PATTERNS IN AVIAN ASSEMBLAGES ON TWO ISLANDS OF THE CENTRAL NICOBAR

WITH EMPHASIS ON INTERACTIONS BETWEEN THE ENDEMIC NICOBAR BULBUL & RED-WHISKERED BULBUL

Dissertation submitted to the Saurashtra University, Rajkot in partial fulfillment of Master's Degree in Wildlife Science (2017)

By

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CERTIFICATE

This is to certify that **Mr. Naman Goyal** has carried out original research titled **Patterns in Avian assemblages on two islands of central Nicobar with emphasis on interaction between endemic Nicobar Bulbul and Red-whiskered Bulbul**, in partial fulfilment of Master's Degree in Wildlife Science from Saurashtra University, Rajkot. The study was carried out under our supervision from December 2016 to June 2017. We hereby certify that this work has not been submitted for any other degree to any other university.

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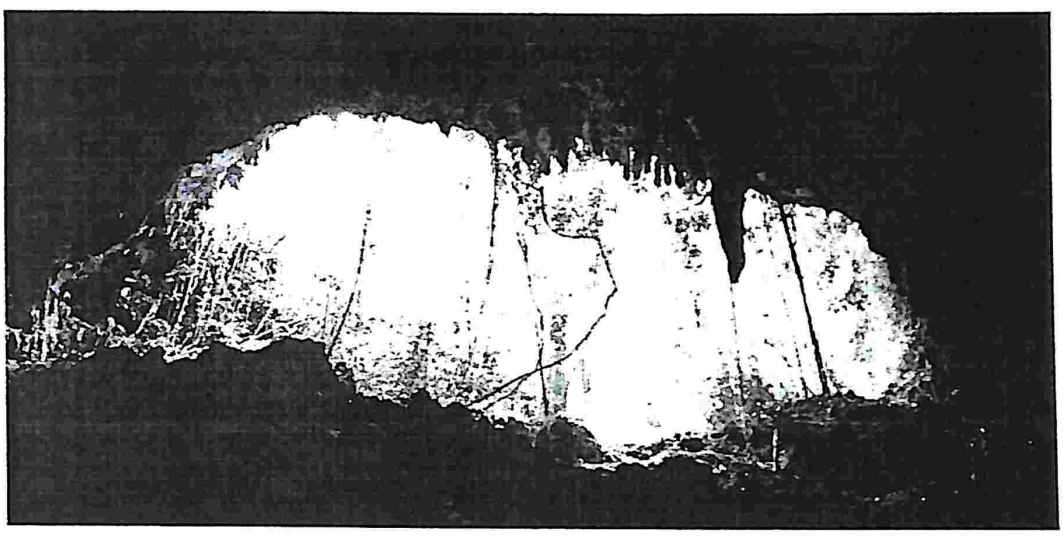

"To do science is to search for repeated patterns, not simply to accumulate facts"

- Robert MacArthur, Geographical Ecology

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Abstract

- Bird Communities were studied on two islands of the central Nicobar, namely Teressa (Large) and Bompuka (Small) between 16th December 2016 and 15th April 2017.

- This study aimed to understand the patterns in avian assemblages on these islands and further understand the nature of interaction between Red-whiskered Bulbul and the Nicobar Bulbul

- 4 major habitats were identified viz Primary forest, Secondary forest, Plantations, and Grassland based on an exhaustive reconnaissance survey

- In total 110 point counts were conducted within these habitats on both the islands

- 56 bird species belonging to 30 families were recorded during the study. Teressa had higher species richness than Bompuka

- Bird assemblage on Bompuka was a complete subset of Teressa and nestedness was found to be significant ($p<0.01$)

- There was distinct segregation within the bird communities of Grassland habitat and the woodland (Primary forest, Secondary forest and Plantation). Within woodland, Plantation was found to be a subset of Secondary forest community

- Two endemics, Nicobar Megapode and Andaman Cuckoo-dove were found to be exclusive to Primary forest. Four endemics, Andaman Green Pigeon, Nicobar Bulbul, Nicobar Imperial Pigeon and Long-tailed Parakeet occurred in woodland habitats. White-rumped Munia, Zitting Cisticola, Rosy Starling and Yellow-

legged Buttonquail were exclusive to the Grassland habitat

- Canopy height and Evenness along vertical strata explained most variation in bird community belonging to Teressa. Nicobar Imperial Pigeon and Nicobar bulbul showed a preference for tall trees that occurred in Primary forest. Birds like Zitting Cisticola and White-rumped Munia showed preference towards Grass cover

- In Bompuka, Foliage height diversity (Shannon in CCA plot) and Grass cover explained the maximum variance in the bird community. Although the associations were not found to be strong, species like Zitting Cisticola and Blue-tailed Bee-eater were found to associate with Grass cover

- This study showed that there was no negative interaction between the Nicobar bulbul and the introduced Red-whiskered Bulbul. Both species showed a differential space-use horizontally, but had overlap in vertical space-use in places where they co-occurred. Further, playback experiments revealed that these species did not respond to each other and no aggression was noted

- The importance of Primary forest to the endemics present on these islands was apparent. However, the increasing anthropogenic pressure is of a major concern for these islands, as habitat is being lost to unmonitored logging for wood and construction

Chapter 1: Introduction

Community Ecology is a field that has been a major area of research since its inception in the early 1900s (Wiens 1989). It has attempted to answer questions from as basic as 'What is a Community?' to as complex as understanding 'Interspecific Interactions'. The recent concern about the 'Changing Climate' has forced ecologists to take a further step in understanding the intricacies inherent in the way faunal and floral communities respond to this threat.

Community Ecology broadly aims to look at the 'Patterns' that communities tend to follow, and the 'Processes' that determine those patterns (Wiens 1989). Understanding the processes that determine the patterns observed in communities is the ultimate idea, but studies on processes are difficult to design and execute (Wiens 1989). Hence, most studies in community ecology of birds also focus on 'patterns' (MacArthur 1971, Emlen et al. 1986, Wiens 1989). Patterns in bird communities mostly include the structure and composition, patterns of species diversity, responses to habitat parameters, and distributional patterns along environmental gradients. Processes are the factors that determine the patterns observed in a community.

What shapes and structures a community in an area is an important question that many ecologists worldwide attempt to answer. Looking at communities allows us to define conservation needs more efficiently (Diamond et al. 1976, Simberloff and Abele 1976, Whittaker and Fernández-Palacios 2007), and hence answering this question becomes important.

Literature Review:

Birds have been widely researched in ecological perspective both in tropical and temperate zones of the world. Various classical studies on birds, encompassing population biology (Fogden 1972, Sillett 2000), biogeography (Diamond et al. 1976, Mayr and Diamond 2001, Newton 2003, Russell et al. 2006, Whittaker and

Fernández-Palacios 2007) and evolutionary ecology (Grant 1998, 2002), have been conducted. Pioneering studies on community ecology of birds are plentiful (MacArthur 1958, 1971, MacArthur and MacArthur 1961, Wiens 1974, Willson 1974, Karr 1977, Hino 1985, Robinson et al. 1995, 2000, Boulinier et al. 2001).

In India, some of the best avian community research has been conducted on the influence of habitat structure and composition, as well as impact of different anthropogenic changes on bird communities (Daniels et al. 1990, 1992, Shankar Raman et al. 1998, Shankar Raman 2001, Shankar Raman and Sukumar 2002, Raman 2004, Raman et al. 2005, Jayapal et al. 2009).

Background of the study:

Islands are unique in the sense that they are ecologically fueled by their isolation and serve as laboratories of evolution (Darwin and Wallace 1958, Funk and Wagner 1995, Grant 1998). Even before the 18th –century, naturalists have been interested in these systems to understand their fauna and flora. Significant insights about our own existence have come from research done on islands, as the very concept of evolution arose from islands with the work of Charles Darwin and Alfred Wallace (Darwin and Wallace 1958). Islands have inherent properties of supporting fewer species and less diversity when compared to a similar mainland system. This leads to the communities of islands being impoverished and makes the overall interactions less complex (Wright 1980).Further adding to their uniqueness, islands notably harbor high levels of endemism. Endemism on islands has been intriguing as it allows scientists to look at evolutionary processes stripped down of all other environmental complexities (Losos et al. 1997, Grant 2002).The concept of how new species form, or in short speciation, arose from studies on islands by Darwin, Wallace, and so on. Being isolated, well-defined, and less complex, they have been taken as model systems to understand patterns on a simpler scale and compare them to more complex systems on the mainland (Crowell 1962, Grant 1966, Diamond 1970, Emlen 1979).

Though isolation makes islands an ideal system to study various ecological patterns and processes, it also makes them vulnerable. Historically over 90% of bird

extinctions and 35% of mammal extinctions have been reported from islands (Peters and Lovejoy 1990). Changes in vegetation structure and composition are also reported to occur due to their vulnerability (Nugent et al. 2001, Donlan et al. 2002, 2004). Ali

The major threats to island systems can be habitat destruction, introduced/invasive species, stochastic events such as diseases, volcanic eruptions etc. and/or over-exploitation of natural resources (Vitousek et al. 1988).

The introduction of exotic birds on islands has been well documented and several studies have been published on their possible impact on the native species (Baker et al. 2014). Garnet *et al* (2011) describe the impact of introduced Crimson Rosella on the native Tasman Parakeet and Southern Boobook hinting towards competition for nesting sites. Blainvillian*et al* (2003) correlate the decline in nesting success of Tahiti Monarch to the aggression by introduced Common Myna and Red-Vented Bulbul on Tahiti Islands. Komdeur (1996) ascribes the decline in the nesting success of Seychelles Magpie-Robin to Common Myna co-occupying nesting trees. Rock-dove introduced into Galapagos is believed to have caused the decline in Galapagos Dove numbers due to the introduction of a disease called 'canter' (Wikelski et al. 2004). Japanese White-eye is known to potentially compete for food with juvenile Hawaiian Akepa, causing a decline in its population due to reduced juvenile survival (Freed and Cann 2009). Also, avian malaria has been an important cause of decline in the numbers and extinctions of some endemic Hawaiian drepaniids (Warner 1968, Lowe et al. 2000). The introduction of Northern Mallard on Hawaii and New Zealand have led to the hybridization of native *Anas* ducks, such as the Hawaiian Duck and the Pacific Black Duck which are listed in IUCN Red list (Gillespie 1985, Rhymer et al. 1994, Fowler et al. 2009).

Andaman & Nicobar are a group of islands in the Bay of Bengal, off the east coast of India. These islands have a long history of human colonization, with some islands being relatively untouched. The studies on these islands have been very limited, particularly for the Nicobar group. Most studies on bird communities of these islands

have focused on the Andaman group (Davidar et al. 1996, Thiollay 1997, Priya Davidar 2001). Studies in the Nicobar have mostly looked at endemic species and the threats they face (Sankaran 1997, 1998, Pande et al. 2007, Vijayan 2009, Rajan and Pramod 2013). One study in Nicobars has looked at structure and composition of Chiropteran communities on these islands (Aul et al. 2014). But no study on bird community structure and composition of these islands has been conducted.

Further, studies on the introduced species and their impact on Andaman & Nicobar have been limited. Rajan&Pramod (2013) have listed out the species that have been introduced along with the probable years of introduction. They have also listed exotic species which are currently having thriving populations on these islands, and the threats they pose to the native biodiversity. A study on the impact of *Axis axis* on the forest floor herpetofauna in the Andaman is the only ecological study that attempts to ecologically measure the destruction caused to the native biodiversity by invasive species (Mohanty et al. 2015). The Nicobar Islands are relatively less disturbed in terms of invasive species when compared to the Andaman Islands, but still are vulnerable to chance introduction events. The Red-whiskered Bulbul is an example of such an introduction to the central Nicobar. It was introduced during the colonial period and is hypothesized to pose a serious threat to the Nicobar Bulbul (Sankaran 1998). The native endemic bulbul, being ecologically poorly known, is listed as a Near Threatened species by IUCN (http://www.birdlife.org/datazone/species/factsheet/22713250). No ecological study has been taken up to look at the interaction between these two species.

Being ecologically understudied, it becomes important to understand the faunal and floral components of these islands so as to attempt to alleviate the threats that come inherent as a part of being insular, all of which simultaneously are being aggravated by anthropogenic pressure.

1.1. Study Objectives

Birds being omnipresent and conspicuous have been ideal models for community studies and studies on interspecific interactions worldwide.

In this study I look at the structure and composition of avian communities on two islands of the Central Nicobar group and attempt to explain the factors behind the patterns observed. Further, I also attempt to understand the impact, if any, of an introduced species, the Red-whiskered Bulbul on a native endemic, the Nicobar Bulbul.

1.2. Research Questions

1. What is the structure and composition of avian community on the two islands?
2. What is the role of habitat structure in shaping the avian community?
3. What is the overlap in spatial use of Nicobar Bulbul and Red-whiskered Bulbul?
4. What is the kind of interaction between Nicobar Bulbul and Red-whiskered Bulbul?

Chapter 2: Study Area

The Andaman and Nicobar are a group of oceanic islands situated in the Bay of Bengal, arching from Cape of Negrais in South Western Burma to Acheen Head in Sumatra between the latitudes 6 45'N and 13 41'N and longitudes 92 12'E and 93 57'E (see Map. 1 & 2). The group comprises of 572 islands, islets and rocks covering a total area of 8249 km^2 (www.and.nic.in, www.andamans.gov.in). Although politically a part of India, biogeographically Andaman & Nicobar Islands share more similarity with Southeast Asian elements of Burma and Indonesia (Ripley and Beehler 1989). They form two distinct groups of islands which are separated by a 150 km wide, 10-degree channel. This forms a major barrier for dispersal of species between the two groups (Ripley and Beehler 1989). Hence, within these two distinct groups, major differences in terms of fauna and flora exist (Wallace 1876, Blanford 1901, Mani 1974, Ripley and Beehler 1989). Nicobar Islands being relatively distinct in terms of fauna from the Andaman Islands are relatively understudied, and therefore information on faunal and floral distribution patterns and their ecology is needed for designing better conservation strategies for these islands. They consist of only 23 islands, covering an area of 1841 km^2

Nicobar Islands are further divided into 3 distinct groups, the Car Nicobar in the north, Central Nicobar or Nancowry Group in the middle and the Great Nicobar Group in the south. The central group is separated by the southern group by a 58 km wide channel, namely Sombrero Channel. The Car Nicobar island in the North is 88 km away from the central group (Ripley and Beehler 1989). Within the central group, Kamorta (along with Trinket), Nancowry and Katchal islands form a distinct cluster, while Teressa, Chowra and Bompuka form a separate cluster. These three islands are unique in having extensive grasslands, which are absent in all the other islands of the Andaman & Nicobar chain (Mani 1974). The climate of these islands is classified as warm Tropical and Oceanic with less seasonal variation in temperature (Mani 1974). The average temperature per annum ranges from 22°C to 30°C along with a mean relative humidity of 80%. These islands are strongly affected by the monsoons. The North-East monsoon sets in the islands towards the end of November till April, being driest during the latter parts. The

South-West monsoon sets in towards the end of May and continues through October. The mean rainfall per annum ranges from 3000 to 3800mm (www.andamans.gov.in).

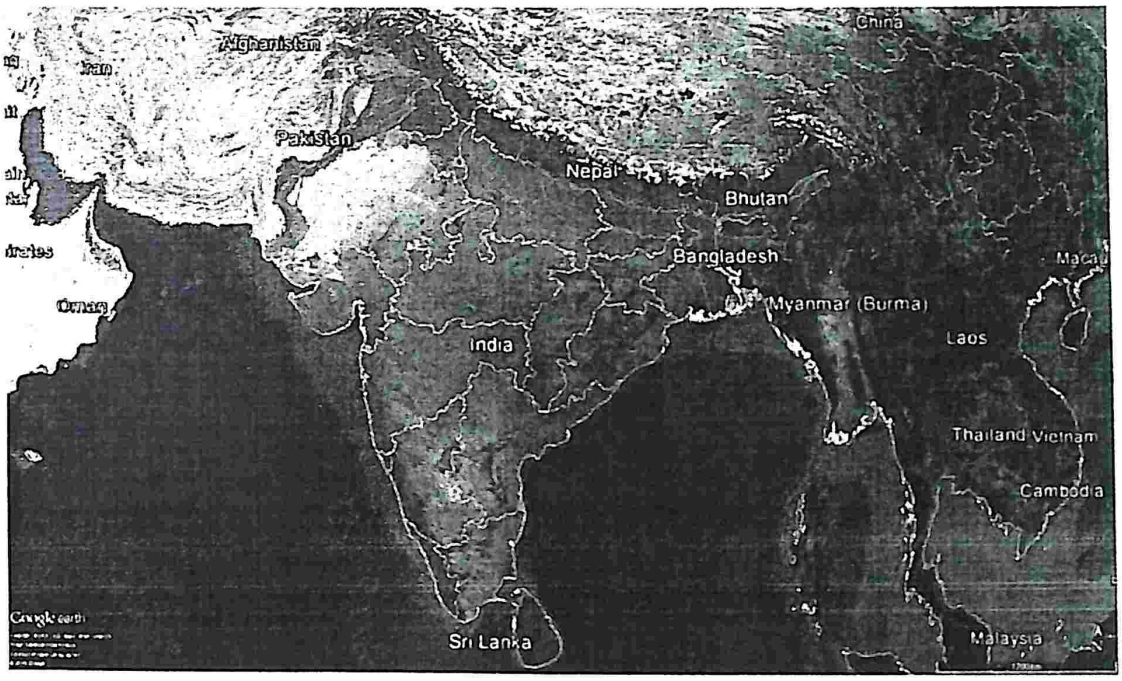
The vegetation of these islands is mostly Moist Evergreen (Mani 1974). The central group of Nicobar has grasslands which are composed primarily of *Imperata cylindrica* and are extensively inte rspersed with *Pandanus* plants (Mani 1974). The major tree species include *Terminalia sp., Canarium sp., Ficus sp., Macaranga sp., Cordia sp.*, etc.

The Nicobar Islands are known to have approximately 100 species of birds out of which 12 species are endemic to India. Within those 12 species, 8 species are just found in the Nicobar group. The Nicobar group can be further divided into two groups, Central and Great Nicobar islands. Out of those 8 species which are endemic to the Nicobar, Nicobar Bulbul is a central Nicobar endemic along with the Central Nicobar Serpent Eagle. Other endemics found in the central group are Nicobar Imperial Pigeon, Nicobar Megapode and Nicobar Sparrowhawk. Being unique in having extensive grasslands, these islands support a unique community of grassland birds which include Blue-breasted Quail, Yellow-legged Buttonquail and Zitting Cisticola. These species occur nowhere else along the entire arc of Andaman and Nicobar because of the special habitat.

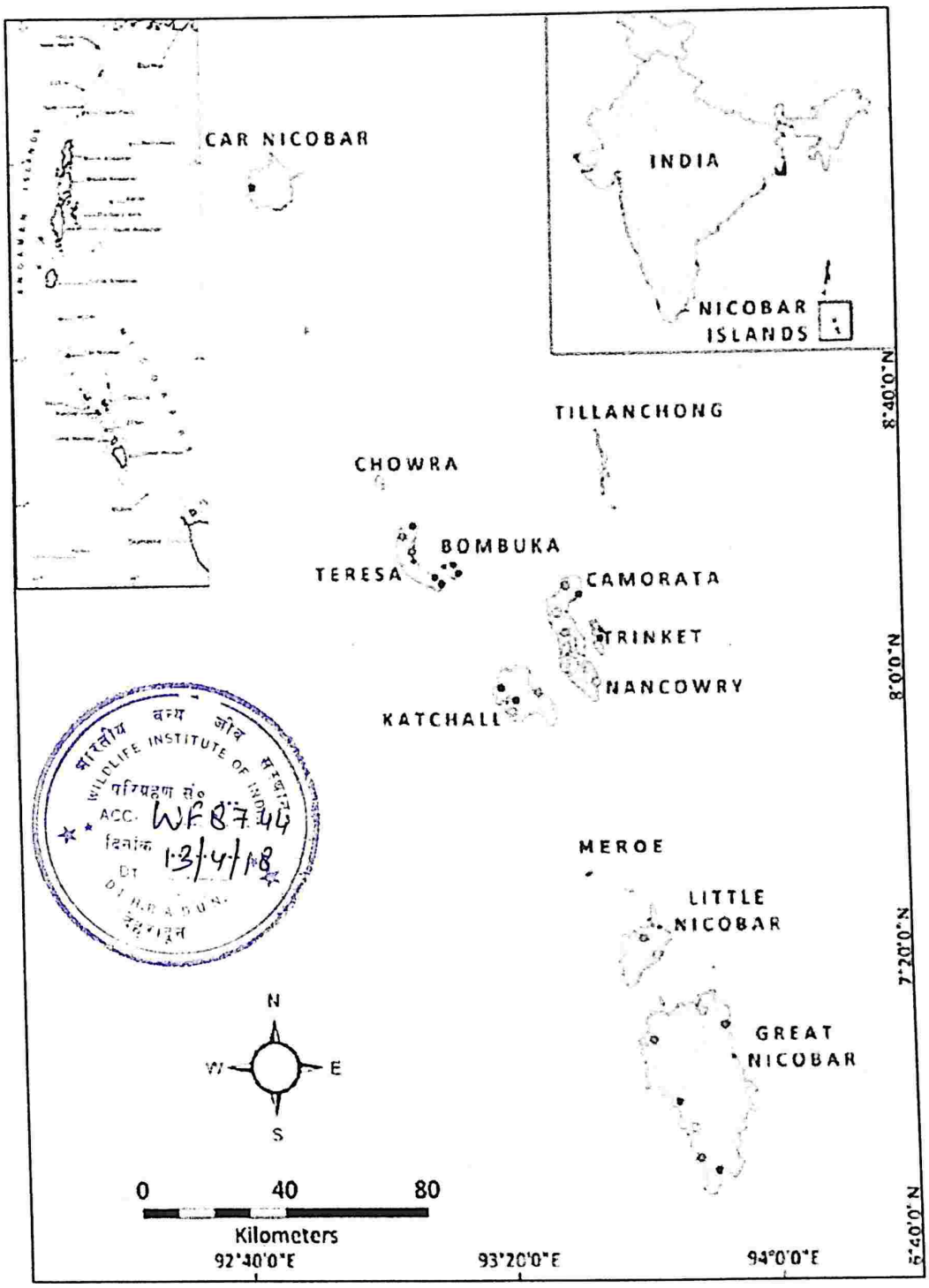
The study focused on two islands belonging to the Central group of Nicobar, namely Teressa and Bompuka. Both these islands are a part of the tribal reserve under the Andaman & Nicobar Protection of Aboriginal Tribes Regulation 1956 and hence access to these islands is restricted by law.
Teressa is a large island inhabited by people and has an area of 86.6km^2. There are 5 villages on this island and a road that connects all the villages. The topography of the island is hilly in the North tip which then gradually flattens down towards the center and the southern tip. The hilly northern part of the island supports a contiguous patch of primary forest which covers only 15% of the island. The flat area of Teressa has extensive grassland and scrub mosaic, which covers almost 70% of the island. Grasslands are interspersed with small patches of Secondary forest giving it an appearance similar to the Sholas of the Western Ghats. Along the coast of Teressa, there are plantations of

coconut and other cultivated fruit species interspersed with secondary forests making up the remaining 15% of the island.

Bompuka is a small island of 9.34 km^2, located 3.5 km east of Teressa. There are only a few families staying on this island making it relatively uninhabited compared to Teressa. The island has a very hilly terrain ranging from 10MASL to 200MASL over very small stretches. Being relatively undisturbed, this island is covered mostly (~70%) with primary forests, only being substituted by grasslands (~30%) on the hill tops and the southern end.



Map 1. Satellite Image of Indian sub-continent



Map 2. Map depicting Nicobar Islands within the Andaman and Nicobar archipelago (Ripley and Beehler, 1989; Prabhakaran and Paramasivam, 2013)

Map 3. Study area in central Nicobar: Teressa and Bompuka Islands

Chapter 3: Methods

A preliminary survey was done on Teressa Island from 27th December 2016 to 31st December 2016. Different areas of the island were visited to get a general idea of the types of habitats present and to look at the extent of human presence. The island was then classified into 4 major habitat types based on the survey (Table 1). Further, the accessibility for different areas and the terrain difficulty were assessed to select an appropriate sampling technique for birds. A preliminary survey could not be conducted on Bompuka Island due to logistical constraint; hence the habitats were classified based on observations made while sampling on the island. The major habitat types classified for the two islands are shown in Table 2.

Between 20th January 2017 and 20th February 2017 a survey on Kamorta, a part of the central group of Nicobar, was done and bird species were recorded *ad libitum* to inventory the species occurring on the island.

A total of 90 point counts were conducted in Teressa between 1st January 2017 and 15th April 2017. Bompuka was sampled between 22nd March 2017 and 30th March 2017 and only 20 point counts could be conducted on this island due to logistical constraints.

Table 1. Habitat Classification for the Study Area

Primary Forest	A forest with no or negligible anthropogenic disturbance, composed of native species.
Secondary Forest	A forest with the presence of anthropogenic disturbances such as logging, lopping and with the presence of a few non-native species.
Plantation	Mono-specific stands of edible fruit species with some secondary growth forest along.
Grassland	Dominated by grass over vast areas with a few shrub species scattered in between.

Table 2. Habitats observed on Teressa and Bompuka Islands

Island	Habitats
Teressa	Primary Forest, Secondary Forest, Plantations, Grassland
Bompuka	Primary Forest, Grassland

3.1. Bird sampling:

The focus of this study was to look at the community composition and structure of terrestrial birds. Point counts and line transects have been widely used as sampling techniques to look at bird communities and to estimate bird populations (Bibby 2000). Point counts allow in recording species in most field conditions and are suited in regions with difficult terrain (Sutherland et al. 2004). Due to the presence of difficult terrain, dense foliage and restricted access to areas, point counts were chosen as an appropriate technique for sampling for birds.
Variable-width point counts were conducted across the 4 major habitats, namely Primary Forest, Secondary Forest, Plantations, and Grassland, on the two islands. Each point count was conducted for 10 minutes wi th a set-in time of 2 minutes (Gregory and Gibbons 2004). All birds seen and heard were recorded systematically along with their distances. The sampling was done mostly in morning hours between 6:00 AM and 10:00 AM.

To understand the habitat segregation between Nicobar Bulbul and Red-Whiskered Bulbul, the point counts were supplemented with perch height data collected on the occurrence of these species along the vertical strata. Further, detailed behavioral observations were collected on both the species on an ad libitum basis. Further, playback experiment was done for Nicobar Bulbul and Red-whiskered Bulbul across all the

habitats to record the interspecific and intraspecific response of these two species. Systematic playbacks have been widely used to understand the interspecific interactions between bird species (Reed 1982, Prescott 1987, Barve and Dhondt 2017). For the experiment, the recordings of bird calls of Nicobar were sourced from Dr Pratap Singh, Wildlife Institute of India. Further, field recordings were done to record calls from multiple individuals of Nicobar Bulbul and Red-whiskered Bulbul for the playback. The experiment was done by playing 1 minute of control call (Nicobar Imperial Pigeon), followed by 2-minute playback of both Red-whiskered Bulbul and Nicobar Bulbul. Each of the species playbacks was accompanied by 30seconds to 1-minute gap to record the response, if any, for the two species. All responses were recorded systematically for each point count station. Total 70 playbacks were done in the study area. Different types of calls recorded for both the species were used to check for interspecific responses (Table 3). Responses were categorized into 'Response' and 'No Response', based on the initial data collection.

The study area had high hunting pressure on birds as they are a primary source of food for locals. Though Columbiformes made up a major chunk of food source for the locals, other birds such as Nicobar Bulbul and Red-whiskered Bulbul were also hunted down very often. Morphometric measurements were taken opportunistically for these hunted down birds and were used to quantify the difference in size of Nicobar Bulbul and Red-whiskered Bulbul.

Table 3. Types of Calls used for Playback

Red-whiskered Bulbul	**Nicobar Bulbul**
Call	Call
Song	Song
Alarm Call	Flock Call
Begging Call	Distress Call

3.2. Habitat Sampling:

For each point count station, the habitat variables were recorded within a 10m radius plot. All the Tree and Shrub species were noted down along with their counts within the plot. Average Canopy Height for the plot and the Percent Canopy cover was also recorded. Percent Shrub Cover and Percent Grass Cover were noted down for the plot within a 5m radius nested plot (Hays et al. 1982). For the vertical strata, data was collected through ocular estimation of the number of vegetation touches along different heights from the center of the plot to the periphery. Further, Shannon-Weiner Index and Evenness Index were calculated for each plot using the vertical strata data to estimate the overall Foliage Height Diversity and complexity (Hays et al. 1982).

3.3. Data Analyses:

The data was entered in Microsoft Excel in the format of Plots as Rows and Species as Columns. Further, a matrix was generated by entering the number of counts of each species in the corresponding plots. Bird species were inventoried by combining *ad libitum* observations with point count observations to obtain the checklist of birds for all the 3 islands.

Basic community characteristics were derived for the two study islands using Excel and 'R'. Rarefaction Accumulation Curves were generated for both the islands to assess the sampling adequacy for both the islands (Chiarucci et al. 2008). For species richness, total bird species recorded in all point count stations were calculated. Chao Turing estimator for species richness was used to account for the species undetected during the point counts (Chao et al. 2017). Rank abundance curves were derived for both the islands to get the dominant and rare species present in the community.

To see the patterns of nestedness between the communities of the two study islands, a matrix of species occurrence was constructed using the species inventory data. Nestedness 'temperature' was derived using the nestedness estimator (http://ecosoft.alwaysdata.net/)(Strona et al. 2014). The 'temperature' of nestedness

calculated using the estimator is low if the communities are highly nested, and is high in communities which do not have significant nestedness and varies between 0 and 100.

To look at how communities segregate within the islands, a matrix of species occurrence across different habitats was constructed and species that occurred in only one habitat were highlighted. Further, dissimilarity matrices with respect to bird species composition were derived using the 'Bray-Curtis' method (Krebs 1989). The graphical plots for Non-Metric Multidimensional Scaling (NMDS) were generated for both the islands using the dissimilarity matrices obtained. The function 'metaMDS' in package 'vegan' was used in R to generate the NMDS plot. Further, 'Habitat' was used as a factor to demarcate the clusters in the NMDS plot using the function 'ordiellipse'.

To obtain the vertical complexity index of the habitat (Foliage Height Diversity), the total foliage touch counts at each height were treated as abundance and height was treated as species. The Shannon-Weiner Index of Diversity and Simpson's Evenness Index were generated for each habitat plot.

Canonical Correspondence Analysis (CCA) was done to check the influence of different habitat variables in explaining the structure of bird community on both the islands (Braak and Verdonschot 1995). CCA was done by using the function 'cca' in the package 'vegan' of 'R'. All habitat variables were used initially in the model and further stepwise ordination was done using the function 'ordistep' to generate the best model, which explained most variability in the data. Further, this model was tested for significance using 'anova.cca' function which is a permutational test for variance.

A guild is defined as a group of species that occupy similar niche but are not necessarily related taxonomically (Root 1967). Based on the available literature (Ali and Ripley 1987) and observations on the field, birds were classified into two different sets of guilds viz., trophic and foraging-behavioural guilds (Jayapal 1997). For trophic guild, all birds recorded in the inventory were classified, while for foraging-behavioural guilds only insectivores (irrespective of their other food preferences) were classified.

To understand the habitat use of Nicobar Bulbul and Red-whiskered Bulbul, the average count of both the species per habitat was derived by dividing the total number of

detections in each habitat by the total effort per habitat. The data was then visualized as bar plot to look at habitat segregation between these two species. For segregation along the vertical strata of the habitat, the average perch height was estimated for both species using data collected during the point count and ad libitum. This data was then visualized using a box-whisker plot.

Playback data was converted into percent frequencies of response by dividing the frequency of responses by the total effort and multiplying by 100 and depicted in a tabular format for interpretation.

Chapter 4: Results

4.1. Bird Community Composition

In total, 73 species of birds belonging to 32 families were recorded in the central group of Nicobar Islands, which included observations from Kamorta, Teressa, and Bompuka (see Appendix). In the study site, 56 species of birds belonging to 30 families were recorded on Teressa and 34 species of birds belonging to 23 families were recorded on Bompuka (see Table 4).

Table 4. Bird species inventory of Teressa and Bompuka

Species	Scientific Name	Teressa	Bompuka
Accipitridae		**3**	**2**
Besra	*Accipiter virgatus*	1	0
Chinese Sparrowhawk	*Accipiter soloensis*	1	1
White-bellied Sea-eagle	*Haliaeetus leucogaster*	1	1
Alcedinidae		**2**	**2**
Black-capped Kingfisher	*Halcyon pileata*	1	1
Collared Kingfisher	*Todiramphus chloris occipitalis*	1	1
Apodidae		**2**	**3**
Edible-nest Swiftlet	*Aerodramus fuciphagus*	1	1
Glossy Swiftlet	*Collocalia esculenta*	1	1
Ardeidae		**6**	**1**
Cattle Egret	*Bubulcus ibis*	1	0
Great Egret	*Ardea alba*	1	0
Indian Pond Heron	*Ardeola grayii*	1	0
Pacific Reef Egret	*Egretta sacra*	1	1
Striated Heron	*Butorides striata*	1	0
Yellow Bittern	*Ixobrychus sinensis*	1	0
Campephagidae		**1**	**0**
Pied Triller	*Lalage nigra*	1	0
Charadriidae		**1**	**0**
Lesser Sand Plover	*Charadrius mongolus*	1	0

Cisticolidae		**1**	**1**
Zitting Cisticola	*Cisticola juncidis*	1	1
Columbidae		**7**	**6**
Andaman Cuckoo-dove	*Macropygia rufipennis*	1	1
Andaman Green Pigeon	*Treron chloropterus*	1	1
Andaman Wood Pigeon	*Columba palumboides*	1	1
Emerald Dove	*Chalcophaps indica*	1	1
Nicobar Imperial Pigeon	*Ducula nicobarica*	1	1
Nicobar Pigeon	*Caloenas nicobarica*	1	1
Pied Imperial Pigeon	*Ducula bicolor*	1	0
Cuculidae		**4**	**1**
Asian Koel	*Eudynamys scolopaceus*	1	1
Asian Drongo-cuckoo	*Surniculus lugubris*	1	0
Himalayan Cuckoo	*Cuculus saturates*	1	0
Indian Cuckoo	*Cuculus micropterus*	1	0
Estrildidae		**1**	**1**
White-rumped Munia	*Lonchura striata*	1	1
Glareolidae		**1**	**0**
Oriental Pratincole	*Glareola maldivarum*	1	0
Hirundinidae		**1**	**1**
Barn Swallow	*Hirundo rustica*	1	1
Laniidae		**1**	**0**
Brown Shrike	*Lanius cristatus*	1	0
Laridae		**2**	**1**
Black-naped Tern	*Sterna sumatrana*	1	1
Lesser Crested Tern	*Thalasseus bengalensis*	1	0
Megapodiidae		**1**	**1**
Nicobar Megapode	*Megapodius nicobariensis*	1	1
Meropidae		**1**	**1**
Blue-tailed Bee-eater	*Merops philippinus*	1	1
Monarchidae		**2**	**2**
Asian Paradise Flycatcher	*Terpsiphone paradisi*	1	1
Black-naped Monarch	*Hypothymis azurea*	1	1
Motacillidae		**2**	**0**

Gray Wagtail	*Motacilla cinerea*	1	0
Yellow Wagtail	*Motacilla flava*	1	0
Nectariniidae		**1**	**1**
Olive-backed Sunbird	*Cinnyris jugularis*	1	1
Oriolidae		**1**	**1**
Black-naped Oriole	*Oriolus chinensis*	1	1
Phasianidae		**1**	**0**
Blue-breasted Quail	*Excalfactoria chinensis*	1	0
Psittacidae		**1**	**1**
Long-tailed Parakeet	*Psittacula longicauda*	1	1
Pycnonotidae		**2**	**1**
Nicobar Bulbul	*Hypsipetes nicobariensis*	1	1
Red-whiskered Bulbul	*Pycnonotus jocosus*	1	0
Rallidae		**3**	**1**
Baillon's Crake	*Porzana pusilla*	1	0
Ruddy-breasted Crake	*Porzana fusca*	1	0
White-breasted Waterhen	*Amaurornis phoenicurus*	1	1
Scolopacidae		**2**	**2**
Common Sandpiper	*Actitis hypoleucos*	1	1
Whimbrel	*Numenius phaeopus*	1	1
Strigidae		**1**	**0**
Otus sp.		1	0
Sturnidae		**2**	**1**
Asian Glossy Starling	*Aplonis panayensis*	1	1
Rosy Starling	*Pastor roseus*	1	0
Turdidae		**1**	**1**
Orange-headed Thrush	*Geokichla citrine*	1	1
Turnicidae		**1**	**1**
Yellow-legged Buttonquail	*Turnix tanki*	1	1
Zosteropidae		**1**	**1**
Oriental White-eye	*Zosterops palpebrosus*	1	1
Total		**56**	**34**

In point counts, 25 out of 56 species were recorded in Teressa and 14 out of 34 species were recorded in Bompuka.

4.2. Bird Community metrics

Pooled Species Richness for Teressa was found to be 25 species, while for Bompuka it was 15 species. The estimated Species Richness on using Chao-Turing Estimator was found to be 33.37±4.24 for Teressa and 25.28±4.58 for Bompuka (see Table 5). Rarefaction curves derived for both the Islands are shown in Figure 4 & Figure 5. Also, Rank Abundance Curve for Teressa showed that Nicobar Bulbul, Red-whiskered Bulbul, Olive-backed Sunbird and Nicobar Imperial Pigeon were the most abundant species. Nicobar Megapode, Nicobar pigeon, White-rumped Munia and Yellow-legged Buttonquail were the rare species (see Figure 3). In Bompuka it is seen that Nicobar Bulbul and Nicobar Imperial Pigeon were the most abundant species, while Asian Glossy Starling and Nicobar Megapode were the rare species (see Figure 4).

Table 5. Observed and Estimated Species Richness for the study Islands

Island	Total Species	Species Richness*	Estimated Richness
Teressa	56	25	33.37±4.24
Bompuka	34	15	25.28±4.58

*These estimates are based on the Point Count data, and hence overall species richness may not reflect the true richness for the study area.

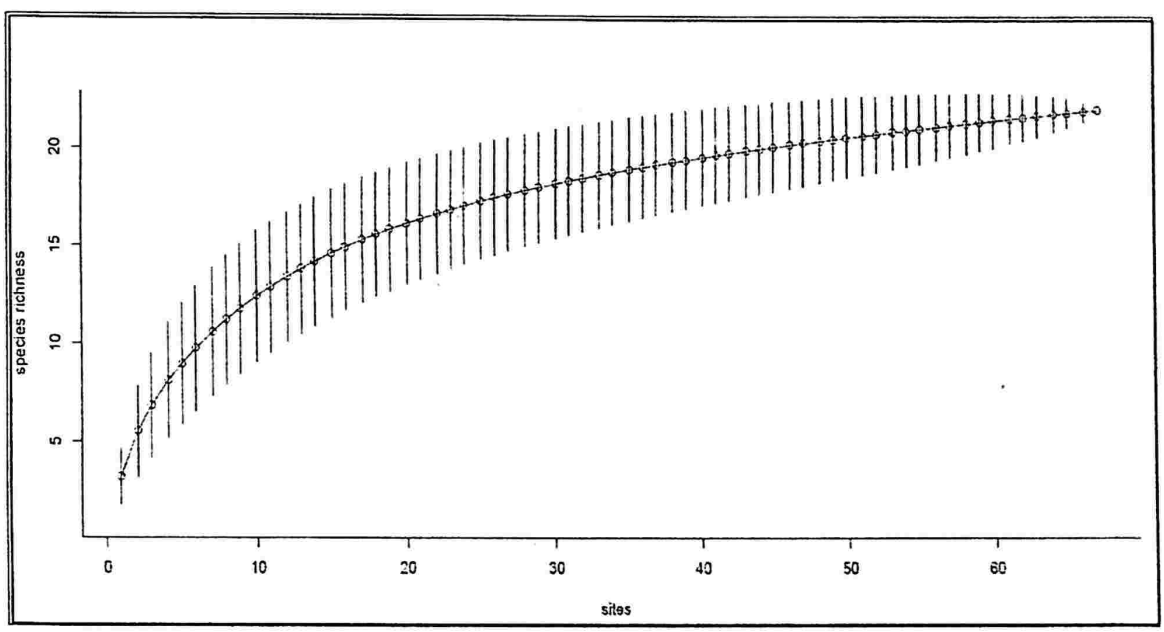


Figure 1. Rarefaction curve for Teressa Island

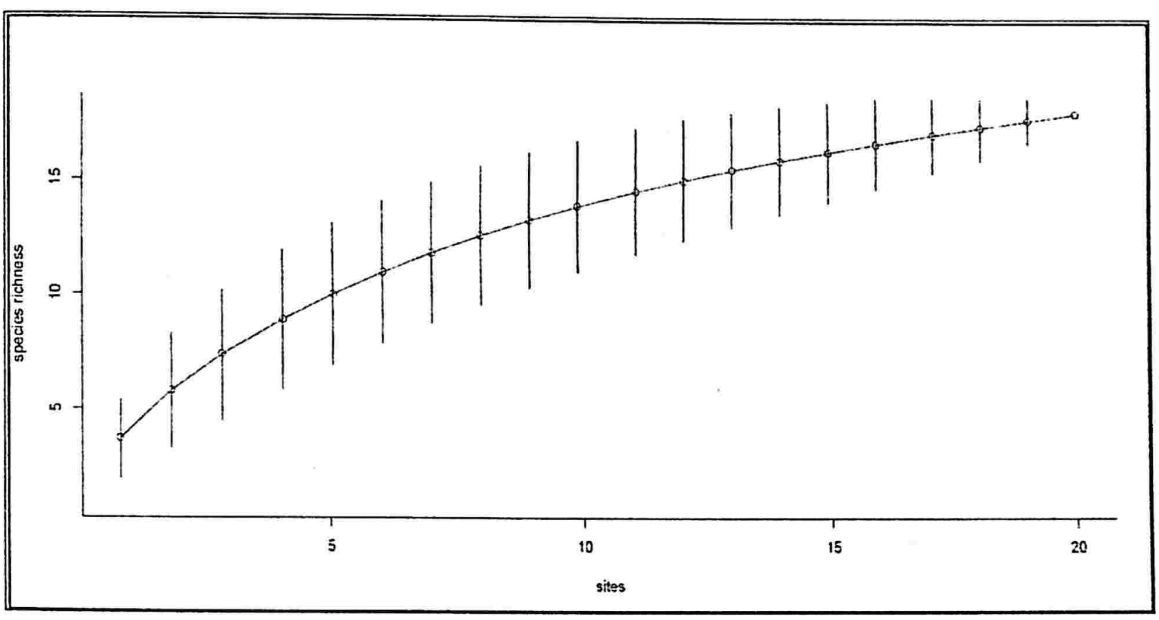


Figure 2. Rarefaction curve for Bompuka Island

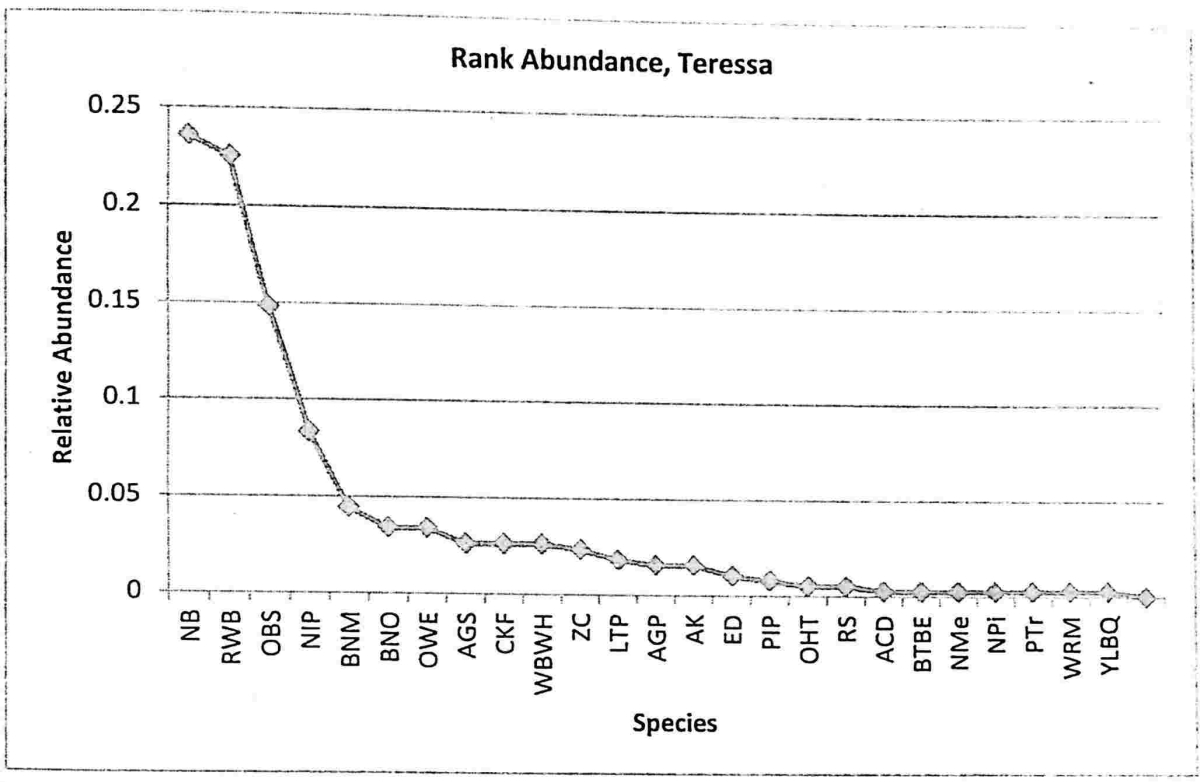


Figure 3. Rank Abundance for species on Teressa

NB = Nicobar Bulbul, RWB = Red-whiskered Bulbul, OBS = Olive-backed Sunbird, NIP = Nicobar Imperial Pigeon, BNM = Black-naped Monarch, BNO = Black-naped Oriole, OWE = Oriental White-eye, AGS = Asian Glossy Starling, CKF = Collared Kingfisher, WBWH = White Breasted Waterhen, ZC = Zitting Cisticola, LTP = Long-tailed Parakeet, AGP = Andaman Green Pigeon, AK = Asian Koel, ED = Emerald Dove, PIP = Pied Imperial Pigeon, OHT = Orange-headed Thrush, RS = Rosy Starling, ACD = Andaman Cuckoo-Dove, BTBE = Blue-Tailed Bee-eater, NMe = Nicobar Megapode, NPi = Nicobar Pigeon, PTr = Pied Triller, WRM = White-rumped Munia, YLBQ = Yellow-Legged Buttion-Quail

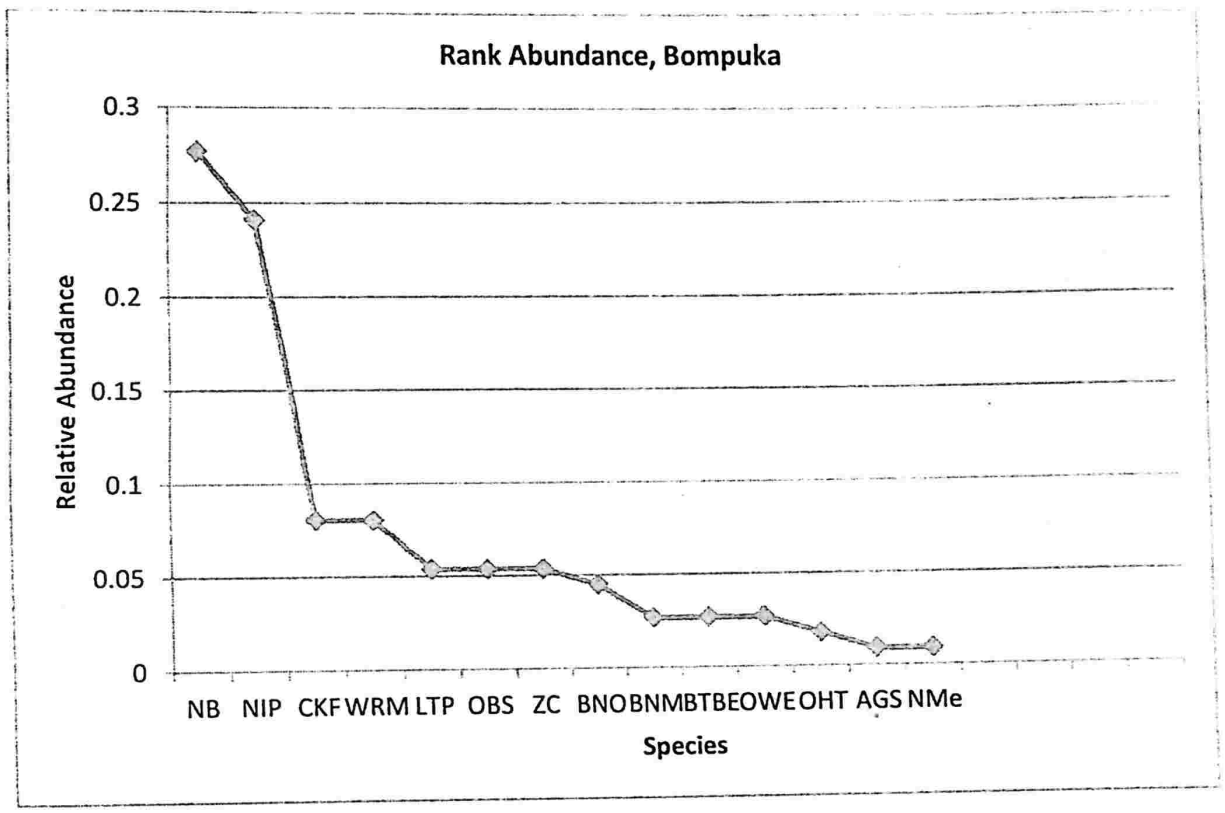


Figure 4. Rank Abundance for species on Bompuka

NB=Nicobar Bulbul. NIP=Nicobar Imperial Pigeon, CKF=Collared Kingfisher, WRM=White-rumped Munia, LTP=Long-tailed Parakeet, OBS=Olive-backed Sunbird, ZC= Zitting Cisticola, BNO= Black-naped Oriole, BNM=Black-naped Monarch, BTBE= Blue-tailed Bee-eater, OWE=Oriental White-eye, OHT= Orange-headed Thrush, AGS= Asian Glossy Starling, NMe= Nicobar Megapode

The results of nestedness calculator showed that the nestedness 'temperature' for the bird communities of Teressa and Bompuka was 0.052, which was significantly low ($p<0.01$). It can be inferred from this result that the bird communities of Teressa and Bompuka were significantly nested (see Table 6). The community matrix depicting the presence-absence of bird species on the two islands is shown in Table 7.

Table 6. Nestedness Temperature for Bird Communities on Teressa and Bompuka

Metric	Index	Z-Score	Nested?
T	0.052	-2.794	Yes($p<0.01$)

Table 7. Species-Island Matrix for Teressa and Bompuka based on cumulative species list.

*1=Present, 0=Absent

Species	Teressa	Bompuka
Nicobar Megapode	1	1
Great Egret	1	0
Cattle Egret	1	0
Indian Pond Heron	1	0
Striated Heron	1	0
Pacific Reef Egret	1	1
Yellow Bittern	1	0
King Quail	1	0
Besra	1	0
Chinese Sparrowhawk	1	1
White-bellied Sea Eagle	1	1
Baillon's Crake	1	0
Ruddy Breasted Crake	1	0
Yellow-legged Buttonquail	1	1
White Breasted Waterhen	1	1
Andaman Wood Pigeon	1	1
Nicobar Imperial Pigeon	1	1

Secondary forest and Plantation, and were not recorded in the Grassland habitat. Olive-backed Sunbird, Collared Kingfisher, and Oriental White-eye were found to be habitat generalists, occurring in all the habitats. It should also be noted that the Red-whiskered Bulbul, an introduced species, was recorded in all the habitats except for Primary forest.

The matrix of species-habitat occurrence for Bompuka is shown in Table 9. Two species of endemic birds, Nicobar Bulbul and Nicobar Megapode occurred exclusively in the Primary forest. While species like Blue-tailed Bee-eater, White-rumped Munia, and Zitting Cisticola were exclusive to the Grassland habitat. Nicobar Imperial Pigeon, an endemic species, occurred in both Primary forest and Grassland and this observation is elaborated in the discussions section.

Table 8. Species-Habitat Matrix for Teressa

Species*	Pforest	Sforest	Plantation	Grassland
Andaman Cuckoo-dove	1	0	0	0
Andaman Green Pigeon	1	1	1	0
Asian Glossy Starling	1	1	1	0
Asian Koel	1	1	0	0
Black-naped Monarch	1	1	1	0
Black-naped Oriole	1	1	1	0
Blue-tailed Bee-eater	0	1	0	1
Collared Kingfisher	1	1	1	1
Emerald Dove	1	0	1	0
Long-tailed Parakeet	1	1	1	0
Nicobar Bulbul	1	1	1	0
Nicobar Imperial Pigeon	1	1	1	0
Nicobar Megapode	1	0	0	0
Nicobar Pigeon	1	0	0	0
Olive-backed Sunbird	1	1	1	1
Orange-headed Thrush	1	0	1	0
Oriental White-eye	1	1	1	1
Pied Imperial Pigeon	1	1	0	0

Pied Triller	0	1	0	0
Red-whiskered Bulbul	0	1	1	1
Rosy Starling	0	0	0	1
White-breasted Waterhen	1	1	1	0
White-rumped Munia	0	0	0	1
Yellow-legged Buttonquail	0	0	0	1
Zitting Cisticola	0	0	0	1

*Species depicted in italics are endemic to Andaman and Nicobar

Green= Primary forest exclusive

Yellow= Grassland exclusive

Table 9. Species-Habitat Matrix for Bompuka

Species*	**Pforest**	**Grassland**
Black-naped Monarch	1	0
Black-naped Oriole	1	0
Blue-tailed Bee-eater	0	1
Collared Kingfisher	1	0
Asian Glossy Starling	1	0
Long-Tailed Parakeet	1	0
Nicobar Bulbul	1	0
Nicobar Imperial Pigeon	1	1
Nicobar Megapode	1	0
Olive-backed Sunbird	1	1
Orange-headed Thrush	1	0
Oriental White-eye	1	0
White-rumped Munia	0	1
Zitting Cisticola	0	1

*Species depicted in italics are endemic to Andaman and Nicobar

Yellow=Grassland exclusive

Dissimilarity matrices using 'Bray-Curtis' distance and Habitat type as a factor were derived for both the islands through program 'R'. The plot of NMDS for Teressa revealed that community of plantation was a subset of the community of secondary forest. Also, it is seen that there was a minor overlap between the communities belonging to Primary forests and the Grasslands (see Figure 5).The NMDS plot for Bompuka showed that there are two separate clusters of communities belonging to Primary forest and Grasslands (see Figure 6).

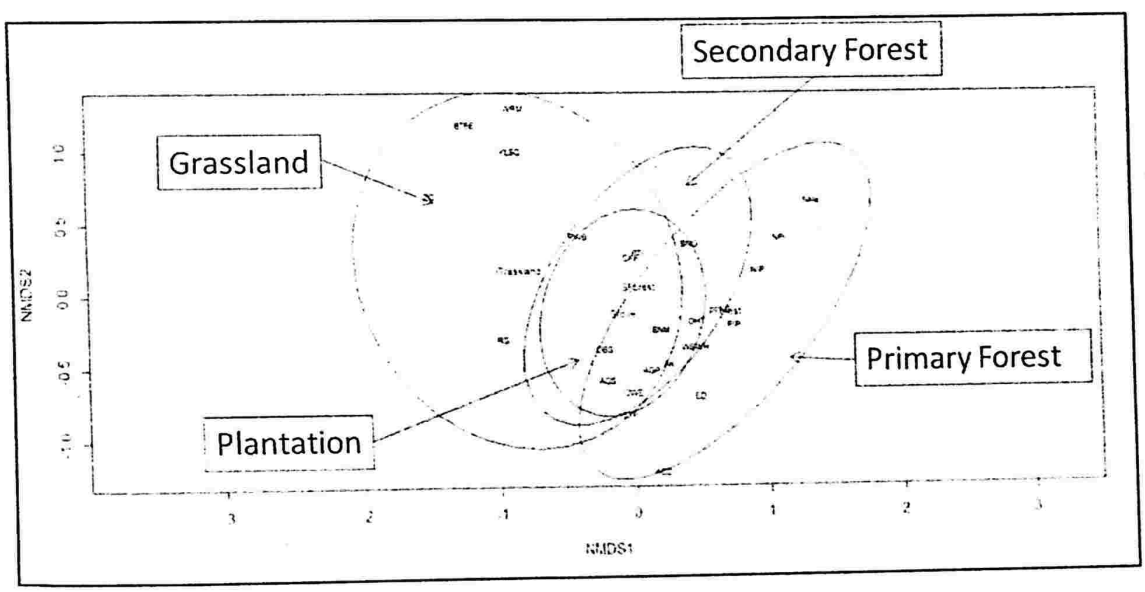


Figure 5. NMDS Plot for Teressa

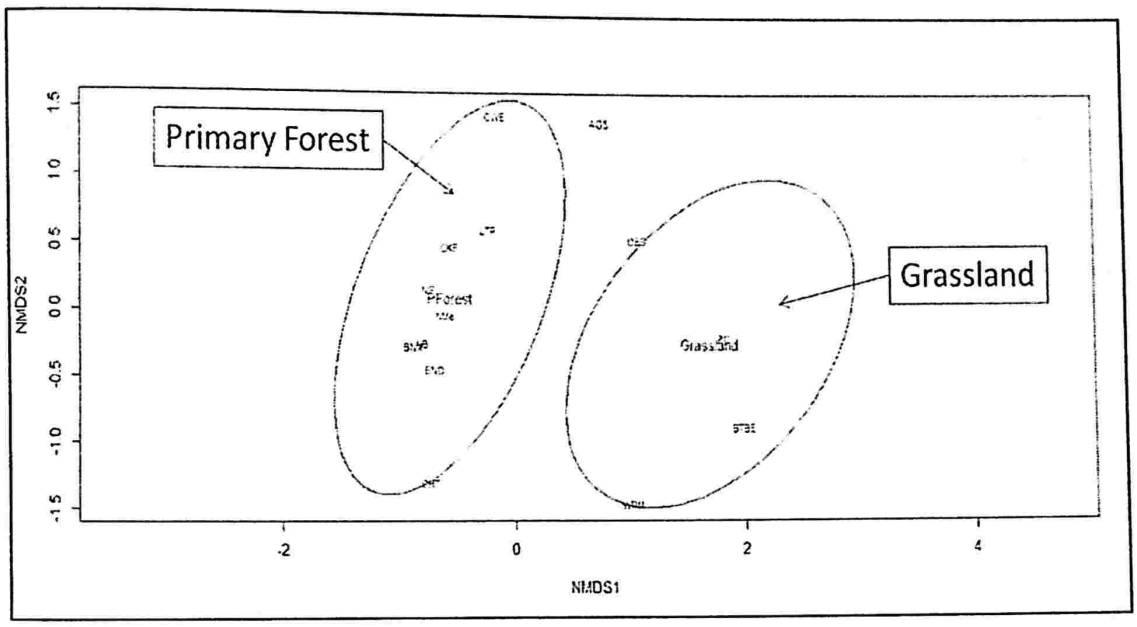


Figure 6. NMDS Plot for Bompuka

4.3. Relationship between the Bird Community and the Habitat

The first canonical variate obtained for Teressa Island explained 69% of the variability in the Community, while the second canonical variate explained 23% only (see Table 11). Further, the total variability explained by the unconstrained variables is just 23% (see Table 10). The first Canonical Variate had high loadings of Canopy Height (-0.979), Grass Cover (0.816) and Evenness (-0.794), while the second variate had high loadings of Evenness (-0.586), Grass Cover (0.573) and Shrub Cover (-0.513)(see Table 12). Tests of significance revealed that the model was highly significant ($p<0.05$). The Evenness ($p<0.05$) and the Canopy Height ($p<0.05$) were found to be highly significant in the model. The first and second variates were found to be significant for the community on Teressa (see Appendix).

The first canonical variate obtained for Bompuka Island explained 50% variability in the community while the second variate explained just 28% of variability (see Table 15). In total, the constrained variables in the model accounted for just 44.9% of total variability (see Table 14). The first canonical variate had high levels of Grass Cover (-0.994), FHD

(0.937) and Canopy Height (0.862), while the second variate had high loadings of Trail (0.614)(see Table 16). Test of significance revealed that the model had a significant value ($p<0.05$). Also, it was found that the Grass Cover, FHD, and Trail were the most significant constraining variables in the model. The first and second variates were found to be the most significant explaining the variability in the community (see Appendix).

Table 5. Total Inertia and Proportion Explained by Constrained and Unconstrained Variables, Teressa

	Inertia	Proportion
Total	2.685	1
Constrained	0.632	0.235
Unconstrained	2.053	0.765

Table 6. Eigenvalues and Proportion Explained by Constrained Variables, Teressa

	CCA1	CCA2	CCA3	CCA4
Eigenvalue	0.437	0.15	0.0356	0.00939
Proportion Explained	0.691	0.238	0.0563	0.01485
Cumulative Proportion	0.691	0.929	0.9851	1

Table 7. Bi-Plot Score for Teressa Island

	CCA1	CCA2	CCA3	CCA4
Evenness	-0.794	-0.586	0.0904	0.1267
Canopy Height	-0.979	0.187	0.0401	0.0751
Shrub Cover	-0.413	-0.513	-0.7135	0.2187
Grass Cover	0.816	0.573	-0.0446	0.0453

Table 8. Species Score for Teressa Island

	CCA1	CCA2	CCA3	CCA4
AGS	0.2871	-2.479	2.919	-0.404
AK	-0.2749	-1.294	2.188	-0.354
BNM	-0.3482	-1.114	-0.948	-1.247
BNO	-0.7597	-0.104	0.622	2.563
CKF	-0.0809	-0.78	0.889	-0.905
LTP	-0.1257	-1.533	0.122	0.669
NB	-1.0096	0.445	-0.849	-0.374
NIP	-1.3848	1.394	1.638	0.287
OBS	0.3438	-0.763	0.205	0.593
OWE	0.0931	-1.185	0.188	3.31
RWB	1.1328	0.192	-0.585	0.425
WBW	-0.7696	-0.201	0.3	1.533
ZC	2.7929	3.544	2.05	-1.923

Table 9. Total Inertia and Proportion Explained by Constrained and Unconstrained Variables, Bompuka Island

	Inertia	Proportion
Total	3.55	1
Constrained	1.59	0.449
Unconstrained	1.95	0.551

Table 10. Eigenvalues and the Proportion explained by each Canonical Variate, Bompuka Island

	CCA1	CCA2	CCA3	CCA4
Eigenvalue	0.807	0.451	0.261	0.0586
Proportion Explained	0.507	0.284	0.164	0.0368
Cumulative Proportion	0.507	0.791	0.955	0.9918

Table 11. Bi-Plot Score for Bompuka Island

	CCA1	CCA2	CCA3	CCA4
FHD	0.937	0.1905	0.27337	-0.00939
Canopy Height	0.862	0.1029	0.42163	-0.1576
Shrub Cover	0.757	0.112	-0.04216	-0.44546
Grass Cover	-0.994	-0.0933	0.00616	-0.01259
Trail	-0.729	0.6148	-0.30024	-0.10768

Table 12. Species Score for Bompuka Island

Species	CCA1	CCA2	CCA3	CCA4
BNM	0.407	-0.05555	0.567	1.043
BNO	0.318	1.0293	-0.173	2.551
BTBE	-3.169	0.7639	-0.436	-1.337
CKF	0.449	-0.4683	-0.412	-0.569
LTP	0.461	-0.7148	-1.384	0.906
NB	0.37	0.4318	0.695	0.334
NIP	0.279	-0.1601	0.457	-0.862
OBS	-0.456	-2.3786	-1.768	0.148
OHT	0.044	4.5544	-4.093	-0.808
OWE	0.473	-0.9318	-1.859	-0.217
WRM	-3.446	0.8437	0.978	-1.194
ZC	-3.048	-0.8309	0.45	2.411

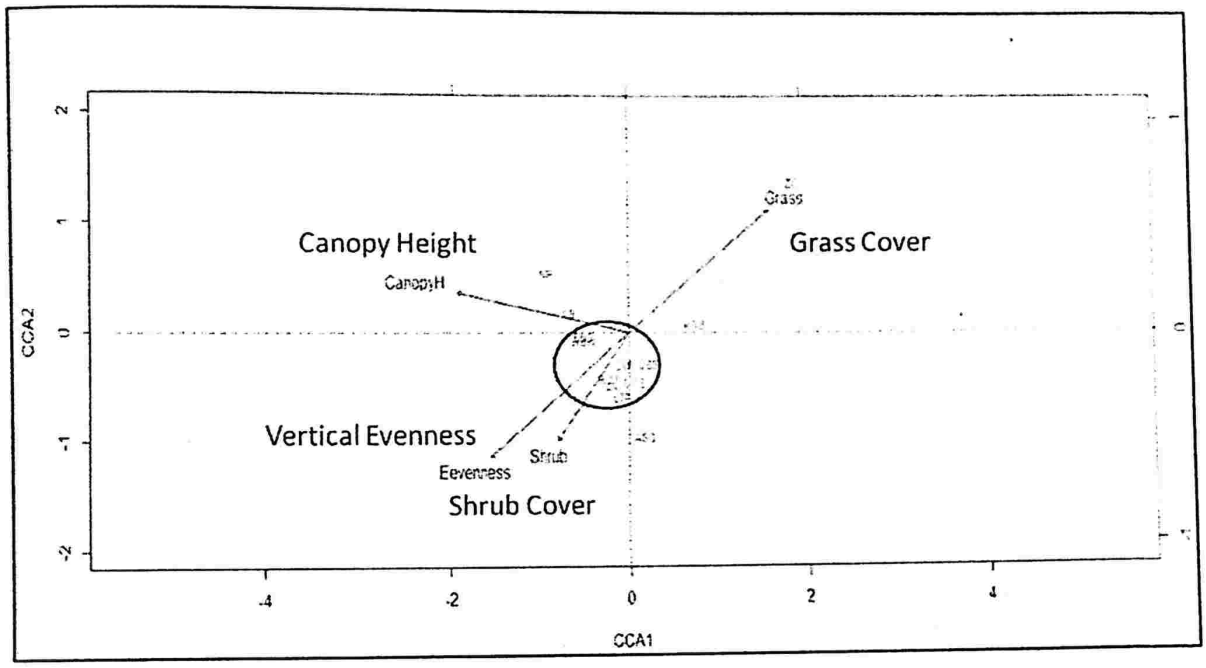


Figure 7. CCA Plot for Teressa (see Appendix for species codes)

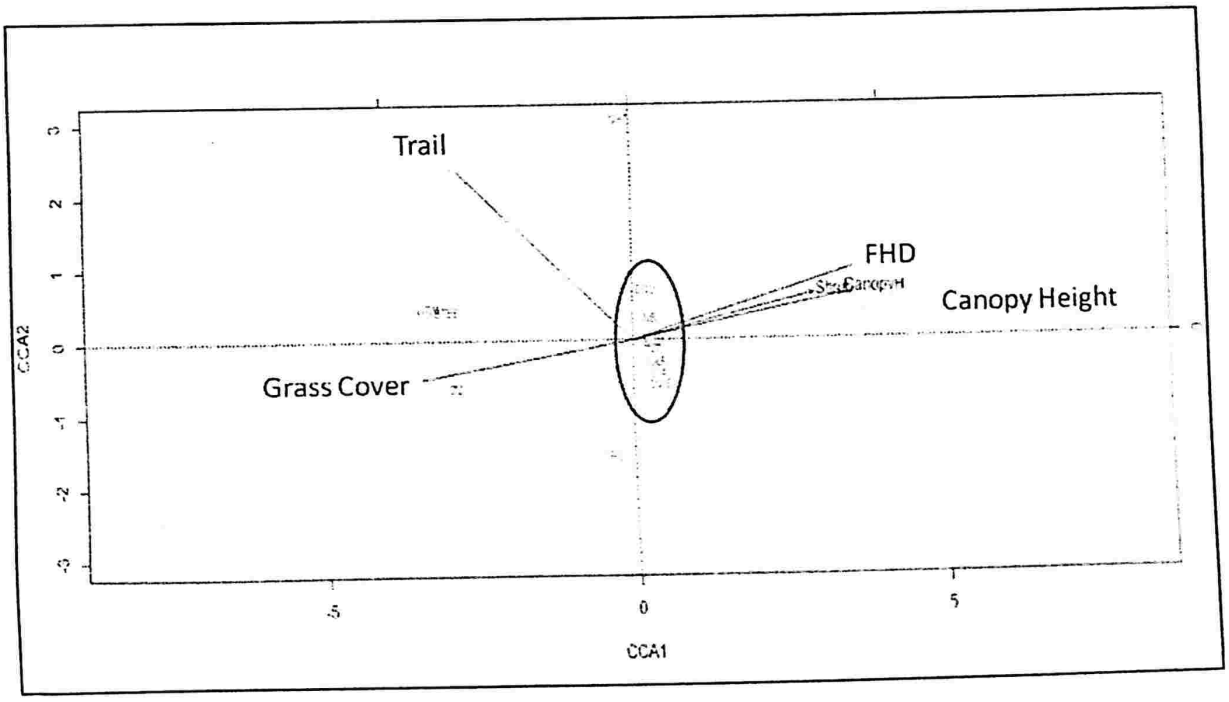


Figure 8. CCA Plot for Bompuka Island

4.4 Avian Guild Structure on both the islands:

There were 10 trophic guilds identified for bird communities of both the islands. Both the islands supported all 10 trophic guilds (see Table 18). In Teressa, Aquatic fauna feeder and Insectivore birds were the most species-rich guilds followed by Frugivore guild. While in Bompuka, Insectivore was the guild having the most species followed by Aquatic fauna feeders and Frugivores (see Table 18). Further, the insectivores were classified into 5 foraging-behavioural guilds (see Table 19). Foliage gleaners made up the highest proportion in the bird communities on both the islands. Ground forager and air-hawker guilds were second richest guild on Teressa. While Air-hawker and Air-sallyer were the second richest guild on Bompuka.

Table 13. Trophic guilds on both islands

Trophic Guilds	Teressa	%	Bompuka	%
Aquatic Fauna Feeder	14	25.5	6	17.6
Carnivore	6	10.9	3	8.8
Omnivore	2	3.6	2	5.9
Insectivore	14	25.5	8	23.5
Frugivore	7	12.7	6	17.6
Insectivore+Frugivore	1	1.8	1	2.9
Insectivore+Frugivore+Nectarivore	6	10.9	4	11.8
Insectivore+Granivore	3	5.5	2	5.9
Frugivore+Granivore	1	1.8	1	2.9
Nectarivore	1	1.8	1	2.9
Total	55	100	34	100

Table 14. Foraging-behavioural guilds for both islands

Foraging-behavioural guild	Teressa	%	Bompuka	%
Foliage gleaner	12	52.2	7	46.7
Ground forager	4	17.4	1	6.7
Air-Hawker	4	17.4	4	26.7
Air-Sallyer	2	8.7	2	13.3
Air-Hawker+Sallyer	1	4.3	1	6.7
Total	23	100	15	100

4.5. Space-use overlap between Nicobar Bulbul and Red-whiskered Bulbul

Average counts per plot for Nicobar Bulbul and Red-whiskered Bulbul, derived for each habitat, are shown as bar plot in Figure 9. It revealed that there was segregation in habitat use between these two species. The average count of Nicobar Bulbul was seen to be declining from Primary forest to Grassland, while the Red-whiskered Bulbul showed the opposite trend.

The average Perch Height of Nicobar Bulbul and Red-whiskered Bulbul in different habitats was shown in Table 20. The box-whisker plot of average perch heights for both the species showed that there was a significant overlap between them in Secondary forest and Plantation (see Figure 10).

Table 15. Average Perch Height of Nicobar Bulbul and Red-whiskered Bulbul across the 4 habitats on Teressa Island

Species	Primary Forest	Secondary Forest	Plantation	Grassland
Nicobar Bulbul	18.7±8.78	11.77±6.61	8.12±5.3	-
Red-whiskered Bulbul	-	10.5±8.1	7.15±5.78	2±1.3

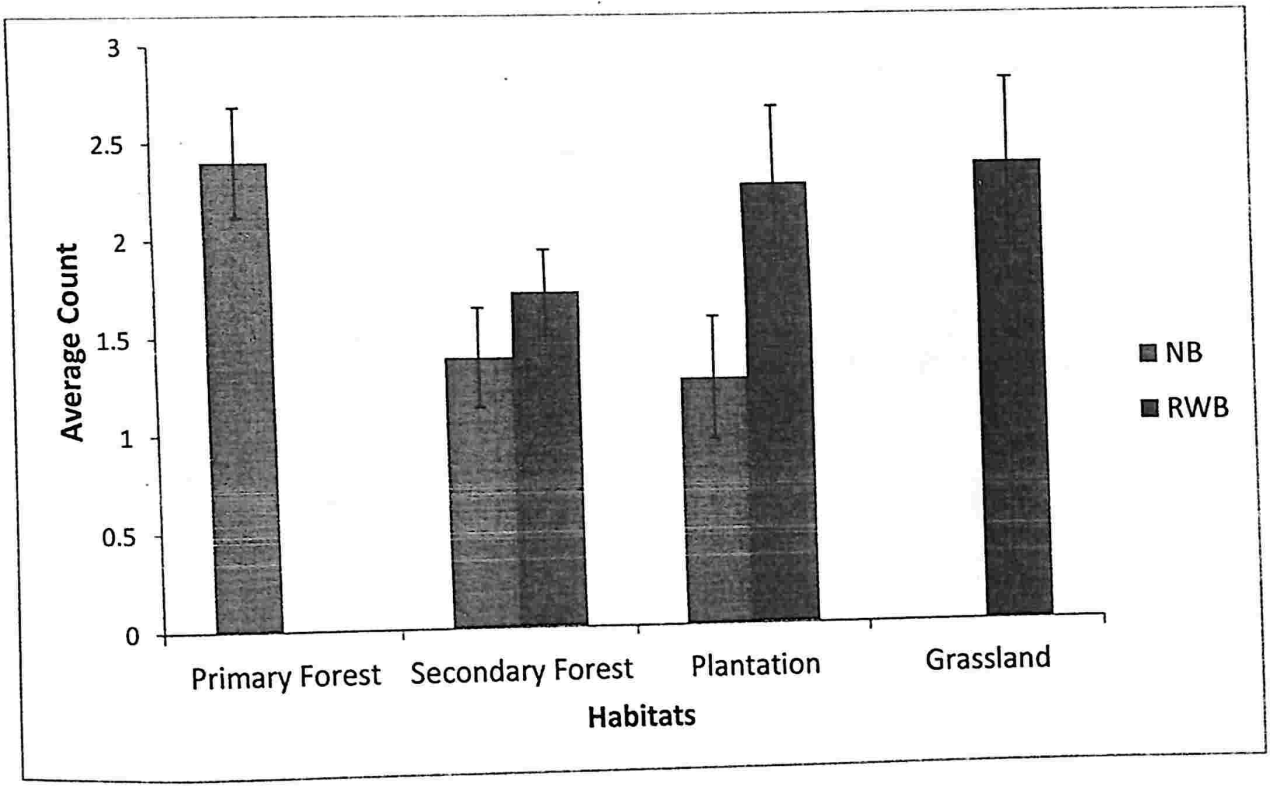


Figure 9. Average counts per plot for both the Bulbul species across the 4 habitats on Teressa Island. Here 'NB' is for Nicobar Bulbul and 'RWB' for Red-whiskered Bulbul

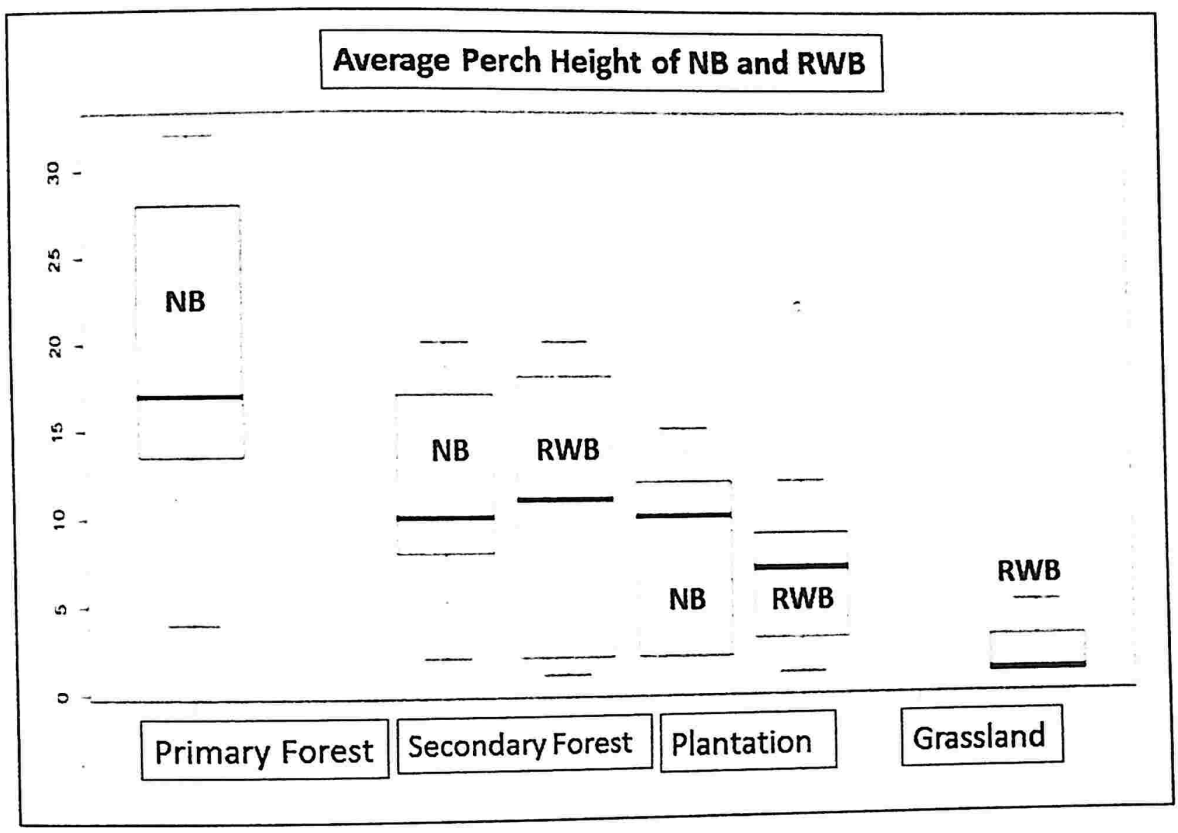


Figure 1. Box Whisker Plot shown for Perch Heights of Nicobar Bulbul and Red-whiskered Bulbul in different Habitats. Here NB stands for Nicobar Bulbul and RWB stands for Red-whiskered Bulbul.

4.6. Interspecific interactions between Nicobar Bulbul and Red-whiskered Bulbul

The percent frequency of response of Nicobar Bulbul and Red-whiskered Bulbul to the playback is shown in Table 21. It is seen in the table that the frequency of response of Nicobar Bulbul to Red-whiskered Bulbul playback was none and similarly Nicobar Bulbul playback yielded no response from Red-whiskered Bulbul. On the other hand, 28.5% playbacks of Nicobar Bulbul call yielded responses from Nicobar Bulbul and 25.7% playbacks of Red-whiskered bulbul calls resulted in response from Red-whiskered Bulbul. It is inferred from this result that the two species responded to intra-specific calls while they did not respond to inter-specific calls.

Table 16. Percent Frequency of responses to the Playback observed for Nicobar Bulbul and Red-whiskered Bulbul

Species	Nicobar Bulbul Playback	Red-whiskered Bulbul Playback
Nicobar Bulbul	28.5	0
Red-whiskered Bulbul	0	25.7

Chapter 5: Discussions

5.1. Bird Community Composition:

Due to lack of long term studies on the central group of Nicobar very little information is available about the bird communities of these islands. The bird species inventory revealed 5 new records for this group of Nicobar, which have not been reported in earlier studies (Sivakumar and Sankaran 2002)(see Table 22). Out of these new records for the region, 4 species were known to be winter migrants, and hence it is highly possible that these birds were recorded during the study period which was from January to April. **Rosy Starling** (*Pastor roseus*) was recorded from two islands, namely Kamorta and Teressa, during the study period. These birds were recorded twice during the month of January 2017 on Teressa where they were seen in groups of 3 to 5 individuals in the grassland. On Kamorta a single individual was first recorded in a human habitation and the second record was a group of 5 individuals in grassland. Rosy Starlings are known to be winter migrants in India and are known to migrate through the western part of the country till southern part and infrequently till Sri Lanka (Ali and Ripley 1987). They have been reported to be vagrants in the Andaman groups, but have never been reported from any of the Nicobar group. **Spotted Redshank** (*Tringa erythropus*) was recorded only in Kamorta on two separate occasions. It was seen foraging on an inland mud flat during the low tide period during the morning hours (8:30 AM, 10:00 AM). This species is known from isolated records in Andamans as a winter visitor but has not been reported the Nicobar groups of islands so far (Ali and Ripley 1987, Grimmett et al. 2011). **Asian Drongo-cuckoo** (*Surniculus lugubris*) was recorded only on Teressa on two separate occasions. The first sighting was during the month of January where it was seen on a *Macaranga* tree feeding on caterpillars. The second sighting was towards the month of March where the species was observed again picking out caterpillars on a *Ceiba* tree. All these observations were made within a human settlement. This species is known from only a few isolated records from the Great Nicobar group (Grimmett et al. 2011) and has not been recorded anywhere else in the Andaman and Nicobar Islands.

Brahminy Kite (*Haliastur indus*), a resident raptor species in Andaman, was recorded from Kamorta Island during the study period. This species was seen on 4 occasions during the stay on Kamorta Island. This species is a strong flier and is known to travel long distances over sea, hence was recorded from Kamorta (Schipper et al. 2001). **House Sparrow** (*Passer domesticus*) is a well-established introduced species in Andamans. It was introduced on Ross Island in 1882 & 1885 but now has established its population all across inhabitations in Andamans (Rajan and Pramod 2013). It was recorded only once during the study period, probably rafted along a ship from Andamans to Kamorta Island. No subsequent records from Kamorta may hint that it was a lone individual.

Table 17. New records for central Nicobar

Species	Kamorta	Teressa	Bompuka
Rosy Starling	1	1	0
Spotted Redshank	1	0	0
Asian Drongo-cuckoo	0	1	0
Brahminy Kite	1	0	0
House Sparrow	1	0	0

Further, species like Pied Triller and Pied Imperial Pigeon were found to be new records for Teressa. Both these species have not been recorded on this island in earlier studies, which may be attributed to the fact that studies on central Nicobar have been short-term and few in numbers. The record of Pied Imperial Pigeon on Teressa further invokes one to think about the concept of super-tramp species. This species was found to visit Teressa from some other island in the morning around 7 AM, in a flock of up to 20 birds. Further, during the evening hours, such flocks were observed flying out of the island. This indicates that this species might follow the super-tramp strategy, where a species might be a good disperser but does not colonize an area (Diamond 1974). It disperses to exploit

resources on larger islands and goes back to small islands for roosting. Further, the absence of certain species like Central Nicobar Serpent Eagle on Teressa and Bompuka was interesting. This species was recorded on several occasions in Kamorta but was never recorded in the study site. Although both, Teressa and Bompuka, have good Primary forest this species has never colonized these islands based on the further anecdotal information. This might be explained by the fact that the overall size of Teressa and Bompuka is smaller than Kamorta, and being a territorial bird of prey, this species of Serpent Eagle might not have colonized these small islands.

5.2. Community Metrics on Islands:

The bird communities of Teressa and Bompukawere found to be highly nested. On looking at Table 7, it can be inferred that almost all the species recorded on Bompuka were found on Teressa, hence forming a subset of Teressa bird community. Two explanations can be given to justify this pattern. First, during the Pleistocene sea level decline, both the islands would have formed a land-bridge due to the shelf getting exposed (Ripley and Beehler 1989)(see Figure 11). This would have allowed species like Nicobar Megapode, Yellow-legged Buttonquail, and White-breasted Waterhen to colonize the island. Second, birds being good dispersers are often among the first colonizers on islands (Diamond 1974, Thornton et al. 1993). The distance between Teressa and Bompuka is just 3.5KM, and it would be safe to assume that it does not serve as a major barrier based on the nestedness pattern.

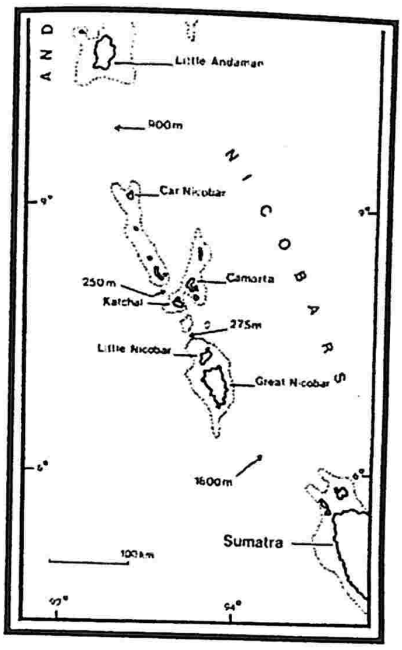


Figure 2. The shelves that would have been exposed during the last Pleistocene sea level fall (Ripley and Beehler 1989)

When we look at the clustering of bird communities on Teressa, plantation and secondary forest communities were found to be similar. This is an expected pattern as plantation and secondary forest formed mosaics along the coast of Teressa. Species like Asian Glossy Starling, Black-naped Oriole, Black-naped Monarch, Andaman Green Pigeon and Long-tailed Parakeet occurred in both these habitats. But in NMDS, we see that community of plantation actually forms a subset of the Secondary forest. This can be explained by the fact that species like Pied Triller, Asian Koel, and Pied Imperial Pigeon were unique to the Secondary forest. Hence, the communities showed a nested pattern within these two habitats. It was further observed that grassland community is not as similar as the communities belonging to other three habitats. Species like Zitting Cisticola and Yellow-legged Buttonquail were totally unique to grasslands, and hence the overall distinct community. Also, species common in other three habitats were not recorded in the grasslands adding to further dissimilarity between grassland and other three habitats. The minor overlap between the primary forest and grassland in NMDS can be explained by looking at species which were habitat generalists. Collared Kingfisher, Olive-backed Sunbird, and Oriental White-eye were found to be generalist species across all the habitats on Teressa. Further, species such as Nicobar Bulbul and Nicobar Imperial Pigeon

were recorded in a Primary forest, Secondary forest and Plantation. Both these species are known to be forest-dwellers (Ali and Ripley 1987) and hence did not occur in grasslands. Species like Red-whiskered Bulbul occurred in the Secondary forest, Plantation and Grassland. Red-whiskered Bulbul was not recorded in the Primary forest which adheres to the fact that this species prefers an open country like grassland and lightly wooded habitats like secondary forest and plantation (Ali and Ripley 1987).

On Bompuka, due to less anthropogenic pressure, the presence of Secondary forest and Plantations were almost negligible. The clustering of communities on Bompuka revealed two distinct groups in NMDS. One community belonged to the primary forest and the other community belonged to the grassland. Grasslands in Bompuka had species which were unique to them, such as Zitting Cisticola, White-rumped Munia, and Blue-tailed Bee-eater, which do not utilize forested habitats. On the other hand, birds that were occurring in forested habitat were never recorded in the grassland habitat. Further, species like Collared Kingfisher and Oriental White-eye, which were habitat generalists on Teressa, were recorded only in primary forest on Bompuka. This may be the reason explaining the two distinct clusters that are formed in the case of Bompuka (see Table 9).

5.3. Relationship between the Bird Community and the Habitat:

Based on the results of CCA for Teressa, two habitat variables had a relatively strong impact on the composition of the bird community. The results indicated that points with higher Canopy Height and Habitat Evenness across vertical strata supported more species and higher abundances. Only two species showed a relatively strong response, Nicobar Imperial Pigeon and Nicobar Bulbul, towards Canopy Height. It can be inferred that these species have higher abundances in habitats with higher canopy height. Primary forest, in general, was a habitat which consisted of trees with tall canopies. Putting into context, these two species of endemic birds showed a preference towards primary forests, although they were observed to occur in other habitats with canopy forming vegetation like secondary forest and plantation. Most other species of birds did not show a

discernible response to these variables. Zitting Cisticola is a species which responded negatively with canopy height. Being a species that prefers grassland habitats, its response to canopy height becomes obvious. Red-whiskered Bulbul showed a slight incline towards Grass Cover and Shrub Cover. These variables being highly related to grassland, secondary forest and plantation, explain the occurrence of Red-whiskered Bulbul in these habitats. Red-whiskered Bulbul is known to occur in habitats which are lightly wooded and mostly open (Ali and Ripley 1987).

On Bompuka, the Foliage Height Diversity, Grass Cover, and Trail Presence were found to be significant variables to explain the majority of variation in the bird community. Most forest bird species showed a relatively low response to FHD and can be seen clustered around the center. This may be attributed to less sample size for the island and hence no strong affinity to FHD is being seen. However, species like White-rumped Munia, Blue-Tailed Bee-eater, and Zitting Cisticola showed a strong affinity towards Grass Cover. These species prefer grassland habitats as seen in the case on Teressa as well. Hence, the affinity of these species to grass cover makes sense. The presence of a trail, on the other hand, is something interesting to note; overall Bompuka Island did not have trail system as the anthropogenic disturbance was negligible. But grassland species such as White-rumped Munia also inclined towards the presence of trails for which it is difficult to find a logical explanation.

5.4. Avian Guild Composition:

Both the islands had the same number of trophic guilds and foraging-behavioral guilds present in their avian communities. However, the number of species composed in those guilds differed for both the islands. The pattern that was observed was that the species richness per guild for Bompuka was lower than that of Teressa. Bompuka is just 9.34 km^2 in size and is almost one-tenth of the size of Teressa. Being smaller in size it supported less number of species, while Teressa being larger in size supported a higher number of species. This was observed in the bird inventory that Teressa had 56 species, while

Bompuka had 34 species. This being the case, the number of species per guild for Bompuka was observed to be less when compared to Teressa. The thing to note in case of guild composition of both these islands is that there are certain guilds which are interestingly absent. Having tall evergreen trees and dense undergrowth in certain areas, both these islands lacked species belonging to bark feeding guild and undergrowth foraging guild. This pattern has been documented in this region and adheres to the general patterns of bird communities observed on islands (Ripley and Beehler 1989). Species like wood-peckers, barbets, and babblers were completely missing from these islands leaving their niches completely empty. No species were recorded occupying any of these guilds on the islands. Moreover, the number of species present per guild on these islands was significantly low when compared to any other mainland forest. The number of empty niches on these islands and the overall poor bird diversity showed that the avifauna of these islands is depauperate.

5.5. Space-use overlaps between Nicobar Bulbul and Red-whiskered Bulbul:

There are two species of Bulbuls that are known to occur on the Nicobar Islands. One is a native endemic, Nicobar Bulbul, while the other is an introduced species, Red-whiskered Bulbul. The introduced Red-whiskered Bulbul has been hypothesized to pose a threat to Nicobar Bulbul since they belong to the same family Pycnonotidae. It is also well known that the birds belonging to same body size class and occupying a similar niche are more inclined towards competing if they are sympatric. Although belonging to the same size class, there were differences in morphology of these two species. The overall bill length was larger for Nicobar Bulbul than the Red-whiskered Bulbul. Also, Nicobar Bulbul was found to be larger in body size than the Red-whiskered Bulbul (see Table 23). Further, the overall occurrence of these two species was segregated across the habitats. Nicobar Bulbul had highest counts in the Primary Forest and it showed a decline towards the Grassland-Scrub. On the other hand, Red-whiskered Bulbul had highest counts towards the Grassland and it slowly declined to zero counts in the Primary Forest. Nicobar Bulbul belongs to the genus *Hypsipetes*, which includes bulbuls like Black Bulbul, Philippines

Bulbul, and Streak-throated Bulbul. Most of the birds belonging to this genus are known to be Tropical Forest dwellers, utilizing mostly forests and edge habitats along the forests (Ali and Ripley 1987). On the other side falls the Red-whiskered Bulbul belonging to a diverse genus *Pycnonotus*. It is a bird well known to utilize lightly wooded areas (Secondary Forests, Plantations) and more open habitats (Ali and Ripley 1987). The only zone of overlap for these two species of evolutionarily distinct Bulbuls was the edge habitat that is Secondary Forests and Plantations.

Table 18. Bill size and Wing length of Nicobar Bulbul and Red-whiskered Bulbul

Species	Bill Length	Wing Length
Nicobar Bulbul	23-25	95-102
Red-whiskered Bulbul	17-20	80-95

When seen within these habitat types, these two species seem to occur at relatively fewer numbers when compared to their zones of exclusive habitats. In the case of competing species, several studies show that niche segregation occurs to allow competing species exploit resources differentially and coexist (MacArthur 1958, Pacala and Roughgarden 1982). Being evolutionarily distinct and having natural differentiation in the habitat use as seen in Figure.7, both species had a small zone of overlap in their niche. Within the zone overlap, there was no segregation in resource use observed; both species were having overlapping vertical zonation. The considerable overlap observed in perch height between these two species in the zone of habitat overlap may hint towards reduced aggression and a higher degree of tolerance towards each other. This was further tested through the playback experiment to see if these species show any signs of aggressions towards each other, which is discussed in the next section.

5.6. Interspecific interaction between Nicobar Bulbul and Red-whiskered Bulbul:

There were no interspecific responses recorded in both the cases as evident from the results of the playback experiment. Different calls, which were recorded from multiple individuals of Nicobar Bulbul and Red-whiskered Bulbul, were played at all the point count stations which yielded no interspecific response. This yields two possible explanations, either that the species do not recognize each other's calls, or they are not bothered by the presence of conspecifics. In the case of most competing birds, playback studies yield aggression as a direct sign of competition. The study on Chaffinches and Great Tits on mainland Scotland and adjacent Isle of Eigg, showed that the mainland populations did not respond to interspecific songs. But on the adjacent islands, the mutually exclusive territories were a result of interspecific competition and were strongly defended (Reed 1982). Further, a study on Alder and Willow Flycatchers showed that the interspecific aggression was observed in the case of sympatric populations during playback experiment, while no aggression was observed in allopatric populations (Prescott 1987). In the case of Nicobar Bulbul and Red-whiskered Bulbul, such an interaction was not observed both in the case of sympatric populations on Teressa and an allopatric population of Nicobar Bulbul on Bompuka. Within the sympatric population on Teressa, the species failed to respond to interspecific calls both in the mutually exclusive habitats and the overlapping habitats.

5.7. Conclusions:

The community structure and composition of the two islands in the Central Nicobar Group gave us insights on how the community is organized on these islands. The nested pattern between the two study islands adhered to the theory of biogeography. Being very close to each other, the communities of these two islands were expected to show a nested pattern.

The habitat variables collected during the study could only explain the response of a subset of species that were recorded during the point count. Hence, there must be other habitat variables, not accounted for in this study, which would drive the structuring of the

bird communities on these islands. This leaves a scope for understanding how the habitat parameters play a role in shaping the community on Islands.

The two species of bulbuls are evolutionarily and ecologically distinct, and differential habitat use allows these species to naturally segregate their resources over space. The constraint of time did not permit to test the hypothesis over the temporal scale and hence, conclusions are limited to only a spatial scale. It is seen that Nicobar Bulbul being primarily a Forest-dwelling species, will not face threats from the introduction of Red-whiskered Bulbul until the primary forests are intact on these islands.

The presence of intact primary forest is not only important to the Nicobar Bulbul, but to the other species of endemic birds as well. Nicobar Megapode, Nicobar Imperial Pigeon, Andaman Cuckoo-dove, Long-tailed Parakeet and Andaman Green Pigeon are all dependent on the intactness of these forests as they provide an undisturbed habitat for these birds. The current scenario on these islands is however concerning. The anthropogenic pressure in terms of development on these islands poses a major threat for all the forest dwelling endemics. Logging of trees for wood and construction is a major problem in some of these islands belonging to the central group of Nicobar. Loss of such habitats would push these forest-dependent species to utilize the human modified habitats like secondary forest and plantation. In the case of Nicobar Bulbul, this could actually lead to competition for the resource in terms of space, as the exclusive zone of habitat for this species would be lost.

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Appendices

Appendix 1. Bird Species Inventory for the 3 Islands, Kamorta, Teressa and Bompuka

Species	Scientific name	Kamorta	Teressa	Bompuka
Nicobar Megapode	*Megapodius nicobariensis*	1	1	1
Great Egret	*Ardea alba*	1	1	0
Intermediate Egret	*Ardea intermedia*	1	0	0
Cattle Egret	*Bubulcus ibis*	1	1	0
Indian Pond Heron	*Ardeola grayii*	1	1	0
Striated Heron	*Butorides striata*	1	1	0
Malayan Night Heron	*Gorsachius melanolophus*	1	0	0
Pacific Reef Egret	*Egretta sacra*	1	1	1
Yellow Bittern	*Ixobrychus sinensis*	1	1	0
King Quail	*Excalfactoria chinensis*	0	1	0
Brahminy Kite	***Haliastur indus***	1	0	0
Central Nicobar Serpent Eagle	*Spilornis minimus*	1	0	0
Besra	*Accipiter virgatus*	1	1	0
Chinese Sparrowhawk	*Accipiter soloensis*	1	1	1
Japanese Sparrowhawk	*Accipiter gularis*			
Nicobar Sparrowhawk	*Accipiter butleri*			
White bellied Sea eagle	*Haliaeetus leucogaster*	1	1	1
Baillon's Crake	*Porzana pusilla*	0	1	0
Ruddy Breasted Crake	*Porzana fusca*	0	1	0
Yellow-legged Buttonquail	*Turnix tanki*	1	1	1
White Breasted Waterhen	*Amaurornis phoenicurus*	1	1	1
Pacific Golden Plover	*Pluvialis fulva*	1	0	0
Lesser Sand Plover	*Charadrius mongolus*	1	1	0
Whimbrel	*Numenius phaeopus*	1	1	1
Common Red Shank	*Tringa tetanus*	1	0	0
Spotted Red Shank	***Tringa erythropus***	1	0	0
Common Sandpiper	*Actitis hypoleucos*	1	1	1
Oriental Pratincole	*Glareola maldivarum*	0	1	0
Lesser Crested Tern	*Thalasseus bengalensis*	1	1	0

Species	Scientific name	Kamorta	Teressa	Bompuka
Black Naped Tern	*Sterna sumatrana*	1	1	1
Andaman Wood Pigeon	*Columba palumboides*	1	1	1
Nicobar Imperial Pigeon	*Ducula nicobarica*	1	1	1
Pied Imperial Pigeon	*Ducula bicolor*	1	1	0
Andaman Cuckoo-dove	*Macropygia rufipennis*	1	1	1
Andaman Green Pigeon	*Treron chloropterus*	1	1	1
Nicobar Pigeon	*Caloenas nicobarica*	1	1	1
Emerald Dove	*Chalcophaps indica*	1	1	1
Long-tailed Parakeet	*Psittacula longicauda*	1	1	1
Indian Cuckoo	*Cuculus micropterus*	1	1	0
Himalayan Cuckoo	*Cuculus saturates*	1	1	0
Lesser Cuckoo	***Cuculus poliocephalus***	0	1	0
Drongo Cuckoo	***Surniculus lugubris***	0	1	0
Asian Koel	*Eudynamys scolopaceus*	1	1	1
Oriental Scops Owl	*Otus sunia nicobarica*	1	0	0
Otus sp.		0	1	0
Brown Hawk Owl	*Ninox scutulata*	1	0	0
Edible Nest Swiftlet	*Aerodramus fuciphagus*	1	1	1
Glossy Swiftlet	*Collocalia esculenta*	1	1	1
Dollar Bird	***Eurystomus orientalis***	1	0	0
Black Capped Kingfisher	*Halcyon pileata*	0	1	1
Collared Kingfisher	*Todiramphus chloris occipitalis*	1	1	1
Little Blue Kingfisher	*Alcedo atthis*	1	0	0
Blue-tailed Bee-eater	*Merops philippinus*	1	1	1
Pied Triller	*Lalage nigra*	1	1	0
Brown Shrike	*Lanius cristatus*	1	1	0
Black-naped Monarch	*Hypothymis azurea*	1	1	1
Asian Paradise Flycatcher	*Terpsiphone paradisi*	1	1	1
Barn Swallow	*Hirundo rustica*	1	1	1
Nicobar Bulbul	*Hypsipetes nicobariensis*	1	1	1
Red-whiskered Bulbul	*Pycnonotus jocosus*	1	1	0
Warbler sp.		0	1	0
Oriental White-eye	*Zosterops palpebrosus*	1	1	1
Rosy Starling	***Pastor roseus***	1	1	0
Asian Glossy Starling	*Aplonis panayensis*	1	1	1
Orange-headed Thrush	*Geokichla citrnia*	1	1	1

Species	Scientific name	Kamorta	Teressa	Bompuka
Black-naped Oriole	*Oriolus chinensis*	1	1	1
Olive-backed Sunbird	*Cinnyris jugularis*	1	1	1
House Sparrow	***Passer domesticus***	**1**	**0**	**0**
White-rumped Munia	*Lonchura striata*	1	1	1
Gray Wagtail	*Motacilla cinerea*	1	1	0
Yellow Wagtail	*Motacilla flava*	1	1	0
Zitting Cisticola	*Cisticola juncidis*	1	1	1
GRAND TOTAL		**61**	**56**	**34**

*Species highlighted are new records for these Islands. The Presence (1) highlighted shows the island that they were recorded on. "?" indicates unconfirmed record

Appendix 2. Food Plants of the Bulbul Species

Plant Species	Red-whiskered Bulbul	Nicobar Bulbul	Parts
Canariumstrictum	0	1	Fruits
Syzigiumsp	1	1	Fruits
Ficussp	1	1	Fruits
Macarangasp	1	1	Fruits, Flowers
Lantana sp	1	1	Fruits
Glochidionsp	1	1	Fruits
Sicurinigasp	1	1	Fruits
Sanup	0	1	Fruits
Tapile	1	1	Fruits
Tapileallo	0	1	Fruits
Carica papaya	1	1	Fruits
Psidiumguajava	1	1	Fruits
Anacardiumsp	1	1	Fruits, Flowers
Musa sp	1	1	Fruits

Appendix 3. Permutational Test for the significance of Model by Terms for Teressa Island

Model: CCA(TC~Evenness + Canopy Height + Shrub Cover + Grass Cover, TH)				
Term	**Df**	**ChiSquare**	**F**	**Pr(>F)**
Evenness	1	0.32767	9.5765	0.001***
Canopy Height	1	0.25326	7.4016	0.001***
Shrub Cover	1	0.03561	1.0406	0.474
Grass Cover	1	0.01569	0.4585	0.941

*Significance codes: 0= '***', 0.001='**', 0.01='*', 0.05='.'*

Appendix 4. Permutational Test for the significance of Model by Terms for Bompuka Island

Model: CCA(BC~FHD + Canopy Height + Grass Cover + Trail)				
Term	**Df**	**ChiSquare**	**F**	**Pr(>F)**
FHD	1	0.8304	6.1083	0.001***
Canopy Height	1	0.11033	0.8115	0.432
Grass Cover	1	0.33246	2.4455	0.014*
Trail	1	0.3759	2.765	0.009**

*Significance codes: 0= '***', 0.001='**', 0.01='*', 0.05='.'*

Appendix 5. Species codes with their Common Names

Species Code	Species Name
ACD	Andaman Cuckoo-dove
AGP	Andaman Green Pigeon
AGS	Asian Glossy Starling
AK	Asian Koel
BNM	Black-naped Monarch
BNO	Black-naped Oriole
BTBE	Blue-tailed Bee-eater
CKF	Collared Kingfisher
ED	Emerald Dove
LTP	Long-tailed Parakeet
NB	Nicobar Bulbul
NIP	Nicobar Imperial Pigeon
NMe	Nicobar Megapode
NPi	Nicobar Pigeon
OBS	Olive-backed Sunbird
OHT	Orange-headed Thrush
OWE	Oriwntal White-eye
PIP	Pied Imperial Pigeon
PTr	Pied Triller
RWB	Red-whiskered Bulbul
RS	Rosy Starling
WBWH	White-breasted Waterhen
WRM	White-rumped Munia
YLBQ	Yellow-legged Buttonquail
ZC	Zitting Cisticola

Appendix 6. Species Richness in regions similar to Central Nicobars

Region	No of Species
Andaman	152
Western Ghats	232
North-East India	519
Sumatra	216
Malaysia	434
Central Nicobar	**73**

(Source: eBird.com)

Appendix 7. Species detected/missed in point counts

Species	Teressa	Bompuka
Andaman Cuckoo-dove	Y	N
Andaman Green Pigeon	Y	N
Andaman Wood Pigeon	N	N
Asian Glossy Starling	Y	Y
Asian Koel	Y	Y
Asian Paradise Flycatcher	N	N
Baillon's Crake	N	N
Barn Swallow	N	N
Besra	N	N
Black Capped Kingfisher	N	N
Black-naped Monarch	Y	Y
Black-naped Oriole	Y	Y
Black Naped Tern	N	N
Blue-tailed Bee-eater	Y	Y
Brown Shrike	N	N
Cattle Egret	N	N
Chinese Sparrowhawk	N	N
Collared Kingfisher	Y	Y
Common Sandpiper	N	N
Drongo Cuckoo	N	N
Edible Nest Swiftlet	N	N
Emerald Dove	Y	N
Glossy Swiftlet	N	N
Gray Wagtail	N	N
Great Egret	N	N
Himalayan Cuckoo	N	N
Indian Cuckoo	N	N
Indian Pond Heron	N	N
King Quail	N	N
Lesser Crested Tern	N	N
Lesser Sand Plover	N	N
Long-tailed Parakeet	Y	Y
Nicobar Bulbul	Y	Y
Nicobar Imperial Pigeon	Y	Y
Nicobar Megapode	Y	Y
Nicobar Pigeon	Y	N
Olive-backed Sunbird	Y	Y
Orange-headed Thrush	Y	Y
Oriental Pratincole	N	N
Oriental White-eye	Y	Y
Otus sp.	N	N

Species	Teressa	Bompuka
Pacific Reef Egret	N	N
Pied Imperial Pigeon	Y	N
Pied Triller	Y	N
Red-whiskered Bulbul	Y	N
Rosy Starling	Y	N
Ruddy Breasted Crake	N	N
Striated Heron	N	N
Whimbrel	N	N
White bellied Sea eagle	N	N
White Breasted Waterhen	Y	N
White-rumped Munia	Y	Y
White RumpedSpinetail	N	Y
Yellow Bittern	N	N
Yellow-legged Buttonquail	Y	N
Yellow Wagtail	N	N
Zitting Cisticola	Y	Y

Plates:

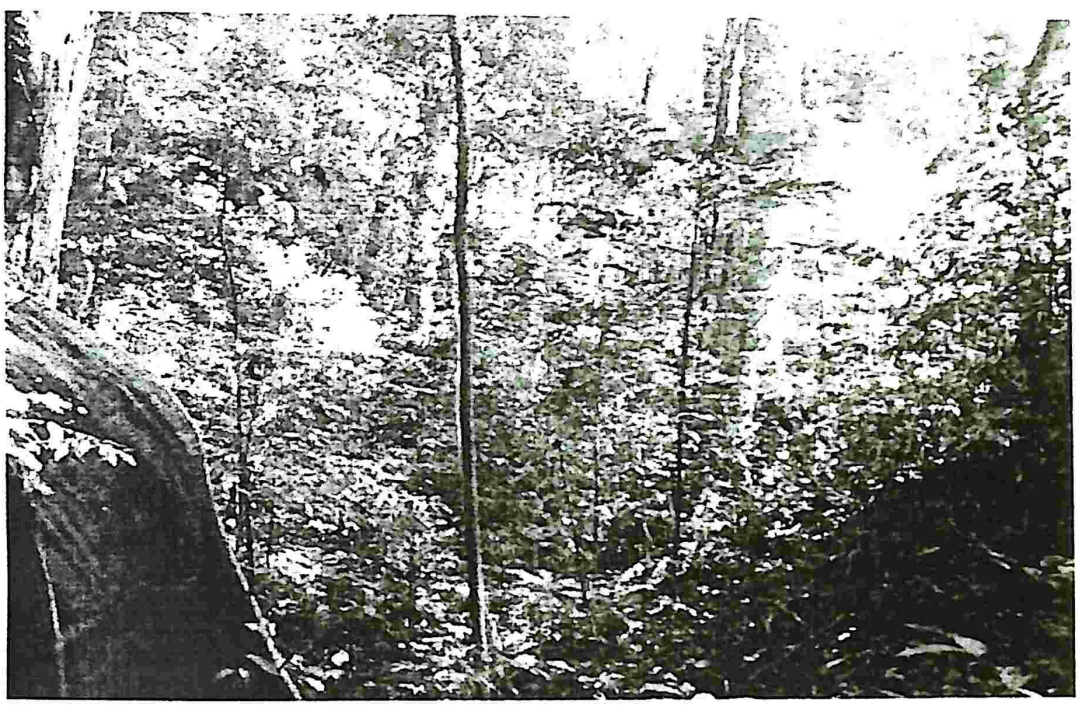

Plate 1. Primary forest in Teressa

Plate 2. Secondary forest amidst Grassland in Teressa

Plate 3. Plantation along coast line in Teressa

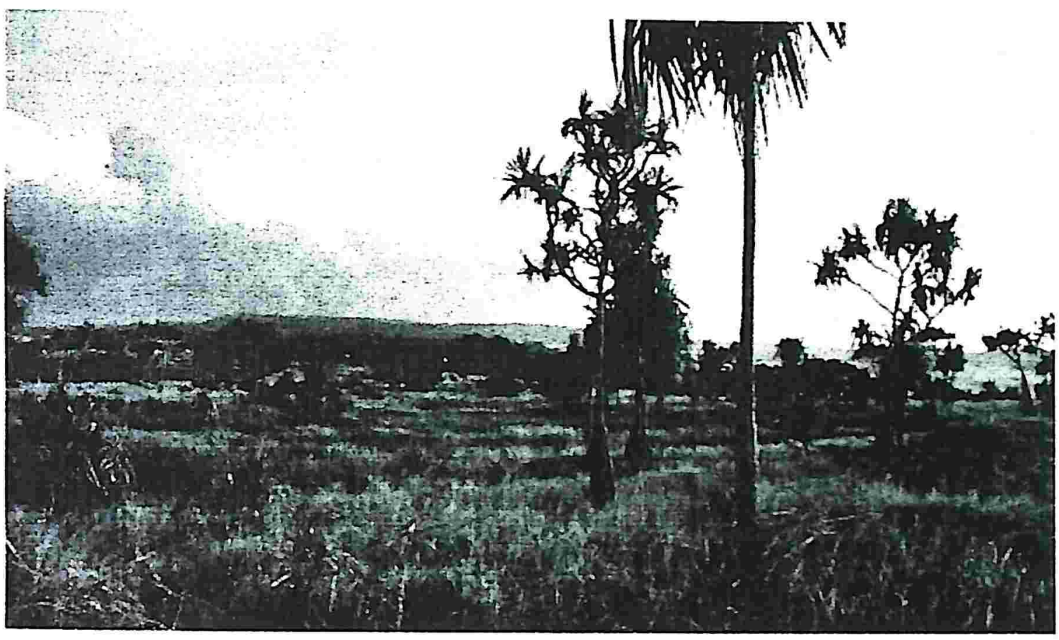

Plate 4. Grassland habitat in Teressa

Plate 5. Nicobar Bulbul feeding on *Sicuriniga sp.* fruit

Plate 6. Nicobar Bulbul and Red-whiskered Bulbul foraging together

Plate 7. Asian Drongo-cuckoo recorded in Teressa

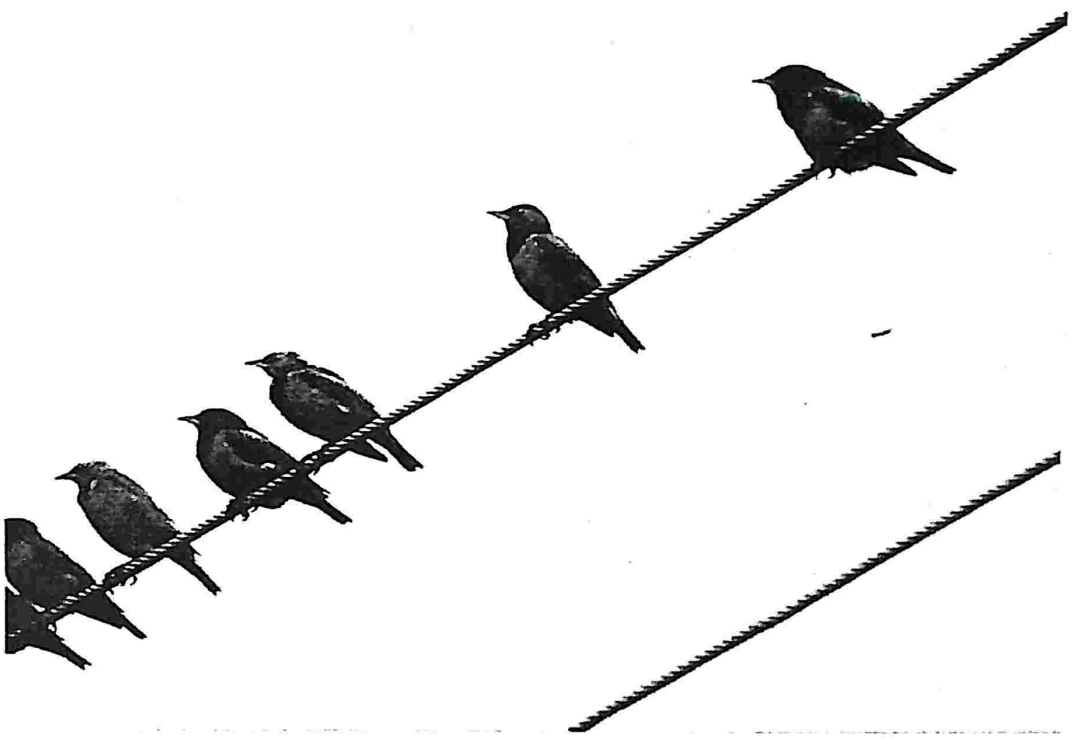

Plate 8. Rosy Starling recorded in Kamorta