Population density estimates of agamid lizards in human-modified habitats of the Western Ghats, India

P. Dilip Venugopal

Group for Nature Preservation and Education (GNAPE), Chennai, India
Institut Français de Pondichéry (IFP), UMIFRE MAE-CNRS 21, Puducherry, India

The agamid lizards of the Western Ghats (WG) mountain chain in India are currently threatened by destruction of forests for conversion to plantations. Accurate information on the population status of the agamid lizards in modified habitats is needed for conservation and management considerations, but detailed data on population densities are currently not available. In this study, I estimated the population densities of agamid lizards in human-modified habitats of the Valparai plateau in the southern WG using distance sampling. Nineteen line transects (0.25 km each) in five study sites including abandoned vanilla, abandoned rubber, vanilla and tea plantations and a degraded evergreen forest patch were sampled a minimum of five times each. The population density (individuals/ha) of *Calotes ellioti* and *Draco dussumieri* in the vanilla plantation was estimated to be 8.95±2.09 and 1.25±0.40 respectively. The density of *Psammophilus blanfordanus*, which was detected only in tea plantations, was estimated as 3.13±1.02. Mean rate of encounters (animals/transect) for *C. ellioti* was highest in the vanilla plantation (1.83, SE=0.41). For *D. dussumieri*, the mean encounter rates were identical in the vanilla plantation (0.80, SE=0.21) and the abandoned rubber plantations (0.80, SE=0.4). The encounter rates of *C. ellioti* in the vanilla plantation were higher than those in rainforest fragments in the Valparai plateau. This study helps us understand the role of modified habitats in supporting populations of endemic agamid lizards.

Key words: density estimation, distance sampling, line transects, plantations

INTRODUCTION

Loss and alteration of native habitats are the main causes of worldwide biodiversity declines. In modified landscapes, patches of remnant natural vegetation are mainly considered as important for conservation efforts, but areas outside these patches also play an important complementary role for a range of organisms (Luck & Daily, 2003), with species within a patch often being affected by the habitats surrounding the patch (Stoufer & Bierregard, 1995; Renjifo, 2001). A landscape approach that increases landscape-level connectivity and restores degraded areas is gaining significance in conservation (Laurance et al., 1997), requiring an assessment of the conservation values of lands outside protected areas (Daily, 2001).

The Western Ghats (WG), a series of hills running along the west coast of peninsular India, is an area where such a landscape approach to conservation would be pertinent (Raman, 2006). The WG have been recognized as one of the important eco-regions of the world (Olson & Dinerstein, 1998), and are listed as a global biodiversity hotspot (Myers et al., 2000). However, human disturbance in the form of deforestation, conversion to plantations and developmental projects have resulted in severely fragmented landscapes (Nair, 1991). Menon & Bawa (1997) reported a 40% decline in forest cover between 1920 and 1990, resulting in a four-fold increase in the number of fragments and a reduction in forest patch size of 83%. The annual rate of forest loss was estimated to be 1.16% (Jha et al., 2000), with 25.6% of the forest cover in the 40,000 km^2 area of WG having been lost during 1973–1995.

Alteration of habitats in the form of conversion of forests into plantations, particularly tea, coffee and *Eucalyptus*, is an ongoing and major cause of forest fragmentation in the WG (Raman, 2006). The total area under plantations is extensive and expanding. Coffee plantations increased in area from 92,523 ha in 1950–1951 to 394,352 ha in 2008–2009 (Coffee Board of India, 2009), and for the same period tea plantations in South Indian states increased by 75.3 % from 68, 277 to 119,740 ha (Tea Board of India, 2009a,b). Forest loss is also severe in the Anamalai Hill ranges, a major conservation area in the southern WG (Raman, 2006) with mid-elevation rainforest in the Indira Gandhi Wildlife Sanctuary (IGWLS) and the unprotected, privately controlled forest fragments on the Valparai plateau (see Mudappa & Raman, 2007, for a review).

In this scenario, the conservation management of modified landscapes requires a sound understanding of how organisms are distributed through space (Fisher & Lindenmeyer, 2006). The altered habitats in the surrounding landscape matrix are a source of potential colonists as

Correspondence: P. Dilip Venugopal, Department of Entomology, University of Maryland, 4124 Plant Sciences Building, College Park, MD 20742-4454, USA. *E-mail:* dilip@umd.edu

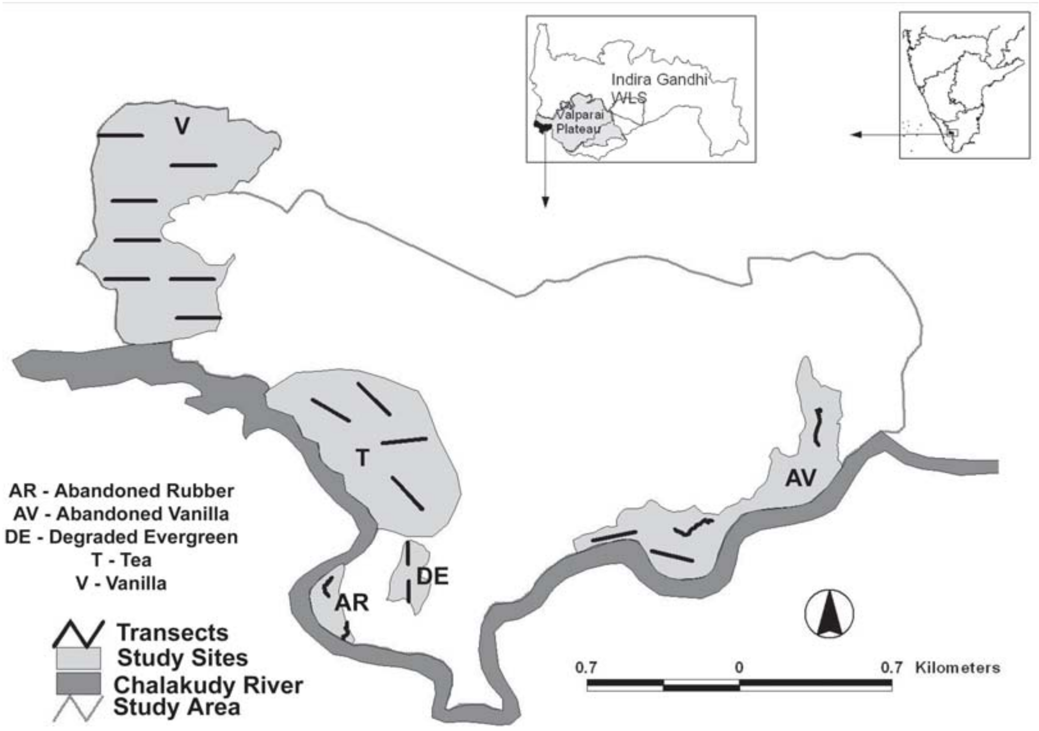

Fig. 1. Map of study area, study sites and transects on the Murugalli estate located on the Valparai plateau of the Anamalai Hills, southern Western Ghats. The inset maps show its corresponding location within the Indira Gandhi wildlife sanctuary in Tamil Nadu, bordering Kerala in south India.

well as being suitable for colonization by species that can persist in such habitats. Local population dynamics, the environment and the degree of dispersal influence recolonization (Johst et al., 2002). Hence, information on the use of matrix – the modified habitats surrounding the forest fragments – by target groups can help us devise management plans to reduce fragmentation and isolation of populations in forest remnants. Studies on the numbers of species and their reproductive output and survival rates would help us in determining the role played by these ecosystems in maintaining overall biodiversity (Petit et al., 1999). Research identifying the usage of habitat mosaics by species in modified environments, including modified habitats, therefore needs to be given priority (Law & Dickman, 1998).

Despite high species richness (approximately 200) and endemism (50%), detailed studies on the community ecology, population status and conservation of WG reptiles are rare (Ishwar et al., 2001). High levels of biodiversity and endemism are particularly apparent in rainforests, which support more than 130 species of reptiles (Kumar et al., 2002). Among agamid lizards, 14 species endemic to the rainforests of WG and four endemic to peninsular India have been reported (Ishwar et al., 2003). Forty-one species of reptiles are known to occur in the rainforest fragments and contiguous forests of the Valparai plateau in the Anamalai hills (Ishwar, 2001). Among agamids, four species (*Calotes ellioti*, *C. nemericola*, *C. grandisquamis* and *Draco dussumieri*) are found in the rainforests at lower elevations (below 1,700 m), while *Salea anamallayana* is reported from higher elevations and two species (*C. rouxii* and *Psammophilus blanfordanus*) are known to occur along the edges of rainforest (Ishwar et al., 2003).

Current knowledge of the natural history and ecology of these lizards is limited (Ishwar, 2001; Rathinasabapathy & Gupta, 1997; Venugopal, 2007; Vijaya, 1984). The available information on the population status of agamid lizard species of peninsular India is restricted to reports on encounter rates (Bhupathy & Kannan, 1997; Ishwar et al., 2003), density based on repeated walks within designated sites (Radder et al., 2005) or the density of agamids as a whole (Ishwar et al., 2001; Noon et al., 2006). Lizard abundances reported by these studies have been obtained with a sampling strategy that is limited in spatial representation and effort in relation to the overall area sampled. Currently, Deepak & Vasudevan (2007) is the only study that provides population estimates of any WG agamid species (*Salea anamallayana*) obtained from distance sampling.

In this study I estimated the population density of small-bodied agamid reptiles using distance sampling, a method that has rarely been applied in tropical Asia for estimating reptilian population densities. Over the past decade, this method has been successfully employed to estimate population densities of many terrestrial and arboreal, but predominantly large-bodied reptile species (e.g. Cassey & Ussher, 1999; Anderson et al., 2001; Hailey & Willemsen, 2000; Harlow & Biciloa, 2001; Young et al., 2008; for small reptiles see for example Akin, 1998; Jenkins et al., 1999; Young et al., 2006; Grant & Doherty, 2007; Deepak & Vasudevan, 2008). Agamid reptiles were cho-

Table 1. Sampling effort and mean encounter rates (animals/250 m) of agamid species in the modified habitats of Murugalli estate, Valparai in southern Western Ghats, India. Values in parentheses represent the standard error of the mean. ER = encounter rate per 250m.

	Sampling details				Detections							
					Calotes elliotti		*Calotes nemoricola*		*Draco dussumieri*		*Psammophilus blanfordanus*	
Study site	Area (ha)	No. lines	Total length (m)	No. walks	*n*	ER	*n*	ER	*n*	ER	*n*	ER
Abandoned rubber	5.84	2	250	5	7	1.4 (0.6)	0	–	4	0.8 (0.4)	0	–
Abandoned vanilla	43.09	4	1000	5	11	0.55 (0.05)	1	0.05	5	0.3 (0.09)	0	–
Degraded evergreen	6.23	2	250	5	0	–	0	–	0	–	0	–
Tea	61.25	4	1000	6	8	0.34 (0.19)	0	–	3	0.13 (0.12)	41	1.71 (1.55)
Vanilla	90.20	7	1750	5	64	1.83 (0.41)	0	–	28	0.8 (0.21)	0	–

sen as the target study group as they are relatively easy to detect.

MATERIALS AND METHODS

Study area

The study was conducted on the Murugalli estate in the western part of the Valparai plateau (735 ha, 10°18'16"–10°19'N and 76°49'56"–76°52'22"E), and is part of an area currently under lease from the revenue department of Tamil Nadu to a private plantation company (Fig. 1). Mean annual rainfall over the past 25 years was 3544 mm. Altitudes range from 760 m to 1114 m above sea level, with mean temperatures of 29° C in summer and 12 °C during winter. The rainforest in Murugalli had been logged around 1915 (Congreve, 1942) for tea planting, leaving very small patches of evergreen forests. A total of approximately 207 ha of different landscape types (Fig. 1) were included for sampling: 1) an abandoned rubber plantation (5.84 ha), adjoining the Chalakudy River, that was converted after select felling of rain forest trees 60 years ago; 2) an abandoned vanilla plantation (approximately 43 ha, cultivated until 2000) bordered by tea estates on one side and the Sholayar River on another side; 3) a vanilla plantation (approximately 90 ha) surrounded by the Chalakudy Reserve Forest (Vazhachal division) in Kerala to the west and tea fields to the north; general habitat modification in this patch includes selective felling of rainforest trees, clearance of the ground vegetation and planting of *Erythrina indica* to provide understory shade and physical support for the vanilla climbers; 4) a degraded evergreen forest patch (6.23 ha) with steep terrain and surrounded by tea plantations on all sides; 5) part of a tea plantation (61 ha), the predominant habitat in the landscape.

Line transect surveys

The study sites were mapped with a handheld GPS to determine their total area. I used systematic sampling with a random start survey design available within the geographic survey design component of the program DISTANCE (Thomas et al., 2006). Using the shape files containing the geographic data on each of the study sites, systematic sets of parallel lines were randomly superimposed onto the study sites based on the inputs provided for the sampling effort. In the vanilla plantation, the length of transects was set at 250 m, while the distance between parallel lines was 150 m, and a sampling survey design with known survey effort was generated. For all the sites, the line length and spacing were specified in the design, with total line length kept proportional to habitat availability.

The automated survey design ensured that the placement of transects was not based on previously known agamid reptile locations within the study sites, and they were placed at random in relation to the agamid reptile distribution, a key assumption of line transect sampling (Buckland et al., 1993, 2001). However, due to steep terrain in the abandoned vanilla and abandoned rubber plantations, I had to slightly modify some transects to follow the contours. A total of 19 straight line and modified transects were used for sampling across the five study sites (Fig.1). Transects were 250 m in length, except in the abandoned rubber and degraded evergreen patch where transects of 125 m were used. Transects were marked with tape and paint, and in rare circumstances, vegetation was minimally cleared to enable complete detection of lizards on the transect, one of the main assumptions of distance sampling (Buckland et al., 1993, 2001). Details of the number and total length of transects in each study site are provided in Table 1.

Prior to actual data collection, all observers were trained for two weeks in the detection of agamid reptiles. Data were collected on clear sunny days between 0800 and 1300, coinciding with the basking activity of reptiles. On each transect sampling survey, three observers moved at a slow pace (100 m/40 min), scanning the understory (on tree trunks, herbs and shrubs) for lizards. For each lizard sighted, the species, the distance from the observer and azimuth to the lizard and transect line were recorded. Distances were measured with a measuring tape or a measured metre stick, and bearings were recorded with a field compass. Sampling occurred before (April 2006 – June 2006) and after the monsoon season (September 2006 – December 2006). In total, each transect was walked five times (six times in the tea plantation), with a cumulative effort of 22.25 km (see Table 1).

Table 2. Summary of models used in program DISTANCE to estimate densities of agamids in Murugalli estate, Valparai in the Western Ghats, India. Models are arranged based on increasing ΔAICc, the difference in AICc (with an adjustment factor for small sample sizes) between a given model and the best model in the set. For *Psammophilus blanfordanus*, the coefficient of variation (CV) was calculated assuming a Poisson distribution and corrected by an over-dispersion factor *b* of 3.0.

Species, site and sample size	Model	Adjustment terms	Δ AICc	Density (reptiles ha^{-1})	CV
Calotes ellioti in vanilla plantation; *n*=64	Half normal	None	0.00	8.95	0.23
	Uniform	2 cosine terms	1.82	9.02	0.23
	Hazard rate	None	2.37	8.00	0.24
	Uniform	3 simple polynomial terms	4.04	8.91	0.24
Draco dussumieri in vanilla plantation; *n*=28	Uniform	1 cosine term	0.00	1.25	0.32
	Half normal	None	0.15	1.23	0.33
	Uniform	2 simple polynomial terms	0.73	1.09	0.31
	Hazard rate	None	2.38	1.37	0.47
Psammophilus blanfordanus in tea plantation; *n*=41	Half normal	None	0.00	3.13	0.33
	Uniform	1 cosine term	0.02	3.08	0.31
	Uniform	2 simple polynomial terms	1.33	2.57	0.30
	Hazard rate	None	2.43	3.14	0.38

Data analyses

Computation of site-specific detection functions, dictated by the number of detections, were required to obtain an unbiased estimate of abundance and density of species at each site. However, the number of sightings of some species at some study sites was too low to estimate detection functions. Hence the rate of encounter, an index of abundance, was computed for each species at each site to enable comparison with existing reports of abundances. Encounter rate was calculated as the number of individuals of a species detected per 250 m of transect. I estimated site-specific detection functions and population density for *Calotes ellioti* and *Draco dussumieri* in the vanilla plantation, and for *Psammophilus blanfordanus* in the tea plantation. The number of detections for other species was too low to attempt any meaningful analysis.

I used the program DISTANCE (version 5.0, release 2; Thomas et al., 2006) to model the probability of detection of each species as a function of perpendicular distance from the transect lines. Exploratory data analysis did not reveal any significant evasive movement prior to detection, or heaping of sightings on or close to the transect centre (for example, the highest number of *C. ellioti* detections in the vanilla plantation occurred within 1m of the transect centre). Thus, the key assumptions of distance sampling, detection of all animals on or close to the transect centre and detection of animals prior to evasive movement (Buckland et al., 1993) appear to have been met. To subsequently improve model fitting, outlier observations were truncated. Models best describing the detection process were selected on the basis of the Akaike information criterion with an adjustment for small sample sizes (AICc; Buckland et al., 2001).

For each model, the variance of *C. ellioti* and *D. dussumieri* densities was estimated as the empirical value derived by a combination of the variances in effective strip width (product of the mean detection probability and the largest detection distance) and encounter rate. However, for *Psammophilus blanfordanus*, which showed

Table 3. Estimates of population density, abundance and detection probability for agamid lizards in Murugalli Estate, Valparai Plateau, Western Ghats, India. For each parameter, the estimates obtained from program DISTANCE are reported with SE, and the log normal confidence interval (95%). Number of detections and the largest perpendicular distance are provided together with the original values prior to data truncation (in parentheses).

	Vanilla plantation		Tea plantation
Parameter	*Calotes ellioti*	*Draco dussumieri*	*Psammophilus blanfordanus*
Density (reptiles ha^{-1})	8.95 (±2.09)	1.25 (±0.40)	3.13 (±1.02)
	5.2, 15.1	0.62, 2.52	1.64, 5.98
Abundance	807	113	192
	477, 1366	56, 227	101, 366
Detection probability	0.40 (±0.04)	0.62 (±0.09)	0.55 (±0.08)
	0.33, 0.48	0.46, 0.83	0.41, 0.73
Number of detections	62 (64)	27 (28)	35 (41)
Max. perpendicular distance of detection (m)	10 (11.77)	19.9 (20.07)	17 (20.84)

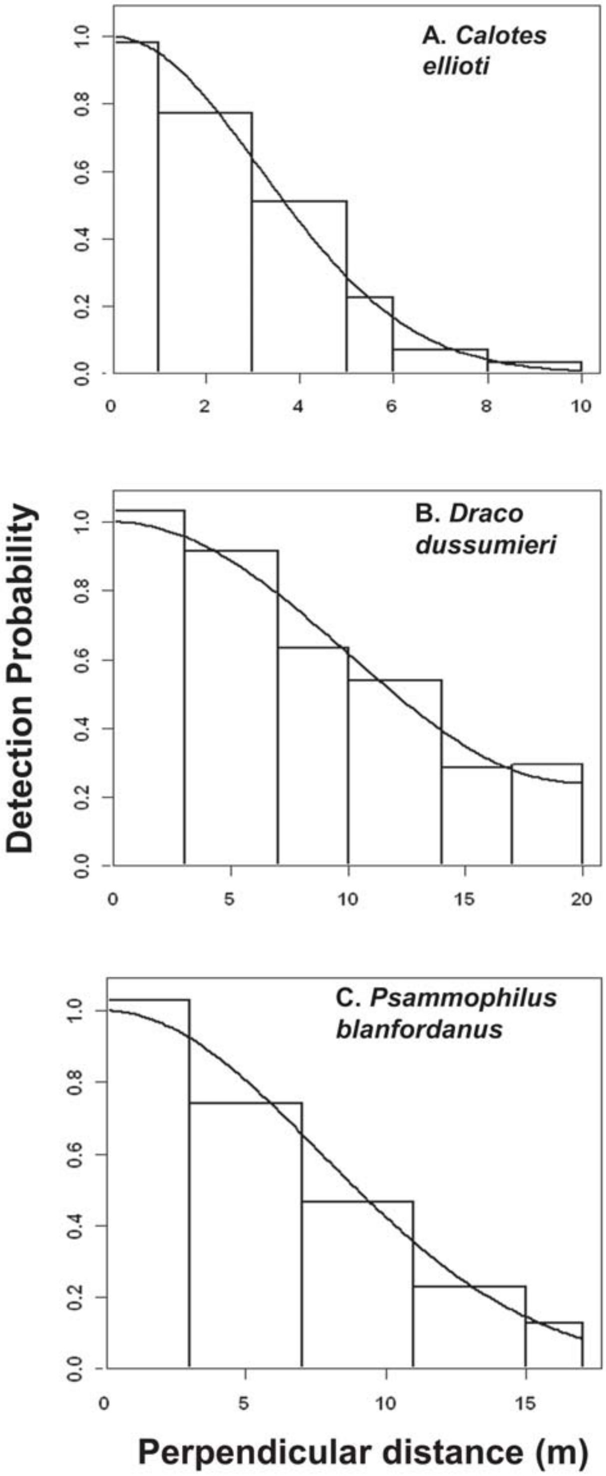

Fig. 2. Histograms of perpendicular distance (m) and fitted detection functions for agamid reptiles from Murugalli estate, Anamalai Hills, Western Ghats, India. A) Half-normal detection function fitted to *Calotes ellioti* detected within 10 m of the transects. B) Uniform key function with one-term cosine adjustment detection function fitted to *Draco dussumieri* detected within 19.9 m of the transects. C) Half-normal detection function fitted to *Psammophilus blanfordanus* detected within 17 m of the transects.

strong spatial patterns in distribution, the encounter rate variance was estimated with assumptions of random distribution of animals and that the encounter rate follows a Poisson distribution. As this treatment might result in serious underestimation of variance, especially for species that have a clumped distribution (Burnham et al., 1980; Buckland et al., 1993, 2001), estimates for the variance in encounter rate of *Psammophilus blanfordanus* were corrected by introducing an over-dispersion factor *b*. I used an over-dispersion factor of three, as recommended by Buckland et al. (1993).

RESULTS

A total of 169 individuals belonging to four species were detected on the line transect surveys (Table 1). Of the two rainforest specialist species, *C. nemoricola* was detected only once during transect surveys. The generalist species *C. ellioti* had the highest number of detections (90), and *D. dussumieri* was detected 40 times. The rainforest edge species *P. blanfordanus* was only recorded from the tea plantation.

Encounter rates for *C. ellioti* (64 detections) were highest in the vanilla plantation, followed by abandoned rubber plantations. For *D. dussumieri*, the encounter rate was similar in the vanilla plantation (28 detections) and abandoned rubber plantation (Table 1). The rainforest edge species *P. blanfordanus* was recorded only in the tea plantation (41detections). However, about 93% of the detections of this species were from a single line transect, thereby demonstrating a strongly spatially clumped distribution. There were no detections of agamid reptiles in the degraded evergreen forest patch.

Detection function models and density estimates

A summary of the models used in DISTANCE is listed in Table 2, while the histograms of perpendicular distance and detection function are provided in Figure 2. The half-normal model without cosine adjustment terms provided the best fit for *C. ellioti* (χ^2_3=0.05; *P*=0.996), while the uniform model with one cosine adjustment term detection function fitted *D. dussumieri* (χ^2_3=0.10; *P*=0.99). For *P. blanfordanus*, a half-normal model with zero-term cosine adjustment had the best fit to the data (χ^2_2=0.07; *P*=0.96).

The estimated probability of detection for *D. dussumieri* in the vanilla plantation was higher than that of *C. ellioti* (Table 3). The population density (ha^{-1}) of *C. ellioti* and *D. dussumieri* in the vanilla plantation was estimated to be 8.95 (5.2–15.1; 95% CI) and 1.25 (0.62–2.52; 95% CI) respectively (Table 3). In the tea plantation, the density (ha^{-1}) of *P. blanfordanus* was estimated to be 3.01 (1.64–5.98; 95% CI) (Table 3).

DISCUSSION

This is the only available study on population densities of three agamid reptile species of the WG. While previous efforts have mainly concentrated on contiguous rainforests or rainforest fragments, this study provides one of the first data on abundances of agamid species in altered habitats. Based on the number of detections, *C. ellioti* was the most common species, and was found in all except one of the study sites. This result is consistent with Ishwar et al. (2003), who reported this species to be the most commonly distributed agamid lizard in many of the rainforest fragments of the Valparai plateau. Field observations of gravid females and existing reports of egg laying (Venugopal, 2007) indicate that vanilla plantations can support reproducing populations of *C. ellioti*. The Western Ghats flying lizard *D. dussumieri* was recorded in all except one of the study sites. The rainforest specialist *C. nemoricola* was not observed in the abandoned plantations and the degraded evergreen patch. Its occurrence in low numbers coincides with existing reports that it occurs in small to medium sized rainforest fragments (Kumar et al., 2002; Ishwar et al., 2003). Although species richness and diversity were higher in contiguous forests, the encounter rates for *C. ellioti* in vanilla (1.83 animals/250m) and abandoned rubber (1.4 animals/250m) were higher than in rainforest fragments (Ishwar et al., 2003). The encounter rates of *D. dussumieri* in vanilla and abandoned rubber are similar to those in medium-sized forest fragments. Although the rainforest specialists *C. nemoricola* and *C. grandisquamis* were not detected in the vanilla plantation during sampling, both were observed on other occasions. The proximity of vanilla plantations to contiguous rainforests of the Vazhachal reserve forests in Kerala, and a similarity in habitat conditions, where canopy is relatively intact and forest trees are retained, could be the reason for high encounter rates of agamid lizards there.

The rainforest edge species *P. blanfordanus* was observed in the tea plantations. However, it was confined to the rocky areas near settlements in the tea estate. We believe this is not due to differences in detection of this species in different areas. All detections occurred on only two transects in the tea plantation. This is due to the fact that the rocky open habitat in the tea plantation represents the only habitable area for this species. It is known to prefer open, rocky habitats (Kumar et al., 2002) and is common in the dry open rocky habitats in the foothills below the Valparai plateau (Dilip Venugopal, pers. obs.). As a result of this clumped spatial distribution, the variance associated with the encounter rate of this species had to be estimated theoretically and corrected for overdispersion. It should be noted that the conversion of forest and other habitats into tea plantations, coupled with increased human settlements, could facilitate the invasion of this species into other landscapes. No agamid reptiles were detected in the degraded evergreen patch, probably a result of poor habitat conditions and a geographical confinement within tea estates.

The detection of herpetofauna in their natural environment poses difficulties (Mazerolle et al., 2007), and the estimation of densities is problematic due to the rarity and patchy distribution of many species (Noon et al., 2006). In this study, the low number of detections for the target species was a major limitation. This also necessitated the pooling of data collected before and after the monsoon season. Consequently, models examining the differences in the probability of agamid reptile detections during these sampling periods could not be developed. Despite these shortcomings, it was possible to estimate the density of three endemic Indian agamid species with reasonable precision (24–34% CV). However, increasing the number of detections for some of these species will be challenging. The rainforest specialists *C. grandisquamis* and *C. nemoricola* occur at very low densities even in contiguous rainforests or large rainforest fragments.

A total effort of 40.5 km in the contiguous evergreen forests of Kalakkad Mundanthurai Tiger Reserve in the southern tip of WG resulted in 10 detections of *C. nemoricola* and a single detection of *C. grandisquamis*. Similarly, in the large and undisturbed rainforests of the Valparai plateau (Akkamalai), surveys over 18 km of transect resulted in 10 detections of *C. nemoricola*, and 15 detections of *C. grandisquamis* (Kumar et al., 2002). Therefore, to obtain the 60–80 detections recommended by Burnham et al. (2001), an effort of about 150–200 km might be necessary. Deepak & Vasudevan (2008), however, detected *Salea anamallayana* more frequently in relation to their effort (72 detections from 2.3 km of sampling across different habitats). This could be attributed to *S. anamallayana* being the only agamid distributed at higher altitudes in the WG (>1400 m) in higher densities. The probability of detection estimated through this study could help in planning sampling efforts for future research studies using the distance sampling method, which could easily be employed for estimating population densities of also other agamid species (such as *C. versicolor*, *C. rouxii*, *C. calotes*, *P. dorsalis* and *Sitana ponticeriana*).

In conclusion, the results of this study show that modified habitats such as vanilla plantations can support some endemic agamid lizards. Given that the habitat modification in vanilla plantations is similar to that of coffee and cardamom plantations (retaining forest trees and canopy and planting at understorey level), the results from this study could also be extrapolated to these plantations. However, detailed research on movement, dispersal, habitat requirements and estimates of population of lizards across the landscape are also required to devise management plans to reduce fragmentation and isolation of populations in forest remnants.

ACKNOWLEDGEMENTS

This study was made possible through partial grants from the Murugappa Research Trust, Chennai and the research permit was provided by the Tamil Nadu Forest Department (WL5/33526/2005). I thank Venky Muthiah, Arun Kumar and Murali Padikkal of Parry Agro Private Limited for providing entry access to the private estate, logistical support, climatic and demographic data, and history of land use within the plantations. N.M. Ishwar and Anand Pakkurti provided administrative and logistical support and arranged for sufficient funds. Siva Kumar, Rajamani and Prakash assisted in field data collection. Comments from two anonymous reviewers helped improve the manuscript.

REFERENCES

Akin, J.A. (1998). Fourier series estimation of ground skink population density. *Copeia* 1998, 519–522.

Anderson, D.R., Burnham, K.P., Lubow, B.C., Thomas, L., Corn, P.S., Medica, P.A. & Marlow, R.W. (2001). Field trials of line transect methods applied to estimation of desert tortoise abundance. *Journal of Wildlife Management* 65, 583–597.

Bhupathy, S. & Kannan, P. (1997). *Status of Agamid Lizards in the Western Ghats of Tamil Nadu, India.* SACON Technical Report No. 5. Tamil Nadu: Salim Ali Centre for Ornithology and Natural History.

Buckland, S.T., Anderson, D.R., Burnham, K.P. & Laake, J.L. (1993). *Distance Sampling: Estimating Abundance of Biological Populations*. London: Chapman & Hall.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. & Thomas, L. (2001). *Introduction to Distance Sampling: Estimating Abundance of Biological Populations*. Oxford: Oxford University Press.

Burnham, K.P., Anderson, D.J. & Laake, J.L. (1980). Estimation of density from line transect sampling of biological populations. *Wildlife Monographs* 72, 3–202.

Cassey, P. & Ussher, G.T. (1999). Estimating abundance of tuatara. *Biological Conservation* 88, 361–366.

Coffee Board of India (2009). *Database on Coffee*. Bangalore: Coffee Board. Available at http://www.indiacoffee.org/userfiles/Dtbs-1.pdf (accessed on 26 December 2009).

Congreve, C.R.T. (1942). *The Anamalais*. Madras: Associated Printers.

Daily, G.C. (2001). Ecological forecasts. *Nature* 411, 245.

Deepak, V. & Vasudevan, D. (2008). Density and microhabitat association of *Salea anamallayana* in Eravikulam National Park, Western Ghats, India. *Herpetological Journal* 18, 165–170.

Fischer, J. & Lindenmayer, D.B. (2006). Beyond fragmentation: the continuum model for fauna research and conservation in human-modified landscapes. *Oikos* 112, 473–480.

Grant, T.J. & Doherty, P.F. (2007). Monitoring of the flat-tailed horned lizard with methods incorporating detection probability. *Journal of Wildlife Management* 71, 1050–1056.

Hailey, A. & Willemsen, R.E. (2000). Population density and adult sex ratio of the tortoise *Testudo hermanni* in Greece: evidence for intrinsic population regulation. *Journal of Zoology* 251, 325–338.

Harlow, P.S. & Biciloa, P. N. (2001). Abundance of the Fijian crested iguana (*Brachylophus vitiensis*) on two islands. *Biological Conservation* 98, 223–231.

Ishwar, N.M. (2001). *Reptilian Species Distribution in Response to Habitat Fragmentation and Microhabitats in the Rainforests of the Southern Western Ghats, India*. PhD thesis. Dehra Dun: Forest Research Institute.

Ishwar, N.M., Chellam, R. & Kumar, A. (2001). Distribution of forest floor reptiles in the rainforests of Kalakkad-Mundanthurai Tiger Reserve, South India. *Current Science* 80, 413–418.

Ishwar, N.M., Chellam, R., Kumar, A. & Noon, B.R. (2003). The response of agamid lizards to rainforest fragmentation in the Western Ghats, South India. *Conservation and Society* 1, 269–286.

Jenkins, R.K.B., Brady, L.D., Huston, K., Kauffmann, J.L.D., Rabearivony, J., Raveloson, G. & Rowcliffe, J.M. (1999). The population status of chameleons within Ranomafana National Park, Madagascar, and recommendations for future monitoring. *Oryx* 33, 38–46.

Jha, C. S., Dutt, C.B.S. & Bawa, K.S. (2000). Deforestation and land use changes in Western Ghats, India. *Current Science* 79, 231–238.

Johst, K., Brandl, R. & Eber, S. (2002). Metapopulation persistence in dynamic landscapes: the role of dispersal distance. *Oikos* 98, 263–270.

Kumar, A., Chellam, R., Choudhury, B.C., Mudappa, D., Vasudevan, K., Ishwar, N.M. & Noon, B.R. (2002). *Impact of Rainforest Fragmentation on Small Mammals and Herpetofauna in the Western Ghats, South India.* Final technical report. Dehradun: Wildlife Institute of India Publications.

Laurance, W.F., Bierregaard, R.O. Jr., Gascon, C., Didham, R.K., Smith, A.P., Lynam, A.J., Viana, V.M., Lovejoy, T.E., Sieving, K.E., Sites, J.W. Jr., Andersen, M., Tocher, M.D., Kramer, E.A., Restrepo, C. & Moritz, C. (1997). Tropical forest fragmentation: synthesis of a diverse and dynamic discipline. In *Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities*, 502–514. Laurance, W.F. & Bierregaard, R.O., Jr. (eds). Chicago: University of Chicago Press.

Law, B.S. & Dickman, C.R. (1998). The use of habitat mosaics by terrestrial vertebrate fauna: implications for conservation and management. *Biodiversity Conservation* 7, 323–333.

Luck, G.W. & Daily, G.C. (2003). Tropical countryside bird assemblages: richness, composition, and foraging differ by landscape context. *Ecological Applications* 13, 235–247.

Mazerolle, M.J., Bailey, L.L., Kendall, W.L., Royle, J.A., Converse, S.A. & Nichols, J.D. (2007). Making great leaps forward: accounting for detectability in herpetological field studies. *Journal of Herpetology* 41, 672–689.

Menon, S. & Bawa, K.S. (1997). Applications of geographical information systems, remote sensing and a landscape ecology approach to biodiversity conservation in the Western Ghats. *Current Science* 73, 134–145.

Mudappa, D. & Raman, T.R.S. (2007). Rainforest restoration and wildlife conservation on private lands in the Western Ghats. In *Making Conservation Work*, 210–240. Shahabuddin, G. & Rangarajan, M. (eds). Ranikhet: Permanent Black.

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

Nair, S.C. (1991). *The Southern Western Ghats: A Biodiversity Conservation Plan.* New Delhi: Indian National Trust for Arts and Cultural Heritage (INTACH).

Noon, B.R., Ishwar, N.M. & Vasudevan, K. (2006). Efficiency of adaptive cluster and random sampling in detecting terrestrial herpetofauna in a tropical rainforest. *Wildlife Society Bulletin* 34, 59–68.

Olson, D.M. & Dinerstein, E. (1998). The global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions. *Conservation Biology* 12, 502–515.

Petit, L.J., Petit, D.R., Christian, D.G. & Powell, H.D.W. (1999). Bird communities of natural and modified habitats in Panama. *Ecography* 22, 292–304.

Radder, R.S., Saidapur, S.K. & Shanbhag, B.A. (2005). Population density, microhabitat use and activity pattern of the Indian rock lizard, *Psammophilus dorsalis*. *Current Science* 89, 560–566.

Raman, T.R.S. (2006). Effects of habitat structure and adjacent habitats on birds in tropical rain forest fragments and shaded plantations in the Western Ghats, India. *Biodiversity and Conservation* 15, 1577–1607.

Rathinasabapathy, B. & Gupta, B.K. (1997). A note on reproduction in *Calotes calotes* at Anaikatty, Western Ghats. *Hamadryad* 22,128–129.

Renjifo, L.M. (2001). Effect of natural and anthropogenic landscape matrices on the abundance of subandean bird species. *Ecological Applications* 11, 14–31.

Stouffer, P.C. & Bierregaard, R.O. Jr. (1995). Use of Amazonian forest fragments by understory insectivorous birds. *Ecology* 76, 2429–2445.

Tea Board of India (2009a). *Tea Statistics 1987–88*. Available at http://teaboard.gov.in/pdf/tea_statistics/Tea_Statistics_1987-88.pdf (accessed on 27 December 2009).

Tea Board of India (2009b). *Growers and Area under Tea.* Available at http://teaboard.gov.in/pdf/stat/Growers%20&%20Area%20under%20Tea.pdf (accessed on 27 December 2009).

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. & Marques, T.A. (2006). *DISTANCE 5.0. Release 2*. Research Unit for Wildlife Population Assessment. St.Andrews: University of St. Andrews.

Thompson, W.L., White, G.C. & Gowan, C. (1998). *Monitoring Vertebrate Populations*. San Diego: Academic Press.

Venugopal, P.D. (2007). Observations on egg-laying by *Calotes ellioti* (Gunther, 1864). *Hamadryad* 31, 366–367.

Vijaya, J. (1984). A *Calotes grandisquamis* nest. *Hamadryad* 9, 19.

Young, R.P., Fa, J.E., Ogrodowczyk, A., Morton, M., Lesmond, S. & Funk, S.M. (2006). The St Lucia whiptail lizard *Cnemidophorus vanzoi*: a conservation dilemma? *Oryx* 40, 358–361.

Young, R.P., Volahy, A.T., Bourou, R., Lewis, R., Durbin, J. & Fa, J.E. (2008). Estimating the population of the endangered flat-tailed tortoise *Pyxis planicauda* in the deciduous, dry forest of western Madagascar, a monitoring baseline. *Oryx* 42, 252–258.

Accepted: 27 January 2010