Divya Balaji, Rachakonda Sreekar, Siddharth Rao
Drivers of reptile and amphibian assemblages outside the protected areas of Western Ghats, India
Journal for Nature Conservation, 2014; 22(4):337-341

Originally published at: http://dx.doi.org/10.1016/j.jnc.2014.03.004

Drivers of reptile and amphibian assemblages outside the protected areas of Western Ghats, India

Divya Balaji[1,2,*], Rachakonda Sreekar[1,3,*, §] and Siddharth Rao[1]

[1] Agumbe Rainforest Research Station, Agumbe, Karnataka, India
[2]Yale University, New Haven, Connecticut, United States of America
[3] Key Laboratory of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Mengla, Yunnan, China
[*]These authors contributed equally to this work

§*Corresponding author:* Rachakonda Sreekar, Key Laboratory of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Mengla, Yunnan, China*;* Email: sreekar1988@gmail.com

Running title: Reptiles and amphibians outside protected areas

Abstract

Biodiversity conservation in forested landscapes outside protected areas is important to sustain populations of species with restricted ranges. However, such habitats face many anthropogenic threats, including logging, extraction of firewood and leaf-litter for mulch in plantations. In this study, we determined the effects of forest degradation on amphibians and reptiles in forests outside protected areas by measuring their species richness and community composition across a disturbance gradient from near pristine to highly degraded forests in Agumbe, Western Ghats, India. Twenty-one strip 15 x 150m transects were laid across the disturbance gradient and diurnal visual encounter surveys were conducted. Sampling was repeated three times per transect covering the dry, intermediate and wet seasons. Amphibian and reptile communities were affected by the decrease in canopy cover and leaf litter volume, respectively. Our results indicate that the collection of firewood and leaf-litter can severely affect amphibian and reptile populations. Structured conservation planning outside of protected areas is therefore imperative.

Keywords. Asia; Canopy cover; Community composition; Firewood; Herpetofauna; Leaf litter; Species richness

Introduction

Protected areas are one of the major ways to conserve tropical biodiversity (Laurance et al., 2013; Thomas et al., 2012; Jenkins and Joppa, 2009). However, in this changing world, it is not sufficient to conserve biodiversity only in protected areas because around 90% of the world's remaining tropical forest area lies beyond the borders of protected areas (WWF, 2002; Chazdon et al., 2009). Forests outside protected areas are often managed and modified by humans actively for a wide variety of traditional and commercial purposes. Examining the factors driving diversity patterns within these unprotected forest habitats can be helpful in assessing their conservation value (Klein et al., 2006; Clough et al., 2009; Sreekar et al., 2013a). The information obtained (direct threats and their contributing factors) from such studies will facilitate managers to more efficiently set priorities and allocate resources for effective management and conservation (Salafsky et al. 2008; Chazdon et al. 2009).

Unprotected forests in the tropics are primary targets for firewood extraction, and around 75% of the wood harvesting in Asia is for firewood (FAO, 2010). Such practices can significantly alter the canopy cover and leaf-litter volume, which are considered to be the most important drivers of amphibians and reptiles respectively (Inger and Colwell, 1977; Wanger et al., 2009; Wanger et al., 2010). Amphibians and reptiles are the most threatened vertebrate taxa globally, with around 41% and 25% of all evaluated species respectively threatened with extinction (Butchart and Bird, 2010; Bohm et al., 2013; Faruk et al., 2013). Though, the biological diversity of reptiles and amphibians in different plantation types have been well documented (Wanger et al., 2009, 2010; Faruk et al., 2013), studies on their assemblages in forests outside protected areas are rare (Anand et al., 2010; Sodhi et al., 2010). Therefore, for better preservation of reptile and amphibian diversity outside protected areas, it is crucial to understand the environmental drivers of species responses to habitat degradation (Wanger et al., 2010; Gillespie et al., 2012).

Scientific studies on reptile and amphibian assemblages are particularly important in biodiversity hotspots such as the Western Ghats in southwestern India where around 86% of amphibians and 62% of reptiles are endemic (Gunawardene et al., 2007; Dinesh and Radhakrishnan, 2011). We determined the drivers of reptile and amphibian species richness, abundance and community composition across a disturbance gradient outside protected areas in Agumbe, Western Ghats, India and provide recommendations for conserving reptiles and amphibians outside protected areas.

Methods

Agumbe (13°50’ N, 75°09’ E; 560 m above sea level; Supplementary Material, Figure S1) experiences low temperature variation (26-33°C), high humidity (75%-96%) and high rainfall (7,000-8,000mm), most of which is during the monsoon season (June-September; Sreekar et al., 2013b). The human population settled in and around Agumbe cultivate *Areca catechu* in their home gardens and an individual household collects an average of 3,490 kg of leaf-litter for mulch and 1,295 kg of firewood per year for domestic use (Gaffar, 2011).

The reptile and amphibian assemblages in the unprotected forests of Agumbe were sampled using a time-constrained visual encounter survey (Campbell and Christman, 1982) between March and August 2011. Twenty-one 15m x 150m strip transects were systematically laid to capture gradients in habitat characteristics from structurally primary to highly degraded forests. These habitats were sampled three times covering the general dry (March-April), pre-monsoon (May-June) and monsoon seasons (July-September). Sampling was conducted between 8:00 and 11:00hrs in the morning. Each transect was thoroughly searched for one hour (in leaves, under logs, on bark and branches); all the reptiles and amphibians observed below 2m height were noted (Supplementary Material, Table S1). Reptiles and amphibians that were sighted above 2m height and outside the strip transect

(15m x 150m) were not recorded, as perfect detection is a central assumption of this method. To control for the time chosen for sampling, only diurnal and crepuscular species were included in the analysis, strictly nocturnal species were removed from the data prior analysis. Two, closely-resembling, fast-moving, leaf-litter skinks *Eutropis macularia* and *Eutropis allapallensis* were grouped together due to difficulties in identifying them by sight and further taxonomic ambiguities (Mirza et al., 2010). This is also justifiable owing to their similar ecological niche and microhabitat use in the study site (RS, *pers. observ.*). Most *Fejervarya* species were only identified to genus level and given morphospecies identity (e.g. sp1, sp2) due to the existence of several cryptic species in this genus (Kuramoto et al., 2007).

To characterise each transect we measured the following habitat characteristics in five randomly selected points and used the mean of each parameter: 1) basal area of trees (tree defined as an individual with diameter at breast height greater than10cm) using point centred quarter method, 2) canopy cover using a spherical densitometer (Forestry suppliers, Jackson, Mississippi, USA) 3) shrub density by counting the number of woody stems (<10cm in girth and > 30cm in height) within 2m radius, and 4) leaf litter volume by collecting leaf litter from an area of $1m^2$ and estimating the amount of litter in each sample by pressing the leaf litter samples in a bucket of known circumference ($5000\ cm^3$) and measuring height (in cm) of the column (Supplementary material, Table S2). Data were suitably transformed for analysis: logit transformation of canopy cover (percentage data) and square-root transformation of shrub density (count data; Zar 1999).

Data analysis

To evaluate the effectiveness of sampling effort, the original reptile and amphibian species richness was transformed to an estimated richness by randomly adding 50 sampling sessions to the original data by using the bootstrap estimator, a measure that is considered more robust than other analytical estimators (Magurran, 2004). We used a regression model to estimate the correlation between the randomised original and bootstrap estimator data (Shahabuddin et al., 2005; Wanger et al., 2010; Sreekar et al., 2013a).

To examine the environmental variables that affect reptile and amphibian species richness and abundance patterns in the unprotected forests of Western Ghats, we used a generalised linear model with Poisson errors and a log link. Predictor variables included canopy cover, leaf litter volume and shrub density. Basal area was not included in the model because it was correlated with canopy cover (Spearman's rho = 0.58, $P = 0.01$). We employed an information-theoretic approach to examine the effects of our predictor variables on response variables (Burnham and Anderson, 1998). For each analysis, the full model, the null model and models with all valid combinations of the explanatory variables were generated. We compared and ranked models using Akaike's information criterion ($\mathrm{AIC_c}$) (Anand et al., 2008; Hobbs and Hilborn, 2006). Akaike weights (wAIC) provided a relative weight for any particular model, which varies from 0 (no support) to 1 (complete support) relative to the entire model set (Burnham and Anderson, 1998). We summed up the wAIC of all the models containing a particular covariate (covariate weight) within the subset to identify the covariates that had the strongest influence (Anand et al., 2008; Burnham and Anderson, 1998). We present model averaged estimates and their unconditional standard errors for covariates with highest Akaike weight (w).

To examine variation in species composition across the landscape, we used a multivariate generalised linear model (Wang et al., 2012) with environmental parameters (canopy cover, leaf litter volume and shrub density) as predictor variables using the function *manyglm* in the package *mvabund*. Negative binomial regression structure was specified in our models. We calculated the test statistics with Monte Carlo resampling (999 iterations). We used multivariate generalised linear models instead of traditional distance-based analyses (e.g. correspondence analysis and non-metric dimensional scaling) because of the community-level heteroscedasticity in point count matrices that causes Type I and II errors (see Warton *et al.* 2012). All analyses were conducted in the programming and statistical language R 2.15.2 (R Development Core Team, 2012).

Results

During this study a total of 199 amphibians and 129 reptiles were recorded (see Supplementary Material Table S1). Consequently, nine (32%) of 28 amphibian species and eight (15%) of 53 reptile species known from the study area were used in the analysis (Purushotham and Tapley, 2011; Ganesh et al., 2013). Sampling across points seemed to be sufficient for analysis, as estimated raw species richness was only slightly higher than observed richness (mean percentage increase in site richness with bootstrap estimator, amphibian = 8.7±6.4%; reptile = 4.6±5.9%). Moreover, the randomised original and the bootstrap estimator data were highly correlated (amphibians: $R^2 = 0.998$; reptiles: $R^2 = 0.995$), so we made further direct comparisons with original species richness data rather than estimated values.

Patterns in amphibian species richness and abundance were best explained by canopy cover (Table 1; Figure 1). Abundances of *Frejervaya rufescens, Frejervarya sp2 and Hylarana aurantica* increased with canopy cover, while the abundance of *Hylarana temporalis* increased with leaf litter volume and the abundance of *Clinotarsus curtipes* decreased with increase in shrub density (Table 1). Reptile species richness and abundances were best explained by leaf litter volume (Table 1; Figure 2). Though leaf litter volume best explained the patterns of reptile species richness, the Akaike weight of the covariate was relatively low (w = 0.34; model average coefficient±SE = 0.15±0.12). Abundances of *Amphiesma beddomei* and *Ristella beddomei* increased with leaf litter volume, while the abundances of *Aheatulla nasuta* increased with the decrease in leaf litter volume (Table 1). Canopy cover and leaf litter volume were also the best predictors associated with the change in amphibian (Dev = 44.4, df = 19, $P = 0.01$) and reptile (Dev = 22.8, df = 19, $P = 0.02$) species composition, respectively.

Discussion

Our study shows that reptiles and amphibians in the unprotected forests of the Western Ghats are highly affected by the decrease in leaf litter volume and canopy cover, respectively. Our results are consistent with other studies throughout the tropics, which also highlight the importance of leaf litter thickness and canopy cover for reptiles and amphibians, respectively (Wanger et al., 2010; Clough et al., 2011; Murrieta-Galindo, 2013). These patterns are often explained by changes in leaf-litter volume that affect reptile microhabitats, and canopy cover that affects heat exposure to amphibians (Whitfield et al., 2007; Luja et al., 2008; Bickford et al., 2010).

Canopy cover was the most important predictor for both amphibian richness and abundance (Figure 1). However, for *Clinotarsus curtipes* and *Hylarana temporalis,* the most important environmental variables that predicted their abundance were shrub density and leaf litter volume, respectively (Table 1). The preference of habitats with low shrub densities by the medium sized forest-dwelling frog *C. curtipes* can be explained by its terrestrial foraging habit (Tapley and Purushotham, 2011). It might not be favourable for a relatively large terrestrial frog species to move through habitats with higher shrub densities. Though *H. temporalis and H. aurantiaca* are sympatric in nature, they breed at different times of the year (RS*, pers. observ.*). In the study site, *H. temporalis* were observed to breed in slow flowing streams during the dry season (March-May) and *H. aurantiaca* were observed to breed in stagnant water pools during the monsoons (July-September). Most of the foraging and breeding activity happens during the night and in the day both species were observed to roost (RS, *pers. observ.*). During the day, *H. aurantiaca* were often found on twigs and leaves in the undergrowth (Mean±SE height from the ground = 0.26±0.05m), whereas *H. temporalis* were always observed on the ground, in the leaf litter (Mean±SE height from the ground = 0.01±0.01m). The preference of habitats with high leaf litter volume by *H. temporalis* can be explained by its preferred roosting habitat.

The large amount of unexplained variance of reptile species richness may be due to the presence of arboreal geckos and agamids that might be less affected by the change in the leaf-litter volume (Table 1; Figure 2). Basal area of trees might be more important for arboreal reptiles as they are ecologically dependent on them. However, as our study suggests, the forests outside protected areas can still sustain arboreal reptiles as none of the arboreal reptile species (*Cnemaspis indraneildasii, Calotes rouxii, Ahaetulla nasuta*) that were included in the analysis showed a positive relationship with increasing basal area (Table 1). This might be explained by their lower disturbance sensitivity and basking behaviour, as moderately disturbed habitat with heterogeneous canopy cover percentage might benefit them by creating more basking spots (Wanger et al., 2009, 2010). Most reptile species showed a positive effect to increasing leaf litter volume, except for the common green vine snake (*Aheatulla nasuta*), which showed an opposite pattern, with increased density in habitats with low leaf litter (Table 1). This pattern can be explained by its tolerance to human modified habitats (Smith, 1943; Daniel, 2002).

As noted earlier, the unprotected forests, especially in the biodiversity hotspots like the Western Ghats serve as important landscapes for biodiversity conservation (Sreekar et al., 2013a). At our study site, the reserve forests in Agumbe and the surrounding unprotected forests may form important ecosystems and stepping-stones for reptile and amphibian movements between Agumbe Reserve Forest and Kudremukh National Park (Supplementary

Material, Figure S1). Our results show that alteration of canopy cover and leaf-litter volume in the reserve forest and its surrounding unprotected forests can significantly affect the species richness and abundance of amphibians and reptiles. Therefore, we suggest that reducing the collection of firewood and leaf-litter by finding substitutes (gas, electricity, fuel oil) and by planting native forest trees within plantations are essential for amphibian and reptilian conservation outside protected areas.

Limitations and directions to future research

Some caution is required while interpreting our results, as our observed species richness was lower than the known species richness of the study area. This was primarily due to the omission of strictly nocturnal and arboreal (>2m) species from our analysis. Sampling at night was not possible due to the presence of rebel activity in the study area. Restricted diurnal sampling means we fail to capture any temporal variation in the drivers that shape reptile and amphibian communities. Snakes were also under sampled probably due to the fact that we only used one sampling technique. Although our study provides a valuable insight into the use of unprotected forests by reptiles and amphibians, we highlight the need of additional studies using multiple sampling techniques (e.g. pitfall traps; Sung et al., 2011). We recommend investigating a wider range of organisms at different study sites to understand how to effectively manage and conserve biodiversity outside protected areas.

Acknowledgements

This study was undertaken with the support of Yale School of Forestry and Environmental Studies, and the Agumbe Rainforest Research Station. We thank Ambika Kamath, S. R. Ganesh, Chetana B. Purushotham, S. R. Chandramouli and K. S. Seshadri for comments on earlier drafts of the manuscript. Finally, we also thank Corrado Battisti and an anonymous reviewer for their comments and suggestions that improved the quality of this manuscript.

References

Anand, M. O., Krishnaswamy, J. & Das, A. (2008). Proximity to forests drives bird conservation value of coffee plantations: implications for certification. *Ecological Applications*, 18, 1754–1763.

Anand, M. O., Krishnaswamy, J., Kumar, A. & Bali, A. (2010). Sustaining biodiversity conservation in human-modified landscapes in the Western Ghats: remnant forests matter. *Biological Conservation*, 143, 2363–2374.

Bickford, D., Ng, T. H., Qie, L., Kudavidanage, E. P. & Bradshaw, C. J. A. (2010). Forest fragment and breeding habitat characteristics explain frog diversity and abundance in Singapore. *Biotropica*, 42, 119–125.

Bohm, M., Collen, B., Baillie, J. E. M., Bowles, P., Chanson, J., Cox, N., et al. (2013). The conservation status of the world’s reptiles. *Biological Conservation*, 157, 372–385.

Burnham, K. P. & Anderson, D. R. (1998). *Model selection and inference: a practical information-theoretic approach*. Springer-Verlag, New York, USA.

Butchart, S. H. M. & Bird, J. P. (2010). Data deficient birds on the IUCN Red List: What don’t we know and why does it matter? *Biological Conservation*, 143, 239–247.

Campbell, H. W. & Christman, S. P. (1982). Field techniques for herpetofaunal community analysis. In Scott, N.J. Jr. ed. *Herpetological communities*. US Fish and Wildlife Service, Wildlife Research Report, 13, 193–200.

Chazdon, R. L., Harvey, C.A., Komar, O., Griffith, D. M., Ferguson, B. G., et al. (2009). Beyond reserves: A research agenda for conserving biodiversity in human-modified tropical landscapes. *Biotropica*, 41, 142–153.

Clough, Y., Putra, D. D., Pitopang, R. & Tscharntke, T. (2009). Local and landscape factors determine functional bird diversity in Indonesian cacao agroforestry. *Biological Conservation*, 142, 1032–1041.

Clough, Y., Barkmann, J., Juhrbandt, J., Kessler, M., Wanger, T. C. et al. (2011). Combining high biodiversity with high yields in tropical agroforests. *Proceedings of the National Academy of Sciences of the United States of America*, 108, 8311–8316.

Daniel, J. C. (2002). *The book of Indian reptiles and amphibians*. Oxford University press, Mumbai, India.

Dinesh, K. P. & Radhakrishnan, C. (2011). Checklist of amphibians of Western Ghats. *Frog Leg*, 16, 15–20.

FAO (Food and Agricultural Organization of the United Nations). (2010). Global forestry resources assessment 2010 — Main report. *FAO Forestry Paper* No. 163. FAO, Rome, Italy.

Faruk, A., Belabut, D., Norhayati, A., Knell, R. J. & Garner, T. W. J. (2013). Effects of oil-palm plantations on diversity of tropical anurans. *Conservation Biology*, 27, 615–624.

Ganesh, S. R., Chandramouli, S. R., Sreekar, R. & Shankar, P. G. (2013). Reptiles of the central Western Ghats, India - A reappraisal and revised checklist, with emphasis on the Agumbe plateau. *Russian Journal of Herpetology*, 20, 181–189.

Gaffar, S. P. A. (2011). *Assessing the dependence of forest fringe communities on forest resources, for subsistence and livelihood: Agumbe, Karnataka*. MSc thesis, In: Institute of Science, Mumbai, India.

Gillespie, G. R., Ahmad, E., Elahan, B., Evans, A., Ancrenaz, M., Goossens, B. & Scroggie, M. P. (2012). Conservation of amphibians in Borneo: Relative value of secondary tropical forests and non-forest habitats. *Biological Conservation*, 152, 136–144.

Gunawardene, N. R., Daniels, A. E. D., Gunatilleke, I. A. U. N., Gunatilleke, C. V. S., Karunakaran, P. V., et al. (2007). A brief overview of the Western Ghats – Sri Lanka biodiversity hotspot. *Current Science*, 93, 1567–1572.

Hobbs, N.T. & Hilborn, R. (2006). Alternatives to statistical hypothesis testing in ecology: a guide to self teaching. *Ecological Applications* 16: 5–19.

Inger, R. F. & Colwell, R. (1977). Organization of contiguous communities of amphibians and reptiles in Thailand. *Ecological Monographs*, 47, 229–253.

Jenkins, C. N. & Joppa, L. (2009). Expansion of the global terrestrial protected area system. *Biological Conservation*, 142, 2166–2174.

Klein, A. M., Steffan-Dewenter, I. & Tscharntke, T. (2006). Rain forest promotes trophic interactions and diversity of trap-nesting Hymenoptera in adjacent agroforest. *Journal of Animal Ecology*, 75, 315–323.

Kuramoto, M., Joshy, H., Kurabayashi, A. & Sumida, M. (2007). The genus *Fejervarya* (Anura: Ranidae) in Central Western Ghats, India, with descriptions of four new cryptic species. *Current Herpetology*, 26, 81–105.

Laurance, W. F., Useche, D. C., Rendeiro, J., Kalka, M., Bradshaw, C. J. A., et al. (2013). Averting biodiversity collapse in tropical forest protected areas. *Nature*, 489, 290–294.

Luja, V. H., Herrando-Perez, S., Gonzalez-Solis, D. & Luiselli, L. (2008). Secondary rain forests are not havens for reptile species in tropical Mexico. *Biotropica*, 40, 747–757.

Magurran, A. E. (2004). *Measuring biological diversity*. Blackwell Publishing, Oxford, United Kingdom.

Mirza, Z. A., Sanap, R. V. & Upadhaye, R. (2010). Comments on the systematic status of Eutropis allapallensis Schmidt, 1926 (Sauria: Squamata: Scincidae). *Russian Journal of Herpetology*, 17, 245–246.

Murrieta-Galindo, R., Gonzalez-Romero, A., Lopez-Barrera, F. & Parra-Olea, G. (2013). Coffee agrosystems: an important refuge for amphibians in central Veracruz, Mexico. *Agroforestry Systems*, 87, 767–779.

Purushotham, C. B. & Tapley, B. (2011). Checklist of amphibians: Agumbe Rainforest Research Station. *Frog Leg,* 16, 2–14.

R Development Core Team. (2012). *R: A language and environment for statistical computing*. R foundation for statistical computing, Vienna, Austria. http://www.R-project.org.

Salafsky, N., Salzer, D., Stattersfield, A. J., Hilton-Taylor, C., Neugarten, R., Butchart, S. H. M., Collen, B., Cox, N., Master, L. L., O'Connor, S. & Wilkie, D. (2008). A standard lexicon for biodiversity conservation: unified classifications of threats and actions. *Conservation Biology,* 22, 897–911.

Shahabuddin, Schulze, C. H. & Tscharntke T. (2005). Changes of dung beetle communities from rainforests towards agroforestry systems and annual cultures in Sulawesi (Indonesia). *Biodiversity and Conservation*, 14, 863–877.

Smith, M. A. (1943). *The Fauna of British India Ceylon and Burma including the whole of the Indo-Chinese region*. Vol. III. Serpentes. Taylor and Francis, London.

Sodhi, N. S., Posa, M. R. C., Lee, T. M., Bickford, D., Koh, L. P. & Brook, B. W. (2010). The state and conservation of Southeast Asian biodiversity. *Biodiversity and Conservation,* 19, 317–328.

Sreekar, R., Mohan, A., Das, S., Agarwal, P. & Vivek, R. (2013a). Natural windbreaks sustain bird diversity in a tea-dominated landscape. *Public Library of Science One,* 8, e70379. DOI: 10.1371/journal.pone.0070379.

Sreekar, R., Purushotham, C. B., Saini, K., Rao, S. N., Pelltier, S. & Chaplod, S. (2013b). Photographic capture-recapture sampling for assessing populations of the Indian Gliding Lizard. *Public Library of Science One*, 8, e55935. DOI: 10.1371/journal.pone.0055935.

Sung, Y., Karraker, N. E. & Hau, B. C. H. (2011). Evaluation of the effectiveness of three survey methods for sampling terrestrial herpetofauna in South China. *Herpetological Conservation and Biology,* 6, 479–489.

Thomas, C. D., Gillingham, P. K., Bradbury, R. B., Roy, D. B., Anderson, B. J., et al. (2012). Protected areas facilitate species' range expansions. *Proceedings of the National Academy of Sciences of the United States of America*, 109, 14063–14068.

Wang, Y., Naumann, U., Wright, S. T. & Warton, D. I. (2012). mvabund – an R package for model based analysis of multivariate abundance data. *Methods in Ecology and Evolution*, 3, 471–474.

Wanger, T. C., Saro, A., Iskandar, D. T., Brook, B. W., Sodhi, N. S., Clough, Y. & Tscharntke, T. (2009). Conservation value of cacao agroforestry for amphibians and reptiles in Southeast Asia: combining correlative models with follow-up field experiments. *Journal of Applied Ecology*, 46, 823–832.

Wanger, T. C., Iskandar, D. T., Motzke, I., Brook, B. W., Sodhi, N. S., Clough, Y. & Tscharntke, T. (2010). Effects of land-use change on community composition of tropical amphibians and reptiles in Sulawesi, Indonesia. *Conservation Biology*, 24, 795–802.

Warton, D. I., Wright, S. T. & Wang, Y. (2012). Distance-based multivariate analyses confound location and dispersion effects. *Methods in Ecology and Evolution,* 3, 89–101.

Whitfield, S. M., Bell, K. E., Philippi, T., Sasa, M., Bolanos, F., Chaves, G., Savage, J. M. & Donnelly, M. A. (2007). Amphibian and reptile declines over 35 years at La Selva, Costa Rica. *Proceedings of the National Academy of Sciences of the United States of America*, 104, 8352–8356.

WWF (World Wildlife Foundation). (2002). *Forest management outside protected areas*. Position paper, WWF, Gland.

Zar, H. J. (1999). *Biostatistical analysis.* Pearson, Singapore.

Table 1. Model-averaged estimates and covariate weights of environmental determinants (canopy cover = CANOPY; leaf litter volume = LITTER; shrub density = SHRUB) for amphibian and reptile species richness (AMPr and REPr, respectively) and abundance (AMPa and REPa, respectively) in Agumbe, Western Ghats, India. In case of individual species abundances, results are reported only for species that occurred in more than two plots and with covariate weights above 0.60. *Fejervarya sp2* was identified to genus level and given a morphospecies identity (sp2).

Response	Covariate	Model-averaged estimate	Covariate weight (*w*)
Species richness response			
REPr	LITTER	0.15±0.12	0.34
AMPr	CANOPY	0.39±0.14	0.93
Species abundance response			
REPa	LITTER	0.21±0.09	0.78
AMPa	CANOPY	0.39±0.08	1.00
Amphiesma beddomei	LITTER	1.43±0.72	0.83
Aheatulla nasuta	LITTER	-0.77±0.39	0.74
Ristella beddomei	LITTER	0.79±0.31	0.92
Clinotarsus curtipes	SHRUB	-0.51±0.11	1.00
Frejervarya rufescens	CANOPY	0.66±0.26	0.90
Frejervarya sp2	CANOPY	0.85±0.26	0.98
Hylarana aurantiaca	CANOPY	0.59±0.21	0.94
Hylarana temporalis	LITTER	0.51±0.24	0.64

Figure legends

Figure 1. The effects of canopy cover on species richness (black) and abundance (grey) of amphibians in the unprotected forests of Agumbe, Western Ghats. Lines are predictions of the models fitted to the data with 95% confidence intervals.

Figure 2. The effects of leaf-litter volume (1 bucket = $0.005m^3$) on species richness (black) and abundance (grey) of reptiles in the unprotected forests of Agumbe, Western Ghats. Lines are predictions of the models fitted to the data with 95% confidence intervals.

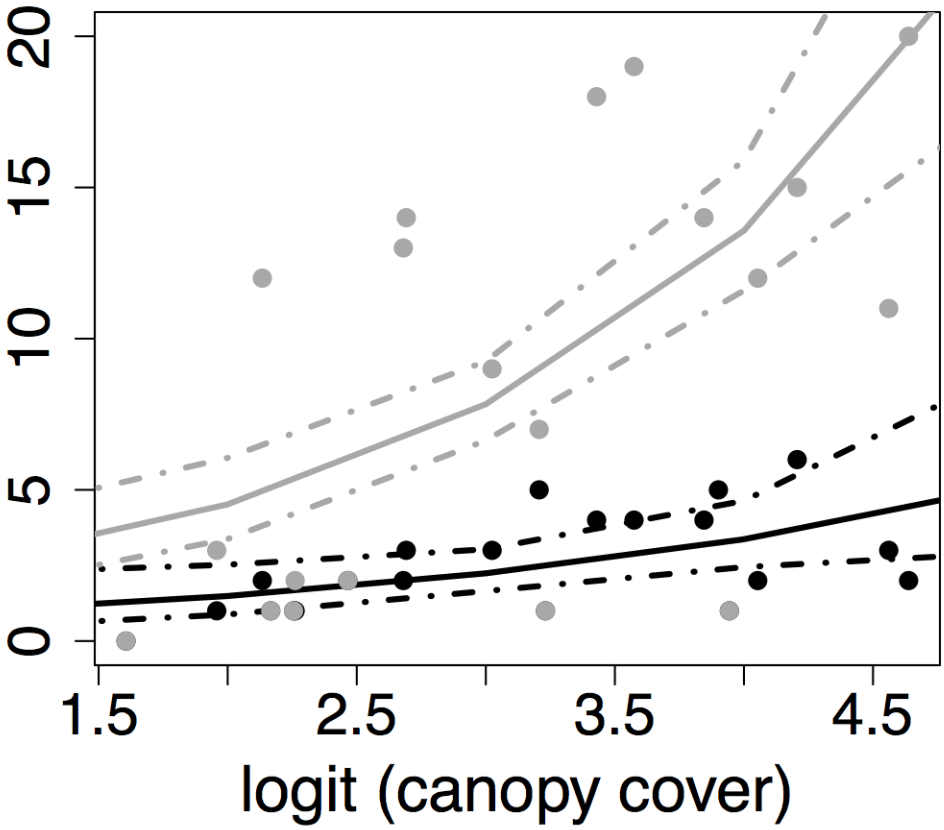

Figure 1. The effects of canopy cover on species richness (black) and abundance (grey) of amphibians in the unprotected forests of Agumbe, Western Ghats. Lines are predictions of the models fitted to the data with 95% confidence intervals.

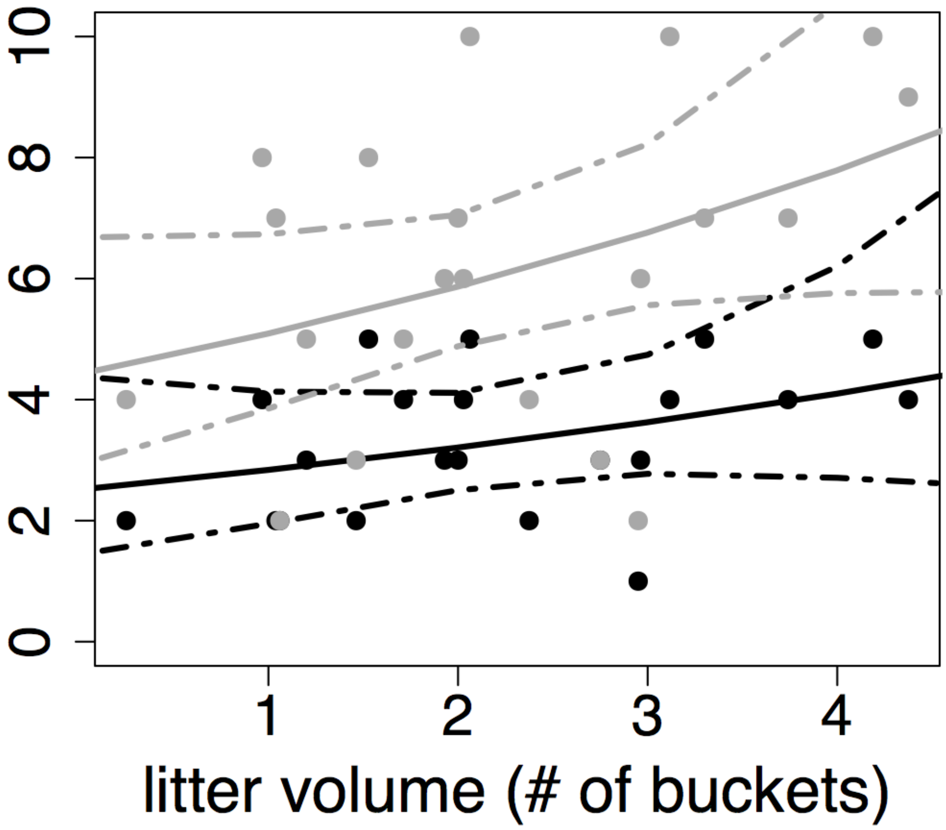

Figure 2. The effects of leaf-litter volume (1 bucket = $0.005m^3$) on species richness (black) and abundance (grey) of reptiles in the unprotected forests of Agumbe, Western Ghats. Lines are predictions of the models fitted to the data with 95% confidence intervals.

Drivers of reptile and amphibian assemblages outside the protected areas of Western Ghats, India

Divya Balaji[1,2,*], Rachakonda Sreekar[1,3,*,#] and Siddharth Rao[1]

[1] Agumbe Rainforest Research Station, Agumbe, Karnataka, India

[2]Yale University, New Haven, Connecticut, United States of America

[3] Key Laboratory of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Mengla, Yunnan, China

[*]These authors contributed equally to this work

[#]*Corresponding author:* Rachakonda Sreekar, Key Laboratory of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Mengla, Yunnan, China*;* Email: sreekar1988@gmail.com

Running title: Reptiles and amphibians outside protected areas

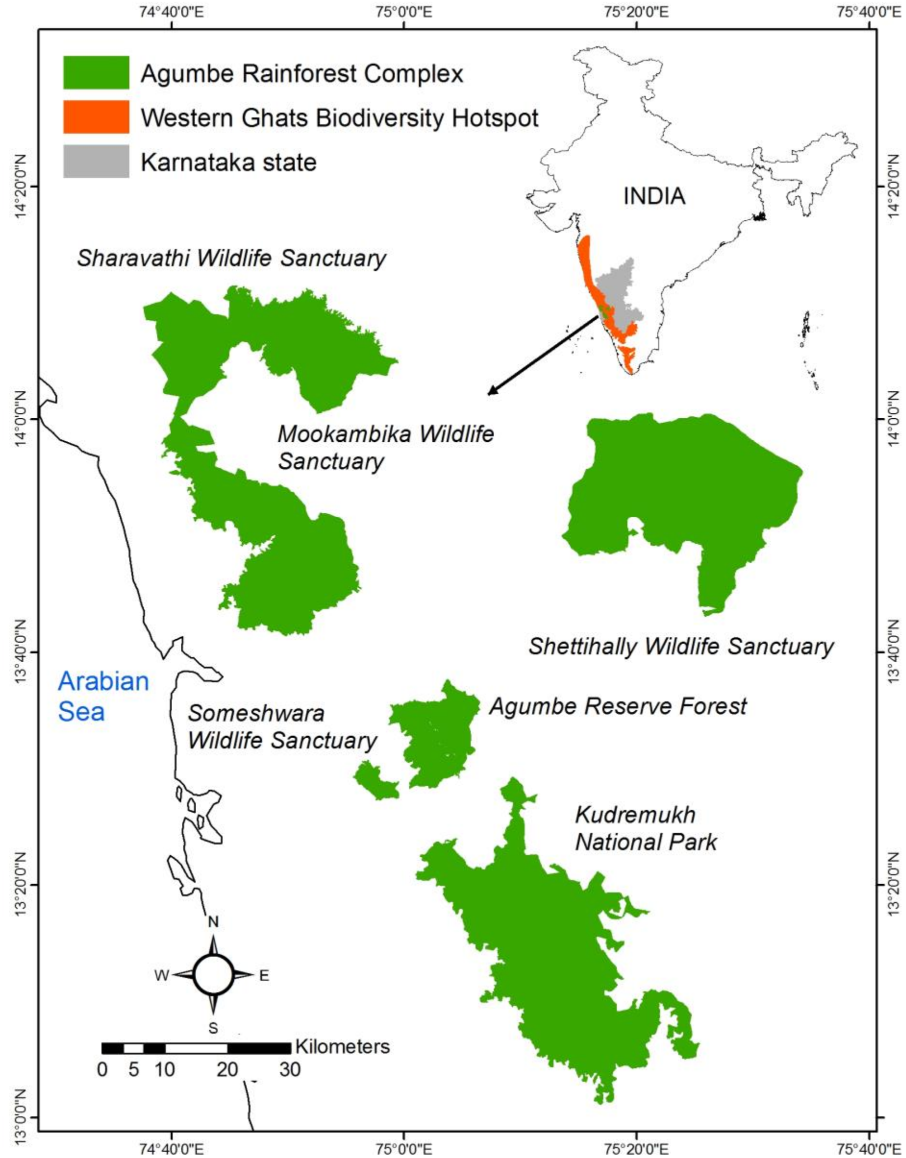

Figure S1. Map of the study site in the Western Ghats, India: Agumbe reserve forest and its surrounding protected areas.

Table S1. Summary information of species recorded in 21 strip-transects along a disturbance gradient in Agumbe landscape. Alphabets in parentheses represent amphibian (A) or reptile (R). Most *Fejervarya* species were only identified to genus level and given morphospecies identity (e.g. sp1, sp2).

Strip transect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Amphiesma beddomei (R)	0	0	0	0	0	1	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0
Ahaetulla nasuta (R)	0	0	0	0	1	0	1	0	0	0	1	2	0	0	0	1	1	1	2	1	0
Clinotarsus curtipes (A)	0	0	19	2	0	2	3	3	12	12	10	11	2	14	13	5	2	3	0	1	1
Cnemaspis heteropholis (R)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Cnemaspis indraneildasii (R)	0	2	1	0	1	2	0	1	1	4	1	0	0	0	0	2	0	1	0	0	0
Calotes rouxii (R)	1	2	0	0	0	1	1	0	3	3	3	3	1	2	1	1	0	0	0	2	0
Dattaphrynus melanostictus (A)	0	0	0	1	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Eutropis carinata (R)	1	0	0	0	0	0	0	0	1	0	0	1	0	2	5	2	1	0	0	0	1
Eutropis macularia (R)	4	2	1	2	3	2	4	4	2	0	3	2	3	2	2	1	0	5	2	1	2
Fejarvarya rufescens (A)	0	0	0	4	1	1	0	0	1	1	0	1	1	2	3	1	0	0	0	0	0
Fejarvarya sp1 (A)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fejervarya sp2 (A)	0	0	0	4	0	0	0	0	0	0	0	1	2	2	1	3	0	0	0	0	0
Fejervarya sp3 (A)	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Fejervarya sp4 (A)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Hylarana aurantiaca (A)	0	0	0	0	0	8	9	3	0	0	2	0	1	0	0	0	0	0	0	0	0
Ristella beddomei (R)	0	3	1	0	0	0	0	2	1	0	0	2	0	0	2	0	0	0	0	1	0
Hylarana temporalis (A)	0	1	1	1	0	11	0	5	1	0	0	0	0	1	0	0	0	0	0	0	0

Table S2. Summary information of important environmental variables (mean values) recorded in 21 strip-transects along a disturbance gradient in Agumbe landscape.

Strip transect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Leaf litter (# of buckets)	2.9	4.3	2.7	2.9	1.2	2.1	1.9	4.2	1.5	1.1	0.9	2.0	2.4	3.7	3.1	3.3	1.1	2	0.3	1.7	1.4
Shrub density	36	34	31	33	22	33	29	19	12	17	6	29	45	23	23	27	35	28	23	40	37
Canopy cover (%)	95	98	99	98	91	98	97	98	93	92	88	97	94	97	96	94	89	86	82	88	88