p* (Humi)	1125.9862	1.9543	0.08782	0.3764	4
Ψ (.) θ (.) *p* (Wind)	1125.9882	1.9563	0.08773	0.3760	4
Ψ (.) θ (.) *p* (Noise)	1125.9887	1.9568	0.08771	0.3759	4
Ψ (.) θ (.) *p* (Temp)	1126.0000	1.9681	0.08721	0.3738	4
(b) Small-scale occupancy (θ)					
Ψ (.) θ (.) *p* (.)	900.1191	0.0000	0.27481	1.0000	3
Ψ (.) θ (USH) *p* (.)	901.0122	0.8931	0.17583	0.6398	4
Ψ (.) θ (CVGBH) *p* (.)	902.0786	1.9595	0.10316	0.3754	4
Ψ (.) θ (CC) *p* (.)	902.1057	1.9866	0.10178	0.3704	4
Ψ (.) θ (USH+USC) *p* (.)	902.7185	2.5994	0.07492	0.2726	5
Ψ (.) θ (USH+CC) *p* (.)	902.9806	2.8615	0.06571	0.2391	5
Ψ (.) θ (USH+CLIM) *p* (.)	903.1204	3.0013	0.06128	0.2230	5
Ψ (.) θ (USH+CVGBH) *p* (.)	903.1506	3.0315	0.06036	0.2196	5
Ψ (.) θ (USH+ELE) *p* (.)	903.1638	3.0447	0.05996	0.2182	5
Ψ (.) θ (USH+CC+CVGBH) *p* (.)	905.1520	5.0329	0.02219	0.0807	6
(c) Large-scale occupancy (Ψ)					
Ψ (AG) θ (.) *p* (.)	887.7565	0.0000	0.29729	1.0000	4
Ψ (AG+DDF) θ (.) *p* (.)	887.8185	0.0620	0.28821	0.9695	5
Ψ (AG+EG) θ (.) *p* (.)	889.1117	1.3552	0.15097	0.5078	5
Ψ (AG+MAN) θ (.) *p* (.)	889.2921	1.5356	0.13795	0.4640	5
Ψ (AG+MDF) θ (.) *p* (.)	889.4954	1.7389	0.12462	0.4192	5
Ψ (.) θ (.) *p* (.)	900.1191	12.3626	0.00061	0.0021	5

Six competitive models were built to identify the factors influencing large-scale occupancy of *N. affinis*. The most parsimonious model included the effect of AG in large-scale occupancy (Table 3.6). The second modest model contained the effect of agriculture fields and dry deciduous forests, and both accounted for more than 58% (0.5855) of the total AICc model weight. The difference in delta AICc values between top model and the second model was negligible (0.0620). AG negatively influenced the large-scale occupancy while dry deciduous forests positively influenced. The evidence ratio indicated that the first two models were ~2 times more plausible than the next three models and more than 470 times more plausible than the constant model.

Table 3.7. Summary of parameter estimates, standard error, lower and upper confidence levels (95%) of top models with less than 2 delta AICc for *N. affinis*

Model Rank	Parameter	Estimate	SE	LCL	UCL
	Naïve occupancy	0.948905			
Top	**Ψ (AG) θ (.) *p* (.)**				
	Ψ (AG)	0.99804	0.00422	0.88211	0.99997
	θ (.)	0.68757	0.02182	0.6433	0.72866
	p (.)	0.85460	0.01973	0.81152	0.88919
2	**Ψ (AG+DDF) θ (.) *p* (.)**				
	Ψ (AG+DDF)	0.99981	0.00077	0.61691	0.99970
	θ (.)	0.68788	0.02179	0.64366	0.72892
	p (.)	0.85460	0.01973	0.81152	0.88919
3	**Ψ (AG+EG) θ (.) *p* (.)**				
	Ψ (AG+EG)	0.99777	0.0044	0.9034	0.99995
	θ (.)	0.68962	0.022	0.64494	0.73102
	p (.)	0.85460	0.01973	0.81152	0.88919

3.3.3. Hume’s Hawk Owl (*N. obscura*)

As above four competitive models built to determine the sampling covariate that influence the detection probability (p) of *N. obscura* during the survey. The best parsimonious model contained the effect of atmospheric temperature with high model weight and low AICc values (Table 3.8) and outperformed other candidate models. The effect of temperature on detection probability of *N. obscura* was ~ 6 times better than the subsequent model. Temperature (β=0.5671917; SE= 0.1460067; CI=0.2810185 to 0.8533648) positively influenced the detection of *N. obscura* during the sampling. Subsequent analysis for small-scale and large-scale occupancy was done with temperature as a function of (p).

Table 3.8. Summary of models developed to understand the factors influencing the detection probability (a), small-scale (b) and large-scale occupancy (c) of *N. obscura* and each models AICc values, delta AICc and AICc model weight

Model	**AICc**	**ΔAICc**	**AICc *wi***	**Model likelihood**	**K**
(a) Detection probability (p)					
Ψ (.) θ (.) *p* (Temp)	737.6211	0.0000	0.80960	1.0000	4
Ψ (.) θ (.) *p* (Humi)	741.3374	3.7163	0.12627	0.1560	4
Ψ (.) θ (.) *p* (Humi+Noise)	742.7162	5.0951	0.06337	0.0783	5
Ψ (.) θ (.) *p* (.)	751.5516	13.9305	0.00076	0.0009	3
(b) Small-scale occupancy (θ)					
Ψ (.) θ (CVGBH) *p* (Temp)	736.8374	0.0000	0.24428	1.0000	5
Ψ (.) θ (.) *p* (Temp)	737.6211	0.7837	0.16508	0.6758	4
Ψ (.) θ (CVGBH+MD) *p* (Temp)	738.8364	1.9990	0.08991	0.3681	6
Ψ (.) θ (CVGBH+CC) *p* (Temp)	738.9890	2.1516	0.08330	0.3410	6
Ψ (.) θ (CVGBH+TH) *p* (Temp)	739.0125	2.1751	0.08233	0.3370	6
Ψ (.) θ (GBH+TD+TH) *p* (Temp)	739.2150	2.3776	0.07440	0.3046	6
Ψ (.) θ (TH) *p* (Temp)	739.2573	2.4199	0.07285	0.2982	5
Ψ (.) θ (GBH) *p* (Temp)	739.6539	2.8165	0.05974	0.2446	5
Ψ (.) θ (GBH+TH) *p* (Temp)	739.8364	2.9990	0.05453	0.2232	6
Ψ (.) θ (GBH+TD) *p* (Temp)	740.5455	3.7081	0.03825	0.1566	6
Ψ (.) θ (CC+TD) *p* (Temp)	741.2795	4.4421	0.00882	0.1085	6
(c) Large-scale occupancy (Ψ)					
Ψ (MDF) θ (CVGBH) *p* (Temp)	730.5198	0.0000	0.40103	1.0000	6
Ψ (DDF) θ (CVGBH) *p* (Temp)	732.3123	1.7925	0.16366	0.4081	6
Ψ (DDF+AG) θ (CVGBH) *p* (Temp)	732.4563	1.9365	0.15229	0.3797	6
Ψ (EG) θ (CVGBH) *p* (Temp)	732.6391	2.1193	0.13899	0.3466	5
Ψ (AG) θ (CVGBH) *p* (Temp)	732.9412	2.4214	0.11950	0.2980	5
Ψ (.) θ (CVGBH) *p* (Temp)	736.8374	6.3176	0.01703	0.0425	5
Ψ (MAN) θ (CVGBH) *p* (Temp)	738.4799	7.9601	0.00749	0.0187	6

Based on the observations from the field and a body of literature, 11 *apriori* hypotheses were developed to identify factors influencing the occupancy of *N. obscura* at small-scale (Table 3.8). The most approximating model included the effect of CVGBH in small-scale occupancy. The second model was a constant model with no effect of covariates on small-scale occupancy and the differences in AICc between two top models are negligible. But there is little improvement in model weight with CVGBH compared to the constant model. CVGBH positively (β=0.2500644; SE=0.1839125; CI= -0.1104041 to 0.6105329) influenced the occupancy of *N. obscura* at small-scale.

To explain large-scale occupancy of *N. obscura* seven candidate models were built. The most parsimonious model included the proportion of MDF within the sampling unit and it positively (β=5.6251712; SE=3.1195524; CI= -0.4891516 to 11.739494) influenced the large-scale occupancy of *N. obscura*. The evidence ratio shows that top model was ~2.4 (*wi* = 0.40103) times better predicted than the subsequent model (*wi* = 0.16366) and ~23 times better predicted than the constant model (*wi* = 0.01703). Other two parsimonious models contained DDF and AG and both of the covariates positively influenced the large-scale occupancy (Table 3.8).

Table 3.9. Summary of parameter estimates, standard error, lower and upper confidence levels (95%) of top models with less than 2 delta AICc for *N. obscura*

Model Rank	Parameter	Estimate	SE	LCL	UCL
	Naïve occupancy	0.95620			
Top	**Ψ (MDF) θ (CVGBH) *p* (Temp)**				
	Ψ (MDF)	0.99994	3.50E-05	0.52097	0.99999
	θ (CVGBH)	0.74218	0.02244	0.69581	0.78368
	p (Temp)	0.92115	0.01497	0.88635	0.94595
2	**Ψ (DDF) θ (CVGBH) *p* (Temp)**				
	Ψ (DDF)	1.00000	0.000000	0.9999	0.99999
	θ (CVGBH)	0.73702	0.022259	0.69113	0.77827
	p (Temp)	0.92115	0.014975	0.88635	0.94595
3	**Ψ (DDF+AG) θ (CVGBH) *p* (Temp)**				
	Ψ (DDF+AG)	1.00000	0.00000	0.9999	0.99999
	θ (CVGBH)	0.74197	0.02248	0.6955	0.78353
	p (Temp)	0.92115	0.014975	0.88635	0.94595

3.3.4. Andaman Barn Owl (*T. deroepstorffi*)

Considering its low detection within the sampling unit, only large-scale occupancy was estimated. Constructed five competitive models and the effect of AG was included in all models (Table 3.10). The best approximating model contained the effect of AG (β=3.4858477; SE=1.6632625; CI=0.2258532 to 6.7458422) and EG (β= 1.2011369; SE=0.8527540; CI= -0.4702610 to 2.8725349) and both positively influenced the occupancy of *T. deroepstorffi* at large-scale. The second best model included the effect of AG and MAN but MAN negatively (β=-1.4599860; SE=1.2623225; CI= -3.9341381 to 1.0141661) influenced the large-scale occupancy of *T. deroepstorffi*. The evidence ratio indicated that top model was ~1.3 times more reasonable than the second top model and ~644 times more than a constant model.

Table 3.10. Summary of models developed to understand the factors influencing large-scale occupancy of *T. deroepstorffi* and each models AICc values, delta AICc and AICc model weight

Model	AICc	ΔAICc	AICc*wi*	Model likelihood	K
Ψ (AG+EG) θ (.) *p* (.)	126.3460	0.0000	0.36765	1.0000	5
Ψ (AG+MAN) θ (.) *p* (.)	126.8849	0.5389	0.28081	0.7638	5
Ψ (AG) θ (.) *p* (.)	127.4324	1.0864	0.21356	0.5809	4
Ψ (AG+DDF) θ (.) *p* (.)	128.3143	1.9683	0.13741	0.3738	5
Ψ (.) θ (.) *p* (.)	139.2968	12.9508	0.00057	0.0016	3

Table 3.11. Summary of parameter estimates, standard error, lower and upper confidence levels (90%) of top models with less than 2 delta AICc for *T. deroepstorffi*

Model Rank	Parameter	Estimate	SE	LCL	UCL
	Naïve occupancy	0.109489			
1	**Ψ (AG+EG) θ (.) p (.)**				
	Ψ (AG+EG)	0.2614	0.1512	0.07088	0.62155
	θ (.)	0.0987	0.0369	0.04633	0.19802
	p (.)	0.0355			
2	**Ψ (AG+MAN) θ (.) p (.)**				
	Ψ (AG+MAN)	0.1811	0.1155	0.04583	0.50453
	θ (.)	0.1091	0.0397	0.05207	0.21418
	p (.)	0.0355			
3	**Ψ (AG) θ (.) p (.)**				
	Ψ (AG)	0.2392	0.1205	0.07908	0.53516
	θ (.)	0.1131	0.0421	0.05303	0.22498
	p (.)	0.0355			
4	**Ψ (AG+DDF) θ (.) p (.)**				
	Ψ (AG+DDF)	0.2640	0.1364	0.08308	0.58675
	θ (.)	0.1041	0.0376	0.05009	0.20378
	p (.)	0.0355			

3.4. DISCUSSION

This study is the first attempt to address the habitat use of endemic and threatened owls of Andaman Islands using multi-scale occupancy modelling.

3.4.1. Andaman Scops Owl

Humidity positively influenced the detection probability of *O. balli* during sampling (Figure 3.4). The responses to call playback calls were more under higher temperature and humidity in Tropical Screech Owl *Megascops choliba* (Braga & Motta-Junior, 2009). Similarly, Clark & Anderson (1997) observed low detection of Northern Saw-Whet Owl *Aegolius acadicusin* a lower temperature range. The detection of endangered Seychelles Scops-owl *Otus insularis* was higher during dry periods (April – high temperature) and lower during June-August (Rainy season – low temperature and humidity) but it was related to the breeding season of the species rather than the weather parameters (Currie et al., 2004). The response of Eurasian Scops-owl to call playback of conspecific calls was higher during the pair formation but spontaneous calls were more during full moon days (Mori et al., 2014). The high activity of *O. balli* in high humidity weather may be attributed two reasons: 1) high availability of insects in increased humidity (Delinger, 1980) and 2) high humidity creates a vacuum in the atmosphere, which might facilitate the owl to spread their calls much longer.

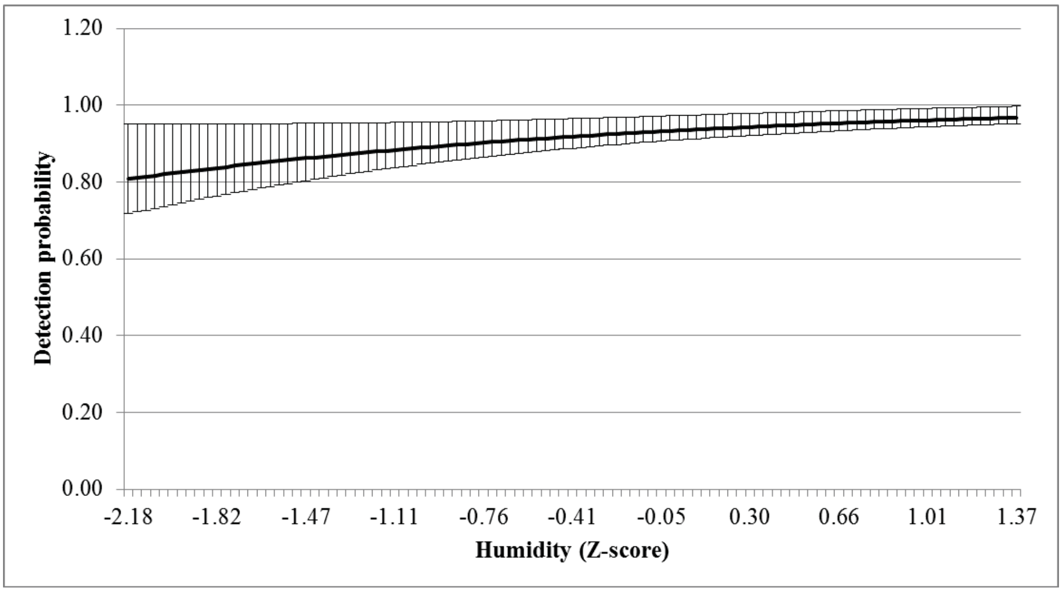
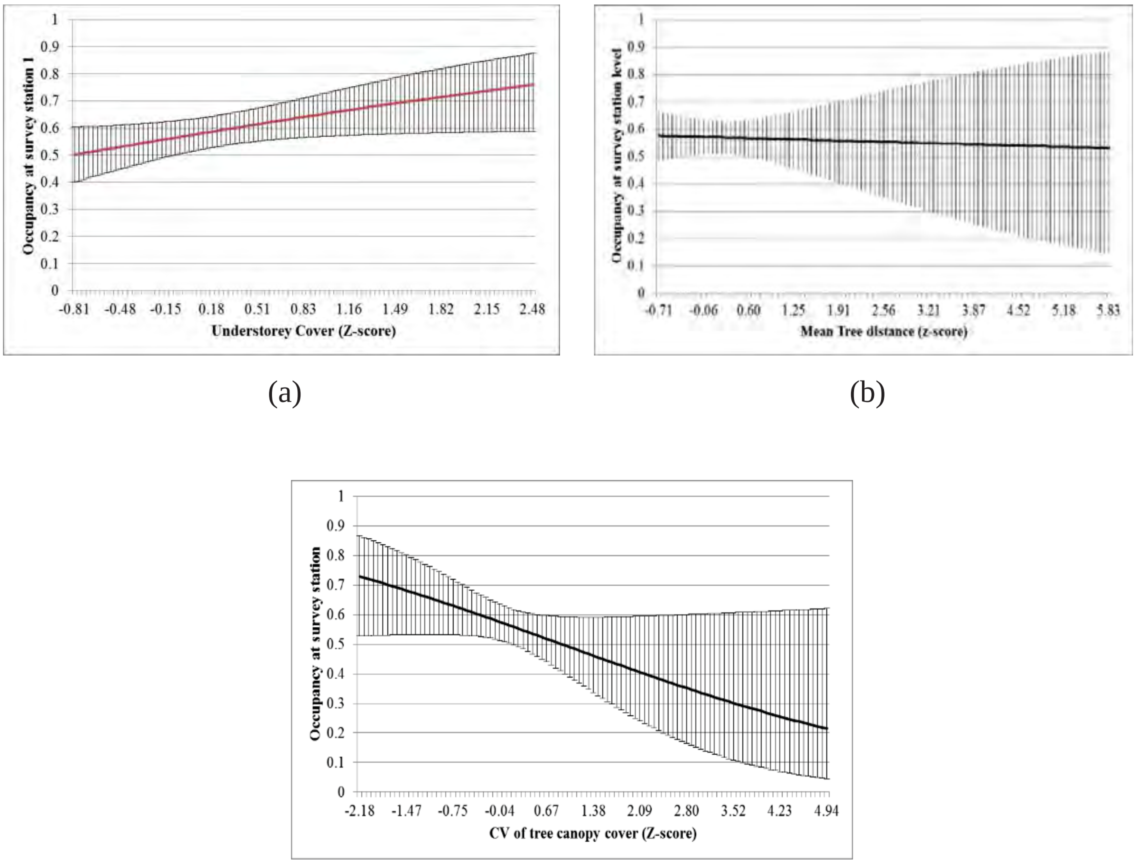


Figure 3.4. Effect of humidity in detecting *O. balli* at survey stations

Bamboo cover around the survey station was not quantified separately and it was included under USC. USC associated positively with small-scale occupancy of *O. balli* (Figure 3.5a) while MD and CVCC associated with marginal negative (Figure 3.5 b & c). *O. balli* occupies survey station that has thick understory cover, dense tree stands with low variation in canopy cover. It is clear that *O. balli* is a typical understory owl found in evergreen forests and moist deciduous forests with thick bushes of native bamboo. *O. balli* is a foliage gleaning insectivore (Ali & Ripley, 1983; Rasmussen & Anderton, 2005) and it forages by moving within the canopy or understory plants (König & Weick, 2008). The abundance of leaf-gleaning insectivore birds in Chile was higher in dense bamboo plots as the invertebrate biomass thought to be higher here (Reid et al., 2004). Also, *O. balli* roosted in bamboo and Cane dominated evergreen or deciduous forests, which provides concealment (dried bamboo leaves and shoots) for roosting. Such concealed roost sites also protect from mobbing species such as Drongos, Treepies, and Crows. This emphasizes the significance native bamboo and cane cover in natural forests for the conservation of *O. balli* and other tropical island endemics. The preference of USC by *O. balli* is hypothesized that interspecific competition with sympatric *O. sunia*, occupies top canopy, might have imposed *O. balli* to opt for understory stratum. Because of its high dispersal ability (recorded in all offshore islands surveyed) and adaptation to living in human-altered habitats (occurred in all surveyed habitat types in North Andaman) enabled *O. sunia* to dominate over habitat use by *O. balli*.

The trend line of MD in response to small-scale occupancy was distributed between 0.5 and 0.6 probability (Figure 3.5b) with low Confidence Interval at low MD values (*i.e.,* high tree density sites). It indicates that the chances of sighting an *O. balli* at high tree density stations were high compared to low tree density stations (CI was high here). High tree density sites with low variation in canopy cover (Figure 3.5c) are the characteristic of evergreen forests which is preferred habitat of the species (as discussed in chapter 1).



(a) (b)

(c)

Figure 3.5. Effect of (a) Understory cover (b) Mean tree distance and (c) CV of tree canopy cover on small-scale occupancy of *O. balli*.

At large-scale, *O. balli* occupied sampling units devoid of agriculture fields. *O. balli* exploits small-sized agriculture fields surrounded by natural forests, preferably evergreen, but they evade extensive stretches of agriculture fields (Figure 3.6). The findings are much coinciding with Eurasian Scops-owl in Spain (Moreno-Mateos et al., 2011) and Scops Owl *Otus scops* in the Alps (Mikkola, 1983, Galeotti & Sacchi, 2001). Eurasian Scops-owls were reported to prefer natural and semi-natural scrubland habitat within an agricultural matrix and such natural habitats are identified nesting and foraging sites of the species (Moreno-Mateos et al., 2011).

The common agriculture practice in North Andaman Island is paddy cultivation and a large proportion of rice for local consumption is supplied from this part of the island. Paddy cultivation is carried out twice in a year and rest of the time it is kept as pastureland for cattle. Usually, paddy fields are devoid of understory and tree cover, which is an important niche for *O. balli* for foraging, roosting and nesting. Furthermore, *O. balli* occupies sites with small-extent of agriculture fields surrounded by natural forests and in such places owl exploits edges between natural and agriculture fields for foraging but roosting and nesting can be undertaken in the natural forests. Furthermore, the intensity of pressure on forests surrounded by small sized agriculture is expected to be negligible. Because a large extent of agriculture fields attracts human settlement around the fields that increases the pressure on nearby natural forests especially on understory cover and climbers. In North Andaman, a large proportion of such agrarian settlers prefer to thatch their home with understory plants such as tea plant, bamboo, and climbers like a cane, which are often collected from the nearby forests. These extractions destroy the ecological niche of *O. balli* and thus, they avoid large extent of agriculture fields. In Andaman, *O. balli* occurrence in a site indicates the wealth of the understory cover (including bamboo) and cane cover in the forests.

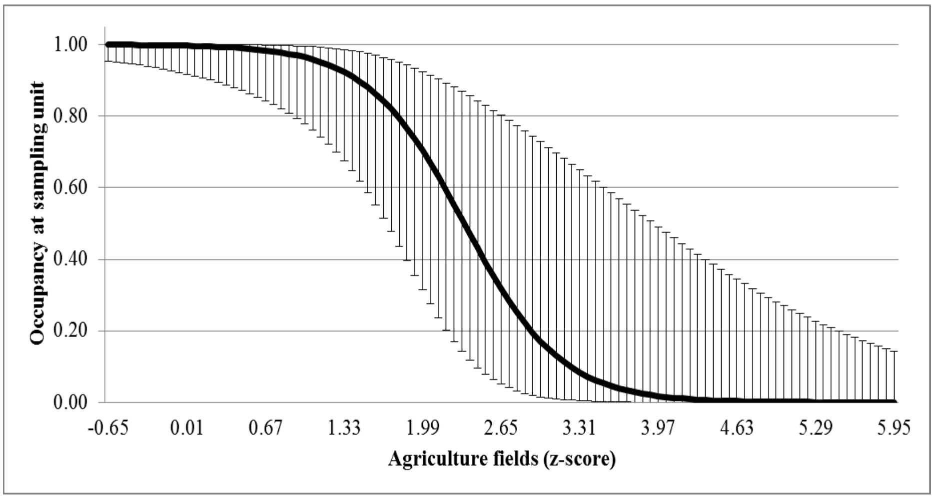
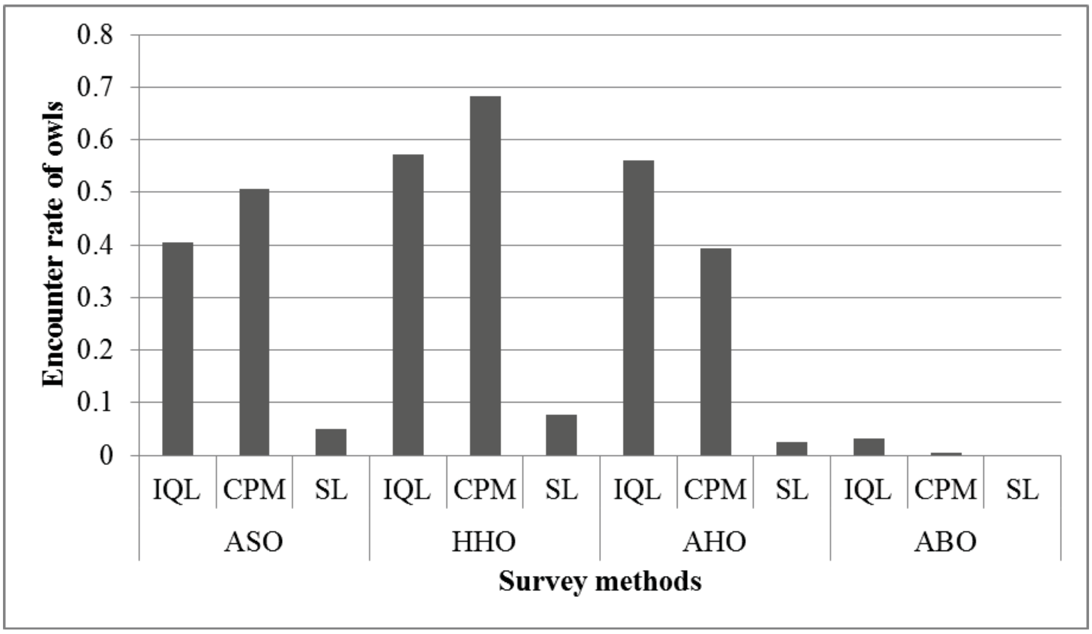


Figure 3.6. Effect of agriculture fields on large-scale occupancy of *O. balli*

3.4.2. Andaman Hawk Owl

None of the sampling covariates influenced detection probability of *N. affinis* and a constant model was predicted as most parsimonious model. This indicates that all individuals of *N. affinis* were detected during the sampling without missing. Field surveys were conducted during dry periods (December to May), which is coinciding with the breeding season of *N. affinis*. During the breeding season, *N. affinis* was very vocal throughout the night and hence maximum detection of *N. affinis* was from Initial quiet listening (IQL) method (Figure 3.7) than call playback method. Thus, no variables influenced *N. affinis* detection.



IQL=Initial Quiet Listening; CPM=Call playback; SL= Spotlight searches, ASO – Andaman Scops Owl; HHO – Hume’s Hawk Owl; AHO – Andaman Hawk Owl; ABO – Andaman Barn Owl

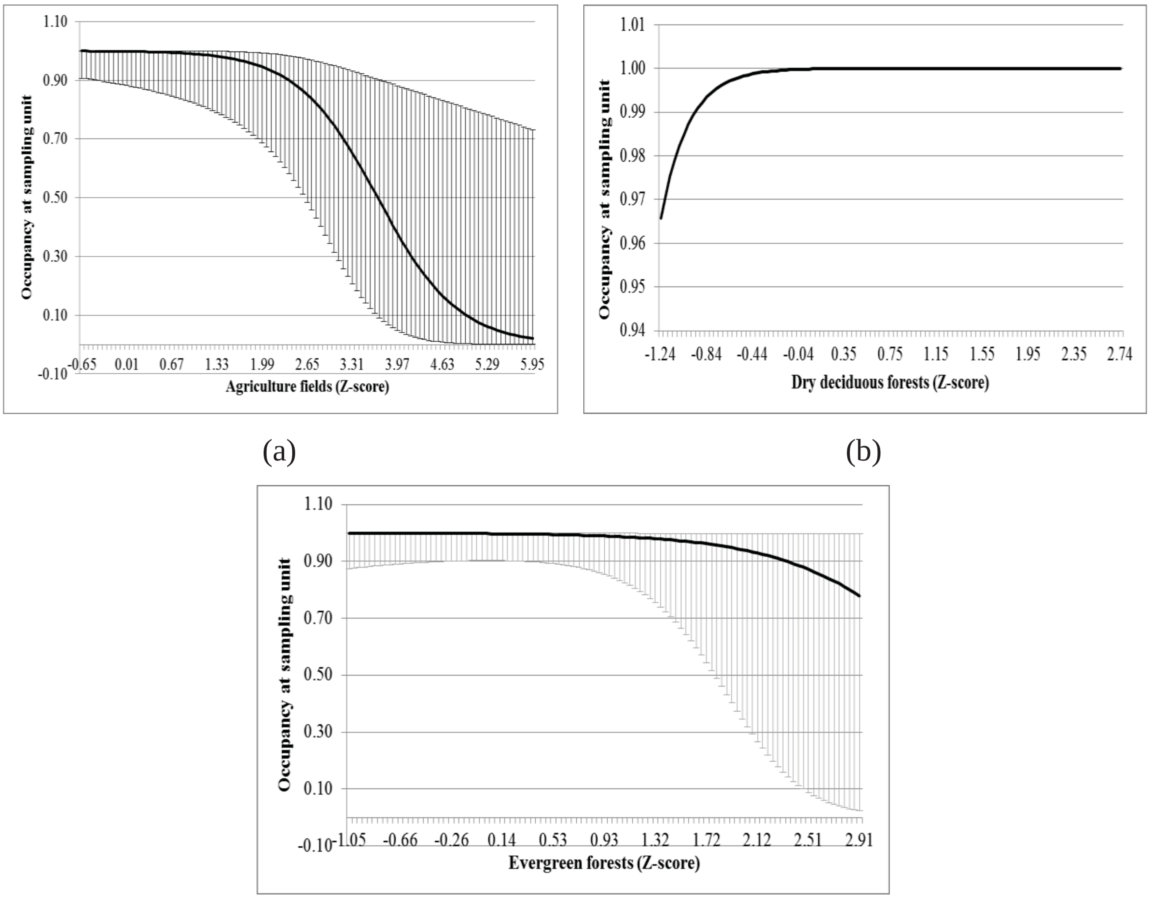
Figure 3.7. Encounter rate of owls in different survey methods

At small-scale occupancy, the constant model was predicted as most parsimonious model with high model weight and low AICc value. However, I considered next three models which are less than 2 delta AICc values as parsimonious models. The effect of three variables such as CC, USH and CVGBH were included in these models. Among them, USH has high summed values compared to other variables (Figure 3.8). All three covariates negatively influenced the occupancy *i.e., N. affinis* preferred sites that have short understory, low canopy cover with less variation in GBH. This characterizes the deciduous forests. *N. affinis* prefers short understory, clear mid-stratum, and low canopy cover because of their hawking foraging behaviour. It requires spacious tree stands with low canopy cover to hunt flying insects between the top and lower canopy.

Figure 3.8. Effect of Understory Height on small-scale occupancy of *N. affinis*

At large-scale level, *N. affinis* occupied sites that had a low extent of agriculture fields but it prefers large extent of dry deciduous forests in sampling unit. Avoidance of agriculture/paddy fields might be attributed to the following reasons 1) lack of perching sites for foraging because it hunts lepidopteran prey and other flying insects by hawking from the tallest perch and such perches are mostly do not exists in large extent of paddy fields 2) absence of roosting and nesting platform (large girth trees) within paddy fields because the shade trees are not usually retained in the paddy fields as it reduces the growth 3) lack of perches in other plantations such banana, coconut and areca, 4) it prefers to perch on dead branches in the deciduous forests which are often collected by nearby agrarian for fire wood, and 5) probable competition with *N. obscura* which is seen frequently in agriculture dominated landscapes. It warrants a detailed study to understand the interaction among the sympatric owls in habitat selection and factors driving such selection.

Compared to selective logging, conversion of natural forests for agricultural practices has caused a tremendous impact on distribution and habitat use of stenotopic owls such as *N. affinis* and *O. balli* in the Andaman Islands as reported for other nocturnal birds in Australia (Kavanagh & Bamkin, 1995). But logging activity often failed to retain virgin natural forests from selective logging in Andaman. Most of the natural forests in the islands had faced the logging activity till 2002. After the ban on timber extraction, selective logging is under practices through government owned mills, to meet local requirements. Like *O. balli*, *N. affinis* also occupies small-sized agricultural fields surrounded by natural forests which are evident from the trend line in figure 3.9a but the trend line went down to till when the extent of agriculture fields increase within the sampling unit. The extent of deciduous forests positively influenced the occupancy of *N. affinis*. It occupies grids when there is a small patch of natural dry deciduous forests within the grid (Figure 3.9b).



(a) (b)

(c)

Figure 3.9. Effect of (a) agricultural fields, (b) deciduous forests and (c) Evergreen forests on large-scale occupancy of *N. affinis*

3.4.3. Hume's Hawk Owl

Temperature positively influenced the detection probability of *N. obscura* (Figure 3.10). This relationship was reported in Northern Saw-whet Owl (Clark & Anderson, 1997) and Tropical Screech Owl (Braga & Motta-Junior, 2009). It was not vocal throughout the night as reported for *N. affinis* but rather they respond to call playback when they are present in a site. This is evident from the Figure 3.7 that *N. obscura* was detected more frequently using call playback method over initial quiet listening. It can also be interpreted that the species which were detected from call playback methods were influenced by weather parameters. It requires much detailed study to understand the physiological mechanisms that trigger vocalization pattern during high temperature and humidity. However, a monthly temperature in North Andaman showed a peak temperature between March and May (Figure 3.11) and it accords with the breeding season of the species (Ali & Ripley, 1983; König & Weick, 2008).

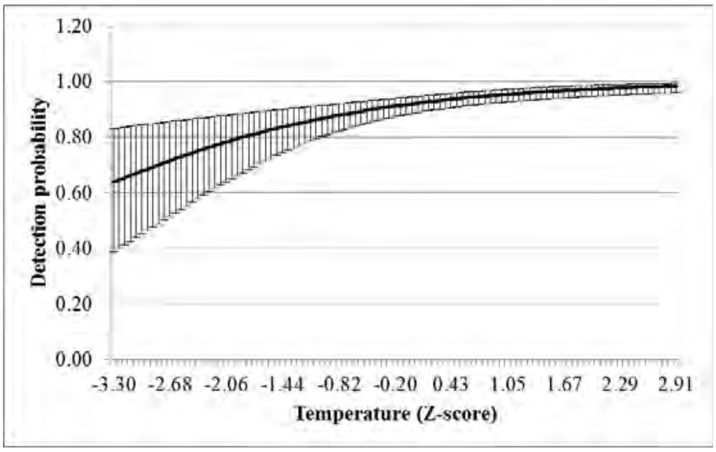


Figure 3.10. Effect of temperature on detection probability of *N. obscura*

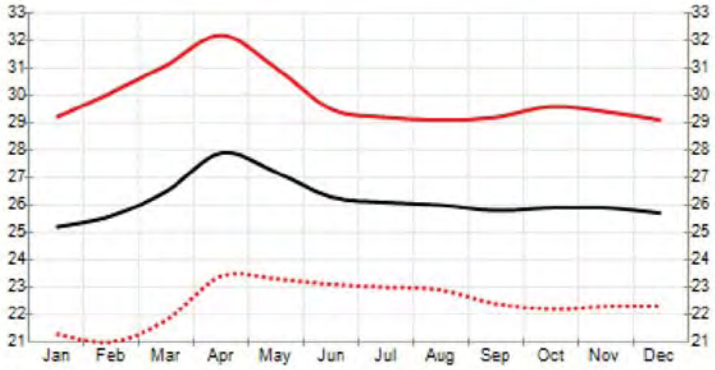


Figure 3.11. Monthly temperature (min-max) of north Andaman Island

Small-scale occupancy of *N. obscura* was positively influenced by a coefficient of variation of GBH *i.e.,* it occupies varied degree of tree stands in Andaman starting from cleared agriculture fields to mature evergreen stands (Figure 3.12). Other parsimonious models contained MD, which was positively influenced the occupancy and it indicates that *N. obscura* exploits sparsely arranged tree stand (Figure 3.13). This matches with the typical habitat characteristics of Brown Hawk Owl (*Ninox scutulata*) in the Western Ghats (Babu, 2011). No profound ecological interaction with agriculture field was observed. Considering its wide ecological niches and habitat use, it can be eurytopic species and it may not face any immediate population decline as it could survive very well in human tailored habitats. One possible reason to occupy a wide array of ecological niches by *N. obscura* might be related to interaction with sympatric *N. affinis*. A clear difference in space-use between *N. affinis* and *N. obscura* may exists, later is more generalist in habitat use while previous one was more specialist restricted to dry deciduous forests. The variation in utilization of dry deciduous and moist deciduous by *N. affinis* and *N. obscura* respectively may be attributed to the availability of areal insects especially moths and grasshoppers. Further studies focusing on vertical stratum use and foraging ecology is required to elucidate the factors segregating the habitat selection.

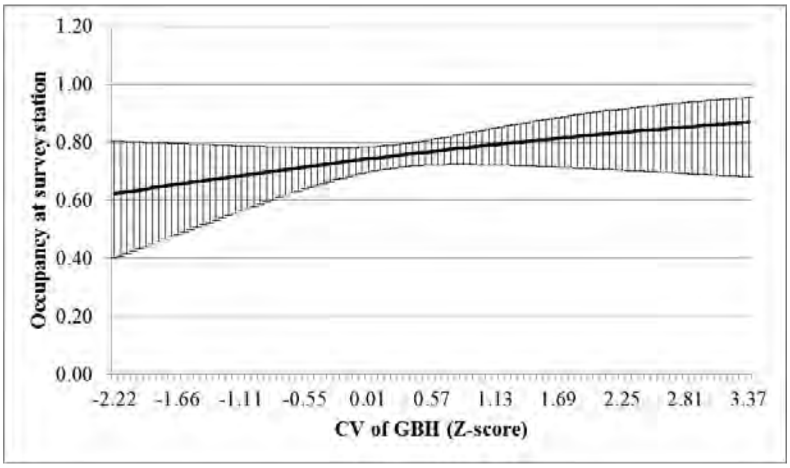


Figure 3.12. Effect of CV_GBH on the occupancy of *N. obscura* at small-scale

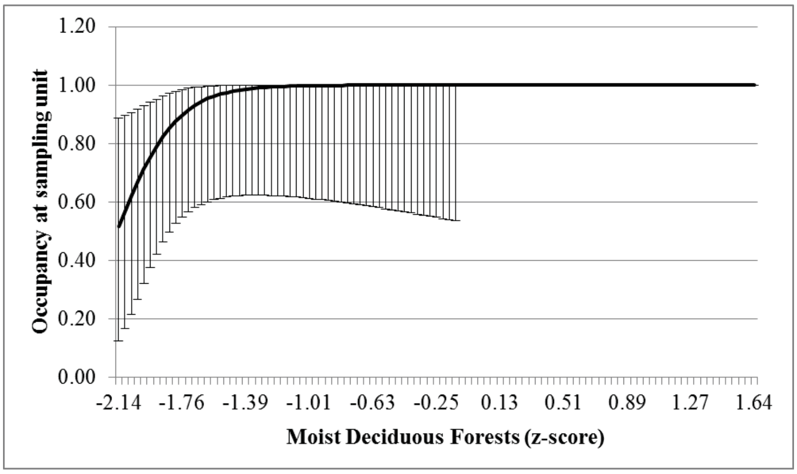
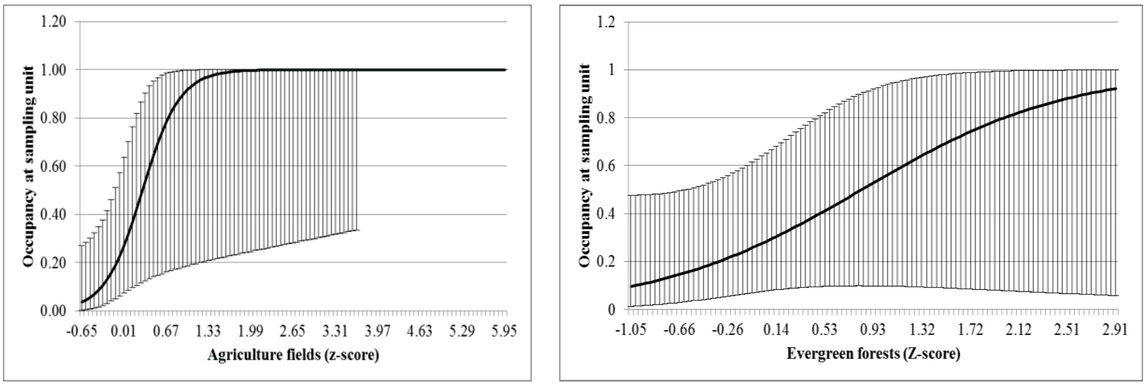


Figure 3.13. Effect of extent of moist deciduous forests on the large-scale occupancy of *N. obscura*

3.4.4. Andaman Barn Owl



(a) (b)

Figure 3.14. Effect of extent of (a) Agriculture field and (b) Evergreen forests on the large-scale occupancy of *T. deroepstorffi*.

Due to low detection and moderate body size, I have estimated p and θ as constant. The extent of agriculture fields positively influenced the large-scale occupancy of *T. deroepstorffi* in North Andaman. This can be related to the availability of the high quantity of rodents in the rice fields and human habitations. Rodents especially the abundance of *Bandicota bengalensis* was reportedly higher in rice fields and agriculture habitats. In mainland sub species, it has been reported occurring in a large proportion of Barn Owl diet (Nagarajan *et al.*, 2002; Babu 2011). In Andaman, agriculture fields or open areas close to evergreen patches were most preferred by *T. deroepstorffi* because the open area and agriculture fields (Figure 3.14a) were the prime foraging ground and evergreen forests (Figure 3.14b) for roosting and nesting. The roost sites of Barn Owl in Andaman are not like mainland India species (Common Barn Owl *Tyto alba*), which roosts in man-modified structures such as temples, church, mosque, bell tower, and sometimes at large apartments in cities (Ali & Ripley, 1983; Nagarajan *et al.*, 2002; Babu, 2011), whereas, in Andaman, they preferred large trees like Padak for roosting and nesting. I observed two nest sites: one in North Andaman on the crotch of Padak and another in South Andaman (Chitayatappu) in a tree-hole.

CHAPTER 4

The role of island characteristics in determining the occurrence of owls

Hume’s Hawk Owl

4.1. INTRODUCTION

The prime objective of biodiversity conservation is to secure the survival of each species in its chosen environment (Frankel & Soulé, 1981). Species prevalence in a closed environment, such as an island biota, is sensitive to both intrinsic (such as competition or genetic) and extrinsic (such as habitat degradation, overexploitation, and imported species) processes (Soulé, 1987; Lande, 1998). The rate at which these processes occur varies with spatial and temporal scales and hence islands are considered more sensitive to disruptions than the mainland (Natarajan, 2013). Seventy percent of the top 50 hotspots in the world are island ecosystems (Stattersfield, 1998), indicating the rapid decline of natural island ecosystems due to severe anthropogenic disturbance. And the Andaman archipelago's eco-system changed dramatically as a result of human colonisation and natural calamities, affecting the distribution and its composition of flora and fauna (Lalitha et al., 2000). Furthermore, species and its populations associated with islands will be more vulnerable to extinction in the future due to more frequent natural calamities and anthropogenic perturbances (Davidar et al., 2002).

To conserve or manage the biodiversity both in an island and mainland ecosystem, different approaches have been followed widely. On the mainland, theories such as source-sink dynamics suggest that safeguarding one large population as well as their identified high-quality habitats by establishing protected areas will be adequate to ensure sustainable population persistence (Boorman & Levitt, 1973; Pulliam, 1988; Watkinson et al., 1989; Watkinson & Sutherland, 1995). Whereas in an island archipelago, community ecology theories highlighted that the persistence of species in islands was stabilised by a continuous process of colonisation and extinctions from local populations (Levins, 1969; Slatkin, 1974; Hanski, 1985, 1991, 1994; Hastings & Wolin, 1989; Hastings, 1991; Harrison, 1991; Hanski & Gilpin, 1997). Thus, one of the primary challenges for conservation managers is recognising and prioritizing the islands in favour of colonization and extinction of species. Because long-term management of complex archipelago systems is difficult and costly due to their complexity and thus management plans for small islands are rarely defined and incorporated (Cook et al., 2006).

Extensive investigations involving the monitoring of every island and species within it are not practical due to the fact that such islands are made up of diverse species. However, it has been discovered that it is more feasible to target a group of species as a surrogate to measure the environmental condition of the area (MacKinnon et al., 1986; Simberloff, 1988; Caro, 2010). Birds have been shown to be a good indicator of environmental health. Species richness of birds in island systems is regulated by several factors including assembly rules and a set of physical and biological factors. In addition, island biogeography theory explains that the species richness of birds is higher in islands that are larger in size and close to the mainland (MacArthur & Wilson, 1967). However, the species richness is not only restricted by those two characteristics, but also by other topological, habitat structure, species interactions, and many others that must be understood in order to define the species occurrence pattern in island systems (Debinski & Holt, 2000; Harrison & Bruna, 1999; Ewers & Didham, 2006; Henle et al., 2004a).

Among the birds, top predators have always been identified as priority species for monitoring or managing the fragmented forest environments. Although several studies in India and elsewhere have used diurnal birds and raptors to prioritize species rich areas, limited or no studies have used nocturnal predators (owls) as indicator species to prioritize the offshore islands. Owls are nocturnal top-predators and pinnacle of the food chain and occupy multifaceted habitats to attain various life history characteristics. Some species of owls are forest habitat specialists, and their presence might signal the health of an eco-system by indicating the high species richness of other forest-dwelling species (Sergio et al., 2006, 2008). Individual species, however, respond differently to different island or fragment quality (Ferraz et al., 2007; Gascon & Lovejoy, 1998; Malcolm, 1995) due to differences in body size (Ewers & Didham, 2006), diet (Johns & Skorupa, 1987; Skorupa, 1986), home range (Dale et al., 1994; Gascon & Lovejoy, 1998; Skorupa, 1986), and rarity (Ewers & Didham, 2006; Henle et al., 2004b). Owls of the Andaman Islands are mostly insectivorous and carnivorous diets (Table 1.1., Page-14), and owls in general live in low concentrations with strong territorial behaviour, necessitating bigger home ranges (Newton, 1998). As a result, it is critical to investigate their occurrence-dependent island characteristics, which may aid in the preservation of viable species populations.

The distribution of birds and butterflies on the Andaman Islands' offshore islands was investigated (Davidar et al., 2002). They discovered that island size is the most important factor influencing bird distributions, which is compatible with the theoretical foundation of island biogeography (MacArthur & Wilson, 1963). *Dentrocitta bayleyi* and *Columba palumboides* were discovered to be species limited to the larger islands. It did not, however, include owls in the analysis, despite the fact that they are easy to survey using well-designed acoustic methods during the nesting season (Johnson et al., 2009). As a result, the goal of this chapter was to identify the presence of an owl species that indicates the vital characteristics of an island.

4.2. METHODS

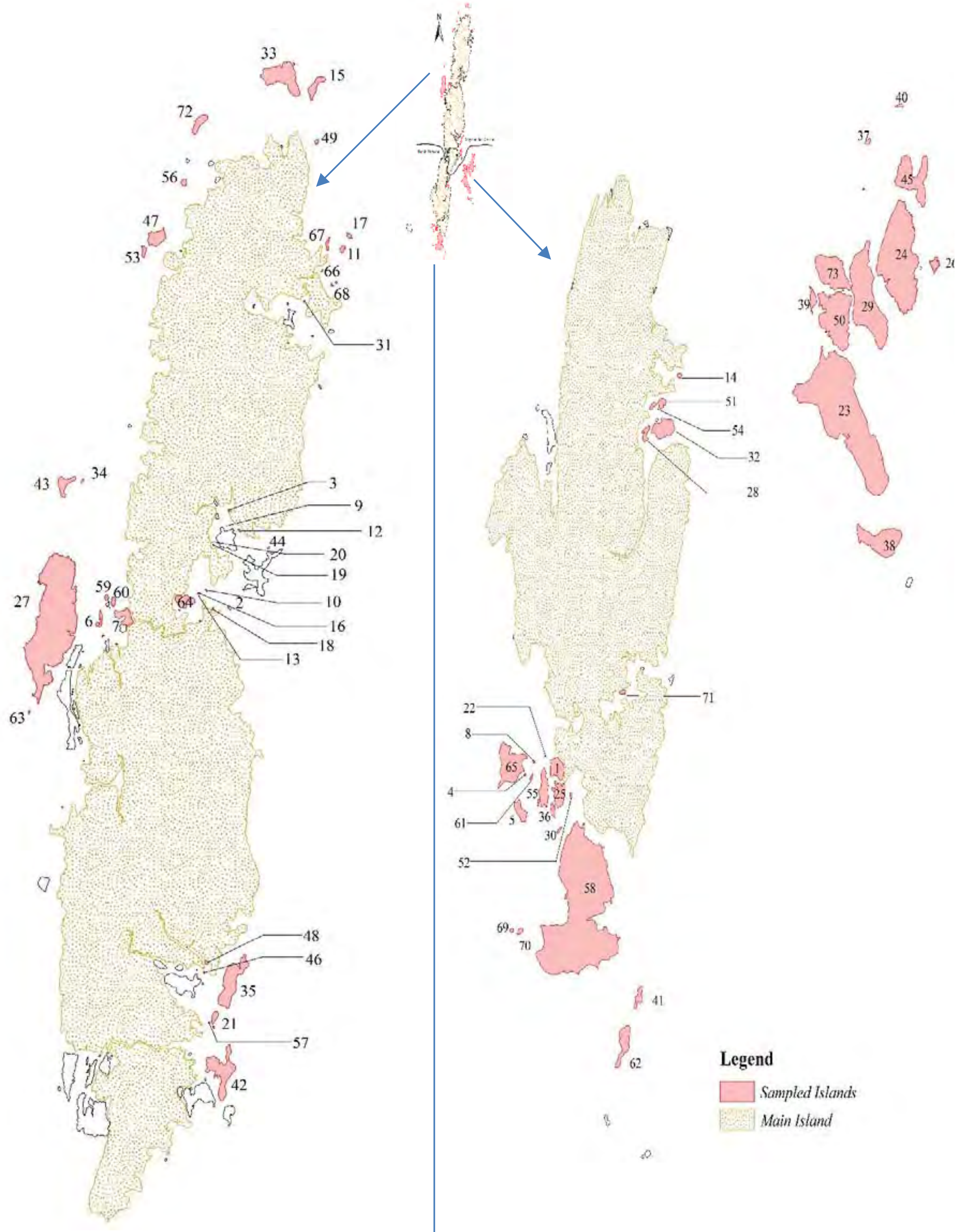
4.2.1. Intensive study area

A total of 73 islands were surveyed for the owl occurrence and island characteristics (Table 4.1, Figure 4.1).

Table 4.1. Characteristics and locations of islands surveyed in Andaman archipelago, India

S. No.	Island Name	Geographical Position		No. of Habitats	Elevation (m)
		Latitude	Longitude		
1	Alexandra	92.608369	11.576194	4	100
2	Avis	92.935171	12.915717	3	40
3	Bamboo	92.93297	13.051095	1	23
4	Belle	92.566349	11.569889	2	45
5	Boat	92.560893	11.529196	4	59
6	Bondoville	92.754911	12.903437	4	58
7	Buchanan	92.794172	12.901653	4	46
8	Chester	92.578841	11.583571	3	39
9	Curlew	92.929944	13.030025	1	0
10	Curlew BP	92.901918	12.940105	1	29
11	Delgarno	93.091319	13.414355	4	49
12	Dot	92.94915	13.022923	3	45
13	Dottrelle	92.892043	12.932373	1	0
14	Duncan	92.773132	12.015735	2	70
15	East	93.052899	13.637898	4	77
16	Egg	92.890259	12.936537	2	27
17	Excelsior	93.09941	13.431963	4	27
18	Gurjan	92.910484	12.913932	4	44
19	Gander	92.912031	13.003316	1	0
20	Goose	92.910318	13.007313	1	0
21	Guitar	92.91283	12.347858	4	94
22	Grub	92.593871	11.589871	1	0
23	Havelock	92.980525	11.982908	5	217
24	Henry Lawrence	93.057858	12.135193	4	170
25	Hobday	92.612295	11.54657	4	90
26	Inglis	93.117344	12.139952	4	57
27	Interview	92.691261	12.895704	5	132
28	James	92.723376	11.951622	4	53
29	John Lawrence	93.013838	12.103071	4	160
30	Jolly buoy	92.611225	11.507665	3	52
31	Jungle	93.037722	13.342218	1	11
32	Kyd	92.740136	11.954992	4	218
33	Landfall	93.009117	13.65503	4	70
34	Latouche	92.730641	13.093675	3	35
35	Long	92.942811	12.397826	5	147
36	Malay	92.604443	11.530865	4	81
37	Middle Button	93.027044	12.274332	4	50

38	Neill	93.044771	11.818725	5	128
39	Nicolson	92.955541	12.101881	4	107
40	North Button	93.070588	12.319304	3	39
41	North Cinque	92.719883	11.32183	4	152
42	North Passage	92.926393	12.268622	5	110
43	North Reef	92.703515	13.088678	4	57
44	Oliver	92.987519	12.999593	2	40
45	Outram	93.075704	12.230372	4	88
46	Oyster II	92.898208	12.409914	1	20
47	Paget	92.831252	13.428267	4	63
48	Parkinson	92.901582	12.423704	2	34
49	Peacock	93.053851	13.562707	2	58
50	Peel	92.986474	12.079276	4	100
51	Pitman	92.749629	11.984966	4	66
52	Pluto	92.628357	11.545499	1	29
53	Point	92.816976	13.41399	4	42
54	Potanma	92.737249	11.981825	4	52
55	RedSkin	92.591951	11.550853	5	84
56	Reef	92.871703	13.506789	3	63
57	Round	92.905963	12.339173	1	41
58	Rutland	92.641599	11.449726	5	469
59	Sea Serpent	92.764429	12.929016	4	44
60	Snake	92.773352	12.922473	4	37
61	Snob	92.574082	11.56513	4	49
62	South Cinque	92.702632	11.277215	4	182
63	South Reef	92.654974	12.771377	1	29
64	Swamp	92.871818	12.926127	4	118
65	Tarmugli	92.558913	11.577622	4	81
66	Temple	93.062409	13.385346	2	33
67	Trilby	93.069428	13.423397	4	68
68	Turtle	93.075496	13.36631	2	48
69	Twins I	92.560459	11.394999	3	55
70	Twins II	92.548562	11.395593	3	46
71	Viper	92.698381	11.661681	5	73
72	West	92.891096	13.586501	4	49
73	Wilson	92.987664	12.131624	4	237



(a) (b)

Figure 4.1. Showing distinction between mainland and offshore islands surveyed in (a) Mayabunder wildlife division and (b) Haddo wildlife division (arrow marks are followed by location codes; *see* Table 4.1)

4.2.2. Owl sampling

Owl surveys were conducted in 73 offshore islands of varying sizes, degrees of isolation, and habitat heterogeneity, for five species of owls (Table 4.1). The large Andaman Islands (North, Middle, Baratang, and South) were treated as source pool here because it contains all five species of owls. A stratified random sampling method was used with island size as a stratum variable to select the number of point count stations per island for large islands (when sufficient point count stations can be taken). Whereas smaller islands were visited many times (three visits) to construct the presence - absence matrix for owl. To increase the detectability of owl species, three census techniques – Initial Quiet Listening, call playback of conspecific calls, and spotlight searches – were used at each sample station (for details please see the chapter 2 in *Owl sampling protocol*; page-28). All sampling locations were marked using a handheld GPS device (GARMIN 10). All sampling was done during the dry season (January to May for the period of the study) to avoid rough weather conditions during the monsoon months. Furthermore, the sample period coincides with the owls' nesting season (Ali & Ripley, 1983; König & Weick, 2008).

4.2.3. Characteristics of the Islands

With it's linear form running north to south, the Andaman archipelago has scattered offshore islands on either side. The central major contiguous islands (North Andaman, Middle Andaman, Baratang, and South Andaman) were deemed mainland despite the fact that they were separated by sea water and connected by ferry services. Out of 73 islands, South Cinque is the southernmost (92.6882 E – 11.2420 N) while Landfall is the northernmost (93.0159 E – 13.6760 N) (Table 4.1). Sixteen island metrics were extracted for each sampled island, comprising 8 topographic and 8 habitat structural traits (Table 4.2.). The 2004 mega earthquake was projected to cause changes in the habitat and geography of each island. All variables were calculated using latest Landsat satellite images of the study period (Landsat-8 image courtesy of the U.S. Geological Survey). The islands' boundaries were determined by measuring the high tide levels on ground and at the margin of mangrove/forest belts.

Table 4.2. Island characteristics quantified for each offshore islands of Andaman archipelago, India

Variables	Description	Code
Topographical		
Area (km^2)	The total area of an island	AREA 2D
Shape	P/[2(A)1/2] is the island shape index. Where P is the island's perimeter length and A is the island's area. The minimum value of shape index is 1 when the island is a circle and value increase when the shape elongated	SAPE
Distance to the nearest island (km)	The closest distance from the sampled island to the nearest large island	DisISLD
Distance to Main Island (km)	The closest distance from the sampling island to the Main Andaman Island.	DisMAIN
Habitat structural		
Proportion of Evergreen	Calculated from the classified LULC map of Andaman to the island extent	EVER
Proportion of Deciduous	Calculated from the classified LULC map of Andaman to the island extent	DECI
Proportion of Mangrove	Calculated from the classified LULC map of Andaman to the island extent	MANG
Proportion of Degraded land	Calculated from the classified LULC map of Andaman to the island extent	DEGR
Proportion of Habitation	Calculated from the classified LULC map of Andaman to the island extent	HABI
Shannon diversity index	Diversity index calculated by the area of habitat types	SHNON
Percent of forest cover	Calculated from the classified LULC map of Andaman to the island extent	COVR
Island properties rejected from the full model due to collinearity (> 0.7)		
Elevation (m)	The highest point of the island from the sea level	ELE
Volume (km^2)	The total surface area of an island	AREA 3D
Perimeter (km)	Total length of the outer boundary of the island	PERI
Number of Habitats		NUMHBI
Number of islands	The count of the islands which are closer than the mainland irrespective of size	NUMIS
Cumulative area (km^2)	The cumulative areas of the islands which are closer than the mainland	CUM

4.2.4. Statistical Analysis

The 16 parameters collected from offshore islands were checked for autocorrelation using Pearson correlation coefficient, and five highly correlated variables (Correlation value 0.7) were removed from further analysis (Table 4.2; Appendix 4.1). A Kurskal-Wallis test with paired permutation testing as post hoc was used on the specified variables to assess the specific difference between each species of owl and the characteristics of the islands they occupied. The procedure Rodríguez et al., (2018) was used to compute significant differences using 9,999 monte Carlo replications. Each species recorded then ranked according to the number of islands they were recorded. Then based on the number of occupied islands the rank was brought into a rarity index between 1 to 5. Species recorded less than 18 islands were ranked to 1 (which is 25% of the islands sampled). 19 to 30 islands are rank 2; 31- 45 islands rank 3; 46 to 60 islands rank 4; and 61 to 73 islands rank 5. Each species presence-absence matrix was created for each island, along with the island characteristics variables. I then used the Generalized Linear Model (GLM) with the binomial distribution family function logit-link to assess the probable structural characteristics of an island based on species occurrence. Along with the predictor variables, species presences were included in the binary form (1/0). First, a global model with specified variables for each species separately were generated, then dredged to generate all feasible models with unique variable combinations. As none of the parsimonious model differences were significantly more than 2 delta AICc values, I averaged models by picking models with less than 2 delta AICc. I used Akaike's Information Criterion framework adjusted for short sample size (AICc) and Akaike weights to rank and assess models (Burnham & Anderson, 2002). The resultant models were then ranked using the Akaike weight. *R- Ver. 4.0.0* was used for the analysis, and the ‘glm’ function was used. Dredging and model averaging were performed using the multimodel inference methods in MuMIn package (Barton, 2013).

4.3. RESULTS

Except for the main islands (North Andaman, Middle Andaman, Baratang and South Andaman), a total of 73 islands were assessed for the five species of owls. The Oriental Scops Owl (*O. sunia*) was the most widespread species, occupying 57 islands (Table 4.3). The distributional ranges of the *T. deroepstorffi* and the *O. balli* were quite limited. Except for the *O. sunia* and the *N. affinis,* all three species were not occupying on the larger islands, which appears to be other factors influencing the occupancy of owls in the sampled islands (Table 4.3).

Table 4.3. Ranks of the five species of owls in Andaman Islands by their occurrence records

Species	**Number of islands**	**Rarity**	**Island size category (km^2)**		
			>20	**20 - 4**	**< 4**
Andaman scops owl	14	1	83 %	57 %	9 %
Oriental Scops owl	57	4	100 %	64 %	68 %
Andaman Hawk owl	30	2	100 %	64 %	26 %
Hume’s hawk owl	23	2	83 %	64 %	16 %
Andaman Barn owl	19	1	50 %	35 %	16 %

Except for the four island variables (Total Area X^2 = 14.49, P < 0.05; Proportion of Evergreen X^2 = 10.281, P < 0.05; Shannon diversity index X^2 = 7.9807, P < 0.05; Shape of the island X^2 = 8.6626, P < 0.05), none of the others (Kruskal–Wallis tests; Total forest cover X^2 = 4.1301, P > 0.05; Proportion of Mangrove X^2 = 0.79416, P > 0.05; Proportion of Habitation X^2 = 4.6076, P > 0.05; Proportion of Deciduous X^2 = 0.93788, P < 0.05; Proportion of Degraded X^2 = 4.7976, P > 0.05; Distance to mainland X^2 = 3.1392, P < 0.05; Distance to nearest large island X^2 = 3.5729, P > 0.05) were significantly different among species. Proportion of evergreen playing a crucial role in delimiting the species preference over offshore islands. The results of post-hoc analysis of Kruskal-wallis test revealed that presence of *O. balli* and *N. obscura* is regulated by evergreen forests in the island. Its congeners *O. sunia* and *N. affinis* presence is not giving importance to the presence of evergreen forests in an island (Figure 4.2). Mangrove, island area, Shannon diversity index, island shape and proportion of habitation also delimiting coexisting species pairs (Appendix 4.2)

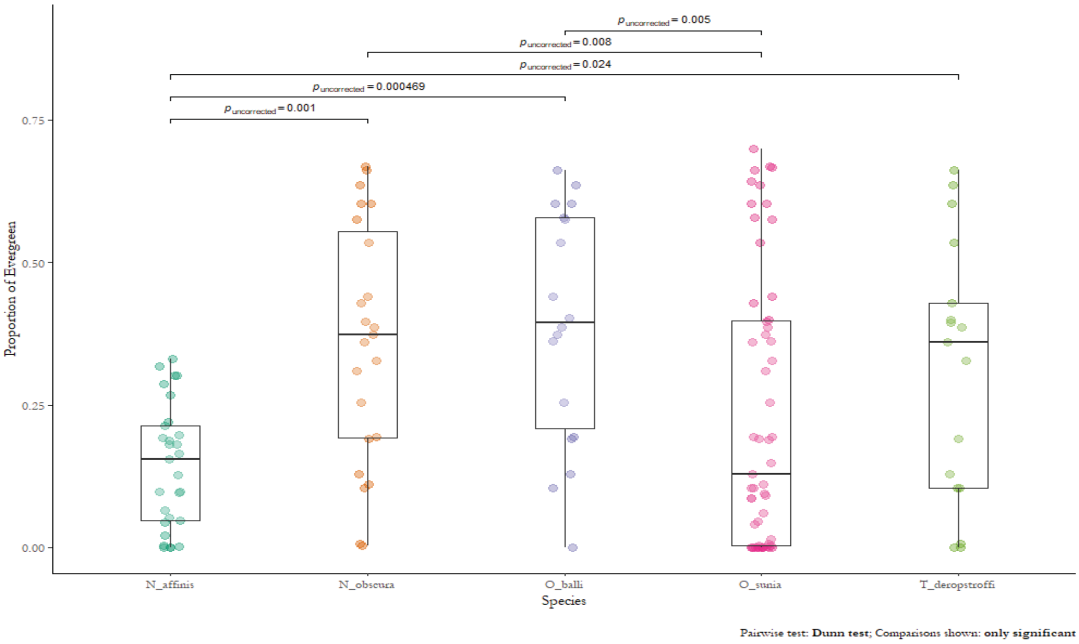


Figure 4.2. Pair wise comparison test of significance on proportion of evergreen forests in Offshore islands.

The multi-model inference of the island characteristics with respect to the species presence indicated that both positive and negative influences of island factors with respect to each species (Appendix 4.3.). The probability occurrence of the endemic *O. balli* increases with the increasing island area and the proportion of the evergreen forest patches. Its congener *O. sunia* occupied islands were closer to the mainland and the elongated shape of the island rather perfect round. The occupancy of *N. obscura* in an island increases with increasing habitat diversity and elongated shape of the island and decreases with increasing proportion of degraded forest and distance from mainland. Larger island area was preferred by *N. affinis*. The large-bodied Andaman Barn owl seemed to be preferred for larger islands with diverse habitat types (Table 4.4).

Table 4.4. Multimodal GLM of significant island characteristics for each owl species occurrence and their relationships

Species	Factor	Estimate	SE	Lower CI	Upper CI	P
O. balli	Area	0.16926	0.08382	0.0301	0.3084	0.0461
	Proportion Evergreen	3.46133	1.74283	0.5585	6.3640	0.0507
O. sunia	Distance mainland	-0.20589	0.07979	-0.3387	-0.0730	0.0111
	Shape index	6.6967	2.30227	2.8582	10.5351	0.0042
N. affinis	Area	0.20105	0.08945	0.0519	0.3501	0.0271
N. obscura	Cover	0.21272	0.08618	0.0689	0.3564	0.0153
	Distance mainland	-0.27651	0.11826	-0.4737	-0.0793	0.0216
	Proportion degraded	-40.9352	18.81909	-72.3085	-9.5618	0.0325
	Shape	10.36648	3.89394	3.8738	16.8590	0.0089
	Diversity	14.96212	6.06204	4.8528	25.0713	0.0153
T.deropstroffi	Area	0.03808	0.0182	0.0077	0.0684	0.0396
	Diversity	3.57862	1.42072	1.2115	5.9457	0.0133

When it comes to the diversity of owl species. The Shannon habitat variety index, the shape of the island, and the amount of all forest cover contributed to a rise in the number of owls. In a near major way, island area contributed to high species richness (Table 4.5). However, an experiment in which the form index was removed from the model constructing Island area was discovered to greatly contribute to the species richness.

Table 4.5. Multimodal GLM of island characteristics for each owl species richness and their relationships

Factor	Importance	Estimate	SE	Pr(>|z|)
(Intercept)		-1.673195	0.566771	0.0035
Area	0.48	0.00571	0.003303	0.0889
Forest cover	1.00	0.011574	0.00475	0.0165
Shape	0.85	0.601313	0.267973	0.0273
Shannon index	1.00	0.909206	0.292795	0.0022
Distance to mainland	0.46	-0.017928	0.012302	0.1524
Proportion Degraded	0.37	-2.502267	2.253593	0.2754
Proportion Deciduous	0.07	-0.388487	0.392562	0.3311
Proportion Evergreen	0.07	0.408208	0.393772	0.3086
Proportion Habitation	0.12	-0.51861	0.637131	0.4240
Proportion Mangrove	0.06	0.347441	0.449206	0.4474

4.4. DISCUSSION

O. sunia was the widely distributed owl species in the offshore islands of Andaman archipelago. Being identified as a eurytopic species (as discussed in chapter 2), it is found in all available forest types and modified landscapes in the offshore islands. Compared with the other owls in the Andaman Islands, global distribution range of *O. sunia* is much wider and it is also reported as both migrant and vagrant in many parts of its distribution range (Song, 2005), which signifies the species ability to move and occupy available places across its distribution range. This is also evident from my results that the proportion of islands occupied by *O. sunia* was the highest, irrespective of island size. The proportion of islands occupied by the endemic owl species were much lesser (Table 4.3) and this could be due to their poor dispersal abilities (Futuyma & Moreno, 1988, Kitahara et al., 2000, Kassen, 2002; Devictor et al., 2008). When relating the distribution of the owl in offshore islands with their relative abundances in the main Andaman Islands (Table 2.6, Page-37), the order of rarity ranking revealed that more abundant owl species had wider distribution range in offshore islands and this finding is corroborating with Davidar et al., (1997).

The post-hoc results showed a differential pattern of island selection among the owl species. Globally, in any island eco-system, the sympatric raptors’ distribution and their coexistence were primarily driven by the hierarchical use of available resource or in other words habitat segregation (Nijman, 2004). The habitat segregation between the two pairs of coexisting congeners namely *O. balli* ~ *O. sunia* and *N. obscura* ~ *N. affinis* in the offshore islands of Andaman were regulated by the proportion of evergreen (Figure 4.2). Among the Otus and Ninox genus, *O. balli* and *N. obscura* occupied an island when there is a large proportion of evergreen forests whereas in the case of *N. affinis* proportion of mangrove forests regulated the distribution (Figure 4.3). A similar kind of habitat segregation was reported between the Spotted Owls (*Strix occidentalis caurina*) and the Barred Owls (*Strix varia*) in their preference over mature conifers forests stands in western Oregon (Wiens et al. 2014). Similarly, a hierarchical use of undisturbed old mature forests was also found between the two congeners namely Elegant Scops-owl (*Otus elegans*) and Japanese Scops-owl (*Otus semitorques*) (Severinghaus, 1989; Brazil & Yamamoto, 1989).

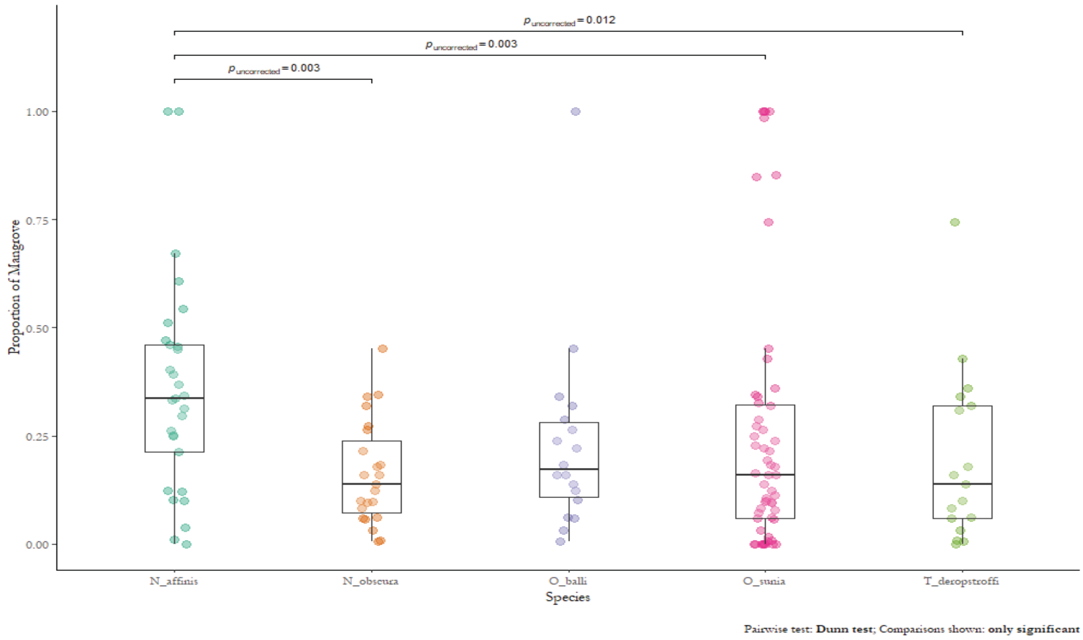


Figure 4.3. Pair wise comparison test of significance on proportion of mangrove forests in Offshore islands.

Factors influencing the occurrence and richness of owls

Island Area and Isolation: Out of four topographic variables considered for the analysis, three variables *viz.*, island area, shape of the island and distance to the mainland were found to influence both overall species richness and occurrence of all owl species. The observed relationship in this study between owl species and island area and isolation follows the global pattern of non-random species distribution in offshore islands (Island species-area relationship Martin et al, 1995). Several hypothesis has been developed using island area and isolation to explain the species-area relationship namely 1) Passive sampling hypothesis states that larger islands are expected to hold higher species richness due to its high carrying capacity and the ability to harvest/colonize larger number of species from the species pool compared with smaller islands (Burns et al., 2010; Connor & Mccoy, 1979), 2) habitat diversity hypothesis states that larger islands have greater number of habitat diversity thus holds high species richness (Bracewell et al., 2018; Gaston & Blackburn, 2000; Hortal et al., 2009) and 3) Equilibrium theory of MacArthur and Wilson, (1963 & 1967) explained that larger islands and closer to the mainland hold more species by minimising stochastic extinction (Gilbert & Levine, 2017; Vellend, 2016).

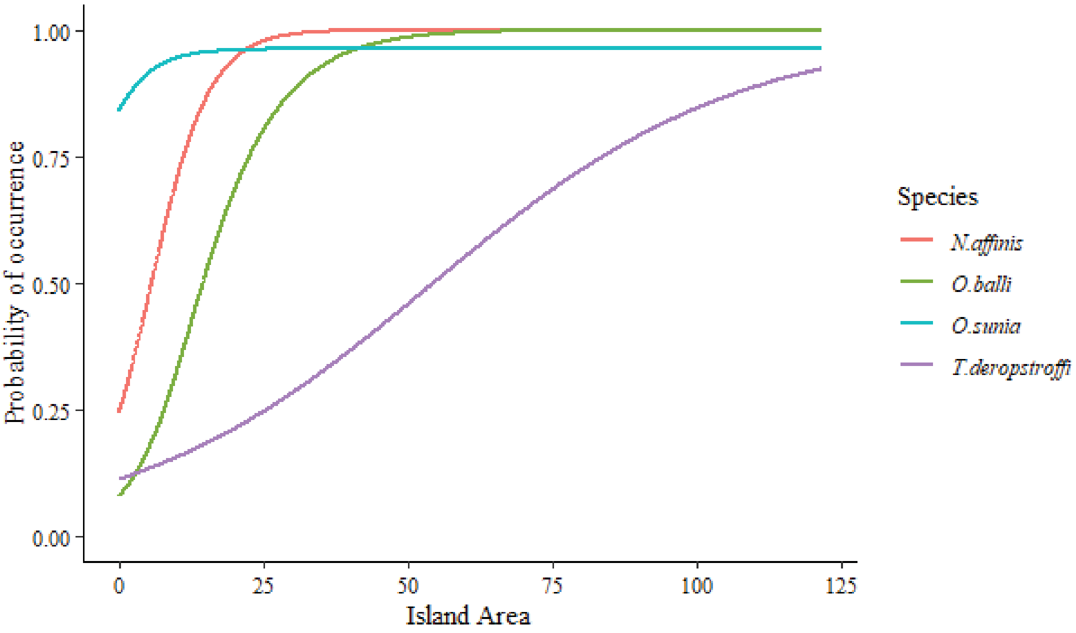


Figure 4.4. Probability of occurrence of different species of owls in response to island area (km^2), Andaman archipelago, India

Response curve of all owl species to distance to main island is not surprising while referring the island equilibrium theory of MacArthur & Wilson (1967). However, the curve of *O. sunia* in response to distance to the mainland (Figure 4.5) showed a negative relationship, which is more profound than other species of owls. Because many closer islands I surveyed are human altered either for tourism or plantation purposes (ex. Viper, Curlew, North passage, Swamp). Previous study (Davidar et al., 1997) showed that habitat quality in the islands of Andaman archipelago is associated with the distance to mainland because of the long history of selective or intensive logging. Usually, islands close to main island stretch are prone higher threat of forest clearing (Thiollay, 1997). This pattern was predicted on birds and butterflies of the same archipelago by Davidar et al. (1997).

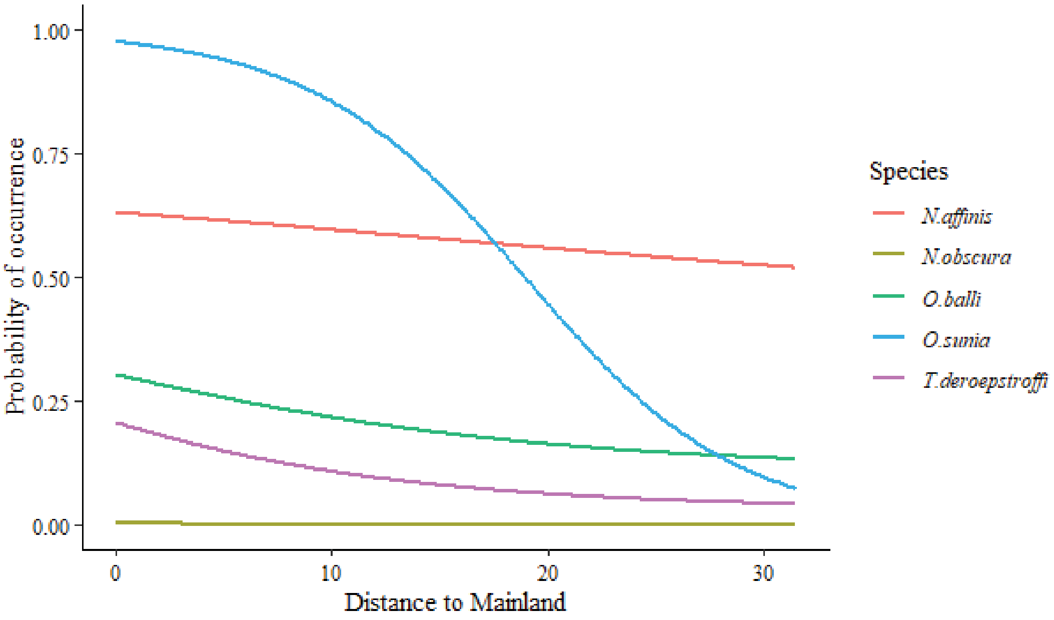


Figure 4.5. Owl species response towards island distance to mainland (km)

Shape of the island: The positive indication of elongated island shape preference by the all owl species except *T. deroepstorffi* and *O. balli* is related to the formation of these islands. The Andaman Islands were formed by the uplift event by the collision and associated subduction of Indian plate below the Eurasian plate (Curray et al., 1978, 1982; Hamilton, 1979). Thus, forming a double chain arc system with an elongated parallel chain of fragmented islands. However, the shape variable here in fact act as a surrogate for the island area for *T. deroepstorffi* and *O. balli*. Three species of owls responded to the shape of the islands *i.e.*, preferred elongate shaped islands (Figure 4.6). This is due to the availability of larger area parallel to the mainland increases the step-over points, which favours colonization. Study on the snail fauna in Ryukyu arc islands, Japan found that elongated islands parallel to the main island have high species richness and abundance than the round islands (Yamasaki et al., 1999). Another study on insect fauna in Aegean Islands found that the elongated islands had a greater number of rare and *K*-selected species because of their high habitat diversity (Fattorini, 2008). My results of species rarity receive this observed pattern, the rare endemic species are more associated with the elongate islands.

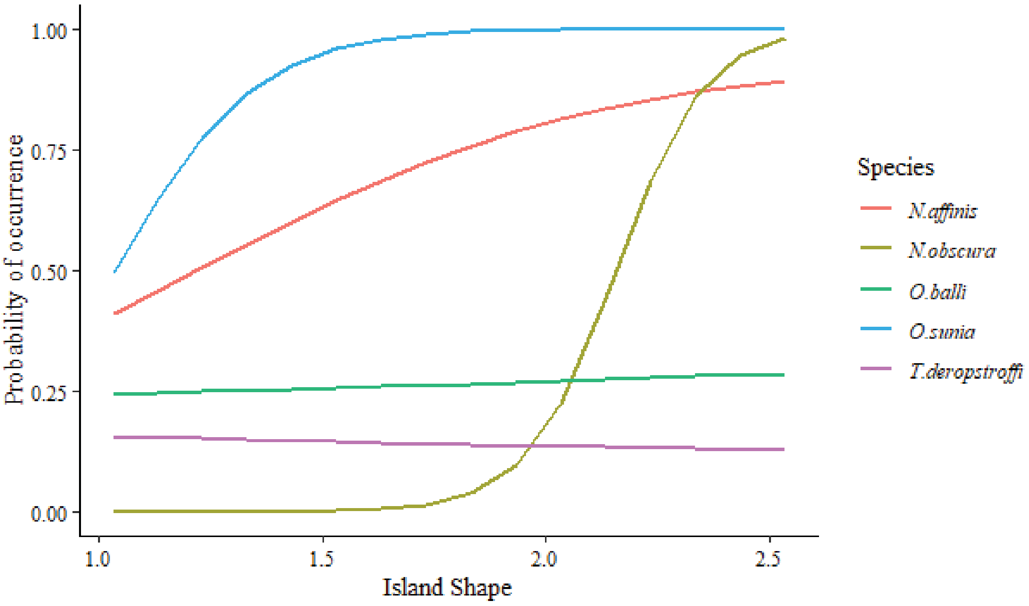


Figure 4.6. Owl species response towards island shape index

Forest cover and diversity: Shannon habitat diversity index and the total percentage of forest cover was found to be most important factor for the species richness of owls in the offshore islands of Andaman archipelago. The positive association with the increase in forest cover is not an uncommon phenomenon for the forest-specialist owl species because 83 insular owl species are associated with dense forest around the world (Marcot, 1995). Owl requires large forest cover and diversity of habitats within the island to meet various functional life history characteristics such as roosting, breeding and foraging (Hill & Lill, 1998a; Marshall, 1939; Gutíerrez et al., 1995). This is also found in smaller Hawk-owls using multiple sites for roosting, nesting, and foraging in their large territory (Hill & Lill, 1998b). And even after breeding, the juvenile may need larger forest cover to secure their population within the island (Lamberson et al., 1994). Since they need very large home ranges and many to survive and reproduce (Williams et al., 2011), the island with higher forest cover contained high species richness of owls in my study. The positive preference for higher diversity of habitat types in islands is the product of species-specific responses to the different habitat types (Figure 4.2 and 4.3). The diversity of habitats may provide higher prey, nest, and roost sites (Palomino & Carrascal 2007; Poirazidis et al. 2007).

Proportion of Evergreen: *O. balli* showed a significant positive relationship with the proportion of evergreen forests in the islands (Figure 4.7). The proportion of evergreen forests also contributed positively to the other two species (*N. obscura* & *O. sunia*) (Appendix 4.3) but their relationships were not significant. The greater species richness of owls in response to the wet evergreen forests in the offshore islands is because evergreen ("wetness") forests provide shelter for owls for day-time roost from the extreme temperature (Ali, 1977) irrespective of their foraging habitat type. For instance, Oriental Scops Owl prefers to forage on the forest edges, open canopied forests, or agricultural lands but it is observed to roost in the thickets of wet forests (Voous, 1988). Because wet evergreen forests in the tropical regions provide stable cooler temperature and very low wind speeds in both interseason and in different solar phases of the day (Thompson & Pinker, 1975).

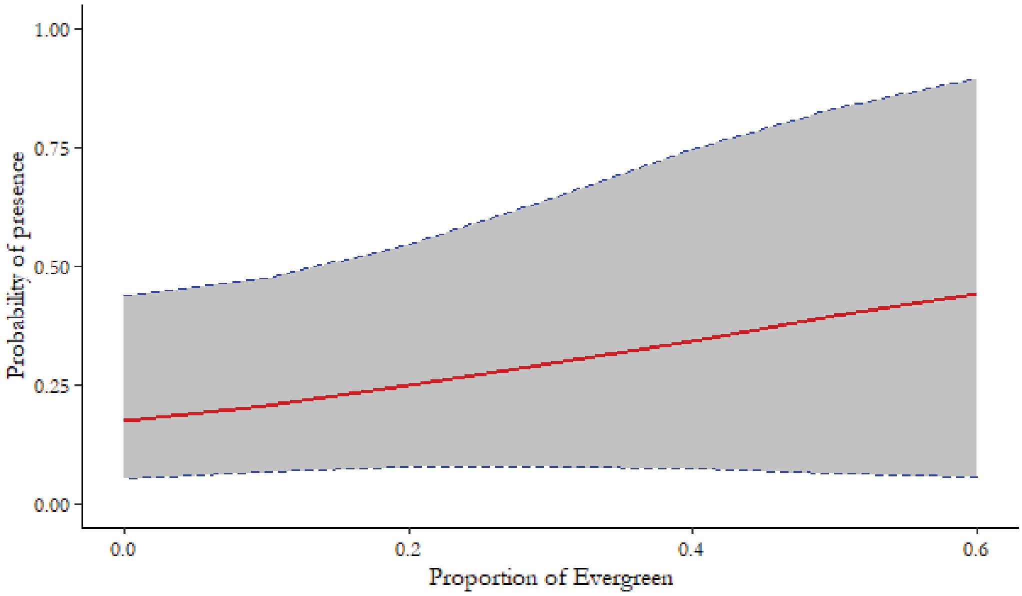


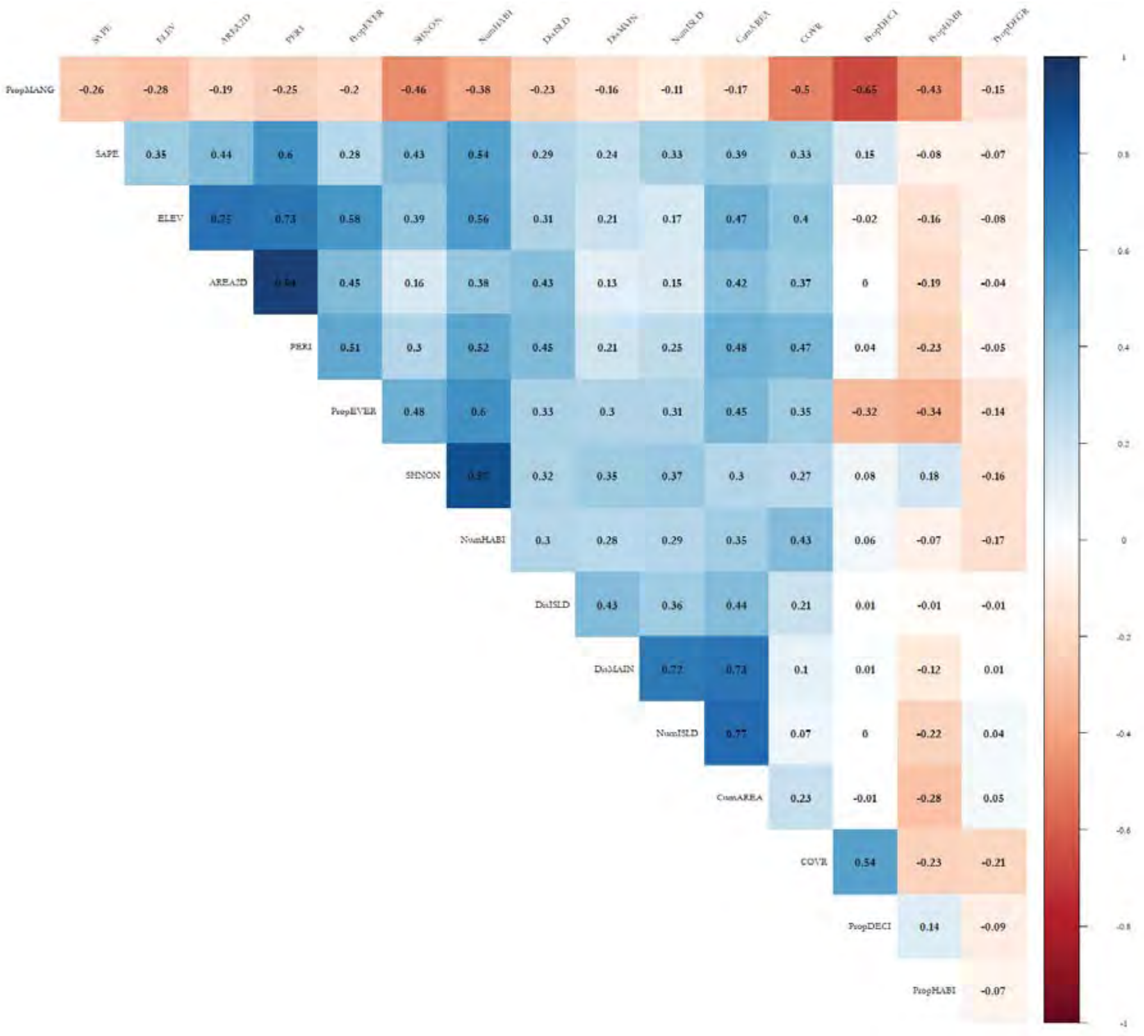
Figure 4.7. The relationship of island evergreen proportion to *O. balli*

Proporition of mangroves: Proportion of mangroves in offshore islands positively influences the species richness of owls in Andaman archipelago, despite a few species are recognized as other forest type specialists. These results were reflected in the previous study, on the habitat association of five species of diurnal raptor community in Andaman Islands, which indicated that four out of five species of raptors regularly use mangrove forests though they are forest specialists (Tholloy, 1997). Raptors are usually concentrated on the forest edges like mangroves during the breeding season for the high abundance of insect and the effect of edge species effect (Sarker & Sarker, 1985). This avoidance of primary forests by preferring forest edges and secondary forests were observed in another similar sized Otus *lempiji cnephaeus*

(Marks et al. 1999). Mangroves in the Andaman Islands were holding high species richness because mangrove species community was found to be primarily composed of aquatic feeders followed by insectivore's species (Jayson, 2001). Except Andaman Barn owl, all other smaller owls of Andaman are insectivores. Richness and abundance of insects is higher in open patches near wet mangroves during the night compared to the daytime (Janzen, 1973). So, the edges of mangroves attract insectivorous owls for foraging during the night hours. During the daytime, owls roost in thick woodlands and forage at night in the edges of mangroves. Sumba boobooks (*Ninox rudolfi*) uses coastal mangroves whereas its congener habitat generalist Little Sumba Hawk-owl (*Ninox sumbaensis*) uses all available habitat (Olsen et al., 2009).

APPENDIX

Appendix 4.1. Correlation matrix of 16 island factors used to predict the probability of species occurrence



	SAPE	ELEV	AREA2D	PERI	PropEVER	SHNON	NumHABI	DisISLD	DisMAIN	NumISLD	CumAREA	COVR	PropDECI	PropHABI	PropDEGR
PropMANG	-0.26	-0.28	-0.19	-0.25	-0.2	-0.46	-0.38	-0.23	-0.16	-0.11	-0.17	-0.5	-0.65	-0.43	-0.15
SAPE		0.35	0.44	0.6	0.28	0.43	0.54	0.29	0.24	0.33	0.39	0.33	0.15	-0.08	-0.07
ELEV			0.75	0.73	0.58	0.39	0.56	0.31	0.21	0.17	0.47	0.4	-0.02	-0.16	-0.08
AREA2D				0.94	0.45	0.16	0.38	0.43	0.13	0.15	0.42	0.37	0	-0.19	-0.04
PERI					0.51	0.3	0.52	0.45	0.21	0.25	0.48	0.47	0.04	-0.23	-0.05
PropEVER						0.48	0.6	0.33	0.3	0.31	0.45	0.35	-0.32	-0.34	-0.14
SHNON							0.87	0.32	0.35	0.37	0.3	0.27	0.08	0.18	-0.16
NumHABI								0.3	0.28	0.29	0.35	0.43	0.06	-0.07	-0.17
DisISLD									0.43	0.36	0.44	0.21	0.01	-0.01	-0.01
DisMAIN										0.72	0.73	0.1	0.01	-0.12	0.01
NumISLD											0.77	0.07	0	-0.22	0.04
CumAREA												0.23	-0.01	-0.28	0.05
COVR													0.54	-0.23	-0.21
PropDECI														0.14	-0.09
PropHABI															-0.07

Appendix 4.2. Species pairs response to each island characteristics. Significant different values are in bold letters.

Species Pair	Variable	X^2	P
N. affinis ~ N. obscura	Evergreen	3.41	**0.00065**
	Mangrove	-2.93	**0.00334**
	Habitation	0.335	0.737
	Deciduous	-0.348	0.728
	Degraded	0.829	0.407
	Cover	0.585	0.558
	Shannon Diversity	0.793	0.428
	Area	0.921	0.357
	Shape	1.04	0.298
	Distance to Mainland	0.133	0.895
	Distance to large Island	0.703	0.482
N. affinis ~ O. balli	Evergreen	3.5	**0.000469**
	Mangrove	-1.89	0.0585
	Habitation	-1.16	0.247
	Deciduous	-0.857	0.391
	Degraded	0.425	0.671
	Cover	0.522	0.602
	Shannon Diversity	0.119	0.905
	Area	1.21	0.227
	Shape	0.415	0.678
	Distance to Mainland	-0.189	0.85
	Distance to large Island	-0.203	0.839
N. affinis ~ O. sunia	Evergreen	1.26	0.208
	Mangrove	-2.93	**0.00335**
	Habitation	-0.339	0.735
	Deciduous	-0.448	0.654
	Degraded	-0.857	0.391
	Cover	-1.07	0.284
	Shannon Diversity	-1.64	0.102
	Area	-2.03	**0.0421**
	Shape	-1.58	0.115
	Distance to Mainland	-1.36	0.173
	Distance to large Island	-1.06	0.29
N. affinis ~ T.deroepstrofi	Evergreen	2.26	**0.0239**
	Mangrove	-2.52	**0.0117**
	Habitation	1.11	0.268
	Deciduous	-0.708	0.479
	Degraded	0.853	0.394
	Cover	-0.498	0.618
	Shannon Diversity	0.394	0.693
	Area	-0.195	0.846
	Shape	-0.668	0.504
	Distance to Mainland	-0.702	0.483
	Distance to large Island	0.0824	0.934
N. obscura ~ O. balli	Evergreen	0.31	0.757
	Mangrove	0.799	0.424
	Habitation	-1.4	0.161
	Deciduous	-0.509	0.611
	Degraded	-0.33	0.741
	Cover	-0.0219	0.983
	Shannon Diversity	-0.59	0.555
	Area	0.335	0.738
	Shape	-0.527	0.598
	Distance to Mainland	-0.298	0.766
	Distance to large Island	-0.817	0.414

N. obscura ~ O. sunia	Evergreen	-2.67	**0.00756**
	Mangrove	0.588	0.556
	Habitation	-0.69	0.49
	Deciduous	-0.0227	0.982
	Degraded	-1.72	0.0846
	Cover	-1.65	0.0994
	Shannon Diversity	-2.4	**0.0163**
	Area	-2.91	**0.00357**
	Shape	-2.63	**0.0086**
	Distance to Mainland	-1.41	0.159
	Distance to large Island	-1.77	0.0769
N. obscura ~ T. deroepstorffi	Evergreen	-0.819	0.413
	Mangrove	0.154	0.878
	Habitation	0.766	0.444
	Deciduous	-0.373	0.709
	Degraded	0.0904	0.928
	Cover	-0.987	0.324
	Shannon Diversity	-0.316	0.752
	Area	-0.99	0.322
	Shape	-1.55	0.122
	Distance to Mainland	-0.786	0.432
	Distance to large Island	-0.535	0.593
O. balli ~ O. sunia	Evergreen	-2.8	**0.00508**
	Mangrove	-0.388	0.698
	Habitation	0.994	0.32
	Deciduous	0.569	0.569
	Degraded	-1.19	0.232
	Cover	-1.48	0.139
	Shannon Diversity	-1.51	0.13
	Area	-3.05	**0.00227**
	Shape	-1.79	0.0732
	Distance to Mainland	-0.942	0.346
	Distance to large Island	-0.67	0.503
O. balli ~ T. deroepstorffi	Evergreen	-1.06	0.288
	Mangrove	-0.598	0.55
	Habitation	2.03	**0.0425**
	Deciduous	0.121	0.904
	Degraded	0.393	0.694
	Cover	-0.913	0.361
	Shannon Diversity	0.25	0.802
	Area	-1.25	0.212
	Shape	-0.971	0.331
	Distance to Mainland	-0.466	0.641
	Distance to large Island	0.255	0.799
O. sunia ~ T. deroepstorffi	Evergreen	1.45	0.148
	Mangrove	-0.349	0.727
	Habitation	1.5	0.134
	Deciduous	-0.409	0.682
	Degraded	1.65	0.0994
	Cover	0.337	0.736
	Shannon Diversity	1.79	0.074
	Area	1.47	0.142
	Shape	0.569	0.569
	Distance to Mainland	0.354	0.723
	Distance to large Island	0.967	0.334

Appendix 4.3. Individual island characteristic contribution to the top predicted model of each species of owls

	Variables	β coefficients	SE	z value	Pr(>|z|)
Otus balli					
	Intercept	-2.94433	1.42309	2.042	0.0411
	Area	0.16926	0.08382	1.995	0.0461
	Proportion of Habitation	-8.46233	5.01019	1.66	0.0970
	Shannon diversity	2.59601	1.60804	1.591	0.1117
	Distance to Mainland	-0.08505	0.05669	1.474	0.1404
	Proportion of Evergreen	3.46133	1.74283	1.954	0.0507
	Total forest cover	-0.02504	0.02389	1.031	0.3026
	Shape of Island	1.18244	1.20222	0.966	0.3339
	Distance to large island	-0.18503	0.20362	0.893	0.3721
Otus sunia					
	Intercept	-6.97361	2.98268	2.301	0.02140
	Area	0.21197	0.14007	1.487	0.13699
	Distance to Mainland	-0.20589	0.07979	2.539	0.01111
	Shape of Island	6.6967	2.30227	2.858	0.00427
	Proportion of Habitation	-3.75063	2.32816	1.59	0.11189
	Total forest cover	0.01839	0.01273	1.423	0.15468
	Proportion of Evergreen	2.70054	2.34199	1.134	0.25692
	Proportion of degraded	-4.34559	5.79714	0.736	0.46148
	Proportion of Mangrove	-2.14459	1.32352	1.594	0.1109
	Proportion of Deciduous	0.84374	1.1048	0.75	0.45318
Ninox affinis					
	Intercept	-4.25155	1.79712	2.333	0.0197
	Area	0.20105	0.08945	2.21	0.0271
	Shape of Island	2.23118	1.20677	1.818	0.0691
	Shannon diversity	1.14952	0.89933	1.257	0.2088
	Distance to Mainland	-0.05497	0.05087	1.062	0.2883
	Proportion of degraded	-4.92287	9.36399	0.517	0.6055
Ninox obscura					
	Intercept	-44.4537	16.20762	2.693	0.00707
	Total forest cover	0.21272	0.08618	2.424	0.01536
	Distance to Mainland	-0.27651	0.11826	2.297	0.02163
	Proportion of Degraded	-40.9352	18.81909	2.137	0.03258
	Shape of Island	10.36648	3.89394	2.615	0.00892
	Shannon diversity	14.96212	6.06204	2.424	0.01535
	Proportion of Mangrove	-6.51521	4.8526	1.32	0.18696
	Proportion of Deciduous	-3.74738	2.94869	1.247	0.21232
	Proportion of Evergreen	2.55346	2.49802	1.004	0.31539
	Proportion of Habitation	3.82881	4.87132	0.772	0.44036
Tyto deroepstroffi					
	Intercept	-4.2452	1.626	2.569	0.0102
	Area	0.03808	0.0182	2.057	0.0396
	Distance to Mainland	-0.09904	0.05906	1.647	0.0995
	Shannon diversity	3.57862	1.42072	2.477	0.0133
	Shape of island	-0.98641	1.21049	0.8	0.4235
	Proportion of Habitation	1.18599	1.93173	0.603	0.5465

CHAPTER 5

Owl assemblage in Andaman Archipelago

Andaman Hawk Owl

5.1. INTRODUCTION

In the early 19th century, the drivers of community assemblage had been viewed under two broad processes *viz.,* deterministic (imposed by abiotic environment and species interactions) and stochastic process (unpredictable disturbances and random birth-death events) (Clement, 1916; Gleason, 1926). Subsequently, community ecology had encountered several crossroads. Prior to 1960s, the ideas about communities in isolated systems (e.g., island communities) had been expected to be static. In the same period, the insightful observations of Hutchinson (1957) and the theoretical model of MacArthur & Wilson (1967) on Island biogeography changed the concept of static species assemblage and encouraged ecologists to explore the relationships between deterministic patterns of community organization and the mechanistic processes that produce them.

Assembly rules are defined as a unifying pattern that predicts the structure and composition of local ecological communities based on the regional species pool (Keddy, 1992). However, it has been highly debated among the community ecologists over several decades (Clements, 1916; Gleason, 1926; MacArthur & Levins, 1967; Pacala & Tilman, 1994; Hubbell, 2001; Lortie et al., 2004) to elucidate whether communities follow any structured assembly rules or it is driven by random processes (Diamond, 1975; Keddy, 1992; Fox & Brown,1993; Weiher & Keddy,1995; Wilson & Whittaker,1995; Watkins & Wilson, 1992). To explain the non-randomness, a set of models on assembly rules has been proposed and tested to explain community composition *viz.,* favoured states (Fox, 1987), Diamond’s rule (Diamond, 1975), guild proportionality (Wilson, 1989), size structure (Hutchinson, 1959; Case et al.,1983), and nestedness (Patterson, 1987) and to identify coalescing patterns in the composition and structure of species communities and the mechanisms driving them. In any assembly rule, two steps are involved 1) identification of which subset would occur on a specified island or habitat fragment from the regional pool and 2) evaluating which deterministic processes drive the identified pattern of assemblage. Weiher & Keddy (1999) grouped all proposed assembly rules into two paradigms 1) dispersal-driven assembly (“island paradigm” – process of immigration and extinction) and 2) niche-based assembly (“trait-environment paradigm” – species’ auto-ecological differences and environmental filters) (Hubbell, 2001; Soininen, 2008). These paradigms are highly inclusive, because species ability to disperse may influenced by their preferred niche characteristics or traits (McBendroth et al., 2005).

Here I evaluate two widely applied assembly rules such as Diamond's rule of interspecific competition and nestedness with the field data collected from Andaman archipelago.

5.1.1. Diamond's assembly rule

Among the proposed assembly rule models, Diamond's (1975) assembly rules are the most influential model till date to explain faunal assemblage, however, the concept of it was inspired from the theoretical concept of Island Biogeography (MacArthur & Wilson, 1967). General themes of "Equilibrium theory of insular zoogeography" (MacArthur & Wilson, 1963) are 1) Species numbers tend to increase with area, 2) Increase in isolation decreases the species numbers, and 3) Species numbers may be constant under these circumstances, but their composition changes due to frequent immigration and extinction.

Diamond (1975) examined the island biogeography theory along with the influential factors such as species dispersal ability, habitat availability, and the chance of colonization. He also emphasized the inter-specific competition was the most important determinant for the stable species combinations within the group of related species (ecological guilds). He was the first termed the concept "assembly rules" in community ecology. He proposed seven assembly rules explaining inter-specific interactions among species that structure the faunal assemblage,

1. "If one considers all the combinations that can be formed from a group of related species, only certain ones of these combinations exist in nature."

2. "These permissible combinations resist invaders that would transform them into forbidden combinations."

3. "A combination that is stable on a large or species-rich island may be unstable on a small or species-poor island."

4. "On a small or species-poor island, a combination may resist invaders that would be incorporated on a larger or more species-rich island."

5. "Some pairs of species never coexist, either by themselves or as a part of a larger combination."

6. "Some pairs of species that form an unstable combination by themselves may form part of a stable larger combination."

7. “Conversely, some combinations that are composed entirely of stable sub combinations are themselves unstable.”

Between 1970-80, an incessant debate began over the existence of inter-specific interaction in structuring faunal communities (for example: Connor & Simberloff, 1984; Diamond & Gilpin, 1982) and that resulted in developing null model approaches (Schluter, 1984; Stone & Roberts, 1990; Gotelli & Entsminger, 2001) to evaluate 1st, 2nd, and 5th rules of Diamond (1975). In most of the studies, the pattern of species assemblage adheres with the Diamond’s assembly rules (Gotelli & McCabe, 2002) and some do not. Rest of the Diamond’s rules have not been assessed hitherto using field data as it may require different set long-term monitoring and complex null models.

5.1.2. Nestedness

Darlington (1957) in his book titled “The Geographical distribution of animals”, coined the idea of subset distribution of animals. He described that species distribution on earth in various geographical regions, which is distinct now, was proper subsets of species derived from a single, formerly, widespread species pool. Although the pattern was first described nearly 50 years ago (Darlington, 1957), studies on nestedness were not widely used until the development of mathematical quantification technique to test the statistical significance against null models by Patterson & Atmar (1986). The nestedness model explains the patterns of observed insular species assemblages without inter-specific or inter-guild species competition (Blake, 1991; Bolger et al.,1991; Patterson, 1987). But the fact is, in nature, species community which are observed highly nested, composed of different ecological traits that minimized the competition (Patterson & Atmar, 1986). The hypothesis on nestedness derived by Patterson & Atmar (1986) explains the observed nested subset pattern, through species colonization or extinction mechanisms mediated by the abiotic factors such as inter-patch distance and area (Wright et al., 1998). The nestedness rule states that “if the species compositions of small communities are subsets of the larger communities, the assemblage is said to be nested in its distribution, and the species present on less diverse island will tend to occur on progressively more diverse islands.” (Patterson & Atmar, 1986; Atmar & Patterson, 1993).

Nested assemblage rule of species community has been observed and tested in various taxa and different type of localities, and it is proved to be the most ubiquitous bio-geographical pattern. (Wright et al., 1998). Although species community of perfectly nested subset has been commonly found in extinction driven land-bridge fragment systems, they also been examined in colonization driven insular oceanic archipelago systems. (Patterson, 1987, 1990; Patterson & Brown, 1991; Feeley, 2003; Burns, 2007). Other than extinction and colonization processes, there are also other factors such as area (Patterson & Atmar, 1986; Wright et al., 1998), isolation (Bender et al., 2017), habitat nestedness (Wang et al., 2010), habitat quality (Hylander et al., 2005), passive sampling (Zelmer & Gross, 2009), in-situ speciation (Rasolonjatovo et al., 2020), different species pools (Taylor, 1997), human factors (Fernández-Juricic, 2002), disturbance (Herczeg & Horvath, 2015), and assembly rules (Diamond, 1975) that form nested assemblage of species in insular communities.

In many studies, the nestedness pattern in species assemblage has been proved across taxa and region. In birds, the perfect nested assemblage was studied in Venezuela (land-bridge islands of Lake Guri) resulted that the nestedness of avian assemblage was found to be driven by the selective species loss by differential extinctions rather inter-specific competition (Feeley, 2003). The same significant nested pattern was found from the 20 bat species composition from 11 seasonal land-bridge islands of Lake Gatun, in Panama (Meyer & Kalko, 2008). Subsequently, it received substantial recognition in the field of conservation and management of fragmented landscapes and their species. Further, the theory has been tested for the proper reserve design and acquisition as its highly deals with the “single large or several small” island debate, however, their usage in the biodiversity conservation is still limited (Martinez-Morales, 2005; Fischer & Lindenmayer, 2002).

The Andaman and Nicobar Islands, a major island group in the Bay of Bengal, consists of three major groups of islands (Andaman group, Nicobar group, and volcanic group) with around 8,249 km^2 area surrounded by offshore islands on either side (Vijayan & Sankaran, 1997). Among them, Andaman group consists of 325 offshores islands of varied sizes (0.36 to 690 km^2), habitats (littoral, evergreen, and mangrove forests) and distance from the main island and 21 islands are occupied by humans either as settlements or plantations (Lakshminarasimhan & Rao, 1996; Vijayan & Sankaran, 1997). This system provides the natural laboratory to test some of the faunal assembly rules. Two studies have been carried out in the Andaman and Nicobar Islands focusing on birds (Davidar et al., 2002; Zaibin, 2016) and butterflies (Davidar et al., 2002) to test the co-occurrence and nestedness patterns. However, these studies ignored the nocturnal birds especially owls from the analysis. Furthermore, no study has been carried out on owls (raptors) to address the co-occurrence and nestedness pattern globally. In this context, this study tested Diamond’s assembly rules and nestedness using owl data collected from 73 offshore islands Andaman Islands, India.

This study would shed light on the factors (competition, selective extinction, and nestedness) that influence assemblage of owls in offshore islands of the Andaman Islands. The results have high conservation value in managing the offshore islands.

5.2. METHODS

5.2.1. Data collection

I used the same owl occurrence records of offshore islands in chapter 4 (Table 4.1. page-85) and the method used to collect the data are described in detail in chapter 4 (Section 4.2). The same set of data was used to evaluate these two assembly rules.

5.2.2. Statistical Analysis

The collected data used to prepare a presence and absence matrix of all owl species in 73 islands for testing the assembly rules *viz.*, Diamond's rules (using C-score and number of species combinations) and nestedness (Nestedness for Dummies – NeD – Strona et al., 2014).

5.2.2.1. Diamond's assembly rule

To test the Diamond's assembly rules 1st, 2nd and 5th, I used two statistical indices of co-occurrence namely C-score (checkerboard score - Stone & Roberts, 1990) and the number of unique species combinations (Pielou & Pielou, 1968). In addition to these two indices, there are rather a few co-occurrence indices that test these three rules. However, these two indices have been widely applied for testing Diamond's assembly rules in island communities (Gotelli & McCabe, 2002; Feeley, 2003). Other Diamond's rules (3rd, 4th, 6th, and 7th) were not appraised as it requires more complex null models and field effort (Gotelli & McCabe, 2002). To test the 1st and 2nd assembly rule of diamond also known as co-occurrence rule, I used the number of unique species combination index. According to these rules of co-occurrence, the predicted unique competing species combinations among fragmented species communities shall be lower than expectation by chance. (Pielou & Pielou, 1968; Gotelli & McCabe, 2002). C-score measures the average number of checkerboard units between all possible pairs of species in the matrix and it supports the fifth assembly rule of Diamond (1975). Checkerboard units are calculated using a simple formula "$CU= (R_i-S)/ (R_j-S)$", where R_i & R_j denotes the sum of i & j species occurrences in all surveyed sites (R) and S denotes the number of sites both species co-occurred. It would result if a community composed of competing species pairs, the observed C-score value is expected to have larger values than expected by chance (Gotelli & Entsminger, 2001; Gotelli & McCabe, 2002).

Null models and randomization algorithms

The standalone EcoSim 7.0 software was used (Gotelli & Entsminger, 2006) to calculate the two co-occurrence indices using presence and absence matrix of species in rows and islands in columns. The usage of correct algorithm for randomization and suitable null model selection is crucial in co-occurrence analysis. Based on the observed pattern, Monte Carlo randomization procedure was conducted 5000 times using fixed row and fixed columns (FF) procedure. To generate appropriate null models, sequential swap algorithm was used, this method was criticized for the validity issue and its prone to type II error (Gotelli & Entsminger, 2001), However its performance and statistical robustness were re-evaluated later by Gotelli & Entsminger (2003) and confirmed the reliability and effectiveness. Two null models were applied by altering the column and row totals: 1) “Fixed-fixed (FF) in which column and row totals are fixed”, 2) “Fixed-weighted (FW) - Column weighting adjusts the probability of a species occurring at a particular site during randomization using factors thought to contribute to inter-site differences in community composition (Gotelli & Ellison, 2002; Jenkins, 2006)”. Weighted the null models using column constraint with the area (FW-area) and isolation (FW-isolation) to check the effect of these characteristics on null model analysis.

5.2.2.2. Nestedness

To calculate nestedness, the data matrix was arranged in way that containing sites in column and species in rows. The nestedness in owls of Andaman Islands were assessed at different levels by grouping the islands into meaningful clusters such as, all sites together, islands within Mahatma Gandhi National Park (MGNP), south Andaman (SA), middle Andaman (MA), north Andaman (NA), and Ritchies’ Archipelago (RA) and details of island come under each group is given in Table 5.1. Several models have been proposed to address the nestedness in insular communities and these models vary in metrics used to calculate nestedness and the null model (Ulrich & Gotelli, 2007). Each model has been highly debated about their own positive and negative aspects in estimating the nestedness (Ulrich et al., 2009). Here I used online package - Nestedness for Dummies (NeD) - to quantify nestedness in owls of the Andaman Islands because it allows selecting different nestedness matrices such as “Nestedness metric based on Overlap and Decreasing Fill – NODF” (Almeida-Neto et al., 2008), “Brualdi and Sanderson discrepancy Index – BR” (Brualdi & Sanderson, 1999) and “Matrix Temperature (MT)” and combining them with different rearrangement null models (Strona et al., 2014). Brualdi and Sanderson discrepancy index (BR) and fixed rows and fixed columns based on Curveball algorithm was used (Strona et al., 2014) as metric and null model respectively for calculating the nestedness using 1000 simulations. Idiosyncrasy analysis was done for owls (Almeida-Neto & Ulrich, 2010). Although the nestedness temperature calculator and the temperature metric proposed by Atmar & Patterson (1993) has been highly criticized for its bias in calculating the nestedness, it has been used in earlier studies in the Andaman and Nicobar Islands (Davidar et al., 2002; Zaibin, 2016) and for comparison purpose those programmes used here using for the owl data.

Table 5.1. Names of islands into different groups for Nestedness analysis. (Specific locations can be referred from table 4.1; figure 4.1)

MGNP	Middle	North	Ritchie's	South
Alexandra	Guitar	Bamboo	Havelock	Duncan
Belle	Interview	Curlew	Henry Lawrence	James
Boat	Long	Delgarno	Inglis	Kyd
Chester	Middle Button	Dot	John Lawrence	North Cinque
Gurb	North Button	East	Neill	Pitman
Hobday	North Passage	Excelsior	Nicolson	Potanma
Jolly buoy	Oyster II	Gander	Outram	Rutland
Malay	Parkinson	Goose	Peel	South Cinque
Pluto	Round	Jungle	Wilson	Twins I
Redskin	Avis	Landfall		Twins II
Snob	Bondoville	Latouche		Viper
Tarmugli	Buchanan	North Reef		
	Curlew BP	Oliver		
	Dottrelle	Paget		
	Egg	Peacock		
	Gurjan	Point		
	Sea Serpent	Reef		
	Snake	Temple		
	South Reef	Trilby		
	Swamp	Turtle		
		West		

5.3. RESULTS

Recorded all five species of owls, observed in the Andaman Islands, in offshore islands. In nine islands (~11%), all five species were recorded. No owls were encountered in 15 islands (~20%). Among the surveyed islands, *O. sunia* occurred in 77% of islands but its sympatric species (*O. balli*) was recorded in less number of islands (18%). Similarly, among the hawk owls, *N. affinis* was recorded in relatively more islands than *N. obscura*. Compared the main stretch, *T. deroepstorffi* was frequently encountered in islands. Log number of species richness in an island is significantly correlated with log island size (Figure 5.1; $R^2 = 0.346$; $P < 0.001$) and marginally significant with log isolation (Figure 5.2; $R^2 = 0.055$; $P < 0.05$).

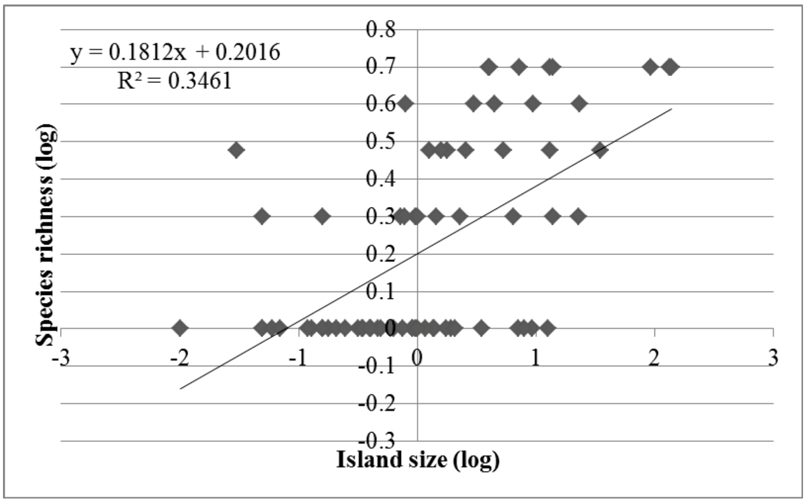


Figure 5.1. The effect of island size on the species richness of owls in Andaman Islands

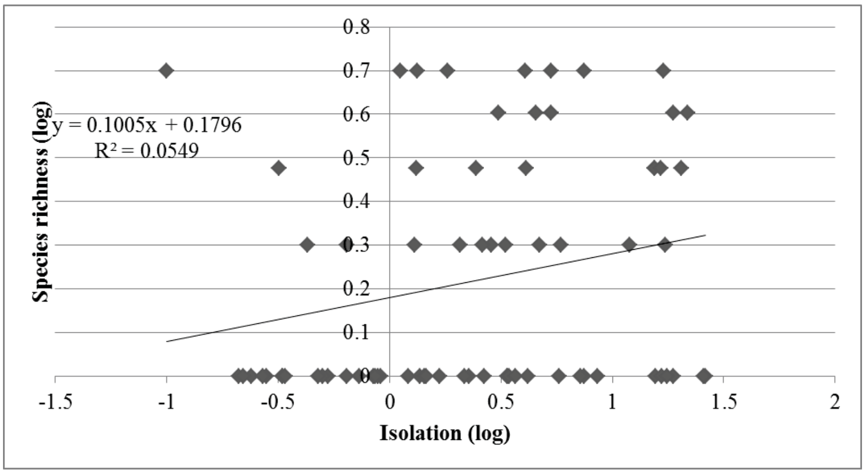


Figure 5.2. The effect of degree of isolation on the species richness of owls in Andaman Islands

5.3.1. Diamond's Assembly Rule

The number of species combinations (Observed index = 11.00; Expected index = 10.310) and C-score (Observed index = 16.1; Expected index = 15.08) were not significantly different from the null values produced using Sequential Swap Algorithm and FF null model (P > 0.05). When used island size and isolation as column constraint in null models for both the co-occurrence indices. The weighted C-score by area and isolation (FW-area and FW-isolation) did not deviate from the null models, which indicates species co-occurrences as random. However, a number of unique species combination with FW-area and FW-isolation produced a significantly non-randomness pattern for owls in the Andaman Islands. It can be interpreted that owl community in offshore islands are structured by inter-specific competition when island area and isolation is used as column constraint in null models (Table 5.1).

Table 5.2. Results of C-score and unique species combinations indices of owls in Andaman Islands with standardized effect sizes [SES] and probability (values)

Index	Matrix	Score			
		Observed	**Sim_{FF}**	**$\text{Sim}_{FW\text{-}area}$**	**$\text{Sim}_{FW\text{-}isolation}$**
C-Score	All species/ All sites	16.1	15.080 (0.152) [0.85]	30.733 (0.959) [-1.60]	54.971 (0.999) [-2.99]
Unique Species Combination	All species /All sites	11	10.310 (0.617) [-0.51]	**13.390** **(0.082)** **[-1.72]**	**15.678** **(0.0016)** **[-3.25]**

5.3.2. Nestedness

When all owl species and islands were considered, the assemblage of owls in the Andaman Islands was not significantly nested than expected by chance. In addition, owl composition in subsets of islands also did not adhere to the nestedness pattern (Table 5.2 & 5.3; Figure 5.3). However, nestedness temperature calculator showed a significant nested pattern of owls in the Andaman Islands than expected by chance (Figure 5.4). Out of five owl species, two species namely *O. balli* and *T. deroepstorffi* showed high idiosyncratic scores and one species, *N. affinis*, showed marginal idiosyncratic scores. All these species are endemic to the Andaman Islands and poor dispersal species. Only two eurytopic species *viz.*, *O. sunia* and *N. obscura* showed high nestedness.

Table 5.3. Summary of results of nestedness measures for all islands and subset of islands in Andaman Islands

Matrix	**Nestedness measures**			
	BR Index	**z-score**	**Relative nestedness**	***p***
All Sites	**15.0**	**-0.028**	**-0.003**	**>0.05**
MGNP	2.0	**0.0**	**0.0**	**>0.05**
MA	0.00	NA	NA	NA
NA	**5.0**	**-0.783**	**-0.071**	**>0.05**
RA	**1.0**	**-0.75**	**-0.265**	**>0.05**
SA	**2.0**	**0.718**	0.205	**>0.05**

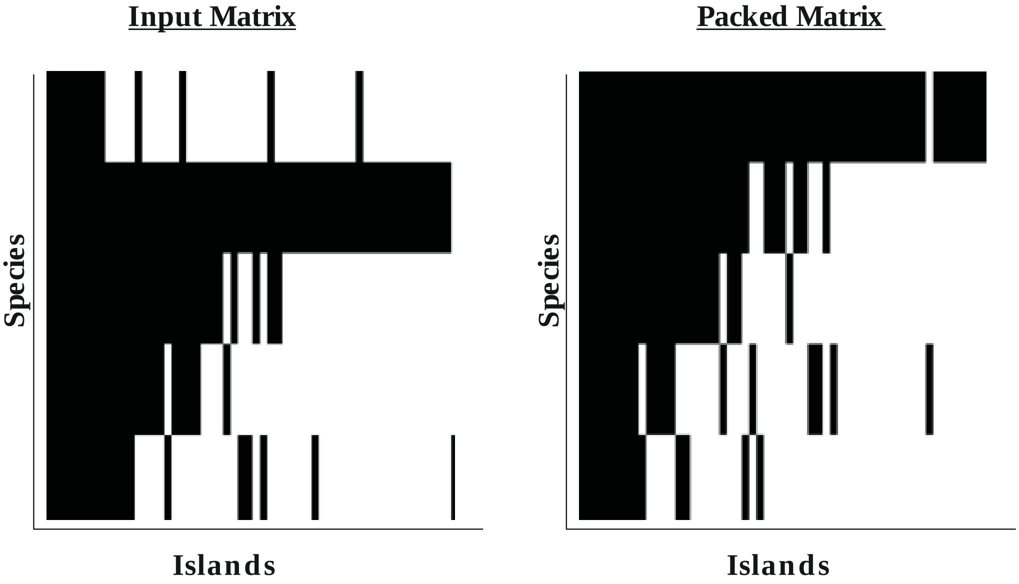


Figure 5.3. details the input matrix and maximally packed matrix by nestedness for Dummies (NeD)

Table 5.4. Maximally packed presence–absence matrix of five owls in 73 offshore islands of Andaman and idiosyncratic scores of each owl species is also given

Islands	***O. sunia***	***N. affinis***	***N. obscura***	***T. deroepstorffi***	***O. balli***
Swamp	1	1	1	1	1
Alexandra	1	1	1	1	1
Landfall	1	1	1	1	1
Long	1	1	1	1	1
Paget	1	1	1	1	1
Boat	1	1	1	1	1
Interview	1	1	1	1	1
Rutland	1	1	1	1	1
Havelock	1	1	1	1	1
Tarmugli	1	1	1	1	0
East	1	1	1	1	0
Point	1	1	1	1	0
South Cinque	1	1	1	1	0
Henry Lawrence	1	1	1	0	1
Hobday	1	1	1	0	1
North Passage	1	1	1	0	1
Bondoville	1	1	1	0	0
Curlew	1	1	0	1	0
Outram	1	1	1	0	0
John Lawrence	1	1	1	0	0
Nicolson	1	1	1	0	0
North Cinque	1	1	1	0	0
Snob	1	1	0	0	1
Trilby	1	1	1	0	0
Delgarno	1	1	0	0	0
West	1	0	1	0	0
Guitar	1	1	0	0	0
Snake	1	0	0	1	0
Sea Serpent	1	0	0	1	0
Oliver	1	1	0	0	0
Egg	1	0	0	1	0
Peel	1	1	0	0	0
Wilson	1	1	0	0	0
Dot	1	0	0	1	0
Gander	1	0	0	0	1
Bamboo	1	1	0	0	0
Curlew BP	1	0	0	0	0
Avis	1	0	0	0	0
Reef	1	0	0	0	0
Buchanan	1	0	0	0	0
Dottrelle	1	0	0	0	0

Gurjan	1	0	0	0	0
North Reef	1	0	0	0	0
RedSkin	1	0	0	0	0
Malay	1	0	0	0	0
Belle	1	0	0	0	0
Excelsior	1	0	0	0	0
Round	1	0	0	0	0
Oyster	1	0	0	0	0
Parkinson	1	0	0	0	0
Pluto	1	0	0	0	0
Peacock	1	0	0	0	0
Inglish	1	0	0	0	0
Kyd	1	0	0	0	0
Potanma	1	0	0	0	0
Pitman	1	0	0	0	0
Viper	0	0	0	1	0
Grub	1	0	0	0	0
Chester	0	0	0	0	0
Middle Button	0	0	0	0	0
North Button	0	0	0	0	0
Turtle	0	0	0	0	0
South Reef	0	0	0	0	0
Jungle	0	0	0	0	0
Latouche	0	0	0	0	0
Goose	0	0	0	0	0
Jolly buoy	0	0	0	0	0
Twins I	0	0	0	0	0
Twins II	0	0	0	0	0
Neill	0	0	0	0	0
James	0	0	0	0	0
Duncan	0	0	0	0	0
Temple	0	0	0	0	0
Species	57	30	23	19	14
Number of islands	57	30	23	19	14
Idiosyncrasy	0.018	0.103	0.091	**0.278**	**0.308**

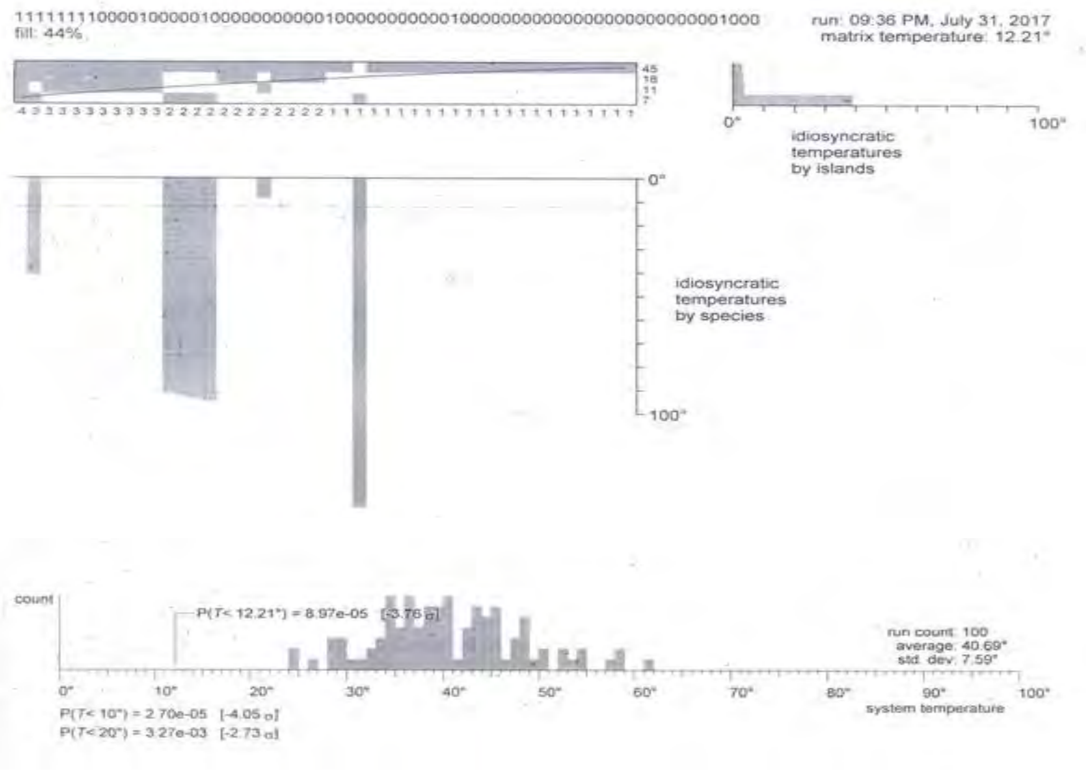


Figure 5.4. Maximally nested matrix of owl distribution with matrix temperature and fill, idiosyncratic island, and species temperatures

5.4. DISCUSSION

This is the first study of its kind in the Andaman archipelago testing the assemblage of nocturnal birds of prey in offshore islands. Low species richness of owls in Andaman Islands limited me to test only two niche-based assembly rules (*i.e.*, Diamond's assembly rule and Nestedness pattern) but not functional-based rules (for example: guild proportionality, favoured states and size structure). No owls were observed in ~20% islands and it can be related to the absence of vegetation cover and small size of the islands. Other than main stretch islands (south, middle, and north Andaman), five owl species were recorded from ~11% of islands. While comparing the encounter rate of owls in main stretch and occupancy of offshore islands, it is found that the *O. sunia* is dominating in both main and offshore islands of Andaman. *N. obscura* and *O. balli* appear like poor dispersers in offshore islands whereas *T. deroepstorffi* and *N. affinis* are good dispersers in offshore islands. This requires further evaluation explaining the antagonistic and synergistic interaction between sympatric owl species

Table 5.5. Encounter rate and occupancy of owls in north Andaman and offshore islands of respectively in Andaman

Common Name	Guild	% Of islands occupied (No.)	Encounter rate in north Andaman
Oriental Scops Owl *Otu ssunia*	Foliage gleaning Insectivore	77.7% (56)	0.79 (375)
Andaman Scops Owl *Otus balli*	Foliage gleaning Insectivore	18.0% (13)	0.55 (260)
Andaman Hawk Owl *Ninox affinis*	Hawking Insectivore	40.3% (29)	0.67 (317)
Hume's Hawk Ow l*Ninox obscura*	Hawking Insectivore	30.5% (22)	0.77 (363)
Andaman Barn Owl *Tyto deroepstorffi*	Carnivore	25.0% (18)	0.032 (15)

Results of C-score and unique species combinations with FF null models indicated that owl species composition in the Andaman Islands is not structured by inter-specific interaction. Co-occurrence indices are highly sensitive to weighing factors as it provides further support for the null model (Jenkins, 2006). Because in FF null models preserve species occurrence totals (both row and column) and compare results with the species forbidden pairs in each given set of occurrence data in respect to their competitive interactions (Gotelli & McGill, 2006). In advanced null model algorithms (FW), additional data weights such as island size, isolation (Peres- Neto & Jackson, 2001) and abundance of species (Gotelli & Ellison, 2002) can be incorporated to assess the effect of both abiotic filters and biotic interactions on species assemblage. In this study, I considered both island size and island isolation as weighing factors for both indices. Even after incorporating the weighing factors, the results of C-score did not provide any evidence for the presence of inter-specific interaction. However, the results of unique species combinations did provide support for the presence of inter-specific competition in structuring the owl assemblage in Andaman, in both FW-area and FW-isolation. It can be concluded that owl assemblage in the Andaman Islands is structured in accordance with Diamond’s 1st and 2nd assembly rules (*i.e.,* a set of islands harbour significantly fewer species combinations than expected by chance). This finding is corroborating with results of the meta-analysis of 96 published presence-absence data of different taxa (Gotelli & McCabe, 2002).

Habitat and stratum use of owls in the Andaman Islands was different between species as discussed in chapter 2 and 4. Within two Scops Owls, *O. sunia* is occupying all available habitats and stratum, however, *O. balli* is using evergreen and deciduous dominating areas with bamboo cover and it preferred understory stratum. This is clear that *O. sunia* is dominating and have high dispersal ability in offshore (evidenced by the high percent of island occupancy), over the endemic *O. balli*. *O. balli* in Andaman appears like suppressive species, and it might have excluded from the competition with the eurytopic *O. sunia*. Similarly, *N. affinis* is dominating over the *N. obscura* in habitat use and stratum use as evidenced by low island occupancy of *N. obscura* in offshore islands. Such competition might be higher in islands close to main stretches and small. Because the island close and small increases the competition between the sympatric species and obviously the suppressive species might vacate the island over dominant species. However, when the island is large with diverse habitats, it is expected to avoid less competition for coexistence and form unique combinations.

Nestedness was assessed using two statistical approaches: NeD (Nestedness for Dummies) and Nestedness Temperature Calculator. Nestedness calculator showed significant nestedness in owl assemblage and it is corroborating with the earlier two studies that tested the nestedness pattern using NTC on birds and butterflies of Andaman and Nicobar Islands. Nestedness temperature calculator was used to predict the nested assembly pattern in different taxa for many decades, including amphibians (Ficetola & De Bernardi, 2004), birds (Patternson & Atmar, 2000), and even insects (Davidar et al., 2002). However, this approach has been highly criticized for overestimating the actual nestedness level (Fischer & Lindenmayer, 2002).

NeD did not show significant nestedness pattern for the owl in the Andaman Islands. In contrast to my observation, Davidar et al., (2002) found that birds and butterfly species in the archipelago assembled as proper subsets of the species rich and large main islands. Furthermore, they also inferred that this archipelago was a land bridge and selective extinction process might have caused the perfect nestedness of species in the offshore islands of Andaman. Recently Zaibin (2016) tested the nestedness pattern in birds of Nicobar Islands and found random species assembly. In contrasting to Davidar et al., (2002), he concluded that colonization is the process for the randomness and Nicobar Archipelago may be oceanic in origin. The findings of Zaibin (2016) are corroborating with my observation in the Andaman Islands. In addition to colonization assumption, the dispersal ability of owls to cross small barriers in search of food and nesting sites might have played a role in the formation of an anti-nested pattern for owls in the Andaman. Due to their dispersal ability and frequency of species exchange between offshore islands may lower the selective extinction process and hence, the anti-nestedness pattern was observed in owls.

CHAPTER 6

Summary and Conclusions

Andaman Scops Owl

Owls are fascinating avian predators dominating the nocturnal skies silently perhaps over 70 million years long. Due to their high metabolic rate, each species defined their ecological niche by prey or habitat selection in a unique way to minimize competition and ensure their constant high demand of food requirement. This selection pressure subsequently improves their survival and reproduction by morphological and anatomical adaptations. The occurrence of owls in Andaman Islands was found couple of centuries back but their elusive behaviour and the dense tropical forest canopy of Andaman Islands makes them difficult to study on their basic ecology, which forbids them to include advance ornithological studies. Due to this fact, Andaman owl's population, distribution pattern and threats have been ideological rather scientific. This thesis is an attempt to develop such base line information on owls with two broad objectives: (1) to assess the relative abundance and occupancy of owls in the Andaman Islands and (2) to evaluate various species assembly rules in offshore islands using owls as model organism.

A detailed review of published literatures and technical reports on the avifauna of Andaman revealed that there is little information available pertaining to population status, anthropogenic threats and ecology of owls. Therefore, I did a survey with an aim to elucidate the environmental gradients (such as land-cover types, logging intensity) that influence the distribution and abundance of owls in the Andaman Islands. In addition, I also assessed the perception of local people about owls and effect of human activities on roosting owls using experimental and evidence-based study. I sampled along the Andaman Trunk Road (ATR) of Andaman Islands (South, middle and north Andaman Islands) following point count method with 100 m radius plots to assess the distribution and abundance of owls. Questionnaire surveys were conducted among the residents of six marketplaces of North Andaman Island to elucidate the people's perception about owls. Effect of human activities on the roosting owls were evaluated using Flight initiation distance and flush response of roosting owls in response to human stumili. I confirmed occurrence of all owls in four major islands viz., South, Middle, Baratang and North of Andaman. The distribution range of owls in the Andaman Islands is much larger than it was depicted in the field guides and previous literature. The overall mean encounter rate of species and abundance of individual owls were 1.48 species/point and 2.09 individuals/point respectively. *Otus sunia* and *Ninox obscura* had significantly higher encounter rate and mean abundance than stenotopic *Ninox affinis* and *Otus balli*. *Otus sunia* and *Ninox obscura* used all available land cover types in Andaman Islands almost equally while *Ninox affinis* and *Otus balli* used deciduous and evergreen forests respectively. Both *Otus balli* and *Ninox affinis* avoid agriculture and plantations. Based on the habitat use pattern, it is found that *Otus balli* and *Ninox affinis* require specialized habitat requirement and thus, it has been categorized as “stenotopic species” while *Otus sunia* and *Ninox obscura* as “eurytopic species” of Andaman Islands.

I interviewed 203 respondents from six marketplaces in North Andaman tehsil and collected data on their socio-economic status as well as their knowledge about owls. All the respondents were familiar with owls. However, only 9% of them identified all species of owls in the Andaman Islands. There were several superstitious beliefs revolving around owls. Two species, *Otus sunia* and *Ninox obscura* were associated with negative beliefs while *Tyto deroepstorffi* was associated with positive beliefs. Generalized linear model with the demographical predictors showed that positive attitudes towards owls was associated with age (older), education (literacy), revenue villages and temporary houses. So, I suggest that *Tyto deroepstorffi* may be considered as a focal species to create awareness about owls and to protect other endemic owls of the Andaman Islands as it has high positive values among the locals. Future awareness programmes targeting younger, illiterate people, and land encroachers may help in the conservation of cryptic owl species of Andaman.

Effects of anthropogenic pressures on birds of the Andaman Islands have been documented to some extent, however studies on the effect of human activities on the behavioural response of these birds are limited. In this scenario the results of the anti-predatory behaviour (flush response - FR and flight initiation distance - FID) of three owl species (*Otus sunia*, *Otus balli*, and *Ninox obscura*) in response to human stimuli and factors influencing it shed some light to the species conservation on the Andaman Islands. Sixty-three percent of owls flew from roost in response to human stumili and varied with species. Similarly, FID varied widely among the species ranging from 4.23 to 6.73 m. The FR of *Ninox obscura* was influenced by the count of climbers, presence of spine, and branch status, while roost height, ambient temperature, and lower count of climbers contributed to a higher FID. For the two *Otus* species, camouflage and pairing were found to influence their FR while FID of *Otus balli* was influenced by roost height, pairing, and presence of spines. Results indicated that the anti-predatory behaviour of owls on the Andaman Islands was species- and site-specific and prolonged disturbance to their roost sites especially removing climbing plants and clearing understory may affect the survival and reproductive rate of these owls. Further studies on the effect of cane extraction and selective logging on the roost selection of these endemic owl species are warranted.

I also employed Hierarchical multi-scale sampling strategy to estimate large-scale (sampling unit level - Ψ) and small-scale (survey station level - θ) occupancy using multi-detection methods (p). Spatial grid cells of 4 km^2 (2 km X 2 km) were demarcated as basic sampling unit and systematic sampling design was followed to select 50% (137 grids) sample units (*N*) over all grids. The *N* sample units were subsampled by four equal sub-units (*R*) of 1 km^2 to determine the detection and non-detection of owls. In each sub-unit, one owl point count was conducted following three census protocols (*K* sessions) – Initial Quiet Listening, call playback of conspecific calls and spotlight searches - and thereby three sessions (*K*) in each sub-units and four survey stations (*R*) for a sampling unit (*N*). Twelve detection histories (K x R) for each sub-unit were generated. Sampling covariates such as temperature, moon status, humidity, wind speed and noise level were measured during the owl sampling while site covariates such as terrain, tree and understory structural characteristics were quantified during the daytime. Site covariates were quantified at two scales: micro and macro scales (proportion of vegetation) to elucidate factor that might influence occupancy of owls in the North Andaman. I fitted the multi-scale occupancy models using program Mark *v.* 8.2. The information-theoretic method was used to select the most parsimonious models among a set of candidate models, and it measures the relative loss of information from the parsimonious model and subsequent candidate models. At large-scale (4 km^2 grid cell), the occupancies of all smaller owls were higher, and it ranges from 0.90 to 0.96 while at small-scale (1 km^2 grid cell) the occupancy was very low. It can be concluded that the north Andaman is highly mosaic landscape and hence, retaining existing natural forests patches within this area is a prerequisite for the conservation of owls in the Andaman Islands. Both *Otus balli* and *Ninox affinis* evidently avoid large extent of agriculture fields within the sampling unit. *Otus balli* is strongly associated with understory cover especially bamboo and cane dominated forest patches. *Ninox affinis* associated with the deciduous forests. While the eurytopic species like *Ninox obscura* and *Otus sunia* were found in wide array of habitat types and exploits agriculture and human tailored habitats.

I modelled the occurrence of each species of owls as a function of island characteristics using the presence-absence of owls and a set of abiotic and biotic variables of 73 offshore islands. Generalized linear model was ran to explore the factors influencing it. Results showed that occurrence of all five species of owls were largely influenced by the availability of habitat types in those islands. Two endemics namely *Otus balli* and *Ninox affinis* showed strong association with the evergreen and mangrove forests respectively, and relatively larger and highly diverse habitat islands. These two species can be used as indicators for the monitoring of the island reserves.

To test the dispersal-driven assembly rules (Diamond's rule and nestedness) on owls of Andaman archipelago, 73 offshore islands comprising of various sizes, distances from main stretch and habitat diversity were selected. The presence and absence of owls in those islands were used for this question. *EcoSim v. 7.0* was used to test the Diamond's assembly rules (1st, 2nd and 5th rules) using two statistical indices *viz.*, *C-score* and number of unique species combinations. NeD and Nestedness Temperature Calculator were used to test nestedness. All five species of owls were recorded in eight islands (~11%) and no owls were detected in 15 islands (~20%). *Otus sunia* occurred in 77% of islands but its sympatric species (*Otus balli*) was recorded in less number of islands (18%). *Ninox affinis* was recorded in relatively more islands than *Ninox obscura*. Log number of species richness in an island was significantly correlated with log island size (R^2 = 0.346; p=0.000) and marginally significant with log isolation (R^2=0.055; p=0.048). A number of unique species combination with FW-area and FW-isolation produced a significantly non-randomness pattern for owls in the Andaman Islands. It can be concluded that owl assemblage in the Andaman Islands is structured in accordance with Diamond's 1st and 2nd assembly rules (*i.e.*, a set of islands harbour significantly fewer species combinations than expected by chance). Competition might be higher in islands close to main stretches and small in size. Because the island close and small in size increases the competition between the sympatric species and obviously the suppressive species might vacate the island over dominant species. However, when the island is large with diverse habitats, it is expected to avoid less competition for coexistence and form unique combinations. The assemblage of owls in the Andaman Islands was not significantly nested than expected by chance. Due to owl's high dispersal ability and frequency of species exchange between offshore islands may lower the selective extinction process and hence, the anti-nestedness pattern was observed in owls.

Overall, this study provided first-hand information about the owls' distribution, their threat, ecological requirements, and the dispersal patterns in Andaman archipelago. It also helped to identify the critical island characteristics to ensure the avian population. The continued alteration of evergreen forests, extraction of minor products (for example: cane) and logging associated understory clearings might bring these endemic species' survival to an end. Steps should be taken to educate people to reduce the negative believes about owls among the locals.

Current findings on the assembly rules and the deterministic island characteristics enhanced our knowledge on preparing the conservation and management plans for these cryptic species.

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