Evaluating the impact of introduced spotted deer (*Axis axis*) on forest floor herpetofauna of Andaman Islands

A thesis submitted in partial fulfilment of

Master's Degree in WildlifeScience

From

Saurashtra University

Rajkot

By

Nitya Prakash Mohanty

Supervisors

Dr. Karthikeyan Vasudevan

Dr. K. Sivakumar

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

CERTIFICATE

This is to certify that **Mr. Nitya Prakash Mohanty** has carried out original research titled

"Evaluating the impact of introduced spotted deer (Axis axis) on the forest floor herpetofauna of Andaman Islands", in partial fulfilment of his Master's Degree in Wildlife Science from Saurashtra University, Rajkot. The study was carried out under our supervision from December 2012 to June 2013. We hereby certify that this work has not been submitted for any other degree to any other university.

KarthikeyanVasudevan, Ph.D.	K. Sivakumar, Ph.D.
Scientist-E	Scientist-E
Supervisor	Co-supervisor

Date: 4th June 2013

Place: Dehradun

Post Box No. 18, Chandrabani, Dehradun – 248 001. INDIA
EPABX : +91-135-2640111 to 2640115; **Fax** : 0135-2640117; **GRAM** : WILDLIFE
E-mail: wii@wii.gov.in

In the memory of,

Liza

Acknowledgement

I would like to take this opportunity to thank the people[i] who made the document you are reading possible. I thank the Dean and Director of Wildlife Institute of India. I owe a lot to my supervisors, who graciously signed and approved my thesis apart from being involved in all stages of the work; the faculty and facilities of the Wildlife Institute of India for keeping me motivated. I am grateful to Dr. Ravi Chellam and Dr. S. K. Dutta for critically reviewing and endorsing the work. Manish Chandi provided valuable comments that improved the proposal and I thank him for his inputs. I thank the Mohammed Bin Zayed Species Conservation Fund (MBZ) for providing the 2nd most important resource required for any study, money; Harikrishnan S. and my supervisors for the first and foremost requirement of a study, the idea. I thank my Course Director and Associate Course Director for their advice.

I would like to thank the Andaman and Nicobar forest department for granting permission and providing support for the execution of this study, especially the PCCF Dr. Shashi Kumar, the PCCF (WL) Sh. Madhav Trivedi, former APCCF Sh. Ajai Saxena, Faculty of IGNFA, Sh. Alok Saxena, the DCF & CF Dr. Senthil Kumar, the ACF Sh. Shaji P. Abraham, RO Sh. Y.P Singh, Mr. Karmakar and Mr. Basu Staff at MGMNP. I am grateful to Dr. Andre Pittet at Indian Institute of Science for providing camera traps and the logistics to carry out a critical component of the study and Ms. Pooja Mugeraya and Sh. Nagamani for an entire afternoon long demonstration of the cameras.

I appreciate the help extended by Dr. C. Murugan at Botanical survey of India with identification of plants. I thank Tasneem Khan, Jocelyn Panjikaran, Saw John, Ravi Sir and everyone else at Andaman and Nicobar Islands environmental team (ANET) for hosting me in the Islands and making everything happen. Dr. Rauf Ali provided valuable advice from time to time and I am deeply indebted to him for this.

This work would never have been possible without the commitment of my field staff, Sudhir Ekka, Bipin Tirkey, Suresh Kujur and Sunil Ekka. I would have not made it through the field days without their support and company.

Back at Wildlife Institute of India, I thank the researchers for being both tutors and friends to us, especially, Abishek Harihar, Moushmi Ghosh-Harihar, Sutirtha Dutta, Kaushik

Banerjee, Chetan Rao, Ridhima Solanki, Anindu Chatterjee, Abesh Sanyal, Indranil Mondal, Dayal Baba and Pawan Kumar.

I am lucky to have been a part of the "thirteenth" MSc batch of the Wildlife Institute of India. I would love to repeat the course all over again with my batch mates if my parents paid for it. Alas, all good things come to an end and so did our time together. Thank you for everything you people taught me and all the bills you paid on my behalf.

I thank my friends at University Of Delhi, my family and last but not the least, me for completing the study as planned, well, more or less.

---

[i] I am sorry if I missed your name

Content

Summary

It is common knowledge that organisms in an ecosystem are connected to each other through trophic levels. Even though the importance of interactions among trophic levels is well established in theory, demonstration of such interactions is not always easy. Over the years, studies that focus on the trophic interactions among starkly different taxonomic groups have come to the fore. These studies have furthered our understanding of ecosystems by demonstrating relationships between trophic levels so apart, the connection among which may not be apparent at first. Along these lines, the situation of introduced spotted deer in the Andaman Islands presented an ideal opportunity to understand the potential effect of a mammalian invasive herbivore on native, insectivorous forest floor herpetofauna. I hypothesised that herbivory is likely to depress folivorous arthropod abundance, which in turn may lead to a decline of insectivorous forest floor herpetofauna. Additionally, reduction in vegetation cover may render the habitat unsuitable for herpetofauna and make them vulnerable to predation. The objectives of this study were to evaluate the effect of chital on the forest floor herpetofaunal abundance and to determine the pathway of interaction between them. A contrasting effect of herbivory by chital on reptiles and on amphibians in the Andaman Islands was observed during the dry season. Forest floor reptiles, which included agamids, geckos and skinks showed reduced abundance in the presence of chital in comparison to an island where chital was absent. This effect of chital on reptiles was found to be mediated by vegetation cover. Chital significantly reduced the vegetation cover below their maximum browse height (1.5 m) in the Islands and which in turn led to a reduction in reptile abundance. Although, it was not clear if any of the observed species was benefitted in the presence of chital, the semi-arboreal *Coryphophylax subcristatus* appeared to be affected. Amphibian abundance on the other hand seemed to be unaffected by the use of the habitat by chital. Litter arthropods influenced the densities of amphibians the most. This study brought to light a pathway of indirect interaction between a mammalian herbivore and insectivorous herpetofauna. In doing so it raised conservation concern about the capability of an introduced species to alter an island ecosystem drastically and acutely impact several endemic fauna.

Chapter 1

Introduction:

It is common knowledge that organisms in an ecosystem are connected to each other through trophic levels. Even though the importance of interactions among trophic levels is well established in theory, demonstration of such interactions is not always easy. As intrusive experimentation to demonstrate such processes may not be practical and ethical, changes induced in a system, such as fluctuations in abundance or extinction of species could be used for this purpose. Along these lines, alteration made in an ecosystem by eradication of species (Donlan et al 2002, Chollet and Martin 2012), depression and introduction of species could throw light on the functioning of ecosystems.

Introduction of species and their subsequent adverse effects on native flora and fauna has been the centre of conservation concern (Clavero and Garcia-Berthou 2005). The introduction of species to island ecosystems is worrisome due to the endemism of species native islands (Peters and Lovejoy 1990). Oceanic islands and other such isolated ecosystems are particularly susceptible to invasive alien species which may result in damage to native biodiversity (Bowen and Vuren 1997, Clout, 2002). Historically over 90% of bird extinctions and 35% of mammal extinctions are reported from islands (Peters and Lovejoy, 1990). Plant species richness, regeneration process and vegetation structure are also known to be altered (Nugent et al. 2001, Donlan et al. 2002, Ali 2004).

A mammalian invasive species introduced into many parts of the world is the spotted deer or chital (*Axis axis*). It is an important prey for large carnivores in the peninsular India (Schaller 1967). As they constitute a large proportion of the biomass of primary herbivores, they should play a significant role in the dynamics of forests. The same species outside its natural distributional range inflicts damage to plant communities (Veblen et al. 1992). The Andaman Islands is one such site where chital has been introduced and has impacted the forests. After introduction into the Islands in 1930s, the spotted deer has proliferated in the absence of natural predators. Now they have colonized most parts of the Andaman Islands (Ali 2004).

The islands are home to at least 52 species of reptiles and amphibians (Harikrishnan 2010). Among them, there is one Critically Endangered species of frog and two species of snakes are that are Vulnerable (IUCN 2012). A genus each of lizard and frog are endemic and about 40% of all herpetofaunal species are endemic to the islands. Importantly, 60% of the species are recognised as data deficient.

Over the years, studies that focus on the trophic interactions among starkly different taxonomic groups have come to the fore. In 1975, Janzen hypothesised the potential influence of herbivores in decimating reptilian biomass. North et al. (1994) observed recovery of tree species and reptilian abundance in response to the removal of rabbits from Round Island, Mauritius. Norbury (2001) reported the complex effects of two introduced predators (ferrets –*Mustela furo* and cats – *Felis catus*) and rabbits on native skinks of New Zealand. McCauley et al. (2006) documented the increase in abundance of snakes with the removal of large herbivores in an African Savannah. Donlan et al. (2007) showed recovery in endemic Galapagos rail (*Laterallus spilonotus*) populations following the eradication of introduced pigs (*Sus scrofa*) and goats (*Capra hircus*). Greenwald et al. (2008) observed an increase in herpetofaunal biomass and diversity in the presence of native white tailed deer. Knox et al. (2012) demonstrated variable response of Jewelled Gecko (*Naultinus gemmeus*) to direct and indirect effects of livestock grazing in New Zealand. Analogous to the effect of proliferating introduced herbivores in an island system is the effect of over abundance of large mammalian herbivore in the mainland. A series of studies document the adverse impact of rapidly growing deer population of the entire North American continent on understory dependent woodland birds (Chollet and Martin 2012). These studies have furthered our understanding of ecosystems by demonstrating relationships between trophic levels so apart, the connection among which may not be apparent at first.

The situation of introduced spotted deer in the Andaman Islands presented an ideal opportunity to understand the potential effect of a mammalian invasive herbivore on native, insectivorous forest floor herpetofauna. While there is a need to document the impact on the herpetofauna, some species are probably threatened to extinction by chital.

Ali (2004) reported the adverse impact of herbivory by spotted deer on vegetation structure of the Islands. Keeping that in mind, I hypothesised that,

Introduced Spotted deer or Chital in the Andaman Islands through their browsing and grazing reduce the abundance of insectivorous forest floor herpetofauna, i.e. lizards and amphibians.

I. Chital reduces the abundance of lizards and amphibians by depressing the available arthropod abundance through direct competition for forage.

II. Chital reduces the abundance of lizards and amphibians by opening up the habitat, thereby making the herpetofauna more vulnerable to predation or altering microhabitat parameters which render the habitat unsuitable for use.

Materials and Methods:

Study area

The Andaman Islands are part of the Andaman and Nicobar Archipelago in the Bay of Bengal, situated off the eastern coast of mainland India. The archipelago runs along an arc from north to south, from Cocos Islands to Great Nicobar Island. The Andaman Islands are situated between lat 10°30`N & 13°40`N, and long 92°10`E & 93°10`E. This island group is divided into two major parts: Great Andamans and Little Andaman Island. Great Andamans comprises of four major islands, *viz.* North Andaman Island, Middle Andaman Island, South Andaman Island and Baratang Island. Little Andaman Island is separated from Great Andamans by a distance of ca. 50 km. These major islands along with numerous other small islands, islets and rocks cover an area of 6428 km^2. Shallow seas separate these islands known to be part of a submerged mountain range, continuous with the Arakan Yomas of Myanmar in the north and Nicobar Islands in the south. These islands are thus oceanic in origin. These tropical islands are subjected to temperatures ranging from 18° C to 34°C. The South-West monsoon, commencing in May and the North-East monsoon commencing in November account for the majority of the average annual rainfall, which ranges from 3000 mm to 3500 mm. Champion & Seth (1968) classify the vegetation into 11 subtypes, with the major classes being Andaman evergreen forest, Andaman semi-evergreen forest, Andaman moist deciduous forest and Littoral forest. In addition to *Axis axis, Rattus rattus,Rattus norvegicus, Felis domesticus, Canis familiaris* are a few of the introduced mammals reported from the Andaman Islands (Andrews and Sankaran 2002).

Intensive Study area:

Spotted deer occur in most parts of Andaman Islands, with the exception of Little Andaman Island and South Sentinel Island (Ali, 2004). To avoid possible confounding factors due to human presence, uninhabited islands of Mahatma Gandhi Marine National Park (hereafter, MGMNP), uninhabited areas of Rutland Island and Little Andaman Island were chosen as the study area (Fig.1). Seven islands in MGMNP were sampled during the study period. Sampling was done in Lowland evergreen forests with little variance in elevation (ranging from -2m to 48m above sea level).

Study Design

A two-step approach was adopted to understand the effects of chital on vegetation cover, folivorous & litter arthropod abundance and forest floor herpetofaunal density in the islands. As a micro level experiment, eight 15m x 15m exclosures were constructed in four islands with presence of deer (two in Alexandra Island, three in Tarmugli Island, two in Rutland island and one in Boat Island). The space inside the exclosures served as 'treatments' and the space outside served as 'controls'. Vegetation cover, folivorous arthropod abundance, litter arthropod abundance were measured in both the treatment and the control. All the exclosures were sampled for these parameters after a time period ranging from 51 days to 90 days. During this time period no breach of the exclosures by chital was observed.

At a macro-level with islands as experimental units, vegetation cover, folivorous arthropod abundance, litter arthropod abundance and forest floor herpetofauna densities were recorded. A total of eight islands were sampled. All the seven islands sampled in Mahatma Gandhi Marine National Park had chital while one island, Little Andaman did not have chital.

Assessing intensity of use by spotted deer of islands: .

The entire study area consisting of eight islands was gridded into squares of 1km x 1km dimension using ArcMap. Areas gridded and sampled were a subset of the total area of islands. Four walks of 200 m each were carried out inside each grid. The starting point and direction of the walk were not random. The walks were carried out so as to cover as much of the grid as possible. All walks were spaced apart by at least 100m. Each 200m walk was divided into four segments and the presence or absence of direct or indirect evidence of deer was recorded. Hoof marks, antler thrashing marks on tree trunks, browsing signs and pellets were considered as indirect evidences of deer presence. Presence of deer in a segment was given a score of 1 and absence was given a score of 0. Each walk was given a score out of four, ranging from 0/4 to 4/4. As the presence or absence of deer in the walks for each island was theoretically auto correlated, a mean of the scores for each island was calculated. A total of 20 grids were covered in the study.

Further, to enhance our understanding of the ecology of chital in the Islands, I deployed four Stealthcam camera traps to observe their group size, forage plants and behaviour. The cameras were placed in every island in both evergreen and littoral forest types (Annexure 1).

Estimating density of insectivorous forest floor herpetofauna:

Seventeen bound plots were sampled in the study area covering all eight islands. The number of plots per island depended on the size of the island. Larger islands had more plots as compared to smaller islands. The placement of the plots in each island was not random. This is due to the fact that the method requires relatively flatter terrain. Each plot was at least 100 m apart from the others and was representative of the island. The number of plots per island varied depending on the size of the island. Each bound plot was of 10 m x 10 m dimension. Sampling of the quadrates was done largely following Rodda and Dean-Bradley (2002). Bound plots of the said dimension were made by demarcating the selected area using a 0.5 m high plastic sheet that had its bottom edge buried in the soil. A boundary around the plot was cleared by removing understory vegetation following which the area was left undisturbed overnight. The next day, the plastic sheet was erected using poles, ropes and clips. Four-inch ductapes were strapped on trees and large saplings to prevent any individual from escaping by climbing up on trees. After fencing, all animals found active or sleeping on the branches were caught and kept in cloth bags (reptiles) or moist zip-lock covers (amphibians). Subsequently, all leaf litter, rocks, and fallen logs were removed from the quadrates. The quadrate was searched thoroughly for forest floor herpetofauna. Search inside the quadrate continued for 30 minutes after the capture of the last individual. The total count for each bound plot was recorded, which was divided in to the categories of reptiles and amphibians. Snout to vent length, tail length and weight of each individual was recorded. The length measurements were obtained using a Vernier calliper of 0.1 cm accuracy, while the weight measurements were taken using a Pesola spring balance with an accuracy of 0.2 g. From this study, 11 bound plots were in islands with chital and 6 in the island without chital. From another study in the same area and season (Harikrishnan unpublished) data from 14 more bound plots were incorporated in the analyses. Thus a total of 31 plots, 21 in islands with chital and 10 in the island without chital were used.

Identifying pathway of impact:

Vegetation cover below 1.5 m (maximum browse height of chital) was measured by holding a white sheet at 1.5 m and positioning a densitometer (Forestry suppliers, USA) close to the ground. Four equally spaced points in each grid of the densitometer were marked prior to sampling. The number of points covered by vegetation was recorded.

Folivorous arthropod abundance was measured by the bagging method (Morse 1976, Katti& Price 1996). In brief, a plastic bag was used to collect branches below the height of 1.5 m at the sampling locations. Cotton balls soaked in chloroform were put inside the bags to anesthetize any arthropods captured. The arthropods were sorted and counted as per their taxonomic order. The weight of the leaves in each sample was also recorded using a Pesola spring balance of 1 gm accuracy. Litter arthropod abundance was measured at sampling locations by collecting litter obtained inside a 0.5 m x 0.5 m quadrate and counting the arthropods present. Weight of collected leaf litter was measured using a Pesola spring balance of 1gm accuracy.

Vegetation cover, folivorous arthropod abundance, litter arthropod abundance were measured at the start and end point of the 200m walks carried out. Measurements were taken 2m away from the trail.

Additionally, major browse plants foraged by chital were identified. The browse plants were identified on the basis of direct and indirect evidence of browsing. The identity of each specimen was identified by Dr. C. Murugan of Botanical Survey of India. A total of 31 browse plants were identified at the end of the study (Annexure 2). Data collection was carried out from December 2012 till April 2013. This period is considered as the dry season in the study site.

Analyses:

Islands served as experimental units in this study. As the bound plots for herpetofauna were only representative of each island and not randomly placed, the observed density in the bound plots of an island could not be extrapolated to compute the overall reptile and amphibian densities of an island. A mean of the herpetofauna densities of the bound plots (hereafter, mean reptile density) were calculated for each island, so that they could be contrasted with the other parameters in the study on the same scale. Abundance for both folivorous and litter arthropods were calculated per 100 g weight of leaf and litter respectively.

One way analyses of variance ($\alpha = 0.1$, Sokal & Rohlf 1981) were carried out to contrast between islands with and without chital for reptile densities and amphibian densities. Reptile and amphibian densities in each bound plot were considered as individual data points and contrasted between islands with and without chital. To ensure that the data did not violate the assumptions of the one way analysis of variance, tests for normality and homogeneity of variance were carried out. Mean reptile density of islands violated the assumption of homogeneity of variance and was thus log transformed. All analyses of variances were accompanied by effect sizes, denoted by - η^2.

In order to test different hypotheses and factors that explained reptile densities and amphibian densities, generalized linear models (GLMs) were constructed. A global model, a null model, models with individual predictors and models with potential combination of the predictors were created. As the response variables, reptile densities and amphibian densities represented continuous data, Gaussian family of error distribution was used in the models. Predictors used to construct the models were vegetation cover, folivorous arthropod abundance, litter arthropod abundance and intensity of use by chital. Total arthropod abundance was also computed by averaging litter and folivorous arthropod abundance. Selection of suitable model was done on the basis of AICc value instead of AIC value as the sample size was low (n = 8). Models with delta AICc value of two or less were selected from the set of candidate models (Burnham and Anderson 2002). As two hypothesised predictors of reptile and amphibian densities, viz. intensity of use by chital and vegetation cover were found to be strongly correlated ($r = -0.96$, $p < 0.001$), variance inflation factor (Hair et al. 2006) was estimated for models which included these two. As these two predictors had a high shared variance level, residual variance of intensity of use by chital, not explained by vegetation cover was computed. This residual variance was used as an independent predictor in the model. The residual variance could be interpreted as any additional effect of chital which was not explained by vegetation cover, such as trampling. Further, to make the models more parsimonious, folivorous arthropod abundance and litter arthropod abundance were summed to compute a single variable for arthropod abundance (total arthropod abundance). Weight of each parameter was also calculated to demonstrate their relative importance following Burnham and Anderson (2002). Predicted scores of the response variables after model selection were also calculated.

Sobel's test was carried out to test for potential mediation effects by vegetation cover, folivorous arthropod abundance and litter arthropod abundance. These tests were carried out for both reptile density and amphibian density as response variables to the predictor, intensity of use by chital. Analyses were carried out using the free statistical software R (version 3.0.1, R core team 2013).

Results:

<u>*Reptile density*:</u>

In the islands that were sampled mean reptile density was 16.5 (S.E = 3.33). The densities differed significantly between islands with and without chital ($F = 40.75$, $p < 0.001$, $\eta^2 = 0.58$, df = 29, Fig.1).Vegetation cover explained the variation in mean reptile density better than other competing models (Table 1). Mean vegetation cover (weight = 0.8, $\beta = 0.32$, S.E = 0.09) significantly influenced mean reptile density, In order to identify the pathways that impact reptile density due intensity of use by chital, mediation analysis (Sokal and Rohlf 1985) was performed using the following mediator variables: mean vegetation cover, mean litter arthropod abundance and mean folivorous arthropod abundance and mean vegetation cover. Among them mean vegetation cover was the most likely variable that mediated the impact. A mediation analysis used intensity of use by chital as the predictor variable, mean vegetation cover as the mediator variable and mean reptile density as the response variable. Three models were constructed, viz., (i) mean reptile density was influenced by intensity of use by chital ($t = -2.2$, $p = 0.07$); (ii) mean vegetation cover was influenced by intensity of use by chital ($t = -8.68$, $p < 0.001$); (iii) mean reptile density was influenced by intensity of use by chital ($t = 1.99$, $p = 0.10$) and mean vegetation cover ($t = 3.03$, $p = 0.03$).

The pathway involving intensity of chital use and mean vegetation cover was identified using Sobel's test. There was mediation involved in the relationship as the predictor (intensity of use by chital) lost partly its explanatory power due to the addition of the mediator variable (mean vegetation cover) to the model ($z = -2.86$, $p = 0.0042$).

Seven species of reptiles were observed in 31 bound plots, namely, *Coryphophylax subcristatus, Coryphophylax brevicaudus, Lygosoma bowringii, Cyrtodactylusrubidus, Eutropis andamanensis, Spenomorphus maculatus and Cnemaspis andersoni.* The proportion of *Coryphophylax subcristatus* and *Lygosoma bowringii* in the community differed between islands with and without chital. While the proportion of individuals of *Lygosoma bowringii* increased from islands with chital to island without chital, the proportion of *Coryphophylax subcristatus* decreased (Fig.2).

Amphibian density:

Amphibian densities did not differ in islands with and without chital ($F = 0.35$, $p = 0.559$, $\eta^2 = 0.01$, df = 29 Fig.3). Models were built in order to address different hypotheses and account for the variation observed in mean amphibian density in islands (Table 2). The model with mean litter arthropod abundance along with the null model were found to be the most likely models that explained the variation in mean amphibian density. Mean litter arthropod abundance was the single most suitable explanatory variable ($\beta = 5.89$, S.E. = 2.52, weight =

0.39). Out of the three hypothesised mediator variables, viz. mean vegetation cover, mean litter arthropod abundance and mean folivorous arthropod abundance, mean litter arthropod abundance was found to be the most probable. A mediation analysis was conducted with intensity of use by chital as the predictor variable, mean litter arthropod abundance as the mediator variable and mean amphibian density as the response variable. The following three models were constructed: (i) mean amphibian density was influenced by Intensity of use by chital ($t = 0.33$, $p = 0.75$); (ii) mean litter arthropod abundance was influenced by intensity of use by chital ($t = - 0.06$, $p = 0.95$); (iii) mean amphibian density was influenced by intensity of use by chital ($t = 0.48$, $p = 0.65$) and mean litter arthropod abundance ($t = 2.19$, $p = 0.08$). No mediation effect was observed as the predictor (intensity of chital use) did not significantly explain the variation in amphibian density. Sobel's test indicated no significant mediation effect ($z = - 0.06$, $p = 0.95$).

Monitoring of vegetation and chital group size:

No significant differences were observed between the treatment (inside exclosure) and the control (outside exclosure) in terms of vegetation cover ($F = 0.09$, $p = 0.77$, Effect size (η^2) = 0.006, df = 14, Fig.4) folivorous arthropod abundance ($F = 0.04$, $p = 0.84$, Effect size (η^2) = 0.003, df = 14, Fig.5) and litter arthropod abundance ($F = 0.01$, $p = 0.91$, Effect size (η^2) = 0, df = 14, Fig.6).Using camera traps the mean group size of chital in the islands was found to be 2.1 (S.E = 0.24) with a strong positive skew of 1.53 (Fig.7). Out of 49 direct observations made during the study 57% were of solitary individuals of chital.

Discussion:

Studies focussing on indirect trophic effects of mammalian herbivory on different taxonomic groups have yielded varying results (North el 1994, McCauley et al. 2006, Donlan et al. 2007, Knox et al. 2012). This study shows a contrasting effect of herbivory by chital on reptiles and on amphibians in the Andaman Islands during the dry season. Forest floor reptiles, which include agamids, geckos and skinks showed reduced abundance in the presence of chital in comparison to islands where chital was absent. Through this study evidence is put forth for the changes induced in the forest structure by chital herbivory. Due to the unavailability of grass, which is the preferred diet of chital (Sankar and Acharya 2004) in many of the islands, it has turned to browsing on seedlings, saplings, shrubs, fallen leaves and feeding on fruits (Annexure 2). Chital significantly reduced the vegetation cover below their maximum browse height (1.5 m) in the Islands. This reduction in vegetation cover could lead to an alteration of microhabitat variables such as temperature and moisture. These microhabitat variables may exert a limiting effect on the reptiles (Dixo and Martin 2008). Alternatively, the observed reduction in vegetation cover could lead to an increase in the vulnerability of the reptiles to predation by snakes and avian predators. Folivorous arthropods and litter arthropods could mediate the observed relationship between chital and reptiles. However, this study does not provide evidence of such mediation. While the use of the habitat by chital could cause increased dung deposition and thereby enhance plant growth, herbivory by chital directly reduces the forage available for arthropods. Though chital were observed to feed on fallen leaf on three occasions, reduction in litter arthropod abundance due to chital was not apparent from this study. The observed reduction in reptile abundance is similar to the findings of North el. (1994) in Round Islands, Mauritius. They documented the increase in abundance of six native reptile species following the eradication of herbivorous rabbit. They attributed the increase in the abundance of reptiles to increased availability of suitable habitats and increased food availability. In contrast, Greenwald et al. (2008) observed an increase in herpetofaunal biomass and diversity in the presence of native white tailed deer.

The difference in composition of species between islands with and without chital, appears to be primarily due to the fluctuation in abundance of two species, *Coryphophylax subcristatus and Lygosoma bowringii* .Individuals of the *genus Coryphophylax* are semi-arboreal in habit (Hariskrishnan et al. 2012). A reduction in vegetation cover due to chital in the stratum inhabited by the species could make the habitat unsuitable and lead to a vertical shift in habitat use. Although, the percentage composition of *Coryphophylax subcristatus* was reduced by almost half in island without chital as compared to the islands with chital, the abundance per bound plot was tripled. An increased vegetation cover in the absence of chital seems to be causing an increase in the abundance of the species. The reduction in percentage composition of *Coryphophylax* in island without chital, is due to the high abundance of *Lygosoma bowringii* in the island. The abundance of *Lygosoma bowringii* in island without chital is almost 27 times its abundance in islands with chital. Out of the eight islands with presence of chital, only one island has a record of *Lygosoma bowringii* occurrence (Harikrishnan et al. 2012). Whether it is an artefact of the effect of chital or just natural biogeographic distribution is not known. Herbivory by chital could cause a reduction in the available leaf litter which the species inhabits, thereby making the habitat not preferable. Difference in the abundance of other species in islands with and without chital, is not apparent, possibly due to low detections. Although, it is not clear if any of the observed species stands to gain in the presence of chital, the semi-arboreal *Coryphophylax subcristatus* appears to be affected.

Amphibian abundance on the other hand seem to be unaffected by the use of the habitat by chital. Litter arthropods influenced the densities of amphibians most. As litter arthropod abundance is unrelated to intensity of chital use, in the short-term, any impact of chital on amphibians seems unlikely. Amphibians are known to be governed by abiotic factors such as rainfall and altitude (Dixo and Martin 2008). Though the altitude and rainfall in the sampling locations were similar, poor rainfall during the study period may account for the low detections of amphibians. This could have obscured possible relationships between amphibians and the hypothesised predictors. The relationship between amphibian density and chital could turn out be completely different if sampling was carried out during the wet season.

Additional abiotic and biotic factors that could explain variation in both reptile and amphibian abundance in the islands were: altitude, latitude, rainfall received, vegetation type, and natural species composition. Since sampling was carried out in islands that were similar in these factors, their influence on the observed variation in abundance were considered negligible. The islands varied considerably in terms of area, the overall density of amphibians as well as reptiles of each island should be the roughly the same, irrespective of island size as per the predictions of the Island biogeography theory (MacArthur and Wilson 1967). I used a robust measure of abundance of reptiles and amphibians and therefore, it was reasonable to conclude that the observed reduction in abundance was attributable to intensity of chital use in the islands.

Contrasts made between the treatment and control in exclosures did not show significant differences in vegetation cover and arthropod abundances. Since, sufficient time has not elapsed since the establishment of the exclosures, and the study was conducted during the dry season when regeneration was poor, the study did not detect changes. Although an alternate interpretation might be offered that chital does not influence vegetation cover and arthropod abundances, given the results obtained from this study it seems unlikely. This study clearly showed a suppression of reptilian abundance due to chital population mediated by vegetation cover in the islands. This evidence can be further strengthened by prolonged monitoring of the exclosures.

Chital is a group living animal throughout its natural distributional range in the Indian sub-continent. Recorded chital group sizes vary from one to 150 and are known to change on a short temporal scale. The only constant unit in a group consists of a mother, her fawn and sometimes her young from the previous year (Sankar and Acharya 2004). Group sizes variations in chital have been observed with respect to season, feeding periods (Schaller 1967), predator presence (Dinerstein 1980) and openness of habitat (Barrette 1991). In contrast to a mean group size of 6.17 (S.E = 0.85) from nine landscapes in India (Jhala et al. 2011), mean group size of chital in the islands was three-fold small and majority of them survived as solitary individuals. The small group size of chital in the islands might be due to the absence of predators, as the benefit accrued in maintaining a group without any advantage of increased vigilance is poor. Further the cost of group living might spiral due to intra-specific competition for patchily distributed food resource in the evergreen forests. Habitat structure, another factor which influences group size in ungulates may not be influential in this scenario as small group sizes were commonly observed in the relatively open littoral forest.

Chital along with other introduced species in the Andaman Islands is recognized as a threat to the local biodiversity, both by local authorities and scientists, but little knowledge exists about the life of this herbivore in the Islands. Practically, nothing is known about their abundance, demographic structure and the perspective of people towards them. This study brings to light a pathway of indirect interaction between a mammalian herbivore and insectivorous herpetofauna. In doing so it raises conservation concern about the capability of an introduced species to alter an island ecosystem drastically and acutely impact several endemic fauna and flora.

Literature Cited

Ali R 2004 The effect of introduced herbivores on vegetation. *Current science* **86**

Andrews H V, Sankaran V and Sankaran V 2002 *Sustainable management of protected areas in the Andaman and Nicobar Islands*

Barrette C 1991 The size of axis deer fluid groups in Wilpattu National Park, Sri Lanka. *Mammalia* **55** 207-220

Bowen L and Vuren DV 1997 Insular endemic plants lack defenses against herbivores. *Conservation Biology* **11** 1249-1254

Burnham KP and Anderson DR 2002 Model selection and multi-model inference: a practical information-theoretic approach (Springer Verlag)

Champion HG and Seth SK 1968 A revised survey of the forest types of India (Manager of Publications Delhi)

Chollet S and Martin JL 2012 Declining woodland birds in North America: should we blame Bambi? *Diversity and Distributions*

Clavero, M. and García-Berthou, E. 2005 Invasive species are a leading cause of animal extinctions. *Trends in Ecology and Evolution* **20** 3: 110

Clout M and Veitch C 2002 Turning the tide of biological invasion: the potential for eradicating invasive species. *Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group, Gland, Switzerland and Cambridge, UK* 1-3

Dinerstein E 1980 An ecological survey of the Royal Karnali-Bardia Wildlife Reserve, Nepal: Part III: Ungulate populations. *Biological Conservation* **18** 5-37

Dixo M and Martins M 2008 Are leaf-litter frogs and lizards affected by edge effects due to forest fragmentation in Brazilian Atlantic forest? *Journal of Tropical Ecology* **24** 551-554

Donlan CJ, Campbell K, Cabrera W, Lavoie C, Carrion V and Cruz F 2007 Recovery of the Galápagos rail following the removal of invasive mammals. *Biological Conservation* **138** 520-524

Donlan CJ, Tershy BR and Croll DA 2002 Islands and introduced herbivores: conservation action as ecosystem experimentation. *Journal of Applied Ecology* **39** 235-246

ESRI (Environmental Systems Resource Institute). 2009. ArcMap 9.2.ESRI, Redlands, California

Graf W and Nichols L 1966 The axis deer in Hawaii. *JBNHS* **63** 701

Greenwald KR, Petit LJ and Waite TA 2008 Indirect effects of a keystone herbivore elevate local animal diversity. *The Journal of Wildlife Management* **72** 1318-1321

Hair J, Black W, Babin B and Anderson R 2006 RL Tatham Multivariate Data Analysis. Upper Saddle River, NJ: Prentice Hall

Harikrisharikrishnan S, Vasudevan K and Chandramouli S 2012 A new species of Coryphophylax Fitzinger in: Steindachner, 1867 (Sauria: Iguania: Agamidae) from the Andaman Islands, India. *Zootaxa* **3451** 31-45

Janzen DH 1976 The depression of reptile biomass by large herbivores. *American Naturalist* 371-400

Jhala Y, Gopal R and Qureshi Q 2011Status of tigers, co-predators, and prey in India (National Tiger Conservation Authority, Ministry of Environment & Forests, and Wildlife Institue of India, Dehradun)

Katti M and Price T 1996 Effects of climate on Palaearctic warblers over-wintering in India. *Journal of the Bombay Natural History Society* **93** 411-427

Kennedy TA, Naeem S, Howe KM, Knops JM, Tilman D and Reich P 2002 Biodiversity as a barrier to ecological invasion. *Nature* **417** 636-638

Knox CD, Cree A and Seddon PJ 2012 Direct and indirect effects of grazing by introduced mammals on a native, arboreal gecko (Naultinusgemmeus). *Journal of Herpetology* **46** 145-152

MacArthur RH and Wilson EO 1967 The theory of island biogeography(Princeton University Press)

McCauley DJ, Keesing F, Young TP, Allan BF and Pringle RM 2006 Indirect effects of large herbivores on snakes in an African savanna. *Ecology* **87** 2657-2663

Morse DH 1976 Variables affecting the density and territory size of breeding spruce-woods warblers. *Ecology* 290-301

North SG, Bullock D and Dulloo M 1994 Changes in the vegetation and reptile populations on Round Island, Mauritius, following eradication of rabbits. *Biological Conservation* **67** 21-28

R Core Team 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.URL http://www.R-project.org/.

Rodda GH and Dean-Bradley K 2002 Excess density compensation of island herpetofaunal assemblages. *Journal of Biogeography* **29** 623-632

Sankar K and Acharya B 2004 Spotted deer or Chital. *Ungulates of India. Wildlife Institute of India*

Schaller GB 1967 The Deer and the Tiger. A Study of Wildlife in India. (University of Chicago Press)

Sokal RR and Rohlf FJ 1981 Biometry W. H. *Lawrence & Co*

Veblen TT, Mermoz M, Martin C and Kitzberger T 1992 Ecological impacts of introduced animals in Nahuel Huapi National Park, Argentina. *Conservation Biology* **6** 71-83

Table 1. Six candidate models were constructed to explain variation in the response variable Mean reptile density / bound plot. Parameters incorporated in the models were, mean vegetation cover (MVC), total arthropod abundance (TA) and intensity of use by chital-unique (IUC (unique)). Model 1 with parameter mean vegetation cover was chosen as the best model based on AICc values.

Model	AICc	delta	weight	Parameters
1	64.27	0	0.72	MVC
2	67.06	2.79	0.18	.
3	68.92	4.66	0.07	IUC(unique)+MVC
4	71.19	6.92	0.02	TA
5	72.32	8.05	0.01	MVC+TA
6	87.42	23.15	0.00	MVC+IUC(unique)+TA

Table 2. Six candidate models were constructed to explain variation in the response variable Mean amphibian density / bound plot. Parameters incorporated in the models were, mean vegetation cover (MVC), mean folivorous arthropod abundance (MFA), mean litter arthropod abundance (MLA) and intensity of use by chital (IUC). Model 1 with no predictors and model 2 with parameter mean litter arthropod abundance were chosen as the best models based on AICc values.

Model	AICc	delta	Weight	Parameters
1	51.39	0	0.48	.
2	51.83	0.43	0.38	MLA
3	55.31	3.92	0.06	MFA
4	56.84	5.45	0.03	IUC
5	56.98	5.58	0.02	MVC
6	132.14	80.75	0	MVC + MLA + MFA + IUC

Fig 1)

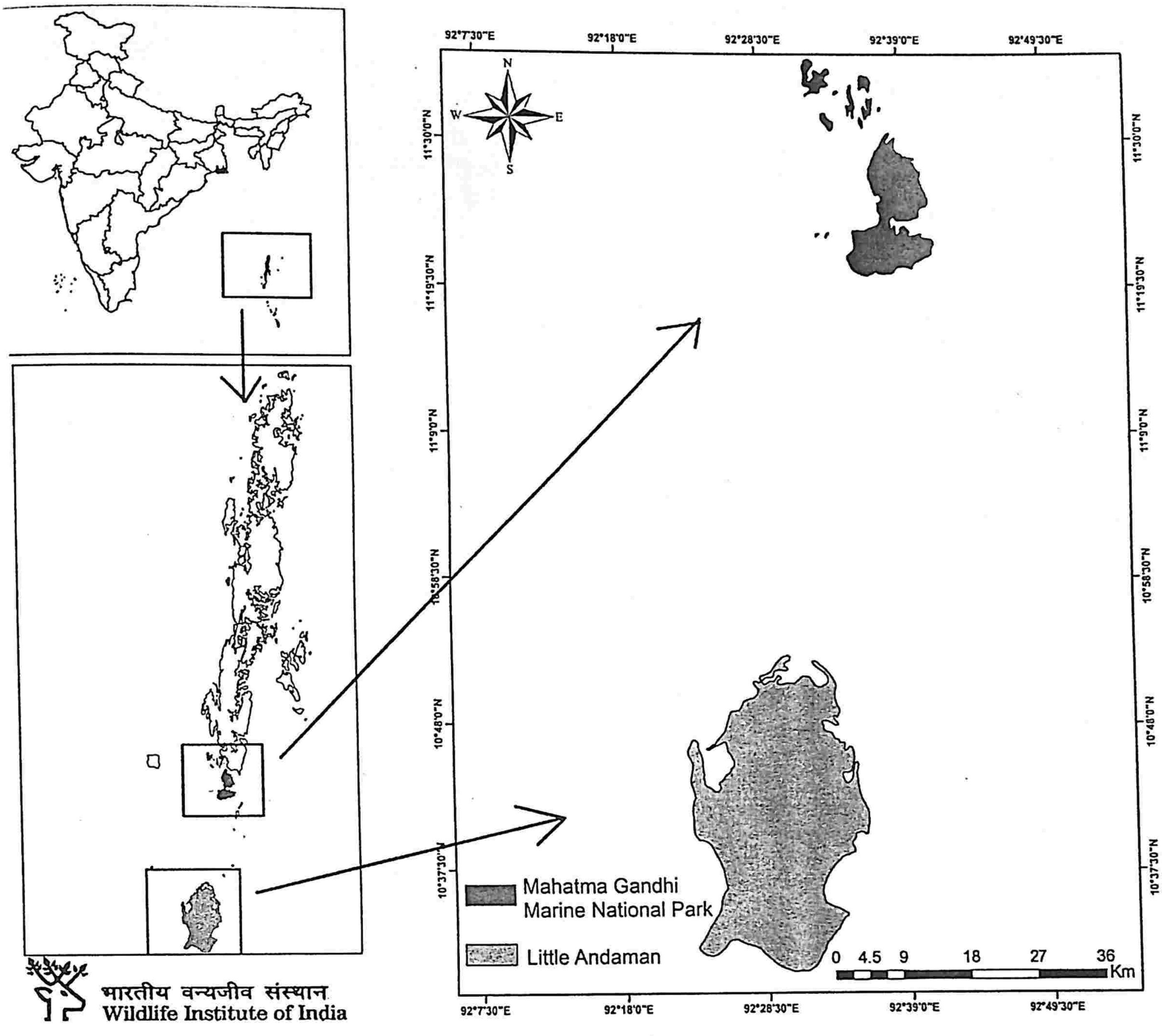

Fig.1 Map of the study area including Mahatma Gandhi Marine National Park and Little Andaman in the Andaman Islands.

Fig. 2)

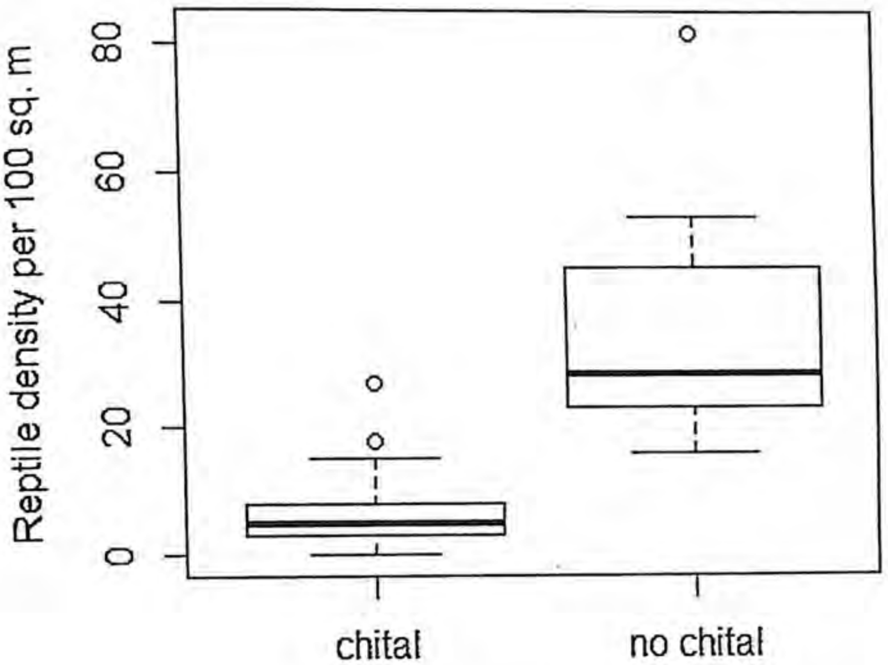

Fig 2. A box plot illustrating the difference in reptile density per bound plot between islands with (n = 21) and without (n = 10) chital (F= 40.75, p < 0.001 (significant), Effect size (η^2) = 0.58) in Andaman Islands. Island without chital showed higher reptile density per bound plot.

Fig. 3)

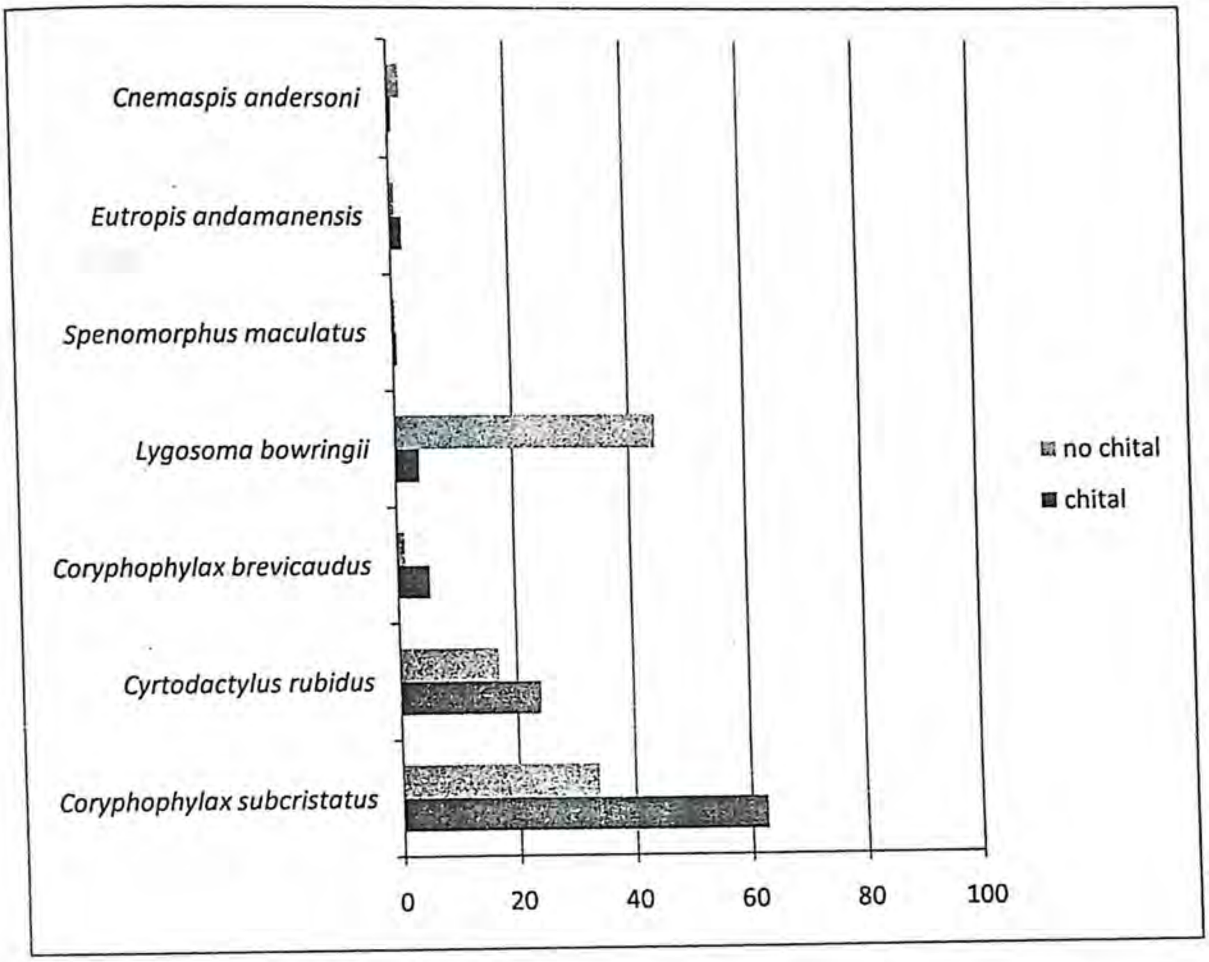

Fig. 3 Stacked column (100%) showing variation in percentage species composition between islands with and without chital in the Andaman Islands.

Fig 4)

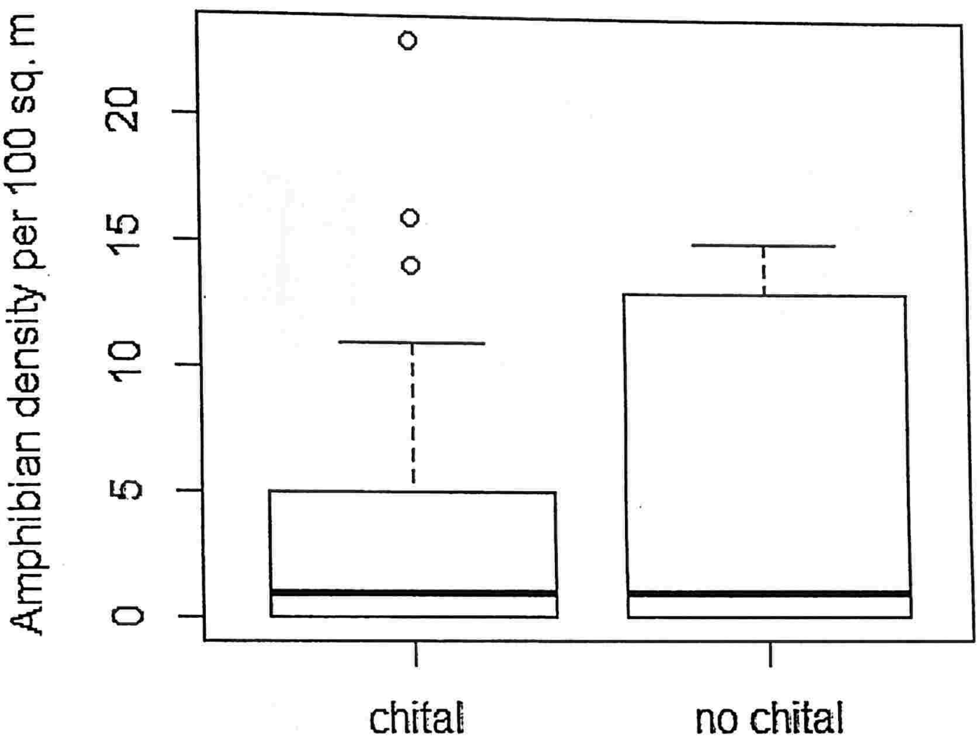

Fig.4 A box plot illustrating amphibian density per bound plot in islands with (n = 21) and without (n = 10) chital in Andaman Islands. No difference between these two categories of islands was observed ($F = 0.35$, $p = 0.559$, Effect size (η^2)= 0.01).

Fig 5)

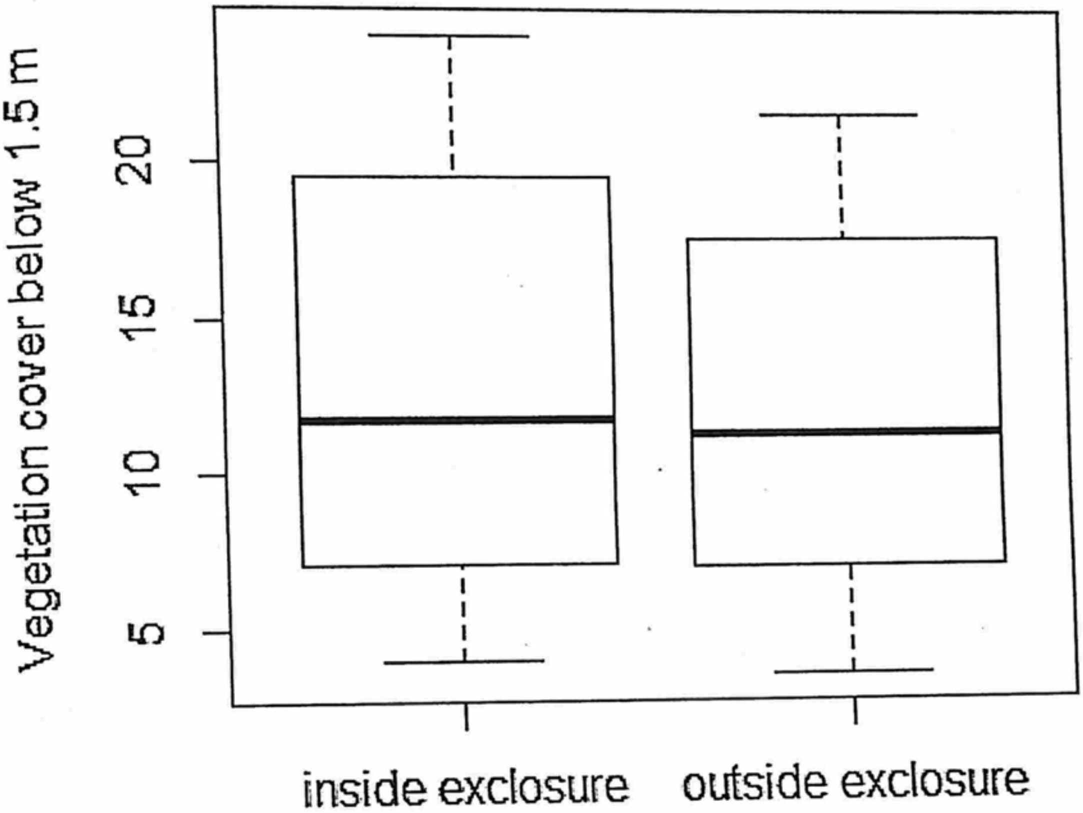

Fig. 5 Box plot contrasting between vegetation cover (below 1.5 m) inside and outside the exclosure, from eight exclosures. No significant differences were observed (F =0.09, p = 0.77, Effect size (η^2) = 0.006) in Andaman Islands.

Fig.6)

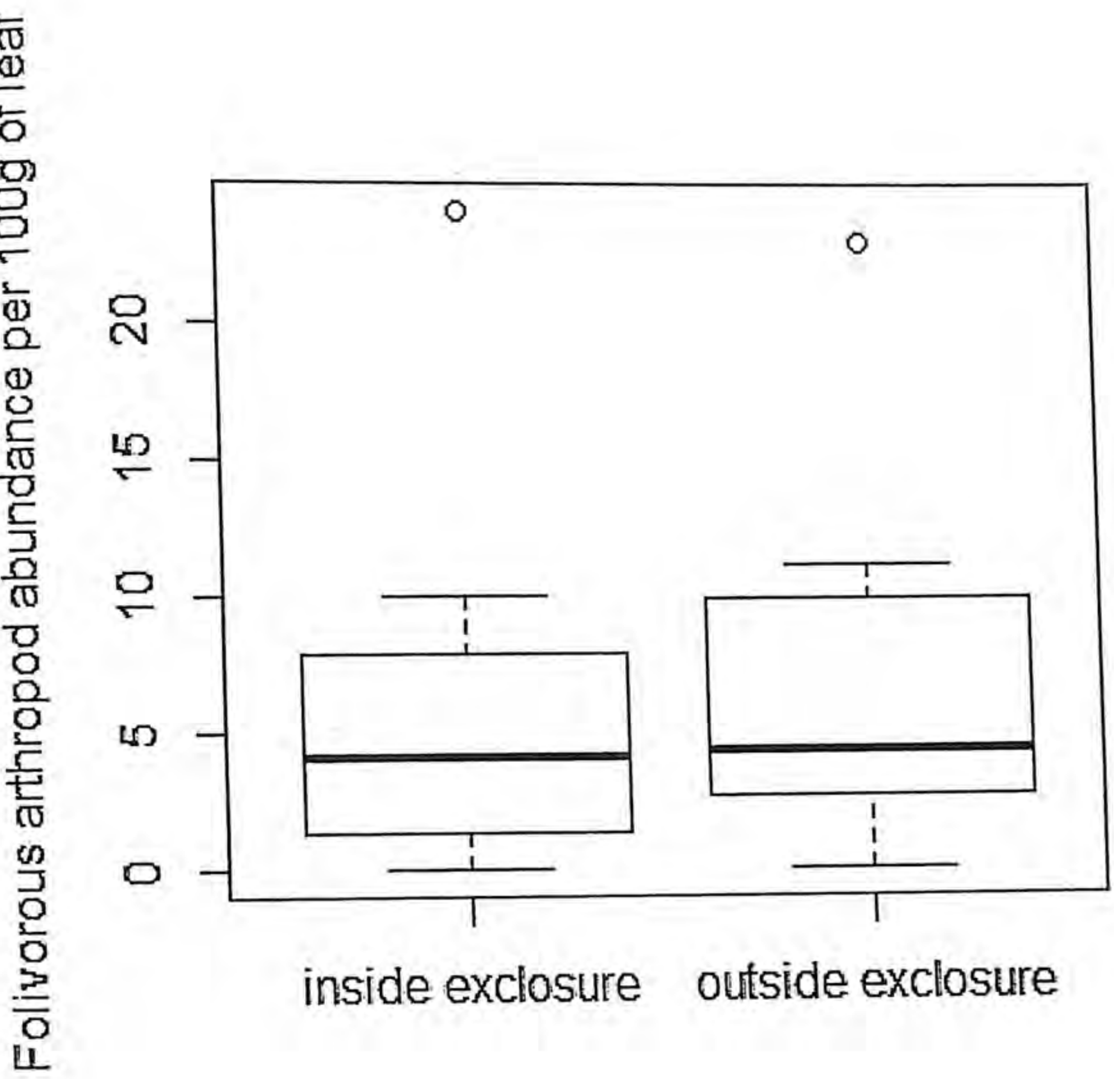

Fig.6 Box plot contrasting between folivorous arthropod abundance/ 100g of leas inside and outside the exclosure, from eight exclosures. No significant differences were observed ($F = 0.04$, $p =0.84$, Effect size (η^2) = 0.003) in Andaman Islands.

Fig.7)

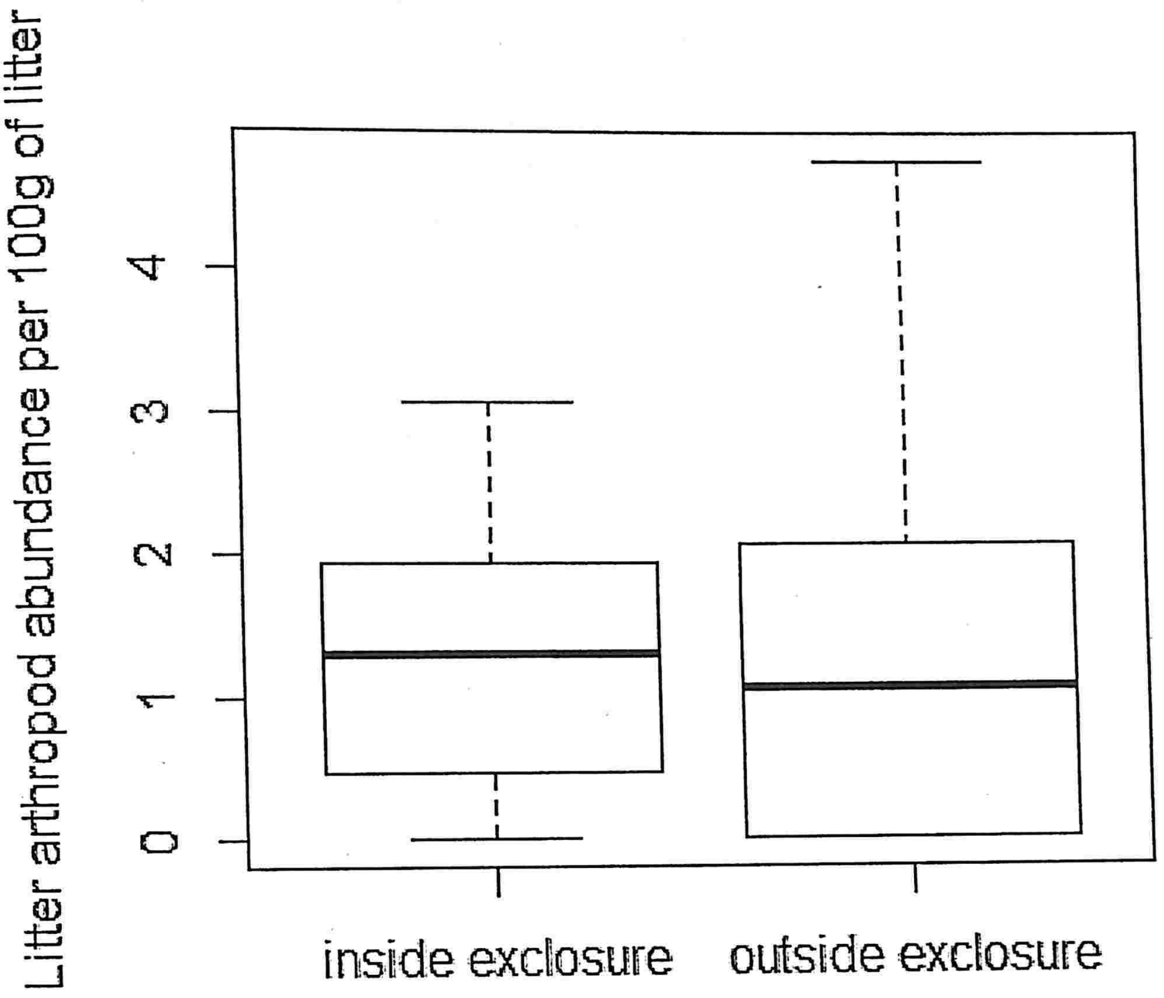

Fig.7 Box plot contrasting between litter arthropod abundance/ 100g of litter, inside and outside exclosures, from eight exclosures ($F = 0.01$, $p = 0.91$, Effect size (η^2) ~ 0) in Andaman Islands.

Fig.8)

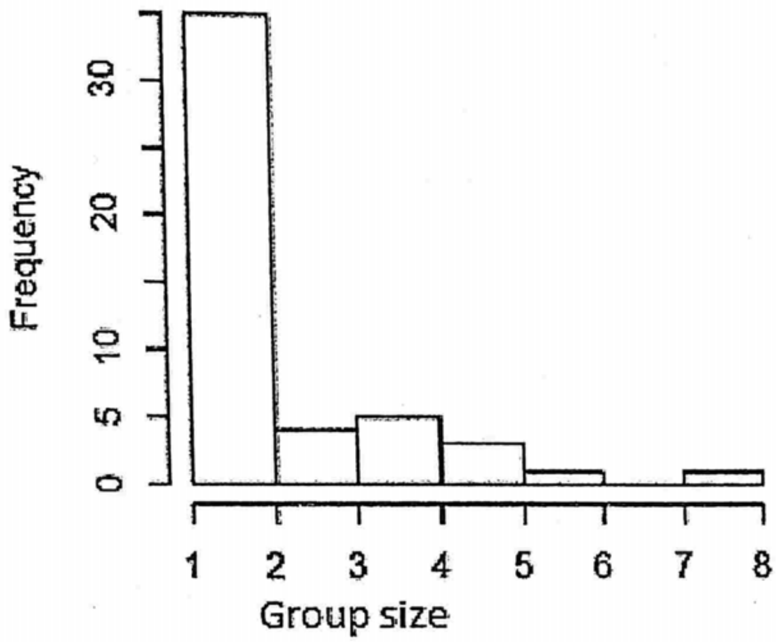

Fig.8 Histogram of group size of chital in the Andaman Islands showing a positive skew. Mean group size was 2.1 (S.E = 0.24).

Annexure 1:

Group size observations of chital in Andaman Islands.

Group size	Sex	Individual	Island	Location	*Source*
5			Rutland	littoral	*ad libitum*
2	F	ad	Rutland	littoral	*ad libitum*
4	F	ad	Rutland	sec.evgrn	*ad libitum*
5	M(1),F(4)	ad	Rutland	sec.evgrn	*ad libitum*
3	F(2)	ad(2),fn(1)	Rutland	sec.evgrn	*ad libitum*
1	F	ad	Rutland	sec.evgrn	*ad libitum*
3	F(1)	ad(1),Fn(2)	Rutland	sec.evgrn	*ad libitum*
2	F	ad(1),sbad(1)	Rutland	sec.evgrn	*ad libitum*
1	F	ad	Rutland	littoral	*ad libitum*
1	F	ad	Rutland	littoral	*ad libitum*
2	F	ad	Rutland	littoral	*ad libitum*
1	F	ad	Tarmugli	littoral	*ad libitum*
2	F	ad	Tarmugli	littoral	*ad libitum*
5	M(1),F(4)	ad	Tarmugli	littoral	*ad libitum*
1	F	ad	Tarmugli	evergrn	*ad libitum*
3	F	ad	Alexandra	evergrn	*ad libitum*
1	F	ad	Alexandra	evergrn	Camera trap
1	F	ad	Alexandra	evergrn	Camera trap
1	F	ad	Alexandra	evergrn	Camera trap
1	F	ad	Rutland	sec.evgrn	Camera trap
1	F	ad	Rutland	sec.evgrn	Camera

					trap
1	F	ad	Rutland	sec.evgrn	Camera trap
1	F	ad	Boat	evergrn	*ad libitum*
1	F	ad	Boat	littoral	*ad libitum*
3	1 F	1 ad, 1 fn, 1(?)	Boat	littoral	*ad libitum*
1	F	ad	Boat	evergrn	*ad libitum*
1	F	ad	Boat	littoral	*ad libitum*
4	F	ad	Boat	littoral	*ad libitum*
1	F	ad	Boat	littoral	*ad libitum*
2	F	ad	Redskin	evergrn	*ad libitum*
1		Fn	Redskin	evergrn	*ad libitum*
4	F	ad	Alexandra	evergrn	*ad libitum*
1	F	ad	Boat	evergrn	*ad libitum*
2	F	ad	Boat	littoral	*ad libitum*
8	3 F	3 ad, 5 fn	Boat	littoral	*ad libitum*
6	3F	3 ad	Boat	littoral	*ad libitum*
1	F	Ad	Boat	littoral	*ad libitum*
1	F	ad	Tarmugli	evergrn	*ad libitum*
1	F	ad	Tarmugli	evergrn	*ad libitum*
1	F	ad	Tarmugli	evergrn	*ad libitum*
4		3 subad,1 ad	Tarmugli	mangrove	*ad libitum*
1	M		Tarmugli	evergrn	Camera trap
1	M	Ad	Tarmugli	evergrn	Camera trap
1	M	Sbad	Hobday	evergrn	Camera trap
4		ad(1),sbad(3)	Hobday	evergrn	Camera

					trap
2		Sbad	Hobday	evergrn	Camera trap
1	F	Ad	Rutland	sec.evgrn	*ad libitum*
1	M		Tarmugli	evergrn	Camera trap
1	F	Ad	Tarmugli	evergrn	Camera trap

F:female, M:male

ad: adult

sbad: sub adult

fn: fawn

Evergrn: evergreen forest

Sec.evergrn: Secondary evergreen forest

Annexure 2:

Identified browse plants of chital in the Andaman Islands.

Vernacular name	Scientific name	Stage and part browsed
Dhada bet	*Calamuslongisetus*	Sapling
JungliSupari	*Areca triandra*	Sapling
Khaksi		Sapling
Mota bet	*Calamusandamanicus*	Sapling
Lamba Patti	*Sideroxylonlongepetiolatus*	Fruits and leaves
Kath Karanj	*Cesalpinneabonducella*	Sapling
Lal bet	*Korthalsialacenosa*	Seedling and sapling
Agiaballi		Seedling and sapling
Latau		Sapling
Lal Bombay	*Planchoniaandamanica*	Seedling
BillliKanta		
Surmai	*Dracaena sp.*	All stages
Taungpeing	*Artocarpuschaplasha*	
Croya	*Cerbavamangas*	Sapling
Garjan	*Dipterocarpus sp.*	Sapling
Safedchuglum	*Terminaliabialata*	Seedling
Fish-tail palm	*Caryotamitis*	Sapling
Mariam		Fruits
KhariMahua	*Mimusopslittoralis*	Fruits
KhariNariyal		Seedling
KhariJamun	*Eugenia claviflora*	
Bakul		Fruits
Bel bamboo	*Dinocloaandamanica*	
JungliPyaj		
Pen Patti	*Suragada sp.*	Seedling

Karanj	*Pongamiaglabra*	
Jahaziballi	*Canthium sp.*	Sapling
Kharibadam	*Terminaliakatapa*	
Hathiganna	*Heptapleurumvenulosum*	
	Litzia sp.	
	Leeaindica	