Responses of Rainforest Lizard Communities to Tea Plantation Edges in the Anamalai Hills of Southern Western Ghats, India

Dissertation Submitted to Saurashtra University, Rajkot
in Partial Fulfilment of the Master's Degree
in Wildlife Science

By

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CERTIFICATE

This is to certify that **Mr. Aditya S. Malgaonkar** has carried out original research titled *"Responses of Rainforest Lizard Communities to Tea Plantation Edges in the Anamalai Hills of Southern Western Ghats, India"* in partial fulfilment of **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.

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Contents

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List of Tables and Figures

Summary

Human-made edges are an omnipresent form of altered habitats across the entire Western Ghats landscape. Furthermore a diverse range of edge types exist differing in the structure and composition of their altered surrounding habitat. Only a few attempts have been made to study the influence of the structure of this adjoining habitat or the 'matrix' on edge effects. Understanding the influence of different matrix habitats on edges will lead to the better understanding of the abiotic and biotic influences of the matrix on forest edges. Vegetation structure and composition has been the subject of several studies pertaining to fragmentation as well as effects of edges and both primary as well as secondary responses to edge effects have been documented. It has also been noted that while the reduction in plant species richness may occur as a result of decreasing forest area, it is more likely that this could be the result of increasing perimeter to area ratio resulting from fragmentation and increased proportion of area exposed to edge effects.

The abiotic as well as biotic changes which affect vegetation not only bring about structural changes such as those in canopy cover, vertical stratification, density etc, but also affect functional aspects of plant communities such as pollination, seed dispersal and germination. Faunal communities respond in various ways to changes in their habitat; these may include changes in abundance, species richness, structure and composition of communities as well as behaviour of individual species. With respect to edge effect these changes or may vary in their magnitude and the distance or depth to which they penetrate into the interior. Magnitude and depth of influence are two complementary but distinct aspects of edge effects. Magnitude of influence is the degree to which a response value (a biotic or abiotic variable used to measure edge effects) differs between the edge and the interior while depth of influence if the maximum distance to which edge effects percolate into a habitat. However, a large amount of research on this topic has been restricted to birds and mammals and the responses shown by them might not be representative of the responses of other lesser known taxa.

Chapter 1

General Introduction, Description of Study Area, Rationale and Objective

1. Introduction

Three global biodiversity hotspots i.e. Eastern Himalayas, Indo-Burma and Western Ghats occur in India, which support a great diversity of endemic species(Myers *et al* 2000). The Western Ghats in particular contain a high diversity of endemic plant and animal taxa(Ali 2002, Daniels 1992, Ishwar *et al* 2001, Nair and Daniel 1986 and Vasudevan *et al* 2008). However, 25.6 % of the forest in Western Ghats has been lost over a period of 22 years from 1973-1995(Jha *et al* 2000). The Western Ghats faces severe threats from human disturbance due to deforestation, developmental activities, conversion to plantations and habitat fragmentation(Nair 1991).This is not surprising given that this region is one of the hotspots with the highest human population densities(Cincotta *et al* 2000).Deforestation has been accompanied by land-use changes such as conversion of forests to coffee and tea plantations, silvicultural plantation-forests and infrastructure facilities such as roads and hydroelectricity projects. Even in protected areas fragmentation has led to the isolation of once contiguous habitats and the deleterious effects of edge influence affect a large proportion of habitats. One of the major causes of forest fragmentation in the Western Ghats is the spread of plantations, particularly tea, coffee, and Eucalyptus. The area under plantations is large and growing. Tea plantations in the south Indian states increased by 17.7% in the period 1987-1998 from 74,765 ha to 87,993 ha (Tea Board 2002). Large areas of Eucalyptus plantations also occur with tea as it is used as fuel-wood for tea-curing in the factories.

Human-made edges are an omnipresent form of altered habitats across the entire Western Ghats landscape. Furthermore a diverse range of edge types exist differing in the structure and composition of their altered surrounding habitat. Only a few attempts have been made to study the influence of the structure of this adjoining habitat or the 'matrix' on edge effects(Mesquita *et al* 1999). Understanding the influence of different matrix habitats on edges will lead to the better understanding of the abiotic and biotic influences of the matrix on forest edges.Vegetation structure and composition has been the subject of several studies pertaining to fragmentation as well as effects of edges and both primary as well as secondary responses to edge effects have been documented(Harper *et al* 2005). It has also been noted that while the reduction in plant species richness may occur as a result of decreasing forest area, it is more likely that this could be the result of increasing perimeter to area ratio resulting from fragmentation and increased proportion of area exposed to edge effects(Laurance and Yensen 1991).The abiotic as well as biotic changes which affect vegetation not only bring about structural changes such as those in canopy cover, vertical stratification, density etc, but also affect functional aspects of plant communities such as pollination, seed dispersal and germination(Bruna 1999, Jardim and Batalha 2009 and Murcia 1995). Faunal communities respond in various ways to changes in their habitat; these may include changes in abundance, species richness, structure and composition of communities as well as behaviour of individual species. With respect to edge effect these changes or may vary in their magnitude and the distance or depth to which they penetrate into the interior. Magnitude and depth of influence are two complementary but distinct aspects of edge effects. Magnitude of influence is the degree to which a response value (a biotic or abiotic variable used to measure edge effects) differs between the edge and the interior while depth of influence if the maximum distance to which edge effects percolate into a habitat. However, a large amount of research on this topic has been restricted to birds and mammals and the responses shown by them might not be representative of the responses of other lesser known taxa(McGarigal and Cushman 2002).

Most species of herpetofauna that inhabit tropical evergreen forests are specific to particular micro-habitats (Inger *et al* 1987). Reptiles and Amphibians being exothermic regulate their body temperature by retaining the heat derived from their surroundings. Amphibians are also vulnerable to desiccation due to their highly permeable non-keratinised skin. It is for these reasons herpetofaunal communities are likely to be affected by edge effects, as they alter vegetation and micro-climate. Moreover, matrix induced changes in edge effect have been documented on the structure and composition of vegetation as well as micro-climatic variables (Didham and Lawton 1999, Gehlhausen *et al*, 2000 and Harper *et al* 2005). These changes include greater magnitude and depth of edge effects with lower relative humidity, decreased soil and leaf litter moisture, lower litter depth in edges with more open matrix. Species richness of herpetofauna in fragmented forests is found to have a significant co-relation with these micro-habitat variables(Urbina-Cardona *et al* 2006). Tropical forest herpetofauna are suitable taxa for a patch level study on edge effects as spatial independence of sampling units can be accounted for due to their poor vagility.

Though a significantly large majority of species are restricted to tropical areas, there exists a disparity with the majority of research being conducted in temperate forests. Tropical forests owing to their biological diversity are also far more complex systems and thus there is a greater need to investigate edge effects in tropical environments. While edge effects for long have been a subject of scientific scrutiny there still exists considerable debate regarding the mechanisms through which they influence species(Dunning *et al* 1992). Edge effects can be manifested in changes in species richness, abundance, interactions among species as well as biochemical processes (Saunders *et al* 1991; Weathers *et al* 2001). The assessment of the conservation value of isolated forest remnants which are surrounded by human altered habitats requires the understanding of edge effects .Reptiles and amphibians are susceptible to a diverse range of alterations in their habitat and therefore can be utilized for monitoring and planning of conservation initiatives. Loss of species due to habitat fragmentation is perhaps the greatest cause of concern in the conservation of biologically diverse areas such as the Western Ghats and a component of this process namely edge effects remains understudied in India. Therefore studying edge effects on herpetofauna is appropriate not only considering the biology of reptiles and amphibians but also the conservation issues in the region.

2. Rationale and Objectives

Edge effects occur due to the interactions between two adjacent but structurally distinct ecosystems separated by an abrupt transition. In fragmented forests where remnants of the once intact ecosystems are juxtaposed with a matrix of human modified habitats such as plantations, agricultural fields and other intrusions such as roads, edges are prominent feature of the landscape. These edges which border two different habitats are influenced by alterations in abiotic factors such as temperature regimes, solar and wind penetration, humidity and soil moisture due to the contrasting structure of the two adjoining habitats. Moreover there may be biological effects which are either direct i.e. those caused by the abiotic factors or indirect, which are caused by changes in species interactions(Murcia 1995).

In a review of 104 studies on forest fragmentation, Prevedello and Vieira (2010) concluded that in majority of the studies (>95%), the parameters investigated were influenced by the matrix although patch size and isolation emerged as more significant determinants. They concluded that matrix quality increases with increasing structural similarity with habitat patch. Matrix similarity was also found to positively affect species richness of reptiles and amphibians in tropical forest fragments(Bickford *et al* 2010, Dixo and Metzger 2010, Santos-Barrera and Urbina-Cardona 2011). These studies only dealt with species richness and abundance in forest patches and did not deal with matrix-edge dynamics. Therefore, how much of the observed variation of species composition in forest fragments is due to matrix induced dynamics of edge effects cannot be ascertained. However, matrix influenced change in edge effect has been documented on the structure and composition of vegetation and micro-climatic variables(Didham and Lawton 1999 and Gehlhausen et al., 2000). These changes which include greater magnitude and depth of edge effects with lower relative humidity, decreased soil and leaf litter moisture, lower litter depth in edges with more open matrix, species richness of herpetofauna in fragmented forests is found to be significantly co-related to these micro-habitat variables (Urbina-Cardona *et al* 2006).

Changes in microclimate and habitat may contribute to changes in species assemblages either directly as the new environment with its altered microclimate and habitat is unacceptable or by favoring competitors, predators or other interactions such as parasitism which could be detrimental to the survival of original fauna(Sartorius *et al* 1999). However species may respond differentially to changes in the various components of their environment according to their particular biological requirements. While edge effects for long have been a subject of scientific scrutiny there still exists considerable debate regarding the mechanisms through which they influence species(Ries *et al* 2004). Edge effects may play a role in altering species diversity either by altering their habitat and abiotic factors such as temperature and humidity or through altering species interactions such as predation and competition(Lahti 2001).A large majority of studies in tropical forests have focused upon the influence of edge effects on a community or assemblages of species using indices of species richness, diversity or other such measure of community composition(Saunders *et al* 1991). This method though of great conservation value does not provide insights as to how individual species respond to edge on account of their different habitat and environmental requirements.Most studies involving herpetofauna also depend on relative estimates of abundance in edge vs. interior plots and do not include sample specific estimates of density and their environmental correlates(Schlaepfer and Gavin 2001). This approach does not facilitate the comparison of edge effects with site specific factors determining herpetofaunal abundance and therefore does not enable us to gauge the relative importance of edge effects and site specific habitat and environmental factors. The study of edge effects which examine the habitat relationship of species would also enable us to determine the mechanism through which edge effects influence species. In the present study we attempt to examine the role of edge effects on the lizard assemblage in a tropical rainforest in Southern Western Ghats with a detailed study of the effect of edges on density and habitat of two species of lizards i.e. *Caloteselliotii* and *Eutropismacularia.*

3. Study Area

The Western Ghats is a 1,600 km long chain of hills running along the west coast of the Indian Peninsula (8°-21° N). The chain of hills is interrupted by the 30 km wide Palghat Gap at around11° N, and a few other minor gaps along its length. This unique biogeographic province(Mani 1974, Rodgers and Panwar 1988) has pronounced north-south, east-west, and elevational gradients, which have profound consequences for the distribution of plants and animals. The southern end of the Ghats has a short dry season (2 – 5 months) as it receives rain from thesouthwest (June – September) and northeast (October – January) monsoons. The northern reaches have a longer dry season (5 – 8 months), receiving rain mostly during the southwest monsoon. The average annual rainfall in the evergreen forests ranges from around 1,800 to 7,500mm depending on the locality(Daniels 1992, Pascal and Ramesh 1988). Most of the higher hills (1,000 – 2,000 m) in the Western Ghats are found towards the south, between 8° N and 13° N. Pascal (1988) has classified the tropical wet evergreen forests of the Western Ghats into low (< 700 m), medium- (700-1,400 m), and high-elevation (> 1,400m) types. Moist forests, including tropical wet evergreen rainforest, are found largely south of 16°N, particularly south of the Palghat Gap, a region often called the southern Western Ghats. This is also the region that contains higher diversity and a greater number of endemics of rainforest plant and animal taxa (Ali 2002, Daniels 1992, Ishwar *et al* 2001, Nair and Daniel 1986 and Vasudevan *et al* 2008).

The Anamalai ranges are a major conservation area in the southern Western Ghats. Much of the key mid-elevational tropical evergreen forest of interest to this study occurs in the Anamalai Tiger Reserve (987 km^2, 10° 12' N to 10° 35' N and 76° 49' E to 77° 24' E). The natural vegetation of this region receiving around 3,000 mm of rainfall annually particularly during the southwest monsoon (June– September), has been classified as mid-elevation tropical evergreen forest of the Cullenia-Mesua Palaquium type(Pascal and Ramesh 1988). The Valparai plateau contains a large area of tea, coffee, and cardamom estates occupying around 220 km^2 and lying almost in the centre of four Wildlife Sanctuaries and National Parks and a large tract of Reserved Forest. The plateau has a small town (Valparai) and a human population of over 106,000 people (Census of India 1991), mostly estate laborers, scattered across the town and estates.

Chapter 2

Responses of rainforest lizard communities to tea plantation edges in the Anamalai hills of Southern Western Ghats, India

1. Introduction

Three global biodiversity hotspots i.e. Eastern Himalayas, Indo-Burma and Western Ghats occur in India, which support a great diversity of endemic species(Myers *et al* 2000). The Western Ghats in particular are contain a high diversity of endemic plant and animal taxa(Ali 2002, Daniels 1992, Ishwar *et al* 2001, Nair and Daniel, 1986 and Vasudevan *et al* 2008). However, 25.6 % of the forest in Western Ghats has been lost over a period of 22 years from 1973-1995 (Jha *et al*2000). Human-made edges are an omnipresent form of altered habitats across the entire Western Ghats landscape. Edge effects may play a role in altering species diversity either by altering their habitat and abiotic factors such as temperature and humidity or through altering species interactions such as predation and competition(Lahti 2001).A large majority of studies in tropical forests have focused upon the influence of edge effects on a community or assemblages of species using indices of species richness, diversity or other such measure of community composition(Saunders *et al* 1991). This method though of great conservation value does not provide insights as to how individual species respond to edge on account of their different habitat and environmental requirements. Most studies involving herpetofauna also depend on relative estimates of abundance in edge vs interior plots and do not include sample specific estimates of density and their environmental correlates(Schlaepfer and Gavin 2001). This approach does not facilitate the comparison of edge effects with site specific factors determining herpetofaunal abundance and therefore does not enable us to gauge the relative importance of edge effects and site specific habitat and environmental factors. The study of edge effects which examine the habitat relationship of species would also enable us to determine the mechanism through which edge effects influence species. In the present study we attempt to examine the role of edge effects on richness and composition on lizard communities and the density and habitat of two species of lizards i.e. *Calotes ellioti* and *Eutropis macularia* in rainforest-tea plantation edges of Southern Western Ghats of Anamalais in India.

2. Methods

2.1 Study Area

The Anamalai Tiger Reserve (ATR) has an area of 987 km^2 located between 10°12' N – 10°54'N and 76°44'E-77°48'E in Tamil Naidu State, India(Figure 9). It is one of the largest protected areas in Western Ghats. It covers an elevational range from 200m to 2500m above mean sea level and is composed of diverse forest types such as tropical dry-thorn, dry deciduous, moist deciduous, semi-evergreen, wet evergreen forests and montane shola grasslands. Like many PAs in the Western Ghats, the reserve has an edge that is dominated by a variety of land-uses and is densely populated. The west facing slopes of the reserve receive more rainfall than the east facing slopes and are climatically conducive for cultivation of cash crops such as tea, coffee, cardamom and pepper. The average annual rainfall recorded over a period of 10 years (1989-1998) on the west facing slopes in Valparai plateau was 3,497mm(Joshi *et al* 2009). There are three distinct seasons i.e. dry season (February-May), south-west monsoon (June-September), north-east monsoon (October-January). Though the region receives rainfall over a period of eight months of the year, 70 % of the annual rainfall is received from the south-west monsoon. The day time temperature ranges from 19° to 28° C and relative humidity ranges from 75% to 95%.

The Valparai plateau covers an altitude ranging from 700 to 1400 m a.s.l. Extensive areas of this plateau were converted to more than 220 km^2 of tea, coffee and cardamom plantations that are now owned by individuals or companies(Shankar and Mudappa 2003). The plantations are located at the center of the plateau and is partially enclosed by ATR. There exists an extensive plantation-forest edge in the Valparai plateau. The forests are mid-elevational tropical wet evergreen forests which have been classified as the *Cullienia exarillata-Mesua ferrea-Palaquium ellipticum* type(Pascal and Ramesh 1988). A majority of adjoining forest areas are secondary in nature due to the previous history of logging and disturbance. A number of invasive species of herbs, shrubs as well as trees have also established themselves in these forests. The plateau has a township and many scattered housing colonies, and a total population of around 106,000 people(1991 Census), comprising of plantation laborers inhabit them. The sampling sites which were within a radius of 10 km from the township were accessed by road.

2.2 Sampling design

Since tea was the most dominant crop in the area, we identified four stretches of rainforest-tea plantation edges and located three sampling blocks in each of the four sites by strategically placing the first block at the access point to the edge and thereafter maintaining a 500 m interval between successive blocks, a total of 12 such sampling blocks were established. Each block consisted of four 100 m long transects placed parallel to the edge at distances of 10, 30, 90 and 270 m from edge. This design provided strata at increasing distance from the edge which was used to measure the response of lizard communities to vegetation and microclimatic factors from edge to interior. The transects at 270 m from edge were not laid in two of the 12 blocks sampled, thus the 270 m strata was represented by ten transects while the rest of the strata were represented by 12 transects. Transects were marked and a small amount of vegetation was cleared to enable a person to walk upright on a straight line.

2.3 Sampling lizards

The transects were sampled by two observers between 9:00 h and 15:00 h and each transect was sampled two to six times during the study period by observers who took one hour to complete one transect. Lizards were encountered on the forest floor, on understory vegetation and on trees, the individuals were identified visually or if required captured to ascertain their species identity. Taxonomic keys in conjunction with regional checklists were used to identify species(Chandramouli and Ganesh 2010, Smith 1935 andVenugopal2008). In December and February only two transects where sampled in a day from 10:00 h to 13:00 h due to infrequent activity of lizards during this season. During summer months, between March and April, four transects were sampled in a day. The sequence of sampling was randomized at two levels i.e. random selection of blocks and then random selection of transects within the block to reduce the confounding effect of time of sampling and seasonal variation might have on detections of animals.

Distance sampling was employed to estimate densities of *Calotes ellioti* and *Eutropis macularia*(Buckland *et al* 1993). The perpendicular distance from transect to the location of an animal sighting was recorded using a measuring tape. In case of *C. ellioti* whenever courting pairs were encountered the distance to the centre of the pair was measured and the pair was deemed to be an independent observation. The lizards did not show any responsive movements until approached at very close distance (2-3 m) and were therefore not disturbed by the observer.

The principal assumptions of distance sampling were satisfied in this study. The program DISTANCE version 6.1 (Thomas *et al* 2010) was used to estimated densities in a Conventional Distance Sampling (CDS) framework. Three key functions i.e. uniform, hazard-rate, and half-normal were respectively paired with cosine, simple polynomial, hermite polynomial series adjustments to arrive at a priori models. Cut-points for distance intervals were set manually and truncation was utilized to fit the detection probability curve. In case of *C. ellioti* both left and right truncation was used while for *E. macularia* only right truncation was required. Left truncation was necessary in case of *C. ellioti* as it is an arboreal lizard and 30 cm were truncated to account for the width of the transect. The model fitting for each of the models was made by visual examination followed by a Kolmogorov-Smirnov test(Thomas *et al* 2010). The relative goodness of fit among the various models was compared using Akaike Information Criterion (AIC) values and the model with the lowest AIC value was deemed to be the best fitting model. Post stratification was utilized to estimate densities at the level of stratum and sample. Each strata consisted of all transects at a particular distance from the edge while samples were individual transects.

2.4 Abiotic variables

The micro-climatic variables such as temperature, relative humidity and average wind velocity were recorded using a KESTREL 3500NV POCKET WEATHER METER (Kestrel Pocket Weather^{TM} Meters, USA). The meter was held 0.8 m away from the body and the readings were allowed to stabilize for a period of 30 seconds. After this period the concordant readings were recorded.Light intensity was measured using a NIKON D3000 DSLR camera with a NIKKOR 18-55 VR lens (NIKNON Corporation, Japan). Four reading of the shutter speed at four different directions on the transects were taken, with the ISO 400, aperture at F 8 and the focal length at 18 mm kept constant throughout the survey. The inverse of the mean of the four readings was used as an index for light intensity. The readings were taken before and after sampling each transect on every sampling occasion and the mean of the two readings was used for analyses.

2.5 Vegetation

A plot less method was followed by selecting three points at the start, centre and end of each transect to measure tree density, basal area, percentage canopy cover and shrub cover. A point-center-quarter method was utilized to measure three density and basal area by selecting four nearest trees in each of the four equal quarters and then recording their distance from the centre point and girth at breast height (1.3 meters) to the nearest centimetre. The density was estimated as the inverse of the mean distance multiplied by 10,000 to produce number of trees/ha, while the total basal area/ha was estimated as the squared sum of the basal area of trees multiplied by the estimated density and the product multiplied by 100to express it as basal area/ha(Krebs 1999). The canopy cover was measured using a canopy densiometer (Forestry Suppliers Inc, USA) to take four reading at four different directions around the centre point, their mean was multiplied by 1.04 and the product subtracted from 100 to yield the percentage canopy cover for each plot. An index of under-story cover was estimated by use of a 1 m measuring tape with ten intervals of ten centimeters. The tape was held vertically by one observer and number of intervals intersected by vegetative matter such as leaves, steams etc recorded by the other observer situated one meter away from the measuring tape. Four such readings were taken at four equidistant points around the centre point and the mean was used as the index. The measures obtained were averaged across the three plots to characterize vegetation of each transect.

2.6 Analyses

All statistical procedures were executed in the statistical software R (version 3.0.1) (R Development Core Team 2013 http://www.R-project.org). An individual based rarefaction was used to compare species richness between the four distances from the edge. I used the package 'Rich' to generate rarefaction curves for lizard communities 10m, 30m, 90m and 270m from the edge with 1000 random bootstrap iterations(Gotelli and Colwell 2001). Rarefaction generates the expected number of species in a small collection of n individuals drawn at random from the large pool of individuals enabling the comparison of communities represented by unequal number of individuals as number of species recorded is also contingent upon the number of individuals sampled. The number of individuals used for rarefaction across all strata was restricted to 18, because it was the least number of lizards detected in transects at 270 m distance from the edge. Randomization tests to compare richness of different strata were carried out with 1000 randomizations for each of the four community matrices (Manly 2002). Pair-wise randomization tests were carried out to compare two strata at a time and each stratum was compared with every other. The randomization test provide for a randomized difference between the two community matrices which is the mean difference between the observed cumulative species richness of the two strata and a significance value (p value).

I used one-way analysis of variance (ANOVA) to establish whether lizard densities, vegetation and microclimatic variables differed at increasing distances from the edge. Tukey's HSD test was used in conjunction with ANOVA to make pair-wise comparison of treatment levels and box-plots were used to ascertain the trend in the change of these variables from edge to interior. Variables which showed a significant change(p>0.05) with distance from the edge were used in Generalized Linear Models with poisson error distribution and a 'log' link function to compare their relative significance in influencing the densities of *Calotes ellioti* and *Eutropis macularia* and to determine if vegetation and microclimatic variables alone determine the observed changes in lizard densities. Model selection was carried out using AICc values and the model with the lowest AICc was deemed to be the best fitting model. AICc was used as it corrects for small sample sizes thus providing better model order choices than Akaike Information Criterion(Hurvich and Tsai 1993).

3. Results

3.1 Species richness and composition

Six species of lizards were encountered, these include *Calotes ellioti*, *Draco dussumeri*, *Eutropis macularia*, *Eutropis carinata*, *Cnemaspis sp1*, *Cnemaspis sp2*. In addition to this, *Keastlea travancorica*, *Psammophilus dorsalis*, *Hemidactylus anamallensis*, and *Calotes grandisquamis* were also recorded during the study period but were not recorded on the transects. The species richness of lizards at 90 m distance from the edge was the highest. The rarefaction curves at 10 m and at 30 m distance from edge has similar trajectories and thereby similar species richness. Lizard species richness at 270 m distance from the edge was the lowest. The pattern of intermediate distance from the edge having greater species richness compared to the interior and the edge was documented for lizard community in this study (Fig. 1). The randomized difference in species composition between strata followed the same trend as shown by the rarefaction analysis with the pair of 10 and 30 showing the least difference followed by 10 & 90, 30&90 and 30 &2 70 while the pair of strata 90 & 270 showed the maximum difference. The p-values were insignificant (>0.5) for all the pairs tested and thus the composition of lizard communities did not vary between strata (Table 1).

3.2 Density estimation

Thirty nine individuals of *E. macularia* were detected in 23 transects, and 57 individuals of *C. ellioti* were detected in 30 transects sampled. Half-normal/hermite polynomial model was selected as the most parsimonious model for both the species (Fig. 2 & 3, Table 2). Estimates of 9.08 ha^{-1} (95% CI: 6.97 and 11.84) for C. *ellioti* and 5.71 ha^{-1} (95% CI: 4.45 and 7.31) for *E. macularia* were obtained.

Density of *Calotes ellioti* increased from 5.9 lizards ha^{-1} (95% CI: 4.57 and 7.77) at the 10 meters from edge to 11.81 lizards ha^{-1} (95% CI: 9.05 and 15.40) at 270 m (Fig. 4). The densities of *Eutropis macularia* showed an inverse trend as compared to that of *C. ellioti* with a decrease from 8.59 lizards ha^{-1} (95% CI: 6.70 and 11.04) at 10m from edge to 2.09 lizards ha^{-1} (95%CI: 1.63 and 2.68) at 270 m (Fig. 5).

3.3 Changes in habitat and microclimate

A one-way analysis of variance was utilized to examine the changes in microclimate and vegetation from an edge to interior gradient. The microclimatic variables were examined using every repeat as well as replicate as independent samples, and in the case of vegetation variables only replicates were used. Light intensity, tree density and canopy cover were found to be significantly different ($p < 0.05$) at different distances from the edge (Fig.: 6, 7 and 8). The difference between all the other pairs was insignificant ($p > 0.05$), (Table 3).

A difference of 7.90 (95% CI: 14.71 and 1.09) between light intensity at 10-270m ($p < 0.01$) was observed. The tree density between 10-90 m were found to differ by 3.10 trees /100 m^2 (95% CI: 0.21 and 5.99, $p < 0.05$), 10m and 270m strata differed by 6.81 trees/100 m^2(95% CI: 3.78 and 9.84, $p < 0.001$) while 30m and 270m differed by 5.59 trees/100 m^2 (95% CI: 2.54 and 8.57, $p < 0.001$) and the difference between 90-270 m was 3.70 trees/100 m^2 (95% CI: 0.67 and 6.73). The difference between 10-30 m pair and 30-90 m pair was found to be insignificant. Canopy cover differed by 2.13 % (95% CI: 0.13 and 4.13, $p<0.05$) between 30m and 270 m however all the other strata did not differ significantly with each other.

3.4 Relationship of lizard densities with edge influenced changes in microclimate and habitat

In case of *C. ellioti* as well as *E. macularia* the generalized linear models with tree density and light intensity as predictor variables were selected as the most parsimonious models with an AICc value of 155.54 and 155.90 respectively (Table 4). In case of models for both species the coefficients had a value of less than 0.1 however tree density was significant ($p<0.05$) even with small coefficients. Tree density positively influenced densities of *C. ellioti* while the effect was negative on *E. macularia*. Light intensity negatively influenced both the species (Fig. 5).

4. Discussion

Several factors such as availability of foraging recourses, refuges and interaction such as predation and competition shape species assemblages. Changes in microclimate and habitat may contribute to changes in species assemblages either directly as the new environment with its altered microclimate and habitat is unacceptable or by favouring competitors, predators or other interactions such as parasitism which could be detrimental to the survival of original fauna(Sartorius *et al* 1999). However, species may respond differentially to changes in the various components of their environment according to their particular biological requirements. Forest edges could be influenced by altered microclimate, invasion of exotic species, influx of matrix tolerant competitor and predator species(Andren 1994, Harris 1988, Murcia 1995 and Saunders *et al* 1991). These edge effects along with the unlimited combinations of predictors that could possibly influence species occurrence or abundance result in high degree of variability in responses of species to edges. Highly variable responses to edge effects among congeneric species have been reported(Schlaepfer and Gavin 2001). Moreover there is no consistency in literature with respect to the microclimatic and habitat features which edges seem to influence(Harper *et al* 2005, Ries *et al* 2004). Edge effects may also be influenced by seasons, local weather patterns and location specific factors such as aspect, elevation and slope(Hylander 2005 and Malcolm 1994). In view of the apparent lack of generality with which species respond to edge it becomes an important task to develop species specific understanding of responses to edges. In the present study we undertook exactly such an approach as we studied species responses in terms of their richness and composition as well as densities of two common species. We also measured microclimatic and vegetation variables and studied their influence on density of species in order to understand how they might mediate edge effects on those species.

Species richness at the intermediate 90 m stratum where five of the six species were recorded showed the highest slope and number of species per individuals compared to the rest of the strata. However, the differences in species composition among the strata were not significantly different ($p > 0.05$). The small number of species used for comparing species composition is likely to have influenced this result and sampling a wider range of lizard species by use of a variety of sampling methodologies in combination with each other to detect species which are more cryptic and occur in low densities could alter the results.

Among the microclimatic variables humidity and temperature did not vary with distance from the edge while light intensity decreased along an edge to interior gradient. Tree density and canopy cover were shown to increase from edge to interior while understory cover and litter cover did not did not reflect any change. The densities of both the lizards studied varied from edge to interior but while density of *E. macularia* was highest at the edge and lowest in the interiors, that of *C. ellioti* was lowest at the edge and highest at the interior.

Among the generalized linear models used to examine the relationship of light intensity, tree density and canopy cover with densities of *C. ellioti* and *E. macularia* the models incorporating both tree density and light intensity were selected as the most parsimonious models for both the species. Tree density significantly influenced the densities of both the species but while the density of *C. ellioti* was positively correlated to tree density that of *E. macularia* showed a negative correlation, this is consistent with the hypothesis that species specific ecological requirements govern their response to edges as *C. ellioti* is a arboreal agamid and mostly inhabits trees and shrubs while *E.macularia*is a terrestrial skink which was most frequently seen along forest openings. Light intensity was negatively correlated with density of both species implying that they avoided highly luminous environments.

Though distance from the edge did not emerge as a significant predictor and its exclusion resulted in more parsimonious models it should be noted that the coefficients of predictor variables were very small and therefore do not seem to entirely predict the variation in densities. The fact that a multitude of environmental variables and species interactions could possibly be influencing abundance of species, both across and within the distance strata could be the reason why the model coefficients had small values.

The variation in transect specific densities within the strata could be the result of unmeasured extraneous variables which did not change along a gradient from edge to interior and hence there effect on densities could not be surrogated by adding distance to edge as a predictor variable. It is also possible that edge effects whose magnitude does not change along a gradient but which affect a particular stratum alone could muddle the relationship between distance from edge and lizard densities. Such factors could include predation and competition from matrix tolerant species whose effect on edge communities might be limited to a very short distance away from the edge. The role of both mammalian and avian predators groups in contributing to higher predation rates along edges is known from studies on avian nest success(Donovan *et al* 1997, Gardner 1998). Snakes have also been identified to have significant effect on nest predation along forest edges(Weatherhead and Blouin-Demers 2004).

Predatory birds and snakes could also contribute to increased predation on lizards along forest edges. In the study site birds which inhabit open country have been shown to occur in higher densities in plantations than in rainforest(Raman 2006). These open country birds include Kestrel (*Falco tinnunculus*), Shikra (*Accipiter badius*), White-breasted kingfishers (*Halcyon smyrnensis*) and Brown Shrike (*Lanius cristatus*) which are known to predate upon lizards (Ali 2002). Four species of snakes were also recorded during the surveys; these are the Malabar Pit-viper (*Trimerisurus malabaricus*), Hump-nosed viper (*Hypnale hypnale*), Green Vine snake (*Ahaetulla nasuta*) and Beddome's keelback (*Amphiesma beddomei*) which are all potential predators for lizard s. Snakes could be attracted to edges as they may provide thermally superior habitats and thus could increase predation rates at edges (Weatherhead 2004). Fragment size may also influence predation as abundance of mongooses (Herpestes spp) is known to be higher in fragments than in continuous forests(Mudappa *et al* 2007). Though the sampling locations in this study were based in continuous tracts of forests various intrusions such as wild fires, grazing by livestock etc, could also compound detection of edge effect as these disturbances though permeating at the edge could be non-linear in terms of their influence on interior forests.

The study concludes that the specific ecological requirements of lizard species could influence their response to edge influenced changes in their environment. Whether a species is edge avoiding, favors edge habitats or is unaffected by edges could depend upon its specific habitat requirements and how it adapts to changes in its habitat and thus ecological plasticity of a species could be critical to its survival. Species specific traits which lead to certain species responding favorably to edges while others respond negatively to it could also explain the higher richness at intermediate distances from the edge as this may represent a point of convergence of edge tolerant and edge affected lizard communities. It is also clear that changes in habitat and microclimate alone cannot explain the observed changes in lizard communities and edge effects are likely to be multimodal in their influence on lizard communities.

Tables

Table I: Pair-wise Randomization test for differences in Species composition along a rainforest- tea plantation edge-gradient in Anamalai Tiger Reserve.

Strata	Difference in Richness	p
10 m and 30 m	0.0549	Not Computed
10 m and 90 m	0.0529	0.3486
10 m and 270 m	0.1808	0.5574
30 m and 90 m	0.0729	0.3486
30 m and 270 m	0.1848	0.5584
90 m and 270 m	0.3683	0.1558

Table II: Summary of candidate models used and model fitting in the distance sampling of lizards along a rainforest- tea plantation edge-gradient in Anamalai Tiger Reserve.

Model	AIC	χ^2	df	p value	Detection Probability	Effective Stripe Width	Density	% CV	95% Confidence Interval	
									Lower	Upper
Calotes ellioti										
Half-normal/hermite	163.12	0.22	5	0.998	0.41	185.77	9.08	13.27	6.97	11.84
Uniform/cosine	163.5	0.59	5	0.987	0.45	204	8.25	7.36	7.12	9.55
Hazard-rate/simple pc	165.22	0.33	4	0.987	0.46	208.04	8.11	16.79	5.8	11.33
Eutropis Macularia										
Half-normal/hermite	103.73	0.012	3	0.999	0.42	223.17	5.71	12.3	4.45	7.31
Uniform/cosine	104.79	1.0263	3	0.794	0.49	262.49	4.85	5.33	4.35	5.4
Hazard-rate/simple pc	106.09	0.35	2	0.83	0.46	244.26	5.12	15.87	3.79	7.18

Table III: One-way ANOVA showing differences in microclimatic and habitat variables along a rainforest- tea plantation edge-gradient in Anamalai Tiger Reserve.

Variables		n	Df		F value	p-value
			Response	Strata		
Microclimate						
	Temperature	149	145	3	0.398	0.755
	Humidity	148	144	3	0.895	0.446
	Wind speed	145	141	3	1.239	0.298
	Light intensity	138	134	3	3.159	0.026*
Habitat						
	Tree density	46	42	3	13.47	<0.001*
	Basal area	46	42	3	1.11	0.355
	Canopy cover	46	42	3	3.235	0.031*
	Understory cover	46	42	3	0.683	0.567
	Litter cover	46	42	3	1.683	0.185

Table IV: Summary of Generalized linear models used to examine the role of habitat and microclimatic variables on lizard densities along a rainforest- tea plantation edge-gradient in Anamalai Tiger Reserve.

Model	Response	Predictor/s	AICc	ΔAICc
Calotes ellioti				
model 1	C. ellioti density	Tree density+Light intensity	155.5433	0
model 2	C. ellioti density	Tree density+Canopy cover+Light intensity	157.5928	2.049489
model 3	C. ellioti density	Tree density+Light intensity+Strata	157.6115	2.06825
model 4	C. ellioti density	Tree density	159.7166	4.173366
model 5/ Full model	C. ellioti density	Strata+Tree density+Canopy cover+Light intensity	160.3455	4.802195
model 6/Null model	C. ellioti density	1	175.2754	19.73213
Eutropis macularia				
model 7	E. macularia density	Tree density+Light intensity	155.9061	0
model 8	E. macularia density	Tree density+Light intensity+Strata	158.7231	2.817011
model 9	E. macularia density	Tree density+Canopy cover+Light intensity	158.8783	2.972231
model 10/Full model	E. macularia density	Strata+Tree density+Canopy cover+Light intensity	162.2936	6.387561
model 11/Null model	E. macularia density	1	207.4058	51.4997

Table V: Coefficients of the best fitting models for densities of *C. ellioti* and *E. macularia*along a rainforest- tea plantation edge-gradient in Anamalai Tiger Reserve.

Caloteselllioti- model 1

Model parameters	Intercept	Tree density	Light intensity
Estimate	1.99345	0.05798	-0.01022
Std. Error	0.23137	0.01657	0.00814
	<2e-16	<0.001	0.209

Eutropis macularia- model 7

Model parameters	Intercept	Tree density	Light intensity
Estimate	3.10598	-0.08351	-0.00649
Std. Error	0.28955	0.02713	0.00874
p-value	<2e-16	0.00208	0.45766

Figures

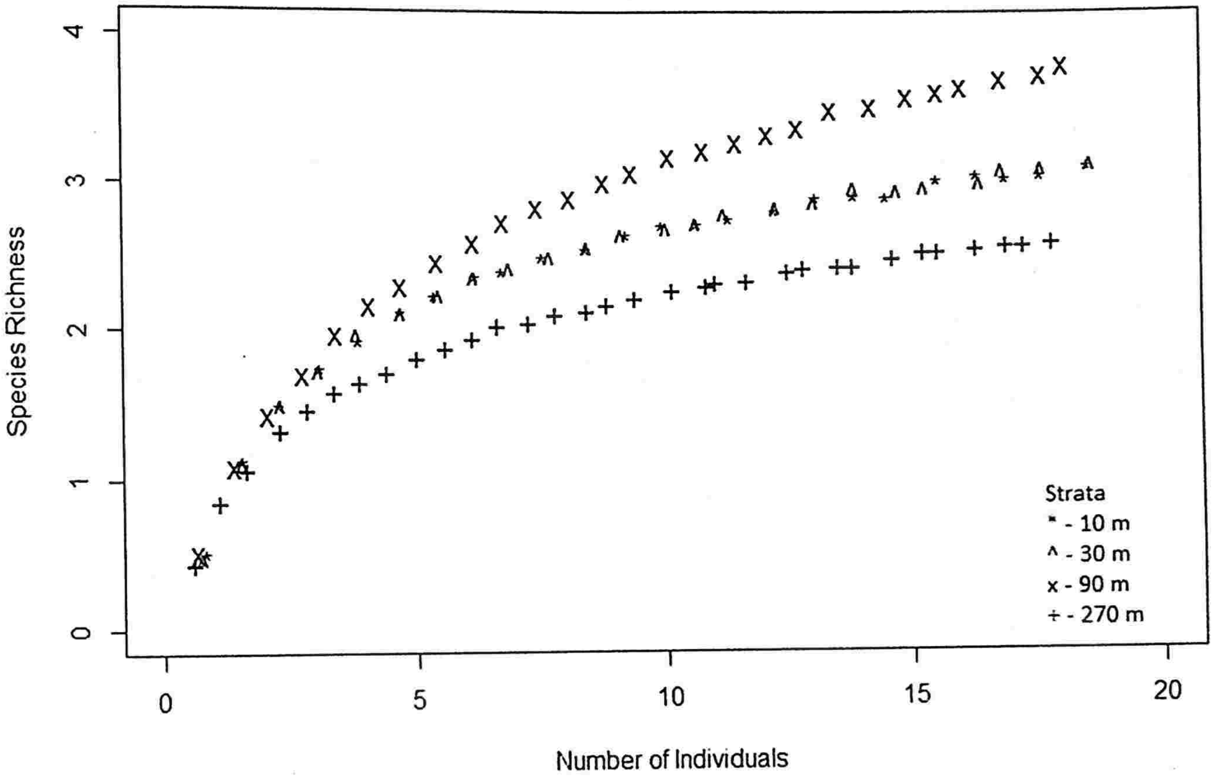

Figure 1: Rarefaction curves for individual based-rarefaction analysis of lizard species richness along a rainforest-tea plantation edge-gradient in Anamalai Tiger Reserve.

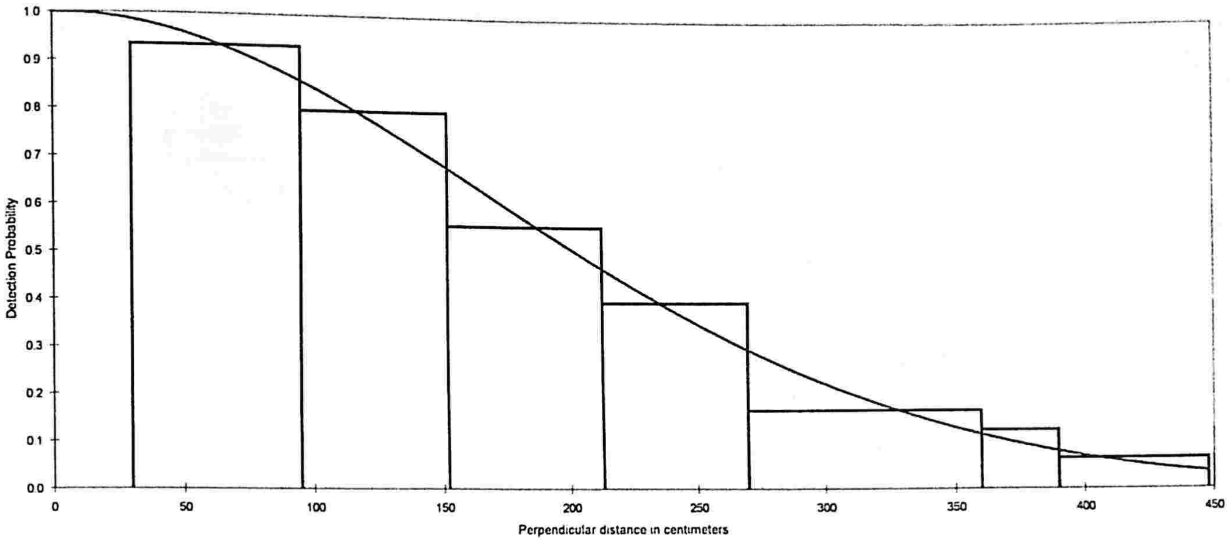

Figure 2: Detection probability curve for half-normal/hermite polynomial model used in estimating densities of *Calotes ellioti* along a rainforest-tea plantation edge-gradient in Anamalai Tiger Reserve.

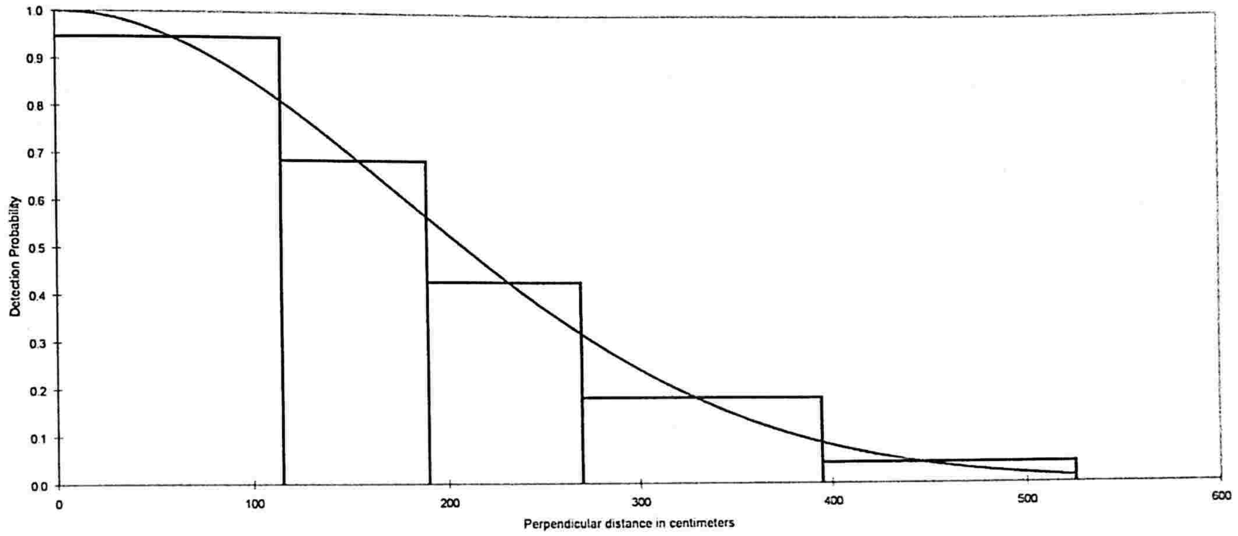

Figure 3: Detection probability curve for half-normal/hermite polynomial model used in estimating densities of *Eutropis macularia*along a rainforest-tea plantation edge-gradient in Anamalai Tiger Reserve.

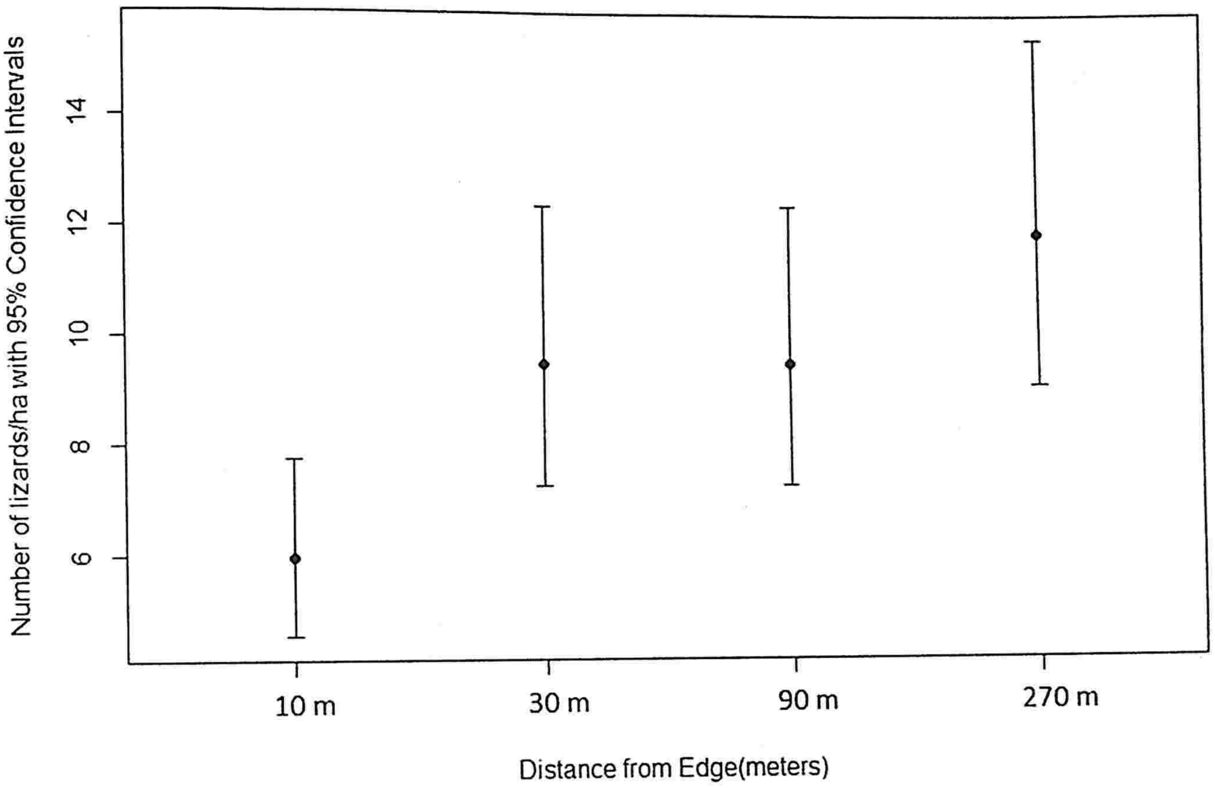

Figure 4: Densities of *C. elliott* along a rainforest-tea plantation edge-gradient in Anamalai Tiger Reserve

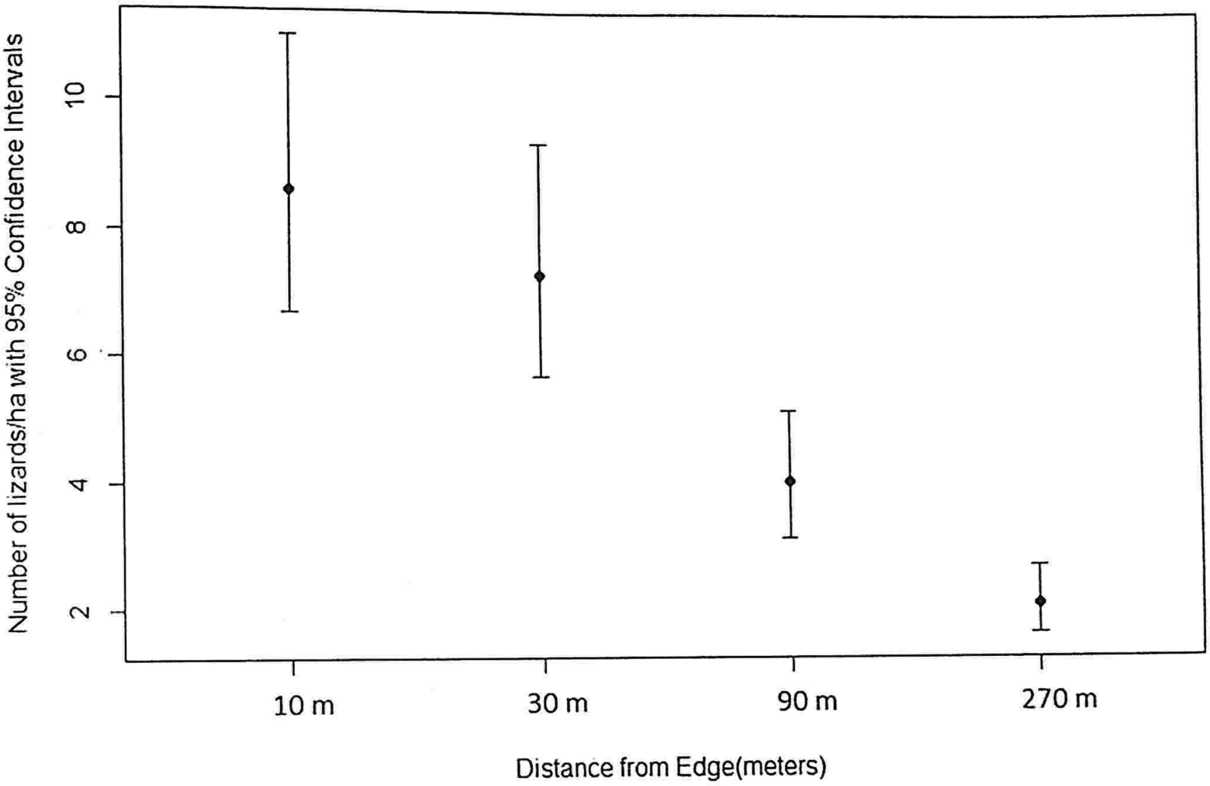

Figure 5: Densities of *E. macularia* along a rainforest-tea plantation edge-gradient in Anamalai Tiger Reserve.

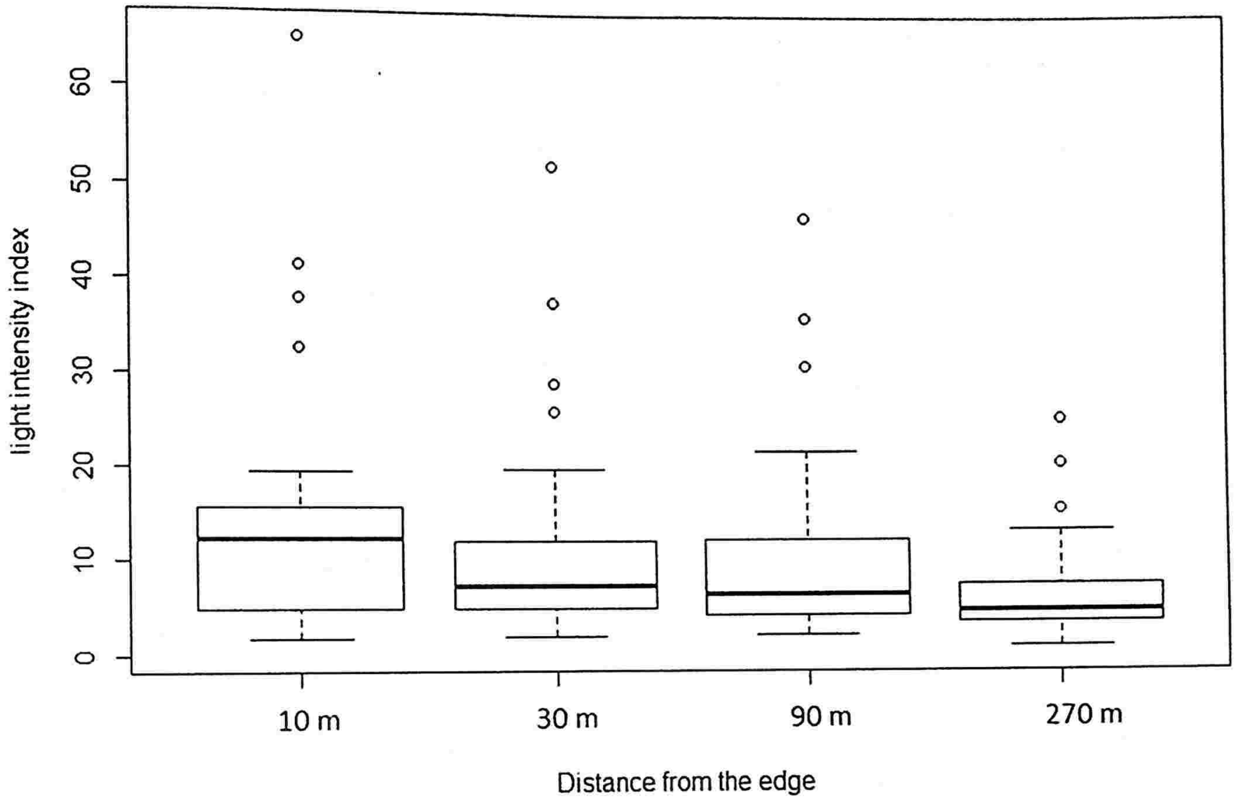

Figure 6: Variation in light intensity along a rainforest- tea plantation edge-gradient in Anamalai Tiger Reserve.

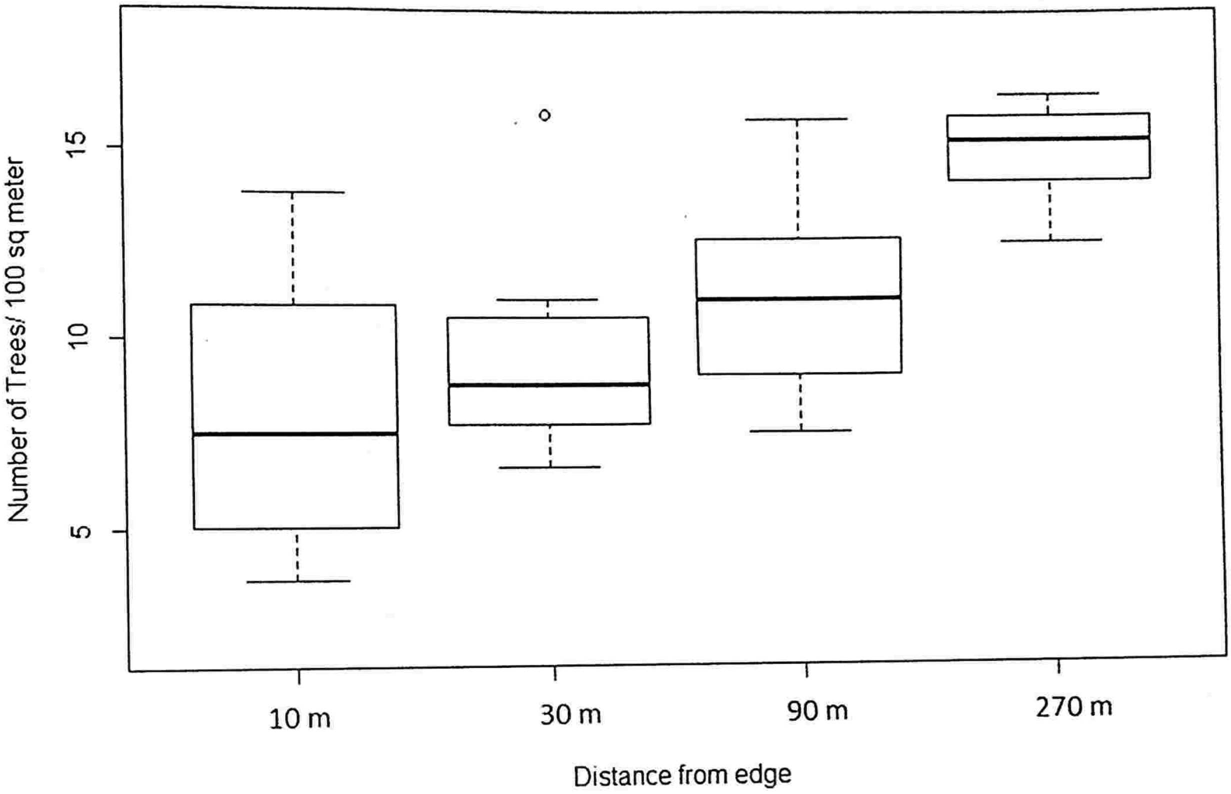

Figure 7: Variation in tree density along a rainforest-tea plantation edge-gradient in Anamalai Tiger Reserve.

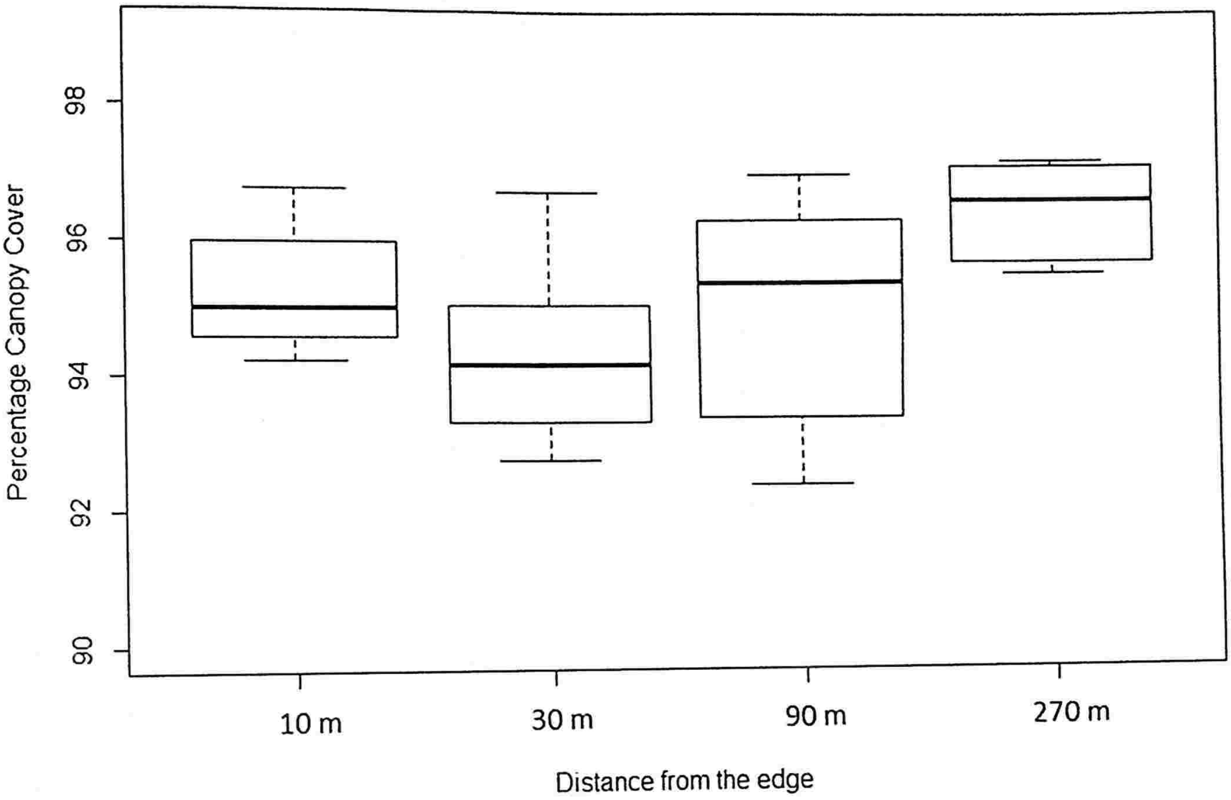

Figure 8: Changes in percent Canopy cover along a rainforest- tea plantation edge-gradient in Anamalai Tiger Reserve.

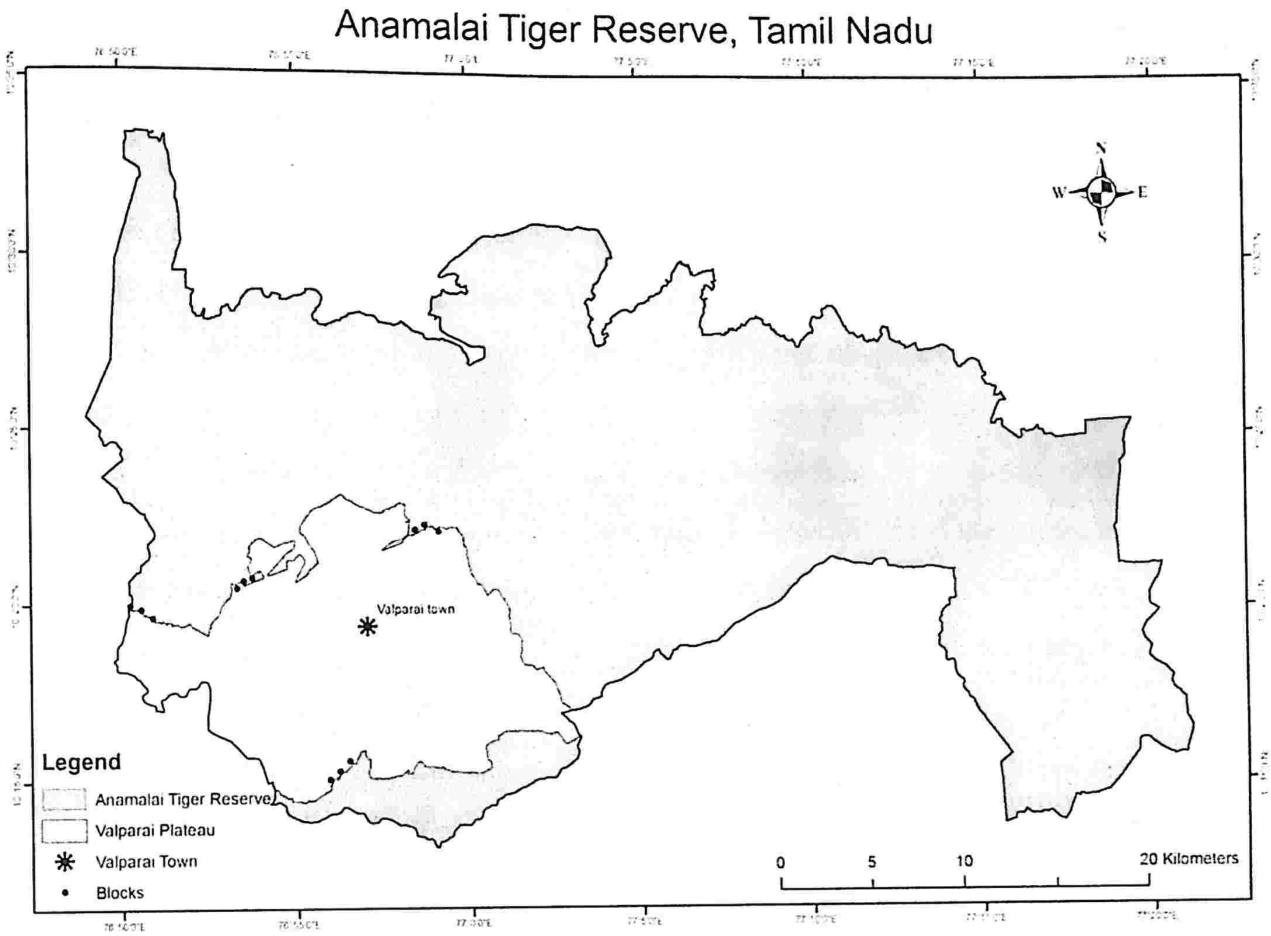

Figure 9: Study area map showing Anamalai Tiger Reserve in Tamil Nadu State, India.

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