MACROECOLOGY OF TERRESTRIAL HERPETOFAUNA IN ANDAMAN & NICOBAR ARCHIPELAGO

HARIKRISHNAN S., KARTHIKEYAN VASUDEVAN, ABHIJIT DAS,
B. C. CHOUDHURY, S. K. DUTTA, & INDRANEIL DAS

WILDLIFE INSTITUTE OF INDIA

Macroecology of Terrestrial Herpetofauna in Andaman & Nicobar Archipelago

Final Report 2014

Submitted by

Harikrishnan S., Karthikeyan Vasudevan, Abhijit Das*, B. C. Choudhury, S. K. Dutta & Indraneil Das

Wildlife Institute of India

Chandrabani, Dehradun, 248001

Uttarakhand

Supported by

Science Engineering Research Board

Department of Science & Technology

Government of India

*E-mail: abhijit@wii.gov.in Phone: 0135 – 2640111 – 205

Acknowledgements

We would like to thank the Science Engineering Research Board, Department of Science and Technology (DST), Government of India, for providing monetary support for this study (Grant No. SR/SO/AS-08/2009). We thank the Department of Environment & Forests, Andaman & Nicobar Islands for permission to conduct surveys in protected areas in the Andaman & Nicobar Islands. We thank Shri Ajay Saxena, Shri Agni Mitra, Dr. Senthil Kumar, Shri C. R. Mallick, Shri M. Rajkumar, Dr. Viswa Kannan, Range Forest Officers and staff in Mahatma Gandhi Marine National Park, Wandoor, Mt. Harriet, Saddle Peak National Park, Mayabunder, Long Island, Havelock, Little Andaman, Camorta, Katchal and Campbell Bay for permissions to conduct surveys and logistic support in many areas. We also thank the Deputy Commissioner (Andaman) for providing the necessary Tribal Area Permits. We thank the Director, Wildlife Institute of India & Dean of Academics, Wildlife Institute of India for the opportunity to work with the Wildlife Institute of India. We also thank Director, Zoological Survey of India, Dr. B. H. C. Murthy and Dr. Kaushik Deuti for facilitating the examination of specimens in the collection of the ZSI, Kolkata. We thank Barry Noon (Colorado State University) for initial discussions on sampling methods for terrestrial herpetofauna. We thank Mogens Andersen (Zoological Museum, University of Copenhagen), Jakob Hallermann (Zoological Museum Hamburg) and Gernot Vogel for help in taxonomic clarifications. We thank Ahmed Ali (Munnabhai), Henry Samuel, & Mehboob for their help and hospitality in Car Nicobar. We also thank Shri Robin Paul and Ismail Kujur for logistic help in Camorta and Katchal. We thank Raoji (AND Beach Resort) for his help in Neil Island and Susheel Dixit (Barefoot group) in Havelock Island. We are grateful to The Andaman and Nicobar Environmental Team (MCBT/ANET) for logistic support. Manish Chandi, Tasneem Khan, Saw John Aung Thong, Anita Prasad, Joselyn Panjikkaran, Ravi Chellam, and the staff at ANET provided immense support during this study. We also thank Prof. Rauf Ali for discussions on the impact of invasive species in the islands. Sincere thanks are due to Anand James Tirkey, Sudhir Kumar Ekka, Saw Glen, Sebe Horo, Anjelos Dungdum, Swati Sidhu, Chetan Rao, Laurence Bara, Ranjit Kumar Tapo and S. R. Chandramouli for help with fieldwork in the Andaman Islands.

Contents

List of Tables **Page**

List of Figures **Page**

Abstract

The islands arc system of Andaman & Nicobar Islands situated in the Bay of Bengal is a major contributor to the overall high biodiversity figures of India. These islands are part of two global biodiversity hotspots and contain an impressive array of endemic flora and fauna. The herpetofauna of these islands have been the subject of explorations since the 19^{th} century when European naturalists started natural history collections in these islands. However, our understanding of the terrestrial herpetofauna of these islands has been restricted to anecdotal observations, field records and taxonomic studies.. We conducted a four year survey of terrestrial herpetofauna in Andaman & Nicobar Islands. During this period 24 islands were surveyed for terrestrial herpetofauna. For the sake of completion, data from prior surveys and museum records were also compiled. We recorded 65 species of terrestrial reptiles and 17 species of amphibians from across the Andaman & Nicobar Islands. We present a presence-absence matrix for all species recorded from various islands. As expected, the largest islands had the highest number of species and smaller islands within an island groups tended to have communities that were subsets of the larger island community. Several new records and some new species were discovered during our surveys. We found that the terrestrial herpetofauna in Andaman & Nicobar Islands occur in relatively high densities in undisturbed habitats, reaching as high as 3630 individuals per hectare in Little Andaman Island. Patterns in body size distributions were mostly right skewed, but inter taxa differences were observed in this. The shape of body size distribution did not change between Andaman Islands and Nicobar Islands. Distribution of body sizes within communities of co-existing species of frogs and lizards revealed a highly structured distribution, but not in the case of snakes. Species co-occurrence patterns showed inter taxa and inter island group differences. Differences in biogeographic and colonization histories of both groups of islands are suspected to be the reasons behind the observed species co-occurrence patterns. Abundance and geographic distribution patterns were less clearly defined for both frogs and lizards. We suspect that introduced species such as chital and Indian bullfrog might have adverse impacts on native herpetofauna in the Andaman & Nicobar Islands. We attempt a classification of island herpetofauna according to their vulnerability to extinction. We also assess the current conservation status according to the IUCN criteria and legal protection status according to WPA, 1972, and show that majority of species occurring in the Andaman & Nicobar Islands have not yet been assessed properly. We conclude this report by providing a checklist of the herpetofauna, other than turtles and crocodiles, of Andaman & Nicobar Islands.

MACROECOLOGY OF TERRESTRIAL HERPETOFAUNA IN ANDAMAN & NICOBAR ARCHIPELAGO

1. Introduction

One of the fundamental questions in ecology is how species are assembled in an area? The possible explanations fall in broadly in two generic perspectives: (1) the niche-assembly perspective, which holds that assemblages of species are necessarily interacting, and (2) the dispersal-assembly perspective, which asserts that assemblages are produced by chance and random dispersal. Ecologists have long been engaged in finding an explanation for assembly of species in a community. Lack of experimentation and tacit resistance to null models has led to accumulating limited evidence in favour of these paradigms. Experimentation in this case could be so elaborate and expensive that it might not be feasible. However, islands have an inherent property of making patterns of community organization stark. Islands present themselves as simplified ecosystems, where one could examine patterns and test theoretical predictions. Therefore, islands become an infallible choice in order to evaluate the supremacy of the two precepts in ecology.

1.1 Patterns of body size

Hutchinson and MacArthur in 1959 plotted the frequency distributions of body sizes among land mammals in continents and noted that these distributions were highly skewed. There were more species of relatively small mammals than large or extremely small ones. They suggested that this pattern reflected the capacity of the modal-sized species to be relatively more specialized, and hence to subdivide space and resources more finely. They suggested that the environment could be visualized as comprising of number of "mosaic elements". Thus the niche of each species would include a different combination of elements, with modal-sized species requiring smaller numbers of mosaic elements (fine grained) than larger or smaller species. Since Hutchinson and MacArthur's study, many investigators have analyzed the frequency distributions of body sizes among different organisms (Van Valen 1973; May 1978, 1988; Morse et al., 1988; Brown and Nicoletto, 1991). Whenever, a diverse assemblage of species from a large region is considered the frequency distribution are highly skewed. Groups of organisms as diverse as bacteria, trees, insects, fishes and mammals all show the pattern described by Hutchinson and MacArthur (1959). A relationship that is apparently so general, begs for an explanation. In an attempt to offer an explanation, Brown and Nicoletto (1991) found consistent variation in the form of the frequency distribution with spatial scale. That is when samples of species from smaller areas were analyzed, the shape of the distribution changed. Species that coexist is small patches of nearly uniform habitat, tended to have uniform distributions, with apparently no skewness (Brown, 1995). It is hypothesized that samples of small areas are nested within the samples of large ones, and there is rapid turnover of species in the modal size class leading to skewness in the distribution when the area is large. Hutchinson-MacArthur model invoked physiological and ecological allometric constraints on body size distributions in communities and inferred that resource available in the environment could support either many small organisms or a few large ones. These theoretical relationships have important implications in understanding species assembly in insular communities and identifying an optimal body size. Such study would enable us to predict impact of introduced species on native fauna in the islands.

1.2 Patterns of species co-occurrence

Understanding the distributional pattern of species in communities is one of the most basic objectives in community ecology. The co-occurrence of species on islands has been an intensely debated subject in ecology and biogeography ever since Jared Diamond proposed the “assembly rules” based on his studies of the bird fauna of Bismarck Archipelago (Diamond, 1975). The “deterministic” view taken by Diamond invited severe criticism (Simberloff, 1978; Connor and Simberloff, 1979) and this opened up a debate on assembly and organization of island communities. The debate also saw a number of different rules being subsequently proposed by various other workers (Patterson and Atmar, 1986; Wilson, 1989; Fox and Brown, 1993; Dayan and Simberloff, 1994). A most important contribution that this debate made to the study of communities is the use of null models. A null model is a pattern-generating model that is based on randomization of ecological data or random sampling from a known or imagined distribution (Gotelli and Graves, 1996). They reveal community patterns that are relevant to the testing of ecological theory (Gotelli and Graves, 1996). Documenting non-random patterns in nature is considered an important step in establishing the generality of many null models that have been proposed to explain the assembly of communities (Gotelli and McCabe, 2002). An important prediction of Diamond’s assembly rules was that individual islands harbour fewer species than expected by chance (Gotelli and McCabe, 2002). While the assembly rules, as originally proposed, may be difficult to accept in the face of competing arguments, many other studies have provided support to assembly rules (Haefner, 1988; Gilpin et al., 1986; Abele, 1984; Cole, 1983). It is now recognized that species distributions are influenced by many factors including competition, predation, dispersal, habitat, climate and chance (Whittaker, 1998). Each of these competing hypotheses should be evaluated on its merits to gain an understanding of the species distributions in any group of islands for any given taxon group (Whittaker, 1998). Such a study would provide insights into the processes that govern species co-occurrence of insular fauna.

1.3 Patterns of abundance and distribution

The abundance and distribution of individual species is yet another interesting and challenging topic often discussed in macroecology. One of the assumptions in the theory of Island Biogeography is that the combined densities of the species remain invariant in the islands (MacArthur and Wilson, 1967; MacArthur et al. 1973). However, there are many cases where densities of island populations differ according to the area (Diamond, 1970). Niche based models predict that the abundance and distribution of the species will be positively correlated even in the presence of barriers to dispersal, though only a few studies have tested this hypothesis (Brown, 1984; Brown, 1995). This would also mean that the most abundant species in any island will also be the most widespread of all the species in that island and that single island endemics will be the least abundant (Brown, 1995). If one assumes that the dispersal abilities of organisms do not vary significantly, as is the case with most closely related species, a null expectation will produce the same pattern as a niche based model. i.e. random dispersal of individuals to islands of varying geographical areas will produce a pattern in which the most abundant species in any given island is also the most widespread species. In such a scenario, the factors influencing the observed patterns can be evaluated by comparing the observed densities of animals in islands of varying areas with the expected values. We expect that the effect of deterministic factors like competition or evolutionary interactions will be greater in larger islands, because in smaller islands the fewer number of species and the greater turn-over over time will reduce the importance of competition. Therefore, the larger islands should show greater deviation in densities from the null expectation. A very strong barrier for dispersal of terrestrial vertebrates is open sea, and therefore, it would be interesting to see whether the patterns predicted by niche based models will hold true in habitats separated by seas.

1.4 Amphibians and reptiles

Amphibians and reptiles offer very good model groups of organisms to study the assembly, and structure of communities in islands. Distribution and abundance of amphibians in islands is particularly interesting because of their sensitivity to saline conditions and the resulting reduction in dispersal ability. In oceanic islands, compensatory effects (Lomolino, 1986) can be considered to be minimal for these groups, unlike in the case of many groups of homoeothermic animals which show greater tendencies for long-distance oceanic dispersal. The patterns in species composition in oceanic islands can be thought to be the result of dispersal assembly rather than relaxation to equilibrium in which the overriding factor is selective extinction. In this case, the predominant factor that determines species composition would be selective colonization. The group is also interesting because there are fewer attempts to study these than other groups like birds (Bierregaard et al. 1997). In this study, we explore the patterns in species richness, composition, abundance and distribution of reptile and amphibian communities across the islands of Andaman and Nicobar. The occurrence of these animals can be positively ascertained, unlike in the case of organisms such as birds which have better dispersal abilities or show migratory behaviour. In terrestrial ecosystems endothermic birds and mammals have metabolic rates one or two order of magnitude greater than ectothermic amphibians or reptiles of similar body size (Brown, 1995). The vast majority of food consumed by birds and mammals is metabolized to support maintenance of their high body temperatures and levels of activity. Only a small fraction is allocated to growth and reproduction. In contrast, ectotherms use a smaller fraction of the energy they consume for maintenance and large fraction is allocated for growth and reproduction. Therefore, ectotherms such as amphibians and reptiles are good candidates to examine patterns in the frequency distribution of body sizes.

1.5 Herpetofauna of the Andaman & Nicobar Archipelago

The herpetofauna of the Andaman & Nicobar Archipelago have attracted the attention of naturalist dating back to the mid 19th century, as shown by publications of Blyth (1846), Steindachner (1867) and Stoliczka (1870; 1873). The Galathea expedition and the Austrian Novara Expedition in the mid 19th century were probably the first major attempts at inventory of the fauna of these islands. Since then, there have been several other subsequent descriptions of new herpetofaunal taxa, studies and reviews (Smith, 1940; Biswas & Sanyal, 1965; 1978; 1980; Tiwari & Biswas, 1973; Das, 1995; 1996; 1997a; 1998a; 1998b; 1999; Das & Vijayakumar, 2009; Vijayakumar, 2005; Vijayakumar & David, 2006; Hallermann, 2009; Harikrishnan et al., 2010a; Harikrishnan et al., 2012; Harikrishnan & Vasudevan, 2013). Smith (1940) provided the first review of biogeography of the herpetofauna of these islands. Half a century later, Das (1999) provided an updated biogeography of herpetofauna of these islands. A partial summary of species descriptions and studies on terrestrial herpetofauna of these islands was provided by Harikrishnan et al., (2010b). Almost every survey conducted in these islands has revealed the existence of species that are new to science and new distributional records for the islands (for the most recent, see Das & Vijayakumar, 2009; Hallermann, 2009; Harikrishnan et al., 2010; Harikrishnan et al., 2012) and also have lead to the rediscovery of certain species, which were known only from the original description (Murthy & Chakrapany, 1983; Das, 1997a; Vijayakumar & David, 2006; Harikrishnan & Vasudevan, 2013).

Despite the various surveys conducted in the past, there is little information on the island-wise distribution and abundance of terrestrial herpetofauna in these islands. There is no published information on terrestrial amphibian and reptile species occurring in protected areas of Andaman & Nicobar Archipelago. We conducted a preliminary survey in the Nicobar Islands during 2008-2009 (Harikrishnan et al., 2009). Following this, in 2010, we initiated intensive surveys in the Andaman & Nicobar Archipelago for terrestrial herpetofauna.

2. Objectives

The objectives of the study are:

1. Survey and documentation of distribution, species richness and abundance of terrestrial herpetofauna of Andaman & Nicobar Archipelago

2. Identification of factors that influence the spatial patterns in species abundance and distribution of reptiles and amphibians in islands

3. Testing ull models in community structure of insular reptiles and amphibians

4. Identifying the factors that influence the community structure of reptiles and amphibians in islands

3. Methods

3.1 The Andaman & Nicobar Archipelago

The Andaman & Nicobar Archipelago consists of 556 islands, islets, and rocks, covering 8249 km^2, situated in the eastern part of the Bay of Bengal (Anonymous, 2007). These islands form a continuous chain of mountains sprawling in a great arc between Cape Negrais of Myanmar and Achin Head of Sumatra, about 155 km southeast of Great Nicobar Island. The length of the island chain is about 1126 km (Biswas & Sanyal, 1980; Das, 1999; Smith, 1940). It is a part of the Great Alpine-Himalayan System (Karunakaran et al, 1968). Paleo plate reconstructions of Southeast Asia by Lee & Lowver (1995) indicate that the emergence of these islands above sea level happened only during the late Miocene (10 million years before present). The present configuration of the islands was achieved about 5 - 10 million years ago. The Mentawei Islands off the coast of Sumatra appear to be a continuation of the Nicobar Islands (Weeks et al., 1967; Rodolfo, 1969). While the Nicobar Islands appear to be truly oceanic in nature, surrounded on all sides by deep channels, it is possible that the Andaman Islands at their northern tip might have been connected to mainland Asia (Ripley & Beehler, 1989). The mean annual rainfall in these islands exceeds 3000 mm. The highest amount of rainfall is in southernmost islands with no major dry season, whereas the northern islands have more seasonal variation (Biswas & Sanyal, 1980).

Owing to this high precipitation and their tropical location, the predominant vegetation type in these islands is wet evergreen forest. There are 11 major forest types in these islands (Champion & Seth, 1968). These are: 1) Giant evergreen forest 2) Andaman tropical evergreen forest 3) Southern hilltop tropical evergreen forest 4) Cane brakes 5) Wet bamboo brakes 6) Andamans semi evergreen forest 7) Andamans moist deciduous forest 8) Andamans secondary moist deciduous forest 9) Littoral forest 10) Tidal swamp forest 11) Submontane hill valley swamp forest (Champion & Seth, 1968).These islands form parts of two biodiversity hotspots: the Andaman Islands are a part of the Indo-Burma hotspot and the Nicobar Islands are part of the Sundaland hotspot (Myers et al, 2000)

Based on their origin and connectivity in the past, these islands can be divided into two major groups: the Andaman Islands in the northern part and the Nicobar Islands in the southern part. They are separated by Ten Degree Channel, named so for the latitude at which it is located. This channel is about 1000 m deep and approximately 140 km wide. This has ensured that the

Andaman Islands and the Nicobar Islands remained separated from each other even during maximum sea level drops during the Pleistocene (Lee & Lowver, 1995). The deep Andaman Sea on the east separated this island chain from Southeast Asia and The Bay of Bengal separates it from the Indian subcontinent.

Towards the north, Great Coco Island which is the northern-most island in the Andamans (geologically) is separated from Preparis Island which is located on the outer continental margin of Southeast Asia, by a channel about 76 km wide and approximately 500 m deep. The distance between Cape Negrais of Myanmar and Great Coco Island is about 215 km, although the sea is less than 100 m deep along most of this separation. The northernmost island in the Andamans administered by India is Landfall Island which is about 40 km southwest of Little Coco Island. The highest peak in the Andaman and Nicobar Archipelago is Saddle Peak, which reaches 732 m above mean sea level (hereafter asl), and is located in North Andaman Island. Narcondam and Barren are the easternmost islands in the Andaman Islands, though they are volcanic in origin and have never had land connection with other islands in the Andamans. North Sentinel Island is the westernmost island in the Andamans. Within Andamans, there are further divisions such as North Andaman, Middle Andaman, Baratang, and South Andaman, which, together with numerous adjoining islands are called Great Andamans. A major hill range occurs on the northeast part of south Andaman, comprising of several peaks such as Mt. Harriet (365 m asl), Mt. Carpenter (373 m asl), Mt. Goodridge (377 m asl), Mt. Koyob (460 m asl), Mt. Hext (424 m asl) and Mt. Warden (422 m asl) (Das, 1997b). Ritchie's Archipelago is a cluster of islands situated towards the east of Great Andamans. The southernmost island in the Andamans is Little Andaman Island, about 140 km north of Car Nicobar Island. Little Andaman is approximately 55 km south of South Andamans. Everywhere within the Andaman Islands, with the exception of Barren and Narcondam, the sea is relatively shallow (50-100 m), which means that all these islands were interconnected during major sea level changes in the Pleistocene.

The Nicobar Islands consist of 23 islands south of the Ten Degree Channel. The total land area is 1841 km^2. Three clusters of islands can be identified in this group. The northern cluster consists of only two islands, Car Nicobar and Batti Malv. The central cluster is collectively known as Nancowry group, and consists of Nancowry, Camorta, Katchal, Trinkat, Bompoka, Terressa, Chowra, Tillangchong, Islets of Mann and Prairie Rock. The southern cluster consists of Great Nicobar, Little Nicobar, Megapode, Pigeon, Kondul, Menchal, Cabra, Meroe, Trac, Treis, and Pilo Milo. Great Nicobar is the southernmost island in this group and is only about 300 km northwest of Sumatra. The channel between Great Nicobar and Sumatra is more than 1000 m deep which rules out any possibility of land connections in the recent past.

Car Nicobar is a relatively flat island with a maximum elevation of 30 m. It is also the most densely populated island and the landscape is dominated by coconut plantations and orchards. Patches of evergreen forests occur intermittently throughout the island. Nancowry group is hillier; Maharani Peak in Tillangchong reaches about 300 m asl. Islands in the Nancowry group also have evergreen forests, though in many areas, they have been replaced by secondary forest. They also support extensive grasslands on hill tops. Islands in the southern group have lower population density and are extensively covered in wet evergreen forests. Mt. Thullier in Great Nicobar is the highest peak in the Nicobar Islands, reaching about 642 m asl.

We surveyed 24 islands in the Andaman & Nicobar Archipelago for amphibians and reptiles. Table 1 summarises the information on islands sampled and methods used. A number of different methods were used to sample herpetofauna as no single method can detect all species.

3.2 What are terrestrial herpetofauna?

We define terrestrial herpetofauna to include all non-marine species of reptiles, and all amphibians. This definition excludes the following species: salt-water crocodile (*Crocodylus porosus*), green sea turtle (*Chelonia mydas*), hawksbill sea turtle (*Eretmochelys imbricata*), olive ridley (*Lepidochelys olivacea*), leatherback sea turtle (*Dermochelys coriacea*), all sea snakes, sea kraits (*Laticauda laticaudata* & *Laticauda colubrina*), file snake (*Achrochordus granulatus*). The reason for this was the widely different methods that were necessary for survey and abundance estimation of these species compared to other terrestrial and semi-aquatic species of amphibians and reptiles. Further species specific studies are necessary for the above mentioned species. Thus, this definition is based on habitat preference of the species, as well as logistical constraints in sampling.

3.3 Survey of terrestrial herpetofauna

The foremost requirement of a macroecological study is obtaining data on species geographic distribution, species richness, abundance and body size. For this, we carried out intensive surveys in the Andaman & Nicobar Archipelago. Geographic distribution of amphibian and reptile species in Andaman & Nicobar Archipelago was assessed through both field surveys and secondary sources (museum specimens and literature). Field surveys were carried from October to June, avoiding peak monsoon. To assess the presence of species in each island quadrat surveys (see below), visual encounter surveys (VES) and pitfall traps with drift fences were used. Each VES was one hour long, where we walked the forests at a slow pace looking for amphibians and reptiles. For amphibians, VES were carried out after sunset (between 6 p.m. and 9 p.m.). For diurnal lizards and snakes VES were carried out in the morning (between 8 a.m. and 10 a.m.). For nocturnal lizards (most Gekkonids) and snakes, VES were conducted after sunset between 6 p.m. and 9 p.m.). Pitfall traps with drift fences were only attempted in four islands due to logistic constraints. These were 25 cm × 30 cm buckets buried in the ground with the rim flush with the ground, and a 30 cm high plastic sheet erected vertically above them to act as a drift fence. A few holes, small enough to prevent animals escaping but large enough for the passage of water, were put at the bottom of the buckets to drain rainwater. A 20 m long plastic sheet was used as drift fence with buckets placed at 5 m intervals. The bottom of the fence was buried in the soil to prevent animals slipping under it. These were checked twice a day and any animal found in the buckets was captured, identified, and released slightly away from the fence. Pitfall traps were not attempted in all islands as they were labour intensive and provided very few unique records. Any species found opportunistically was also recorded. We also used the locality data of specimens in the collection of Zoological Survey of India, Kolkata and Zoological Survey of India, Port Blair. In addition, we used published literature to obtain data on distribution of species. From all such records, distribution of species across islands and species richness of each island was enumerated.

3.4 Abundance of terrestrial herpetofauna

We started our surveys in Long Island (Middle Andamans) using time constrained VES (2 hrs) (Harikrishnan et al, 2012). The times constraint was later abandoned, and VES surveys were done opportunistically since the primary purpose of VES was to detect as many species as possible. Instead, for estimating abundance, we used 10 m × 10 m quadrats, demarcated with a nylon rope, for sampling forest floor and understorey herpetofauna (Scott, 1976). Since quadrat sampling was restricted to primary evergreen forest and most islands did not have significant elevation gradient, a simple random sampling design was used. Quadrats were not sampled in mangroves, beaches and disturbed secondary forests or plantations. Within evergreen forest, quadrats were placed at random sites by selecting a random distance and direction from pre-existing forest trails or a pre-defined point. Once a sampling quadrat site was located, one person quickly walked around placing wooden stakes at the four corners and tying a nylon rope around the quadrat. Four people (rarely six) searched the quadrat for amphibians and reptiles. The quadrat was divided into four equal halves and each person searched a half, beginning with the outermost corners and edges and working his way to the centre. Diurnally active arboreal species were captured at the beginning of the searches before the understorey was disturbed. Leaf litter was slowly removed to the outer edges of the quadrat with a small stick and every individual amphibian or reptile exposed was captured and placed in plastic zip-lock covers (small lizards and amphibians) or cloth bags (large lizards and snakes). They were identified, counted and released at the same site at the completion of quadrat search. We assigned all individuals that escaped out of the quadrat before capture to known species based on morphological features visible from a distance (dorsal colour and pattern, approximate size, and behaviour). These methods followed Scott (1976).

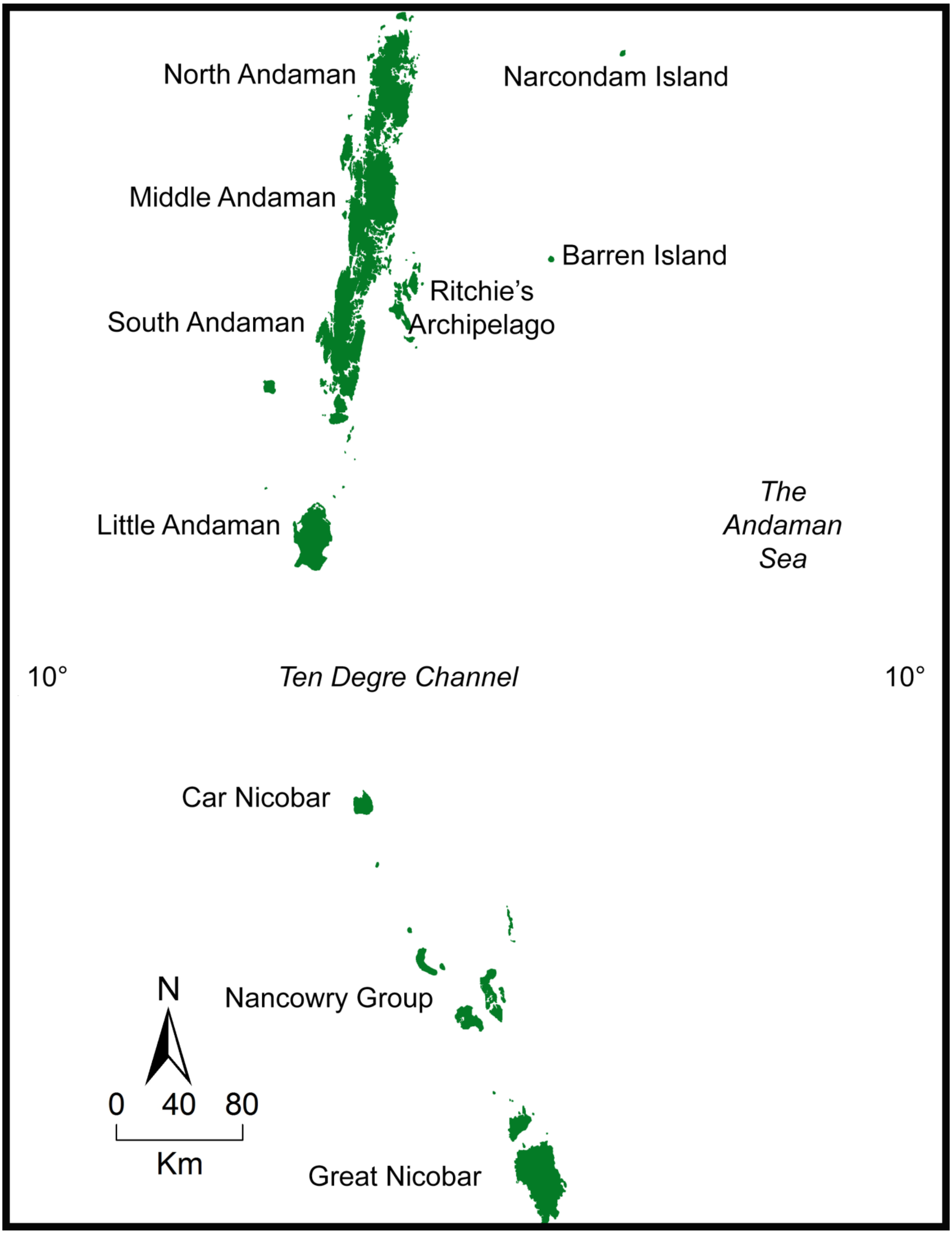

Figure 1. The Andaman & Nicobar Archipelago, with the major island groups labelled. Cocos Islands, which are geologically part of the island chain, are not included.

Table 1. Details of islands surveyed in the Andaman & Nicobar Archipelago

Island	**Area (km^2)**	**Bounded quadrats (Yes/No)**	**Surveyed elevation (in meters)**	**Perennial freshwater bodies (Yes/No)**
South Andaman	1350.82	Y	0-350	Y
North Andaman	1375.99	Y	0-700	Y
Middle Andaman	1535.5	N	0-20	Y
Little Andaman	734.39	Y	0-131	Y
Rutland	137.17	Y	0-400	Y
Havelock	113.93	Y	0-66	Y
Neil	18.9	Y	0-29	Y
Long Island	17.9	Y	0-56	N
Tarmugli	11.5	Y	0-33	N
Alexandra	3.6	Y	0-32	Y
Hobday	3.6	Y	0-48	N
Boat	2.8	Y	0-30	N
Redskin	3.3	Y	0-53	N
Snob	0.22	Y	0-33	N
Chester	0.09	Y	0-7	N
Grub	0.03	N	0-15	N
Great Nicobar	1044.54	Y	0-203	Y
Kondul	4.66	N	0-10	N
Menchal	1.5	N	0-5	N
Pigeon	0.5	N	0-10	N
Camorta	188.03	Y	0-50	Y
Katchal	174.3	Y	0-53	Y
Nancowry	66.82	N	0-20	Y
Car Nicobar	126.91	N	0-20	Y

Open quadrats provide only an uncalibrated index of density of animals because there is no information on number of individuals that escape the quadrat without being detected or remain hidden. To calibrate these estimates, we also sampled bounded quadrats of the same dimension (10 m × 10 m). These quadrats were demarcated with a 50 cm high plastic sheet erected to prevent the escape of animals during sampling. The procedure was modified from Rodda *et al* (2001a). We could not place these quadrats randomly because of uneven terrain, hard or rocky substrate, or large fallen tree trunks. Therefore, we placed these quadrats in areas that had vegetation structure representative of the area (visual assessment only), and in relatively flat terrain devoid of large fallen trees and rocky substrate (Fauth *et al* 1989; Rodda *et al* 2001a). Our quadrats differed from Rodda *et al* (2001a) in that we used a 50 cm high plastic sheet with its bottom buried in soil to enclose the quadrat. We did not grease the top of the sheet, as our study area had only two species of lizards with expanded sub digital lamellae, which were both arboreal species, recorded rarely in quadrats. Once established, we detached the top of the plastic sheet from the supporting stakes so that it fell flat on the ground allowing free movement of animals and left it undisturbed for about 24 hours. The following day, we approached the quadrat from four sides and quickly raised the plastic sheet, securing the top edge to the stakes so that no animals escaped. Then we sampled the quadrats using methods from Rodda *et al* (2001a) except that we did not cut any trees. We captured most agamid lizards in all quadrats (both open and bounded) using a fishing line noose at the

Figure 2. Low elevation wet evergreen forest in Great Nicobar Island

Figure 3. Searching a bounded quadrat in wet evergreen forest in Great Nicobar Island.

beginning of quadrat search as these were more likely to escape by climbing up trees. We checked tree trunks to a height of about 2m beyond which they could not be effectively searched. These intensive bounded quadrats yielded total counts of forest floor and understorey species of herpetofauna.

3.5 Data analysis

Body size distribution: Amphibians and reptiles presented a challenge to using the commonly used measure of body size, i.e. body length, for an analysis of patterns in size distribution as they exhibit a number of starkly different body structures, from having elongated limbless bodies such as limbless lizards, snakes and caecilians to rounded bodies as in many burrowing frogs. Therefore, we used body mass as a measure of body size. Body mass measurements were taken for several individuals of all species recorded (in grams), using which average body mass of each species was calculated. Histograms of log (body mass) were created for all herpetofauna as well as frogs, lizards and snakes separately. Skewness and kurtosis of these distributions were also examined, along with visual examination of the shape of these distributions. The variance in segment length was used to test the hypothesis that species sizes are evenly spaced, even if there is no particular minimum separation (Poole and Rathche 1979). For this analysis, a parametric log normal distribution was used to draw random body sizes from, and the sizes were converted to log, so that essentially, size-ratios were obtained. 10,000 randomizations were used to create null body size distributions, and compared with the observed body sizes.

Species co-occurrence patterns were examined using C-score (Stone & Roberts, 1990), with 1000 randomizations. For this analysis, the observed row and column totals, i.e. the observed species richness of each island and the total number of occurrences of each species, were kept constant. This model was chosen based on the recommendations in Gotelli & Entsminger, (2001).

To analyze the patterns in geographic distribution and abundance, population density was calculated for every terrestrial species recorded in bounded quadrats. The geographic distribution of each species was calculated as the number of islands of occurrence. Based on this data set, null models were created through randomization algorithms, using 10000 repetitions. The expected distribution was a ‘right triangle’, and we tested for a linear relationship between abundance and distribution. We tested for greater than expected aggregation of points within the two dimensional space, as well as for a top right boundary and less than expected occurrence of points outside this boundary. All such null model analyses were performed in Ecosim (Ver. 7.71) (Gotelli & Entsminger, 2001).

4. Results

During the period of the present study (March 2010-January 2014), 24 islands in the Andaman & Nicobar Archipelago were surveyed for terrestrial reptiles and amphibians. This covered 16 islands in the Andaman Islands and 8 islands in the Nicobar Islands. 65 Species of terrestrial reptiles and 17 species of amphibians were recorded from across the archipelago. This included 33 of the 35 species of lizards, 32 of the 38 species of terrestrial snakes, and 17 of the 19 species of frogs known from these islands.

4.1 Distribution of terrestrial herpetofauna

24 islands in the Andaman & Nicobar Archipelago were surveyed for assessing the distribution of herpetofaunal species. For Nicobar Islands, species distribution in seven additional islands was obtained from Vijayakumar (2005). Thus, the total number of islands for which we have presence-absence data is 31. A presence-absence matrix for all terrestrial species is given in Table 2 and Table 3 for Andaman Islands and Nicobar Islands respectively. Bay Island forest lizard (*Coryphophylax subcristatus*) was the most widely distributed species occurring in 26 islands, followed by Water monitor lizard (*Varanus salvator*) which occurs in 25 islands. Water monitor lizard, however, could potentially occur in more islands as it is a species with excellent swimming ability. Smaller islands tended to have fewer species and formed subsets of larger island faunas. The accompanying checklist (Appendix 1) includes all species known to exist in the Andaman & Nicobar Archipelago, and any species not recorded during our study is explicitly mentioned.

Table 2. Terrestrial herpetofauna of the Andaman Islands and their distribution in surveyed islands. Abbreviations: SA – South Andaman, MA – Middle Andaman, NA – North Andaman, LA – Little Andaman, RL – Rutland, HL – Havelock, LI – Long Island, NI – Neil, TA – Tarmugli, AL – Alexandra, HB – Hobday, RS – Redskin, SN – Snob, CH – Chester, GB – Grub, BO – Boat,

		SA	MA	NA	LA	RL	HL	LI	NI	TA	AL	HB	RS	SN	CH	GB	BO
	Amphibians																
1	*Bufo melanostictus*	+	+	+	+	+	+	+	+		+						
2	Bush toad[1]	+		+	+	+	+										
3	*Kaloula baleata ghoshi*	+	+	+	+	+		+									
4	*Microhyla chakrapanii*	+	+	+	+	+		+	+								
5	*Microhyla ornata*[2]	+															
6	*Micryletta inornata*[2]	+															
7	*Fejervarya andamanensis*[3]	+		+				+									
8	*Fejervarya cancrivora*	+						+									
9	*Rana charlesdarwini*	+		+	+	+	+	+	+	+	+		+				
10	*Limnonectes* sp.[3]	+	+	+	+	+	+	+	+		+	+					
11	*Hoplobatrachus tigerinus**	+	+														
	Lizards																
1	*Coryphophylax subcristatus*	+	+	+	+	+	+	+	+	+	+	+	+				+
2	*Coryphophylax brevicaudus*	+	+	+	+	+	+		+	+							
3	*Calotes versicolor**	+	+	+	+												
4	*Pseudocalotes andamanensis*	+	+	+		+		+									
5	*Phelsuma andamanense*	+	+	+	+	+	+	+	+						+		
6	*Cnemaspis andersoni*	+		+	+		+		+	+							
7	*Cyrtodactylus rubidus*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8	*Gehyra mutilata**	+					+	+	+								
9	*Gekko verreauxi*	+	+	+	+	+	+	+	+	+	+	+	+				
10	*Hemidactylus frenatus**	+	+	+	+	+	+	+	+								
11	*Hemidactylus brookii**	+						+									
12	*Hemidactylus patyurus*	+	+	+		+		+	+	+							
13	*Hemiphyllodactylus typus*	+						+									
14	*Lepidodactylus lugubris*	+			+												
15	*Lipinia macrotympanum*[4]	+															

16	*Lygosoma bowringii*	+	+	+	+	+	+	+	+							
17	*Eutropis andamanensis*	+	+	+	+	+	+	+	+	+	+		+		+	+
18	*Eutropis tytleri*	+	+	+	+	+		+	+							
19	*Sphenomorphus maculatus*	+	+	+		+	+									
20	*Varanus salvator*	+	+	+	+	+	+	+	+	+	+	+			+	
	Snakes															
1	*Indotyphlops braminus*	+		+				+	+							
2	*Typhlops andamanensis*	+														
3	*Asiatyphlops oatesii*	+	+	+			+									
4	*Lycodon hypsirhinoides*	+	+	+	+	+		+	+	+	+					
5	*Dendrelaphis andamanensis*	+	+	+	+	+	+	+	+		+					
6	*Ptyas mucosa*	+	+			+		+			+					
7	*Coelognathus flavolineatus*	+														
8	*Gonyosoma oxycephalum*	+	+		+	+	+									
9	*Xenochrophis tytleri*	+	+	+	+	+		+			+					
10	*Boiga andamanensis*	+	+	+	+	+		+		+						
11	*Cerberus rynchops*	+	+	+	+	+	+	+		+						
12	*Gerarda prevostiana*[5]			+												
13	*Cantoria violacea*[5]		+	+												
14	*Bungarus andamanensis*	+				+		+								
15	*Naja sagittifera*	+	+	+			+									
16	*Ophiophagus hannah*	+	+	+	+		+									
17	*Trimeresurus andersoni*	+	+	+	+	+		+			+	+				

Notes: * These species are human commensals, and probably introduced into the islands during recent past through human agency.

1. An unidentified species
2. Both these species are reported in literature from single records each. Their occurrence in the Andaman Islands needs further confirmation.
3. These are tentative field identifications. The taxonomic status of small Ranid frogs from Andaman & Nicobar Islands requires a review for properly assessing the status of species reported from these islands.
4. Included here based on type specimen which is from "a sandy beach in McPherson's Strait" which separates South Andaman and Rutland.
5. Mangrove specialist species not recorded during this study.

Table 3. Terrestrial herpetofauna of the Nicobar Islands and their distribution in surveyed islands. Abbreviations: CAR – Car Nicobar, CHO – Chowra, BOM – Bompoka, TIL – Tillangchong, TAR – Tarrasa, KAT – Katchal, TRI – Trinkat, CAM – Camorta, NAN – Nancowry, PIL – Pilo Milo, LNI – Little Nicobar, MEN – Menchal, KON – Kondul, PIG – Pigeon, GNI – Great Nicobar

		CAR	CHO	BOM	TIL	TAR	KAT	TRI	CAM	NAN	PIL	LNI	MEN	KON	PIG	GNI
	Amphibians															
1	*Bufo melanostictus*	+		+	+	+	+	+	+	+	+	+		+		+
2	*Microhyla heymonsi*											+				+
3	*Fejervarya* cf. *nicobariensis*	+				+	+	+	+	+						
4	*Fejervarya cancrivora*											+				+
5	*Limnonectes shompenorum*										+	+	+			+
6	*Limnonectes* sp.															+
7	*Hylarana erythraea*	+			+	+	+	+	+							+
8	*Hylarana nicobariensis*	+			+	+	+		+	+	+	+				+
9	*Hylarana chalconota*															+
10	*Polypedates insularis*										+	+				+
	Lizards															
1	*Bronchocela cristatella*	+														
2	*Bronchocela danieli*													+		+
3	*Bronchocela rubrigularis*		+	+	+	+	+	+	+	+						
4	*Calotes versicolor**	+														
5	*Coryphophylax subcristatus*	+	+	+	+	+	+	+	+	+	+	+	+	+		
6	*Cnemaspis* sp.									+						+
7	*Cyrtodactylus adleri*							+			+	+	+	+		+
8	*Gehyra mutilata*		+			+	+	+	+	+				+		+
9	*Gekko smithii*								+		+	+	+	+	+	+
10	*Ptychozoon nicobarensis*	+	+	+	+	+	+	+	+	+						
11	*Hemidactylus frenatus**	+	+	+	+	+	+	+	+	+	+	+		+		+
12	*Hemidactylus garnotii*						+									
13	*Hemiphyllodactylus typus*															+
14	*Lepidodactylus lugubris*															+
15	*Dasia nicobarensis*	+														
16	*Dasia olivacea*		+	+	+	+	+	+	+	+	+	+	+	+		+
17	*Lipinia macrotympanum*[1]											+				+

18	*Eutropis multifasciata*	+		+	+	+	+	+	+	+		+	+			+
19	*Eutropis rudis*										+		+			+
20	*Eutropis rugifera*		+	+	+	+	+	+	+	+		+				+
21	*Scincella macrotis*[2]															+
22	*Sphenomorphus maculatus*	+	+	+	+	+	+	+	+	+						
23	*Dibamus nicobaricus*							+	+	+		+				+
24	*Varanus salvator*	+		+	+	+	+	+	+	+	+	+	+	+		+
	Snakes															
1	*Indotyphlops braminus*	+	+			+				+						+
2	*Xenopeltis unicolor*															+
3	*Malayopython reticulatus*	+		+	+	+	+	+	+	+	+	+	+			+
4	*Gongylosoma nicobarense*[3]							+								
5	*Oligodon woodmasoni*		+	+	+	+	+	+	+	+						
6	*Sibynophis bistrigatus*[4]								+							
7	*Lycodon subcinctus*															+
8	*Lycodon tiwarii*	+		+	+	+		+	+	+						
9	*Dendrelaphis humayuni*		+	+	+	+	+	+	+	+	+	+				+
10	*Coelognathus* sp.															+
11	*Boiga wallachi*										+	+				+
12	*Amphiesma nicobariense*[3]							+								
13	*Xenochrophis trianguligerus*											+				+
14	*Cerberus rynchops*	+					+	+	+	+		+				+
15	*Enhydris plumbea*															+
16	*Fordonia leucobalia*															+
17	*Trimeresurus andersoni*	+														
18	*Trimeresurus cantori*		+	+	+	+	+	+	+	+						
19	*Trimeresurus* cf. *albolabris*	+														
20	*Trimeresurus mutabilis*		+	+	+	+	+	+	+	+						
21	*Trimeresurus labialis*	+														

Notes: * These species are human commensals, and probably introduced into the islands during recent past through human agency.

1. Known from Little Nicobar and Great Nicobar based on two specimens. It was not recorded in our survey.
2. Known only from Galathea Bay in Great Nicobar. Not recorded in our survey.
3. Both these species are known only from type specimens collected in the 19th century.
4. Known from a single specimen collected in 19th century. As Smith (1943) remarked, the origin of the specimen needs to be verified.

4.2 Species richness of terrestrial herpetofauna

65 species of terrestrial reptiles and 17 species of amphibians were recorded during our field surveys. We recorded nine species of frogs, 19 species of lizards and 15 species of terrestrial snakes from the Andaman Islands. From the Nicobar Islands, we recorded 10 species of frogs, 20 species of lizards and 16 species of terrestrial snakes. Two species of frogs, seven species of lizards and three species of terrestrial snakes were shared between the Andaman Islands and the Nicobar Islands. Species richness was highest in the largest islands in both the island groups. Species richness was also influenced by the presence of human habitations in large islands, through anthropogenic introduction of species. Species richness of each island as recorded during our survey is summarized in Table 4.

Table 4. Summary of species richness of terrestrial herpetofauna in various islands in the Andaman & Nicobar Archipelago. (* Species occurrence data from past surveys)

	Island	Area (km^2)	Species richness Frogs	Lizards	Snakes
Andaman Islands	South Andaman	1350.82	11	20	14
	Middle Andaman	1535.5	5	14	12
	North Andaman	1375.99	7	15	12
	Little Andaman	734.39	6	13	8
	Rutland	137.17	6	13	9
	Havelock	113.93	4	12	6
	Long Island	17.9	7	14	9
	Neil Island	18.9	4	13	3
	Tarmugli	11.5	1	8	3
	Alexandra	3.6	3	5	5
	Hobday	3.6	1	4	1
	Redskin	3.3	1	4	0
	Snob	0.22	0	1	0
	Chester	0.09	0	4	0
	Grub	0.03	0	2	0
	Boat	2.8	0	2	0
Nicobar Islands	Car Nicobar	126.91	4	10	7

Chowra*	8.28	0	8	5
Bompoka*	13.3	1	9	6
Tillangchong*	16.83	3	9	6
Tarasa*	101.4	4	10	7
Katchal	174.3	4	11	6
Trinkat	36.26	3	12	9
Camorta	188.03	4	12	7
Nancowry	66.82	3	12	8
Pilo Milo*	1.29	4	7	3
Little Nicobar*	159.02	6	9	5
Menchal	1.5	1	7	1
Kondul	4.66	1	8	0
Pigeon	0.5	0	1	0
Great Nicobar	1044.54	9	16	10

4.3 Abundance of terrestrial herpetofauna

Andaman & Nicobar Archipelago has relatively high density of forest floor and understorey herpetofauna. Density estimates from open quadrats for frogs and lizards in the Andaman Islands was 1.3±10.2 and 6.5±4.1 respectively. However, bounded quadrats gave a considerably different picture, i.e., 7.2±10.2 and 15.5±15.5 for frogs and lizards respectively. This confirmed our doubts that open quadrats were severely underestimating densities, and they were discontinued in the Nicobar Islands. Although more species of lizards were recorded in bounded quadrats in the Nicobar Islands, density was considerably lower compared to the Andaman Islands (Table 5). Such a comparison is difficult in the case of frogs as they tend to have greater seasonal fluctuation in abundance. Greatest abundance of frogs is likely to occur during the wet season, but it was logistically not possible to sample all islands during the wet season. The relatively high variation in estimates from bounded quadrats could be a true reflection of spatial variation in abundance of frogs and lizards in evergreen forests in Andaman & Nicobar Archipelago. Density estimates for frogs and lizards in every sampled island is given in Table 6.

Table 5. Density estimates for frogs and lizards in the Andaman & Nicobar Archipelago. Since open quadrats seemed to underestimate density, they were not sampled in the Nicobar Islands. (n – Number of quadrats, S_{obs} – number of species recorded in quadrats, D – individuals/100m^2±standard deviation)

		Bounded quadrats			Open quadrats	
		n	S_{obs}	D	S_{obs}	D
Andamans	Frogs	42	8	7.2±10.2	7	1.3±10.2
	Lizards	49	7	15.5±15.5	7	6.5±4.1
Nicobars	Frogs	16	6	2.1±1.9	-	-
	Lizards	16	10	5.9±3.4	-	-

It is evident from Table 6 that there is wide variation in the abundance of terrestrial herpetofauna between islands in the archipelago. The highest abundance of frogs in the Andaman islands were recorded in the larger islands, and also those that were sampled during post monsoon (October-December: South Andaman, Little Andaman and Alexandra). The three Nicobar Islands sampled using quadrats were all sampled during December-January. Great Nicobar Island received consistent rainfall during this period but still had fairly low abundance of frogs, indicating that other unknown factors might be of greater influence on the abundance of frogs in these islands. There was also no significant relationship between island area and density, and it may be that variation in density might be determined by other local level factors. One such factor seemed to be the presence or absence of introduced Chital (*Axis axis*) which seemed to have a detrimental impact on understorey flora in islands where they occurred. Little Andaman Island where there is no chital, and Neil Island, where chital pellets were not recorded, seemed to have the highest lizard densities.

Table 6. Estimates of density of lizards and frogs from bounded quadrats sampled in 17 islands in the Andaman & Nicobar Archipelago. Density is expressed as no. individuals/100m^2. For snakes, only the number of individuals detected in quadrats is given as quadrats were not efficient in detecting snakes. (n – Number of quadrats, D – individuals/100m^2±standard deviation)

		Lizards		Frogs		Snakes
Island	n	Individuals	D	Individuals	D	Individuals
North Andaman	4	37	9.3±4.8	9	2.3±1.5	2
South Andaman	8	113	14.1±5.5	149	18.6±15.9	1
Little Andaman	10	363	36.3±20.0	55	5.5±6.8	2
Rutland	5	66	13.2±8.5	48	9.6±8.8	0
Havelock	2	35	17.5±3.5	1	0.5±0.7	1
Neil	2	54	27.0±16.9	1	0.5±0.7	2
Long Island	2	10	5.0±4.2	3	1.5±2.1	0
Tarmugli	4	13	3.3±1.4	6	1.5±2.9	1
Alexandra	3	19	6.3±4.9	29	9.7±7.1	1
Redskin	3	32	10.7±6.4	1	0.5±0.7	0
Hobday	2	8	4.0	0	0	0
Boat	2	2	1.0	0	0	0
Chester	1	1	1.0	0	0	0
Snob	1	4	4.0	0	0	0
Great Nicobar	10	46	4.6±3.3	23	2.3±2.1	0
Camorta	4	31	7.8±2.2	10	2.5±1.7	2
Katchal	2	18	9.0	1	0.5	2

4.4 Patterns in body size distribution of herpetofauna

Body size distribution of herpetofauna was analysed by plotting histograms of log body mass for frogs, lizards and snakes in Andaman & Nicobar Archipelago. The distribution of body masses of all herpetofauna showed a right skewed distribution (Fig. 4). The highest number of species occurred in the modal size category 3 – 7 g. 14 species were included in this category, among which 12 are endemic to Andaman & Nicobar Archipelago. This indicates a high turnover of species in this size class.

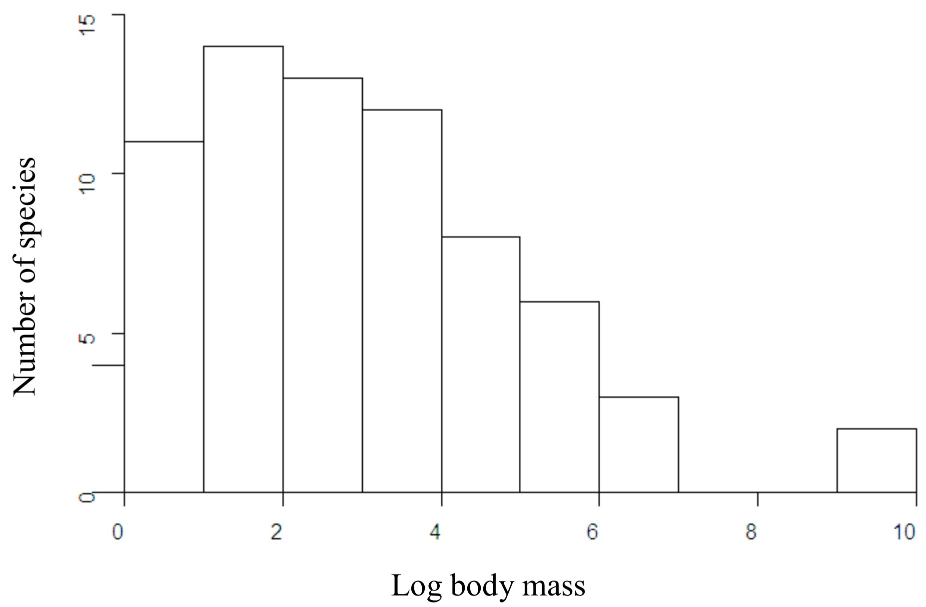

Figure 4. Body size distribution of all terrestrial herpetofauna across the Andaman & Nicobar Archipelago

The body size distribution of frogs in the Andaman & Nicobar Archipelago also showed a slightly right skewed distribution (skewness = 0.18, kurtosis = -0.72) (Fig. 5a). However, the distribution was not unimodal, and this probably is an artefact of the small size of the frog community in the islands. The size distribution of lizards showed prominent right skewness (2.40) and kurtosis (8.78) (Fig. 5b). The modal size class in this case was once again between 3 – 7 g, with 11 species. On the other hand, the distribution of body sizes of snakes did not show significant skewness and very nearly approached a normal distribution (skewness -0.04, kurtosis 1.49) (Fig. 5c).

A comparison of the size distributions in the two major island groups, viz., Andaman Islands and Nicobar Islands, was made using lizard body sizes (Fig. 6, A & B). This indicated that, though the two groups of islands share only a few species of lizards, the size distributions were remarkably similar, and had a strong right skew (Fig. 6, A & B), with modal size class being less than 7 g.

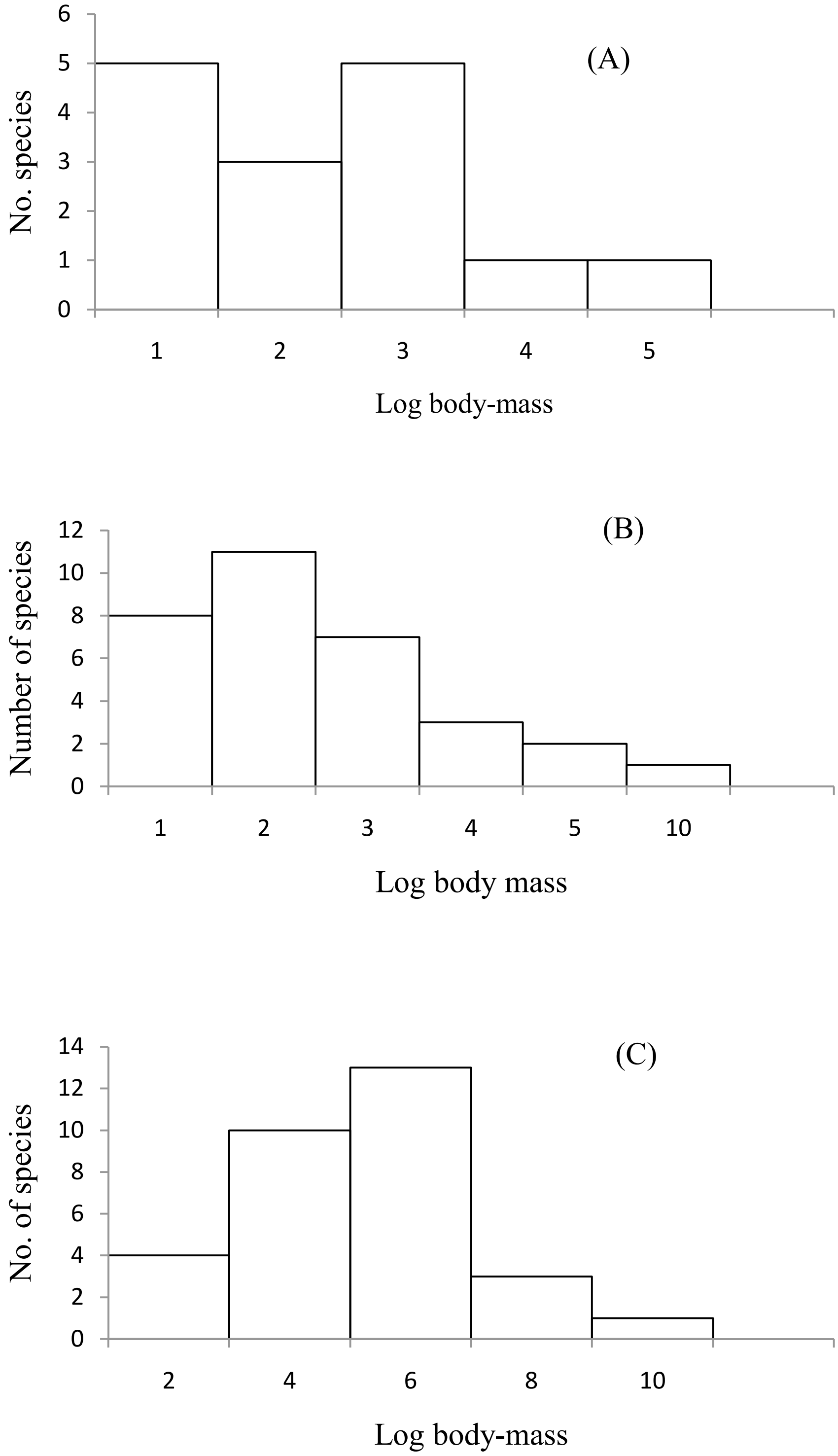

Figure 5. Body size distributions of (A) frogs, (B) lizards, and (C) snakes in the Andaman & Nicobar Archipelago

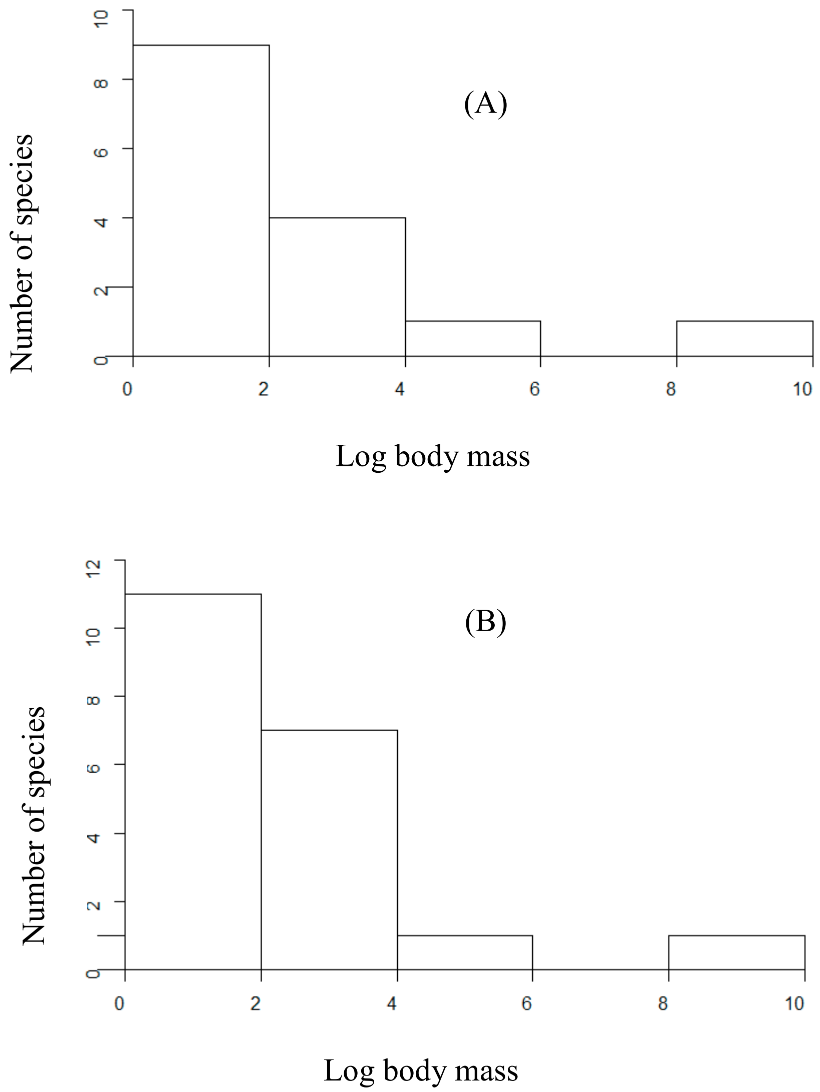

Figure 6. Comparison of size distribution of lizards in (A) Andaman Islands and (B) Nicobar Islands

The size ratios of co-existing frog, lizard and snakes species in Andaman Islands and Nicobar Islands were also analysed using null models. This specifically tested the hypothesis that the body-sizes of co-existing species are evenly spaced, with a constant ratio of adjacent body-sizes. In case of frogs and lizards in both Andaman Islands and Nicobar Islands, there were significant differences between observed size ratios and null expectation (Table 7). In all cases, observed size ratios were much lower than expected values, indicating that the variance of differences in body sizes in both frog and lizard communities were relatively low. i.e. There was relatively constant spacing of body sizes within communities. This was particularly so in the case of lizards in the Andaman Islands, suggesting strong competitive structuring of body sizes within a community. In the case of snakes, however, the differences between observed size ratios and null expectation were not significant, indicating less competitive structuring of body sizes within snake communities.

Table 7. Size-ratios of co-existing species of frogs, lizards and snakes in the Andaman Islands and Nicobar Islands. * indicates significant difference at α = 0.05.

		Size-ratio		
		Expected	Observed	*P*
Andaman Islands	Frogs	0.12	0.03	0.03*
	Lizards	0.10	0.02	<0.001*
	Snakes	0.40	0.18	0.05
Nicobar Islands	Frogs	0.40	0.18	0.03*
	Lizards	0.09	0.02	0.03*
	Snakes	0.01	0.02	0.94

4.5 Patterns in species co-occurrence of herpetofauna

The species co-occurrence patterns of frogs, lizards and snakes in the Andaman Islands and Nicobar Islands were analyzed using the index C-score (Stone & Roberts, 1990), testing the hypothesis that if species interactions play a major role in assembly of communities, there will be fewer combinations of species than expected by chance. Separate analyses were conducted for Andaman Islands and Nicobar Islands as the objective was to detect evidence of competitive structuring within communities. Herpetofaunal communities in Andaman Islands did not show significant species co-occurrence patterns (Table 8). However, in the Nicobar Islands, species co-occurrence patterns were significantly different from the null expectations (Table 8).

The difference in species co-occurrence patterns between the Andaman Islands and the Nicobar Islands is interesting. It is likely that the Andaman Islands had land connection to the southern tip of the Arakan Yomas, or were only separated by a narrow channel during Pleistocene lowering of sea level. This would have facilitated the colonization of Andaman Islands by fauna from the Indo-Chinese region. Also, the lowering of the sea levels would have joined most of the Andaman Islands in to one large island. Thus, the present configuration of the herpetofauna of the Andaman Islands is a result of lowering of sea levels isolating the small islands at the end of the Pleistocene. This could be the reason behind the lack of evidence of negative species co-occurrence in the Andamans as most islands retained subsets of the original herpetofauna. On the other hand, there is no evidence of the Nicobar Islands ever being connected to any major land mass or to the Andaman Islands, since the sea floor surrounding this group of islands is more than 1000 m deep. The differentiation of Nicobar Islands into three different groups of islands, viz., Car Nicobar group, Nancowry group and Great Nicobar group by channels could also contribute to this pattern as this division causes some species turnover. Nicobar Islands seem to have received its herpetofauna through over-water dispersal, and it is likely that the turnover is influenced by differential colonization of the island groups. Further analyses at smaller scales are necessary to tease apart the factors responsible for the observed strong negative species co-occurrence in the Nicobar Islands.

Table 8. Species co-occurrence patterns of frogs, lizards, and snakes in Andaman Islands and Nicobar Islands. * indicates significant difference at α = 0.05.

		C-score		*P*	Standardized Effect Size
		Expected	Observed		
Andaman Islands	Frogs	0.43	0.43	0.54	0.01
	Lizards	1.66	1.64	0.52	-0.16
	Snakes	1.81	1.74	0.81	-0.81
Nicobar Islands	Frogs	2.27	3.20	0.001*	5.42
	Lizards	3.86	5.47	P<0.001*	14.48
	Snakes	2.71	3.35	P<0.001*	6.75

Figure 7. Negative co-occurrence patterns can be created by species turnover between islands. The three *Bronchocela* spp. shown here are distributed in Great Nicobar group, Nancowry group and Car Nicobar respectively. However, whether this is a result of vicariant evolution or independent colonisations is not known, which is necessary to get a complete understanding of the observed patterns.

4.6 Patterns in abundance and distribution of herpetofauna

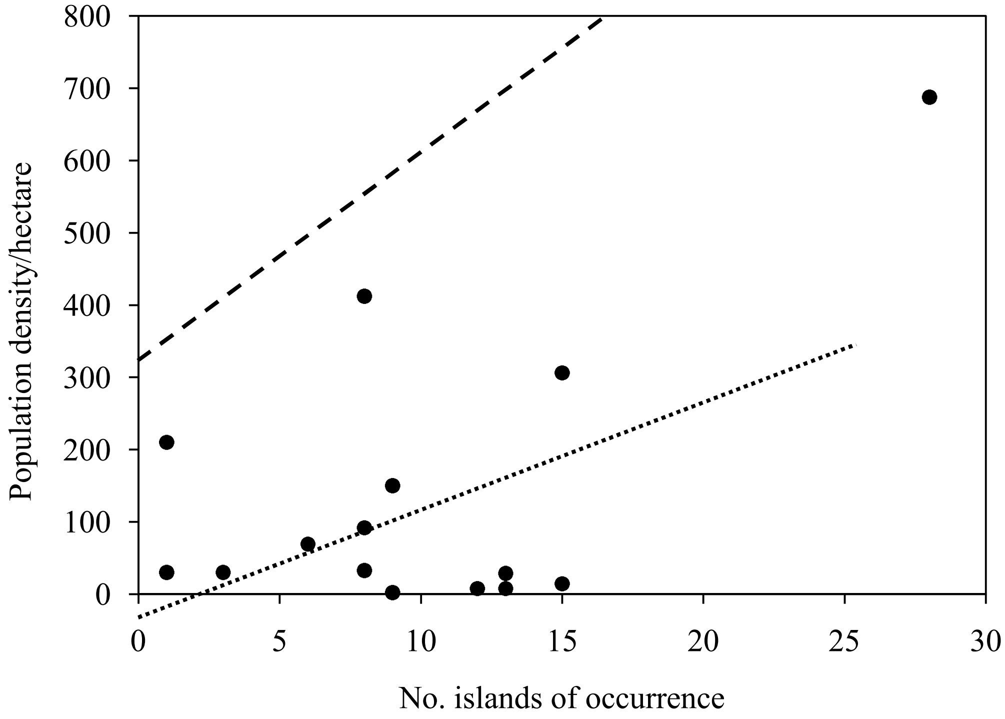

Figure 8. Density-distribution relationship of lizards in the Andaman & Nicobar Archipelago. The dotted line indicates the linear regression between abundance and distribution while the dashed line indicates the left border of the expected right triangle shape of the distribution.

We explored the relationship between abundance and distribution of species using null models. The expected relationship was considered a right triangle, with rare species having greater variability in distribution and abundant species having mostly wide distributions. This analysis could only be conducted for those species for which we had abundance data. In the case of lizards, there was significant aggregation of data points in the two dimensional plot (observed dispersion =1.42, expected dispersion = 1.15, P = 0.39) (Fig. 8). Also, there was a significant positive relationship between abundance and distribution (Observed slope of the regression line = 16.09, expected slope = - 0.08, P = 0.03) (Fig. 8). However, the expected right triangle shape of the distribution was not observed. The difference between observed and expected number of points in the triangle was not significant (observed number points inside right-triangle = 11, expected number of points inside right-triangle = 10.14, P = 0.92) (Fig. 8). Also, the observed number of points outside the upper left boundary was not different from the expected number (observed number points outside upper left boundary = 0, expected number of points outside upper left boundary = 1, P = 0.15) (Fig. 8).

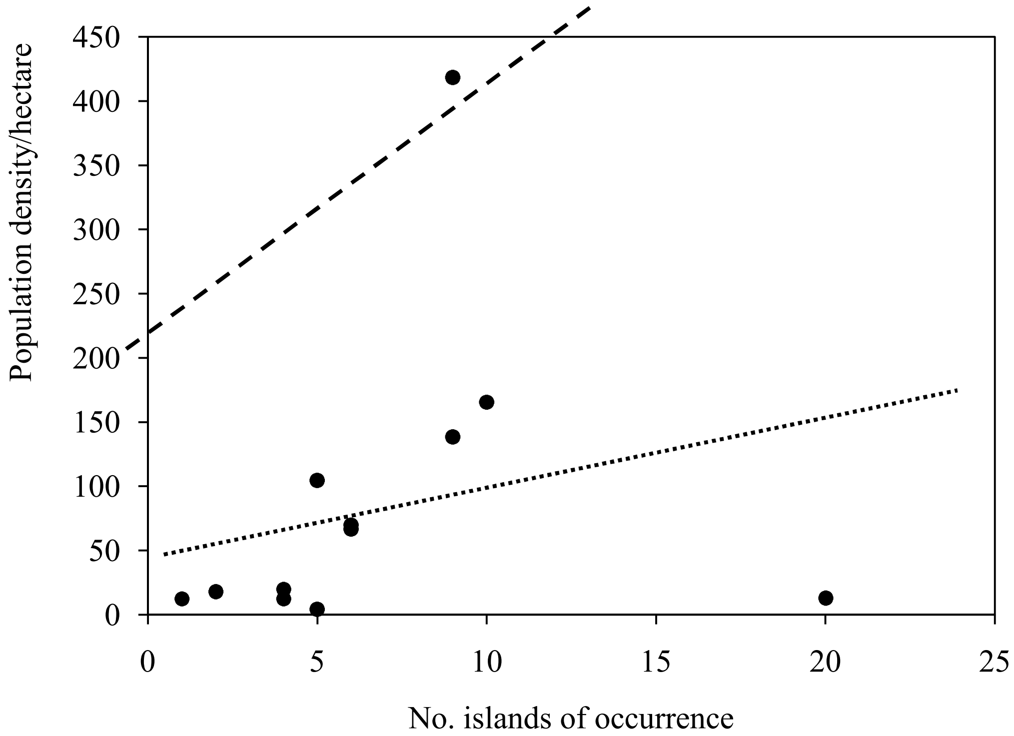

Figure 9. Density-distribution relationship of frogs in the Andaman & Nicobar Archipelago. The dotted line indicates the linear regression between abundance and distribution while the dashed line indicates the left border of the expected right triangle shape of the distribution.

In the case of frogs, we could not detect any significant clumping of the points (observed dispersion = 5.33, expected dispersion = 1.10, $P = 0.08$), or a significant positive relationship between abundance and distribution (observed slope of the regression line = 5.19, expected slope of the regression line = 0.01, $P = 0.17$). Also, there was no significant difference between observed number of points within the right-triangle and the expected number of points (observed number points inside right-triangle = 9, expected number of points inside right-triangle = 8.18, $P = 0.92$). Similarly, there was no significant difference between observed number of points outside the upper right boundary and the expected number of points (observed number points outside upper left boundary = 1, expected number of points outside upper left boundary = 0.91, $P = 0.15$).

These analyses indicated that the distribution and abundance of frogs and lizards in the Andaman and Nicobar Archipelago did not follow a simple expected pattern. Further analyses are required to fully understand these relationships. No such analyses could be performed in the case of snakes, as density estimates could not be obtained for snakes.

4.7 New species and other noteworthy records

The genus *Coryphophylax* Fitzinger in Steindachner, 1867 is endemic to the Andaman & Nicobar Archipelago. Prior to our survey, only a single species of this genus was recognized, *Coryphophylax subcristatus*, which is widespread in the Andaman & Nicobar Islands, except in Great Nicobar. During fieldwork in Mt. Harriet National Park, South Andaman Island, we identified a new species of lizard belonging to this genus (Fig. 10). Though the new species lived in sympatry with *C. subcristatus*, it was considerably rarer and occurred only in very few islands in the Andaman Islands. It was named Short-tailed forest lizard, *Coryphophylax brevicaudus* (Harikrishnan *et al.*, 2012). Further, *C. subcristatus* in the Andaman & Nicobar Islands show considerable morphological variation, and further investigations in to systematics and taxonomy of these lizards is necessary.

Figure 10. Short-tailed forest lizard (*Coryphophylax brevicaudus*), a new, endemic, species discovered from near Mt. Harriet National Park, South Andaman Island.

Figure 11. An unknown bush toad (new genus and species) from South Andaman Island – this species is a perfect example of the unexplored biodiversity of Andaman & Nicobar Islands.

Toads of the family Bufonidae are represented by a single species, the widespread *Duttaphrynus melanostictus*, in the Andaman & Nicobar Archipelago. We discovered a new, diminutive member of this family, from near Mt. Harriet National Park. It was later recorded in a few other islands in the Andaman Islands. Phylogenetic analyses have revealed that this new species also belongs to a new genus (Fig. 11).

Calotes andamanensis Boülenger, 1891 was a species known only from a type specimen collected in the 19th century. Later, it was suspected to be a species from southern Western Ghats (Ishwar & Das, 1998), or the Nicobar Islands (Krishnan, 2008). We rediscovered this species from Andaman Islands in 2010, after a gap of 119 years (Fig. 12). Morphological data indicated that this species is not a member of the genus *Calotes* but belonged to the primarily Southeast Asian genus of *Pseudocalotes*. Therefore, we re-assigned it to the genus *Pseudocalotes* (Harikrishnan & Vasudevan, 2013).

Figure 12. Andaman canopy agama (*Pseudocalotes andamanensis*) from South Andaman Island. This species was rediscovered after 119 years.

The island wolf snake that exists in the Andaman Islands was always considered conspecific with the south-east Asian species *Lycodon capucinus* Boie, 1827. However, our work showed that the population from Andaman Islands was morphologically distinct from the south-east Asian populations, and that it was indeed described as a separate species in the 19th century. We resurrected the name *Lycodon hypsirhinoides* (Theobald, 1868) for this species (Vogel & Harikrishnan, 2013) (Fig. 13). This species is thus endemic to the Andaman Islands.

Figure 13. Island wolf snake (*Lycodon hypsirhinoides*) from Little Andaman Island. This is one of the most common and widespread species of snakes in the Andaman Islands.

There are several other species of amphibians and reptiles that are only tentatively identified or unidentified from various islands in the Andaman & Nicobar Archipelago. Further systematic studies are in progress on all these species.

4.8 Conservation status of terrestrial herpetofauna of Andaman & Nicobar Archipelago

Very few studies have evaluated the conservation status of terrestrial herpetofauna in India, and it is especially so in the case of the Andaman & Nicobar Islands. Conservation status assessment is hindered by the fact that for majority of herpetofaunal species, population and distribution data are not available. In this study, we collected population density and distribution data for terrestrial herpetofauna in the Andaman & Nicobar Islands. Though for several species, quantitative data on abundance could not be obtained, field observations on these species have enabled us to obtain some qualitative measures of population abundance for most species. Based on all available information, we calculated Rabinowitz's States of Rarity (Rabinowitz, 1981; Rabinowitz et al, 1986). For forest floor frogs and lizards, abundance data from quadrats was used to assess rarity (rare – occurring in less than 5% of quadrats). But for snakes, arboreal lizards, and *Varanus salvator andamanensis* a subjective classification was used based on field observations. For a classification of geographic distribution, species that were found in more than half the islands sampled were considered having a wide distribution, which is a conservative approach. All non-endemics are treated as having a wide distribution. Species that were rarely found in more than 1-2 habitats were considered as exhibiting habitat specificity. Table 9 summarizes all terrestrial herpetofauna of Andaman & Nicobar Islands in this scheme.

Majority of endemic species had narrow distributions even within the Andaman & Nicobar Islands. However, it is also evident that many endemic species with narrow distributions have locally abundant populations. 40% of all endemic species had very narrow distribution even within the Andaman & Nicobar Islands (Table 9). This would place these species at the top of conservation priority.

We also compared the global conservation status of species using IUCN Red-List (IUCN, 2014) (Fig. 14). More than 80% of lizards and 50% of snakes were not assessed (NA), and a good proportion of frogs and snakes are also categorized as Data Deficient (DD) (Fig. 14). Conservation decisions can only be decided up on and implemented once this major gap in information is filled. This highlights the necessity of further field studies on terrestrial herpetofauna in Andaman & Nicobar Islands. The checklist at the end of this report summarizes all the information used in this status assessment (Appendix 1).

Table 9. Rabinowitz's states of rarity for 88 species of terrestrial herpetofauna (including rare species not recorded during current study) in the Andaman & Nicobar Islands. For forest floor frogs and lizards, abundance data from quadrats was used to assess rarity. But for snakes, arboreal lizards and *Varanus salvator andamanensis* a subjective classification was used based on field observations. Extinction risk increases to the right and downward, as indicated by darker shading. Further details are in Appendix 1.

		Geographic distribution			
		Wide		Narrow	
Population size	Locally common	27 (5 endemics)	7 (2 endemics)	18 (all endemics)	7 (6 endemics)
	Everywhere rare	5 (all non endemics)	8 (all non endemics)	1 (endemic)	15 (all endemics)
		Broad	Specific	Broad	Specific
		Habitat specificity			

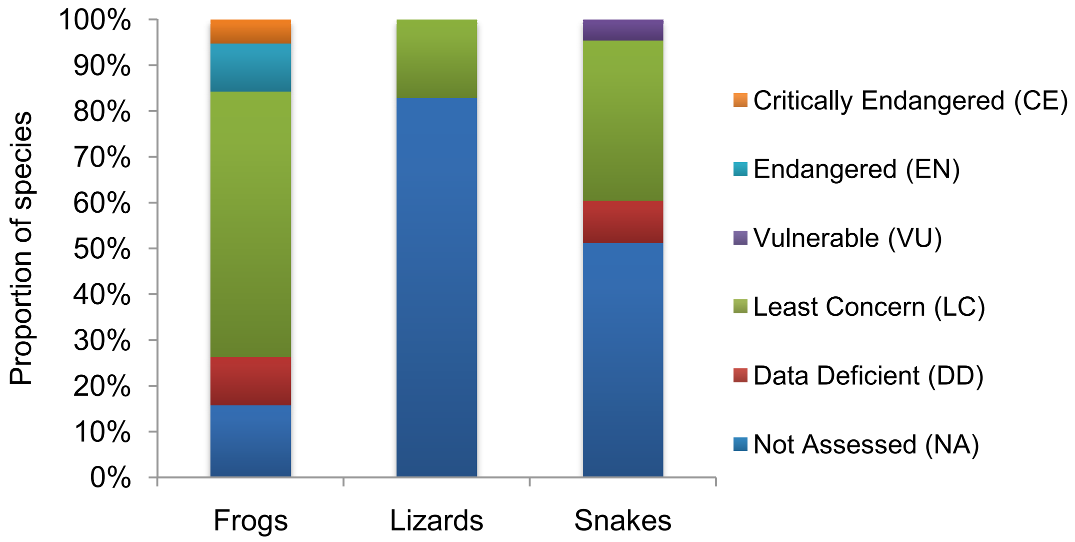

Figure 14. IUCN Red-List status of terrestrial herpetofauna in the Andaman & Nicobar Islands.

4.9 Threats to terrestrial herpetofauna

Habitat degradation and reduction: Degradation and reduction in natural habitat is a major cause of extinction. In the Andaman & Nicobar Islands, this seems to be a major threat to herpetofauna in the Nicobar Islands. Car Nicobar and Nancowry group are most affected by habitat reduction for herpetofauna. The causes for this are developmental activities as well as the tsunami that hit the islands in December 2004. Coastal land inundation in the Nicobars has destroyed the natural habitat of many species such as *Hylarana erythraea*, which has not been recorded from Nancowry group post 2004 (Vijayakumar & Choudhury, 2006). This also resulted in human settlements moving towards the interior of the islands in Car Nicobar and Nancowry group, resulting in habitat reduction for many endemic species.

Invasive and feral species: Probably the most important cause of species extinctions in island habitats is invasive species. Ali (2004 & 2006) first drew attention to the problem of invasives in the Andaman Islands, by listing several invasive species and demonstrated the negative impact of chital (*Axis axis*) and elephants (*Elephas maximus*) on natural vegetation in those islands where they occur. During our studies, we noticed that islands that had maximum signs of chital (pellets) had lowest abundances of understorey herpetofauna, while the only major island devoid of chital, i.e. Little Andaman Island, had highest density of understorey herpetofauna. Such reduction in abundance of herpetofauna due to the presence of introduced herbivores has also been reported elsewhere (Knox et al, 2012). A targeted study is currently underway to examine the effect of chital on understorey herpetofauna.

During our surveys, we found Indian bull frogs (*Hoplobatrachus tigerinus*) (Fig. 15) to be abundant in parts of Mayabunder, Middle Andaman (Harikrishnan & Vasudevan, 2013b). Later, we also recorded this species from South Andaman and had reports of it from North Andaman. While it seems to be confined to a few localities in the Andaman Islands, the bullfrog has the potential to become yet another problematic invasive in the Andaman Islands. 1) Its large size could enable this species to competitively exclude and predate on other frog species in the Andaman Islands. 2)

Figure 15. Indian bull frog (*Hoplobatrachus tigerinus*) from Webi, Mayabunder, Middle Andaman.

It is a prolific breeder and the population could increase rapidly. 3) This species breeds in the beginning of the monsoon and the tadpoles are carnivorous, feeding on tadpoles of other species of frogs (Khan, 1996). In mainland India, it is also known to feed on small snakes, lizards and rodents, all of which have numerous endemic species in these islands (Das, 1999b). This species seems to be a recently introduced in to the Andaman Islands, perhaps deliberately for consumption. It is a species protected by Wildlife (Protection) Act, 1972, Schedule IV Part II.

5. Summary

An extensive survey was carried out for terrestrial herpetofauna in the Andaman & Nicobar Islands between March 2010 and March 2014. This is the first systematic survey for herpetofauna that has covered both the Andaman Islands and the Nicobar Islands. 65 species of terrestrial reptiles and 17 species of amphibians were recorded from all islands surveyed. For the very first time, distribution data for amphibians and reptiles in individual islands within the Andaman & Nicobar Islands is reported here. This study documented relatively high densities of reptiles and amphibians in evergreen forests in these islands. Macroecological patterns of species co-occurrence, body size distribution and abundance-geographic distribution patterns were explored. Analysis of species co-occurrence patterns revealed that the Andaman Islands and the Nicobar Islands exhibited drastically different patterns of species co-occurrence. However, in patterns of body size, the two archipelagos were similar, but differences were found between taxonomic groups. We did not find the expected relationship between abundance and geographic distribution. However, getting abundance estimates for more species might change this scenario. We largely documented patterns in the distribution and abundance of species, but process based approaches are necessary in the future for a better understanding of the species abundances, body sizes and distributions, and their relationships between each other.

This study also documented potential threats to endemic herpetofauna from invasive exotic species. We also make a preliminary assessment of the vulnerability of this fauna based on primary data. Finally, this survey also showed that there are several species of reptiles amphibians in the Andaman & Nicobar Islands that require further systematic studies. It is our hope that the information provided here will be useful for further studies and conservation action for the herpetofauna of these islands.

Literature cited

1. Abele, L. G. (1984). Biogeography, colonization and experimental community structure of coral-associated crustaceans. pp. 123-137 in: Ecological communities: Conceptual issues and the evidence. D. R. Strong, Jr., D. Simberloff, L. G. Abele and D. Thistle (eds). Princeton University Press, Princeton

2. Ali, R. (2004). The effects of introduced herbivores on vegetation in the Andaman Islands, India. *Current Science*, 10(2): 221-223

3. Ali, R. (2006). Issues relating to invasives in the Andaman Islands. *Journal of Bombay Natural History Society*, 103(2-3): 349-355

4. Anonymous. (2007). Forest Statistics 2007. Department of Environment and Forests, Andaman and Nicobar Islands. 144 pp.

5. Bierregaard, R. O., Jr., Laurance, W. F., Sites, J. W., Jr, Lytlam, A. J., Didham, R. K., Atldersen, M., Gascon, C., Tocher, M. D., Smith, A. P., Viana, V. M., Lovejoy, T. E., Sieving, K. E., Kramer, E. A., Restrepo, C. & Moritz, C. (1997). Key priorities for the study of fragmented tropical ecosystems. Tropical forest remnants: ecology, management and conservation of fragmented communities (eds. by W. F. Lauratlce and R. O. Bierregaard, Jr), University of Chicago Press, Chicago.

6. Biswas, S. & Sanyal, D.P. (1965). A new species of Wolf-snake of the genus *Lycodon* Boie (Reptilia: Serpents: Colubridae) from the Andaman & Nicobar Archipelago. *Proceedings of the Zoological Society of Calcutta*, 18: 137-141

7. Biswas, S. & Sanyal, D.P. (1978). A new species of Krait of the genus *Bungarus* Daudin, 1803, [Serpentes: Elapide] from the Andaman Island. *Journal of Bombay Natural History Society*, 75: 179-183

8. Biswas, S. & Sanyal, D.P. (1980). A report on the reptilian fauna of Andaman and Nicobars Islands in the collection of Zoological Survey of India. *Records of the Zoological Survey of India*, 77: 255-292

9. Blyth, E. (1846). Notes on the fauna of Nicobar Islands – Reptilia. *Journal of Asiatic Society of Bengal*, 15: 367-379

10. Brown, J. H. (1984). On the relationship between abundance and distribution of species. *American Naturalist*, 124 (2): 255-279

11. Brown, J. H. (1995). Macroecology, The University of Chicago Press, Chicago, USA

12. Brown, J. H., and Nicoletto, P. F. (1991). Comparative population ecology of eleven species of rodents in the Chihuahuan Desert. *Ecology,* 70: 1507-1525

13. Champion, H. G. & Seth, S. K. (1968). A revised survey of the forest types of India. Natraj Publishers, Dehra Dun. Pp. 404

14. Cole, B. J. (1983). Assembly of mangrove ant communities: patterns of geographical distribution. *Journal of Animal Ecology*, 52: 339-347

15. Connor, E. F. and Simberloff, D. (1979). The assembly of communities: chance or competition? *Ecology*, 60: 1132-1140

16. Das, I. & Chandra, K. (1994). Two snakes new to the Andaman and Nicobar Islands. *Journal of Andaman Science Association*, 10(1 & 2): 114-115

17. Das, I. & Vijayakumar, S.P. (2009). New species of *Ptychozoon* (Sauria: Gekkonidae) from the Nicobar Archipelago, Indian Ocean. *Zootaxa*, 2095: 8-20

18. Das, I. (1995). A new tree frog (Genus: *Polypedates)* from Great Nicobar, India (Anura: Rhacophoridae). *Hamadryad,* 20: 13-20

19. Das, I. (1996). *Limnonectes shompenorum*, a new frog of the *Rana macrodon* complex from Great Nicobar, India. *Journal of South Asian Natural History,* 2: 60-67

20. Das, I. (1997a). A new species of *Cyrtodactylus* from the Nicobar Island, India. *Journal of Herpetology*, 31: 375-382

21. Das, I. (1997b). An ecological reconnaissance of Mount Harriet National Park, Andaman Islands, India. Final Report submitted to Andaman and Nicobar Environmental Team, Flora & Fauna International and Darwin Initiative for the Survival of Species. 19

22. Das, I. (1998a). A new species of *Boiga* (Serpents: Colubridae) from Nicobar Archipelago. *Journal of South Asian Natural History*, 31: 59-67

23. Das, I. (1998b). A remarkable new species of Ranid (Anura: Ranidae), with phytotelmonous larvae, from Mount Harriet, Andaman Island. *Hamadryad*, 23: 41-49

24. Das, I. (1999a). Biogeography of the amphibians and reptiles of the Andaman & Nicobar Archipelago, India. In: Ota, H. (Eds) Tropical Island herpetofauna. Origin, current diversity and current status, *Elsevier*, pp. 43-77

25. Das, I. (199b). A noteworthy collection of mammals from Mount Harriet, Andaman Islands, India. *Journal of South Asian Natural History*,4(2): 181-185

26. Davidar, P., Yoganand, K. & Ganesh, T. (2001). Distribution of forest birds in the Andaman Islands: importance of key habitats. *Journal of Biogeography*, 28: 663-671

27. Dayan, T., and Simberloff, D. (1994). Morphological relationships among coexisting heteromyids: An incisive dental character. *American Naturalist*, 143: 462-477.

28. Diamond, J. M. (1970). Ecological consequences of island colonization by southwest pacific birds, II. The effect of species diversity on total population density. *Proceedings of the National Academy of Science*, USA. 67: 1715-1721

29. Diamond, J. M. (1975). Assembly of species communities. In Ecology and evolution of communities (ed. M. L. Cody and J. M. Diamond), Harvard University Press, Cambridge, Massachusetts, USA

30. Fauth, J. E., Crother, B. I., & Slowinski, J. B. 1989. Elevational patterns of species richness, evenness, and abundance of the Costa Rican leaf-litter herpetofauna. Biotropica. 21: 178–185.

31. Fox, B. J., and Brown, J. H. (1993). Assembly rules for functional groups in North American desert rodent communities. *Oikos*, 67: 358-370.

32. Gilpin, M. E., Carpenter, M. P. and Pomerantz, M. J. (1986). The assembly of a laboratory community: multispecies competition in Drosophila. Pp. 30-40 in Community Ecology. T. J. Case and J. M. Diamond (eds), Harper & Row, New York

33. Gotelli, N. J. and Graves, G. L. (1996). Null models in ecology. Smithsonian Institution Press, Washington, USA

34. Gotelli, N. J. and Entsminger, G. L. (2007). EcoSim: Null models software for ecology. Version 7. Acquired Intelligence Inc. & Kesey-Bear. Jericho, VT 05465. http://garyentsminger.com/ecosim.htm.

35. Gotelli, N. J. and McCabe, D. J. (2002). Species co-occurrence: a meta-analysis of J. M. Diamond's assembly rules model. *Ecology*, 83: 2091-2096

36. Gotelli, N.J. and G.L. Entsminger. 2001. EcoSim: Null models software for ecology. Version 7.0. Acquired Intelligence Inc. & Kesey-Bear. http://homepages.together.net/~gentsmin/ecosim.htm.

37. Haefner, J. W. (1988). Assembly rules for Greater Antillean Anolis lizards. Competition and random models compared. *Oecologia*, 74: 551-565

38. Hallermann, J. (2009). A new species of *Bronchocela* (Squamata: Agamidae) from Nicobar Island. *Bonner Zoologische Beiträge*, 56: 279-284

39. Harikrishnan S., Choudhury, B.C. & Vasudevan, K. (2010a). Recent records of snakes (Squamata: Serpentes) from Nicobar Islands, India. *Journal of Threatened Taxa*, 2: 1297-1300

40. Harikrishnan, S. & Vasudevan, K. (2013a) Rediscovery of *Calotes andamanensis* Boülenger, 1891 and assessment of its generic allotment. *Herpetozoa*, 26, (1/2): 3-13

41. Harikrishnan, S. & Vasudevan, K. (2013b). Recent introduction and spread of Indian bullfrog *Hoplobatrachus tigerinus* (Daudin, 1802) into the Andaman Islands. *Aliens: The Invasive Species Bulletin* (Newsletter of the IUCN/SSC Invasive Species Specialist Group), 33: 42-43

42. Harikrishnan, S., Vasudevan, K. & Choudhury, B. C. (2010b). A review of herpetofaunal species descriptions and studies from Andaman and Nicobar Islands, with an updated checklist. *In* Ramakrishna, Raghunathan, C. & Sivaperuman, C. (Eds) 2010. *Recent Trends in Biodiversity of Andaman and Nicobar Islands*: 1-542 (Published by the Director, *Zool. Surv. India*, Kolkata)

43. Harikrishnan, S., Vasudevan, K., Chandramouli, S. R., Choudhury, B. C., Dutta, S. K. & Das, I. (2012) A new species of *Coryphophylax* Fitzinger in Steindachner, 1867 (Sauria: Iguania: Agamidae) from the Andaman Islands, India. *Zootaxa*, 3451: 31-45

44. Hutchinson, G. E. and MacArthur, R. H. (1959). A theoretical ecological model of size distributions among species of animals. *American Naturalist*, 93: 117-125.

45. Ishwar, N. M. & Das, I. (1998). Rediscovery of *Calotes andamanensis* Boülenger (1891) and a re-assessment of the type locality. *Journal of the Bombay Natural History Society*, 95: 513-514.

46. Karunakaran, C., Ray, K. K. & Saha, S. S. (1968). A revision of the stratigraphy of Andaman and Nicobar Islands, India. *Bulletin of the National Institute of Science*, 38: 436-441

47. Khan, M. S. (1996). The oropharyngeal morphology and feeding habits of tadpole of Tiger frog *Rana tigerina* Daudin. *Russian Journal of Herpetology*, 2: 163-171.

48. Knox, C. D., Cree, A., & Seddon, P. J. (2012). Direct and indirect effects of grazing by introduced mammals on a native, arboreal gecko (*Naultinus gemmeus*). Journal of Herpetology, 46(2): 145-152

49. Krishnan, S. (2008). New species of *Calotes* (Reptilia; Squamata: Agamidae) from the southern Western Ghats, India. *Journal of Herpetology*, 42 (3): 530-535.

50. Lee, T. Y. & Lowver, L. A. (1995). Cenozoic plate reconstruction of Southeast Asia. *Tectonophysics*, 251(1995): 85-138

51. Lomolino, M. V. (1986). Mammalian community structure on islands: Immigration, extinction, and interactive effects. *Biological journal of the Linnean Society*, 28: 1-21

52. MacArthur, R. H. and Wilson, E. O. (1967). The theory of island biogeography, Princeton University Press, Princeton, USA

53. MacArthur, R. H., MacArthur, J., MacArthur, D. and MacArthur, A. (1973). The effect of island area on population densities. *Ecology*, 54 (3): 657-658

54. May, R.M. (1978). The dynamics and diversity of insect faunas. In Diversity of insect faunas (eds. L.A. Mound and N. Waldoff), Blackwell, Oxford, UK

55. Morse, E. S., Stork, N. E., and Lawton, J. H. (1988). Species numbers, species abundance and body length relationships of arboreal beetles in Bornean lowland rain forest trees. *Ecological Entomology*, 13: 25-37

56. Murthy, T. S. N. & Chakrapani, S. (1983). Rediscovery of the blind snake *Typhlops oatesii* in Andamans, India. *The Snake*, 15: 48-49

57. Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403: 853-858

58. Owen, J. G. (1989). Patterns of herpetofaunal species richness: relation to temperature, precipitation and variance in elevation. *Journal of Biogeography*, 16 (2): 141-150

59. Patterson, B. D. and Atmar, W. (1986). Nested subsets and the structure of insular mammalian faunas and archipelagos. *Biological Journal of the Linnean Society*, 28: 65-82

60. Perry, G., Rodda, G. H., Frittis, T. H. and Sharp, T. R. (1998). The lizard fauna of Guam's fringing islets: Island biogeography, phylogenetic history and conservation implications. *Global Ecology and Biogeography Letters*, 7 (5): 353-365

61. Poole, R. W., & Rathcke, B. J. (1979). Regularity, randomness, and aggregation in flowering phenologies. *Science*, 203: 470-471

62. Rabinowitz, D. (1981). Seven forms of rarity. pp. 205-217 in The Biological aspects of rare plant conservation. Ed. by H. Synge. Wiley.

63. Rabinowitz, D., Cairns, S. & Dillon, T. (1986). Seven forms of rarity and their frequency in the flora of the British Isles. In M.E. Soule; (ed.) Conservation Biology: The Science of Scarcity and Diversity. pp. 182-204. Sinauer.

64. Ripley, S. D. & Beehler, B. M. (1989) Ornithogeographic affinities of the Andaman and Nicobar islands. *Journal of Biogeography*, 16: 323–332.

65. Rodda, G.H. & Dean-Bradley, K. (2002). Excess density compensation of island herpetofaunal assemblages, *Journal of Biogeography*, 29: 623-632

66. Rodolfo, K. S. (1969). Bathymetry and marine geology of the Andaman Basin, and tectonic implications for Southeast Asia. *Geological Society of America Bulletin*, 80: 1203-1230.

67. Scott, N. J. (1976). The abundance and diversity of the herepetofaunas of tropical forest litter. *Biotropica*, 8: 41–58.

68. Simberloff, D. (1978). Using island biogeographic distributions to determine if colonization is stochastic. *The American Naturalist*, 112: 713-726

69. Smith, M. A. (1940). The herpetology of the Andaman & Nicobar Archipelago. *Proceedings of the Linnaean Society of London*, 1940: 150-158

70. Smith, M. A. (1943). The Fauna of British India, Ceylon and Burma, including the whole of the Indo-Chinese subregion. Reptilia and Amphibia. Vol. III, Serpentes, Taylor and Francis, London. xii + 583 pp.

71. Steindachner, F. (1867). *'Reptilien*' in: *Reise der Osterreichischen Frigatte Novara um die Erde in den Jahren 1857, 1858, 1859, unter dem Befehin des Commodore B. von Wüllerstorf-Urbair. Zoologischer Theil.* Kaiserlich-Königlischen. Hof-und. Staatsdrückerei,Wien, 1-98

72. Stoliczka, F. (1870). Observations on some Indian and Malayan amphibia and reptilia. *Journal of Asiatic Society of Bengal*, 39: 134-228

73. Stoliczka, F. (1873). Note on some Andamanese and Nicobarese reptiles, with the description of three new species of lizards. *Journal of Asiatic Society of Bengal*, 92: 162-169

74. Tiwari, K. K. & Biswas, S. (1973). Two new reptiles from the Great Nicobar Island. *Journal of Zoological Society of India*, 25: 57-63

75. Van Valen, L.M. (1973). Body size and numbers of plants and animals. *Evolution*, 27: 27-35

76. Vijayakumar, S. P. & Choudhury, B. C. (2006). Post Tsunami assessment of herpetofaunal diversity in the Nicobar Islands. Final Report. Submitted to Wildlife Institute of India. 27.

77. Vijayakumar, S.P. (2005). Status and distribution of Amphibians and Reptiles of the Nicobar Islands, India. Final Report. Rufford Foundation / Madras Crocodile Bank /Wildlife Institute of India: 48.

78. Vijayakumar, S.P. and David, P. (2006). Taxonomy, natural history and distribution of the snakes of Nicobar Islands (India), based on new materials and with an emphasis on endemic species. *Russian Journal of Herpetology*, 13: 11-40

79. Vogel, G. & Harikrishnan, S. (2013). Revalidation of *Lycodon hypsirhinoides* (Theobald, 1868) from Andaman Islands (Squamata: Serpentes: Colubridae). *Taprobanica*, 5(1): 19-31

80. Weeks, L. A., Harrison, R. N. & Peter, G. (1967). Island arc system in Andaman Sea. *Bulletin of the American Association of Petrological Geology*, 51: 1803-1815

81. Whittaker, R. J. (1998). Island biogeography: ecology, evolution and conservation, pp. 300, Oxford University Press, Inc., New York, USA

82. Wilson, J. B. (1989). A null model for guild proportionality, applied to stratification of a New Zealand temperate rainforest. *Oecologia*, 80: 263-267

Appendix 1: Checklist of herpetofauna of the Andaman & Nicobar Archipelago, with an assessment of their conservation status. The species shaded in grey are endemic to Andaman & Nicobar Archipelago. For a classification of geographic distribution, species that were found in more than half the islands sampled were considered having a wide distribution, which is a conservative approach. All non-endemics are treated as having a wide distribution. Species that were rarely found in more than 1-2 habitats were considered as having habitat specificity. Rarity was assessed based on quadrat surveys for frogs and lizards (rare – occurring in less than 5% of quadrats). For snakes and *Varanus salvator andamanensis* a subjective classification was used based on field observations. Abbreviations: NA – Not Assessed, DD – Data Deficient, LC – Least Concern, VU – Vulnerable, EN – Endangered, CE – Critically Endangered, NL – Not Listed, Sch – Schedule of WPA (1972). IUCN Status was assessed following IUCN 2014. *The IUCN Red List of Threatened Species. Version 2013.2*. <http://www.iucnredlist.org>. Downloaded on 7 May 2014.

Species	Distribution within Andaman & Nicobar Archipelago	Geographic distribution	Habitat Specificity	Commonness/Rarity	IUCN Status	WPA (1972) Status
Amphibians						
Family: Bufonidae						
Duttaphrynus melanostictus	Andaman & Nicobar	Wide	Broad	Common	LC	NL
Unknown toad	Andamans	Narrow	Specific	Rare	NA	NL
Family: Microhylidae						
Kaloula baleata ghoshi	Andamans	Narrow	Broad	Common	NA	NL
Microhyla chakrapanii	Andamans	Narrow	Broad	Common	DD	NL
Microhyla ornata	Andamans	Wide	-	-	LC	NL
Micryletta inornata	Andamans	Wide	-	-	LC	NL
Microhyla heymonsi	Nicobars	Wide	Broad	Common	LC	NL
Family: Dicroglossidae						
Fejervarya andamanensis	Andamans	Narrow	Broad	Common	LC	NL
Fejervarya cf. nicobariensis	Nicobars (Nancowry group)	Narrow	Specific	Common	EN	NL
Fejervarya cancrivora	Andaman & Nicobar	Wide	Broad	Common	LC	NL
Ingerana charlesdarwini	Andamans	Narrow	Specific	Common	CE	NL

Limnonectes shompenorum	Nicobars (Great & Little Nicobar)	Narrow	Specific	Common	LC	NL
Limnonectes sp.†	Nicobars (Great Nicobar)	Narrow	Specific	Common	NA	NL
Hoplobatrachus tigerinus	Andamans	Wide	Broad	Common	LC	Sch IV
Limnonectes doriae	Andamans	Wide	Broad	Common	DD	NL
Family: Ranidae						
Hylarana erythraea	Nicobars	Wide	Specific	Common	LC	NL
Hylarana nicobariensis	Nicobars	Wide	Broad	Common	LC	NL
Hylarana chalconota	Nicobars	Wide	Specific	Common	LC	NL
Family: Rhacophoridae						
Polypedates insularis	Nicobars (Great Nicobar)	Narrow	Specific	Common	EN	NL
Lizards						
Family: Scincidae						
Dasia nicobarensis	Nicobars (Car Nicobar)	Narrow	Broad	Common	NA	NL
Dasia olivacea	Nicobars	Wide	Broad	Common	LC	NL
Eutropis andamanensis	Andamans	Wide	Broad	Common	NA	NL
Eutropis multifasciata	Nicobars	Wide	Broad	Common	NA	NL
Eutropis rudis	Nicobars	Wide	Broad	Common	NA	NL
Eutropis rugifera	Nicobars	Wide	Broad	Common	NA	NL
Eutropis tytleri	Andamans	Narrow	Specific	Rare	NA	NL
Lipinia macrotympanum	Andaman & Nicobar	Narrow	Specific	Rare	NA	NL
Lygosoma bowringii	Andamans	Wide	Specific	Common	NA	NL
Scincella macrotis	Nicobars (Great Nicobar)	Narrow	Specific	Rare	NA	NL
Sphenomorphus maculatus	Andaman & Nicobar	Wide	Broad	Common	NA	NL
Family: Agamidae						
Bronchocela cristatella	Nicobars	Wide	Broad	Common	NA	NL
Bronchocela danieli	Nicobars	Narrow	Specific	Common	NA	NL
Bronchocela rubrigularis	Nicobars	Narrow	Broad	Common	NA	NL
Pseudocalotes andamanensis	Andamans	Narrow	Specific	Rare	NA	NL
Calotes versicolor	Andamans & Car Nicobar	Wide	Broad	Common	NA	NL
Coryphophylax subcristatus	Andaman & Nicobar	Wide	Specific	Common	NA	NL
Coryphophylax brevicaudus	Andamans	Narrow	Specific	Rare	NA	NL

Family: Gekkonidae						
Cnemaspis aff. *'kandianus'*	Nicobars	Narrow	Specific	Rare	NA	NL
Cnemaspis andersoni	Andamans	Narrow	Specific	Rare	NA	NL
Cyrtodactylus adleri	Nicobars	Narrow	Broad	Common	LC	NL
Cyrtodactylus rubidus	Andamans	Wide	Broad	Common	NA	NL
Gehyra mutilata	Andaman & Nicobar	Wide	Broad	Common	NA	NL
Gekko smithii	Nicobars	Wide	Broad	Common	LC	NL
Gekko verreauxi	Andamans	Wide	Specific	Common	NA	NL
Hemidactylus frenatus	Andaman & Nicobar	Wide	Broad	Common	LC	NL
Hemidactylus garnotii	Nicobars	Wide	Broad	Common	NA	NL
Hemidactylus brookii	Andaman & Nicobar	Wide	Broad	Common	NA	NL
Hemidactylus patyurus	Andamans	Wide	Broad	Common	NA	NL
Hemiphyllodactylus typus	Andaman & Nicobar (Great Nicobar)	Wide	Broad	Common	NA	NL
Lepidodactylus lugubris	Andaman & Nicobar (Great Nicobar)	Wide	Specific	Common	NA	NL
Phelsuma andamanense	Andamans	Wide	Broad	Common	LC	NL
Ptychozoon nicobarensis	Nicobars	Narrow	Broad	Common	NA	NL
Family: Dibamidae						
Dibamus nicobaricus	Nicobars	Narrow	Specific	Rare	NA	NL
Family: Varanidae						
Varanus salvator	Andaman & Nicobar	Wide	Broad	Common	LC	Sch I
Snakes						
Family: Acrochordidae						
Acrochordus granulatus	Andaman & Nicobar	Wide	-	-	LC	Sch IV*
Family: Typhlopidae						
Asiatyphlops oatesii[1]	Andamans & Cocos	Narrow	Specific	Rare	DD	Sch IV*
Indotyphlops braminus	Andaman & Nicobar	Wide	Broad	Common	NA	Sch IV*
Typhlops andamanensis	Andamans	Narrow	Specific	Rare	NA	Sch IV*
Family: Pythonidae						
Malayopython reticulatus	Nicobars	Wide	Broad	Rare	NA	Sch I
Family: Xenopeltidae						
Xenopeltis unicolor	Nicobars (Great Nicobar)	Wide	Broad	Common	LC	Sch IV*

Family: Colubridae						
Gongylosoma nicobarense	Nicobars (Camorta)	Narrow	Specific	Rare	NA	Sch IV*
Coelognathus flavolineatus	Andamans	Wide	Broad	Rare	NA	Sch IV*
Coelognathus sp.[2]	Nicobars (Great Nicobar)	Narrow	Broad	Rare	NA	Sch IV*
Gonyosoma oxycephalum	Andamans	Wide	Specific	Rare	LC	Sch IV*
Ptyas mucosa	Andamans	Wide	Broad	Rare	NA	Sch II
Sibynophis bistrigatus[3]	Nicobars (Camorta)	Wide	Specific	Rare	DD	Sch IV*
Oligodon woodmasoni	Nicobars	Narrow	Specific	Rare	NA	Sch IV*
Chrysopelea paradisi	Andamans (Narcondam)	Wide	Specific	Common	NA	Sch IV*
Dendrelaphis andamanensis	Andamans	Narrow	Broad	Common	NA	Sch IV*
Dendrelaphis humayuni	Nicobars	Narrow	Broad	Common	NA	Sch IV*
Lycodon hypsirhinoides	Andamans	Narrow	Broad	Common	NA	Sch IV*
Lycodon subcinctus	Nicobars (Great Nicobar)	Wide	Specific	Rare	LC	Sch IV*
Lycodon tiwarii	Nicobars	Narrow	Broad	Common	NA	Sch IV*
Boiga andamanensis	Andamans	Narrow	Broad	Common	NA	Sch IV*
Boiga cyanea[4]	Nicobars (Great Nicobar)	Wide	Broad	Rare	NA	Sch IV*
Boiga wallachi[5]	Nicobars (Great & Little Nicobars)	Narrow	Specific	Common	DD	Sch IV*
Family: Natricidae						
Amphiesma nicobariense	Nicobars (Camorta)	Narrow	Specific	Rare	NA	Sch IV*
Xenochrophis trianguligerus	Nicobars	Wide	Broad	Common	LC	Sch IV*
Xenochrophis tytleri	Andamans	Narrow	Broad	Common	NA	Sch IV*
Family: Homalopsidae						
Cantoria violacea	Andamans	Wide	Specific	Rare	LC	Sch IV*
Cerberus rynchops	Andaman & Nicobar	Wide	Specific	Common	LC	Sch II
Enhydris plumbea	Nicobars (Great Nicobar)	Wide	Specific	Rare	LC	Sch IV*
Fordonia leucobalia	Nicobars	Wide	Specific	Rare	LC	Sch IV*
Gerarda prevostiana	Andamans	Wide	Specific	Rare	LC	Sch IV*
Family: Elapidae						
Bungarus andamanensis	Andamans	Narrow	Broad	Common	VU	Sch IV*
Naja sagittifera	Andamans	Narrow	Broad	Rare	NA	Sch II
Ophiophagus hannah	Andamans	Wide	Broad	Rare	VU	Sch II

Laticauda colubrina	Andaman & Nicobar	Wide	-	-	LC	Sch IV*
Laticauda laticaudata	Andaman & Nicobar	Wide	-	-	LC	Sch IV*
Pelamis platurus	Andaman & Nicobar	Wide	-	-	LC	Sch IV*
Hydrophis cantoris	Andamans	Wide	-	-	DD	Sch IV*
Hydrophis ornatus[6]	Andamans	Wide	-	-	LC	Sch IV*
Family: Viperidae						
Trimeresurus andersoni	Andaman & Nicobar	Narrow	Broad	Common	NA	Sch IV*
Trimeresurus cf. *albolabris*	Nicobars	Wide	Broad	Common	LC	Sch IV*
Trimeresurus cantori	Nicobars	Narrow	Broad	Common	NA	Sch IV*
Trimeresurus labialis	Nicobars (Car Nicobar)	Narrow	Broad	Common	NA	Sch IV*
Trimeresurus mutabilis	Nicobars (Nancowry Group)	Narrow	Broad	Common	NA	Sch IV*

† *Limnonectes hascheanus* has been included in past check-lists of herpetofauna of Andaman & Nicobar Islands. However, Inger & Stuart (2010) in a review of this species and of *Limnonectes limborgi*, provided evidence that the former is restricted to southern parts of Malay Peninsula and expressed doubts on its occurrence in the Andaman & Nicobar Islands. It is kept out of this checklist as we have not yet recorded any species that matched the description provided by Inger & Stuart (2010).

* According to The Wildlife (Protection) Act, 1972, "Snakes (other than those species listed in Sch I, Pt II; and Sch II, Pt II)" are included in Schedule IV. Therefore, this is not a list based on information on individual species.

1 - This species was originally described from Cocos Islands, which though under the rule of Myanmar, is biogeographically part of the Andaman & Nicobar Archipelago.

2 – Harikrishnan et al (2010) recorded this *Coelognathus* sp. from Great Nicobar Island, but its identity is as yet unknown as no voucher specimen was collected. Subsequent surveys by us failed to collect this species.

3 – Smith (1943) and Wall (mentioned in Smith, 1943) have raised doubts on the occurrence of this species in Camorta. It is known from a single specimen collected by Adolph deRoepstorff.

4 – *Boiga cyanea* is species widely distributed in North-east India and the Indo-Chinese region. The occurrence of this Indo-Chinese species in Great Nicobar Island was reported by Das & Chandra (1994) based on a specimen collected from Galathea, Great Nicobar by D. V. Rao.

5 – *Boiga ochracea walli* Smith, 1943 has been mentioned in several check-lists presumably based on Smith, 1943. We are not aware of any specimens of this species from the Andaman & Nicobar Islands, nor have there been any new records of this species in the islands since 1943. A single specimen labelled *B. o. walli* from Andaman Islands (ZSI 14623) in the collection of Zoological Survey of India, Kolkata, is a misidentified *Boiga andamanensis.*

6 – The holotype of *Distira andamanica* Annandale, 1905 (ZSI 15238) from 'Andamans' (in the Bay of Bengal), which is a junior synonym of *Hydrophis ornatus* (Gray, 1842) was overlooked in previous checklists.