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Fine Scale Habitat Selection in Travancore Tortoises (*Indotestudo travancorica*) in the Anamalai Hills, Western Ghats

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Abstract.—**Travancore Tortoises (*Indotestudo travancorica*) are endemic to the Western Ghats, south India. Landscape level surveys showed no clear habitat selection by the species. Therefore, we used radiotelemetry to study home-range size and fine-scale spatial movement habitat use of four tortoises from 2008–10. Minimum convex polygon home-range sizes of four tortoises varied between 5.2 and 34 ha. Tortoises spent a majority of their time in evergreen forest edge that had bamboo–lantana–grass. Eighty-two percent of the locations in the evergreen forest, and 95% of the locations in the bamboo–lantana–grass habitat, were at the edge of these habitats. Therefore at a fine scale, tortoises used the forest edge, possibly because it provided opportunities for foraging and thermoregulation.**

The heterogeneity of tropical forests offers a wide range of habitats that promote habitat use specialization among species (Plotkin et al., 2000). The rapid loss of tropical forests has prompted ecologists to investigate interactions between habitats and endemic species to understand the factors crucial for their persistence (Morris, 2010). Understanding the factors that influence space use by individuals is crucial to identifying important habitats for endemic species and aids in formulating in situ conservation strategies of the species (Johnson et al., 2004).

Travancore Tortoises (*Indotestudo travancorica*) are endemic to the Western Ghats of South India (Iverson et al., 2001; Le et al., 2006). The species is listed as Vulnerable on the IUCN Red List and in Appendix II of CITES (Asian Turtle Trade Working Group, 2000) and a protected species under the Wildlife (Protection) Act of India (Deepak et al., 2011). *Indotestudo travancorica* is a medium-sized (maximum carapace length = 330 mm) omnivore that feeds primarily on grasses and herbs but occasionally on animal matter that includes insects, scorpions, crabs, and mammalian carrion (Ramesh, 2008b; Deepak et al., 2011). Among the habitats occupied by *I. travancorica* are tropical evergreen and semievergreen, moist deciduous, bamboo forests, and plantations such as rubber and teak. *Indotestudo travancorica* is most frequently observed close to marshes, grass-dominated openings in the forest, and rocky areas close to streams (Vijaya, 1983; Bhupathy and Choudhury, 1995; Ramesh, 2008a; Deepak et al., 2011). On the forest floor, tortoises use leaf litter, ground level cavities in trees, rocks, fallen logs, and occasionally, pangolin burrows for shelter (Vijaya 1983; Bhupathy and Choudhury 1995; Deepak et al., 2011). In this study, we intensively monitored movements of these tortoises to greatly expand what we know about their natural history.

Anamalai Tiger Reserve (ATR) and Parambikulam Tiger Reserve (PTR) encompass roughly 2,000 km^2 and are comprised of several habitat types at the elevation zone where *I. travancorica* occurs. Using radiotelemetry, we determined movement patterns and home range size to understand fine scale habitat use in the ATR and PTR. Because adult males in the species show aggressive interactions and mate with several females during a breeding season (Deepak et al., 2011), we hypothesized that home-range size of males should be larger than that of females. Because *I. travancorica* showed no habitat preference at the landscape level (Deepak and Vasudevan, 2012), we wanted to know whether this holds true at a fine scale, after riparian patches and forest edges were included in the habitat-use analyses.

Materials and Methods

Study Area.—We conducted our study in the Karian Shola National Park, ATR and adjoining areas in PTR, located in the states of Tamil Nadu and Kerala in south India, respectively. The two tiger reserves are located between 10°13′–10°33′N and 76°37′–77°21′E in the southern Western Ghats. The forest type is comprised chiefly of *Dipterocarpus bourdilloni–Strombosia ceylanica* type (Pascal et al., 2004). The areas adjoining the perennial stream are bamboo-dominated habitat with *Bambusa arundinacea*, *Lantana camara*, and other climbing vegetation (*Strychnos colubrine*, *Acacia sinuate*, and *Naravelia zeylanica*) comprising the understory and with grass and herbs as the dominant ground vegetation. Eleven percent (12.1 ha) of the total 110-ha study area had bamboo–lantana–grass (BLG) habitat. The evergreen and the BLG habitats formed a discernible edge.

Recording precise measurements of tortoise movements was a challenge. Geographical Positioning System (GPS) readings under dense canopy cover (> 95%) would lead to imprecise locations; further, tortoises move short distances (< 1 m), which cannot be measured using GPS locations. To avoid measurement errors in mapping, we manually plotted the locations of all tortoise sightings in the study area using a measuring tape, clinometers, and compass (Suunto™, Tandem; Vantaaa, Finland). We mapped the 110-ha study area into 110 uniformly shaped, 100 × 100 m two-dimensional grids after correcting for the contours of the terrain (Fig. 1).

Radiotelemetry and Home Range.—Radio transmitters (25–27 g, G3 type: AVM Instruments, CA) were adhered to the left or right side of the tortoise carapaces using epoxy adhesive Hysol E–120 HP (Loctite Corp; Westlake, OH). The tortoises were located using a portable radiotelemetry receiver (Model: LA 12Q) and a handheld collapsible Yagi antenna (AVM instrument Co.; Colfax,

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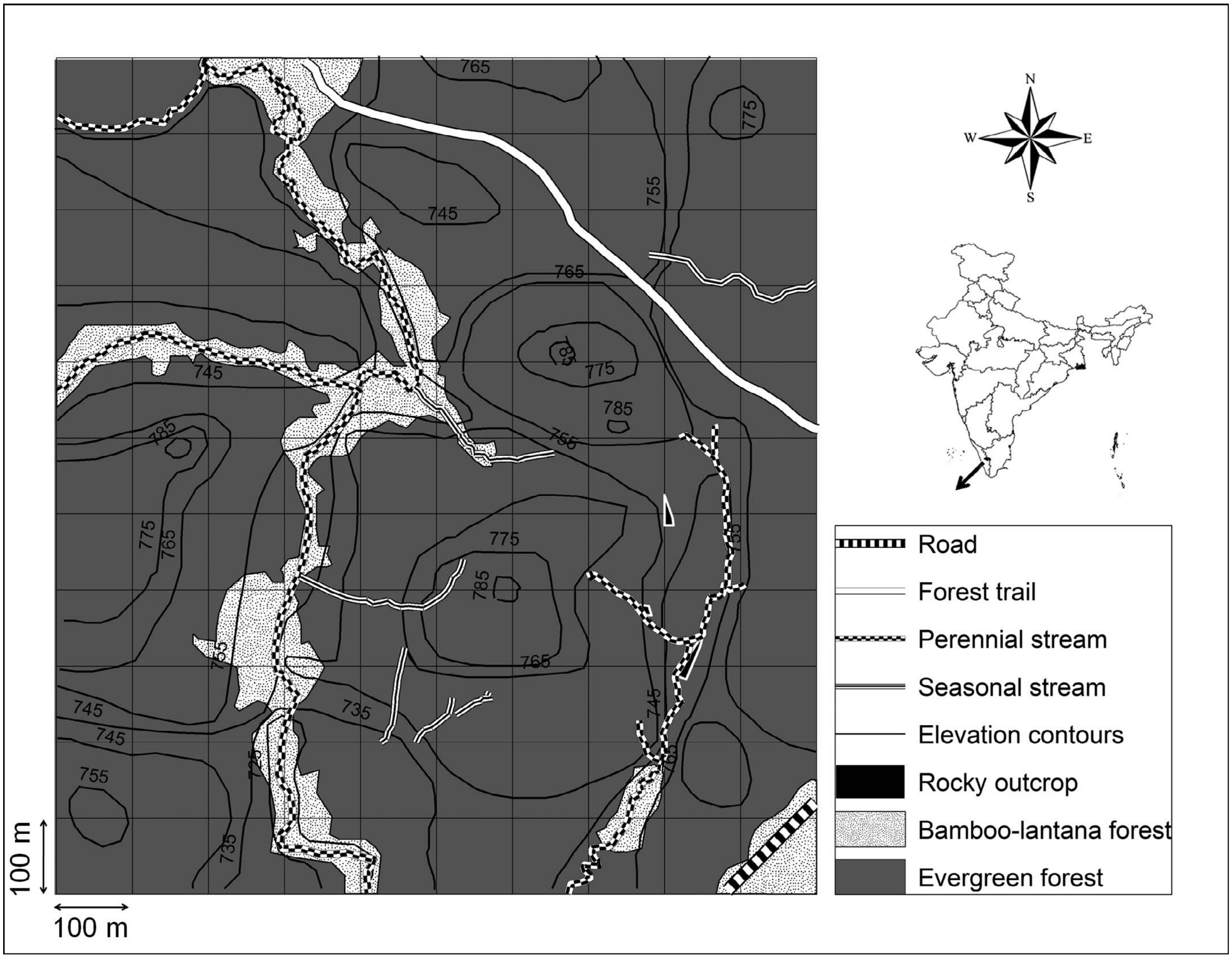

FIG. 1. Physical features in the 110-ha intensive study area. Elevation at contours shown in meters.

CA). Initially, we attached transmitters on five individual Travancore Tortoises (2 males and 3 females). Four of the five radio-tagged tortoises were monitored regularly, although the transmitter of one female failed after 15 days of tracking. In all, we used nine radio-tags on four individuals that were followed regularly by replacing tags on them after their batteries drained. The tortoises were secretive and difficult to detect in the study area (Deepak and Vasudevan, 2014). During four years of our study, we found only seven Travancore Tortoises in the intensive study area. We recorded at least one daily location where searches were initiated from the corner of a permanently marked 100 × 100 m grid. The locations were measured with an accuracy of 0.1 m. Two observers made one to three visits per day to the study site and obtained exact locations of tortoises. Home-range sizes were estimated using 100% minimum convex polygon (MCP) in Program R with "adehabitat" package (Calange, 2006). Minimum convex polygon home-range overlaps were calculated using scripts as per Huck et al. (2008). Twenty random location points were drawn from the pool of locations for a tortoise and plotted incrementally. An asymptote in this graph was inferred as the minimum number of locations required to arrive at the home range of each tortoise.

Spatial Movement Pattern.—We used a cell size of 100 × 100 m for spatial data analysis, because the smallest home range (1 ha) of the four radio-tracked tortoises was approximately equal to the area enclosed by each cell. All tortoise locations were pooled together for analysis. We created a 95% kernel contour to avoid assigning false absence of occurrence of tortoises in the neighboring grids. Least-squares cross-validation was used to calculate the kernel contours in ArcMap v9.2 GIS software package (ESRI Inc, Redlands, CA). Grids that overlapped by a kernel contour were assigned with a value of 1, whereas the unoccupied grids were assigned 0. Nine grids were not sampled frequently and were removed from the analysis to avoid inferring false absence.

Fine-Scale Habitat Use.—Variables were collected in four 10 × 10 m quadrats within every 100 × 100 m cell within the 110-ha intensive study area. The quadrats were placed 10 m away from the center of each cell in four perpendicular directions. Nine variables were measured: 1) visual estimation of percentage leaf litter cover; 2) number of lianas; 3) number of trees with buttress; 4) number of fallen logs > 250 mm width; 5) rock index, a weighted average from each of three classes of rocks, small (< 0.5 m), medium (> 0.5 to < 1 m), and large (> 1 m); 6) canopy cover, measured using a canopy densitometer four times in different

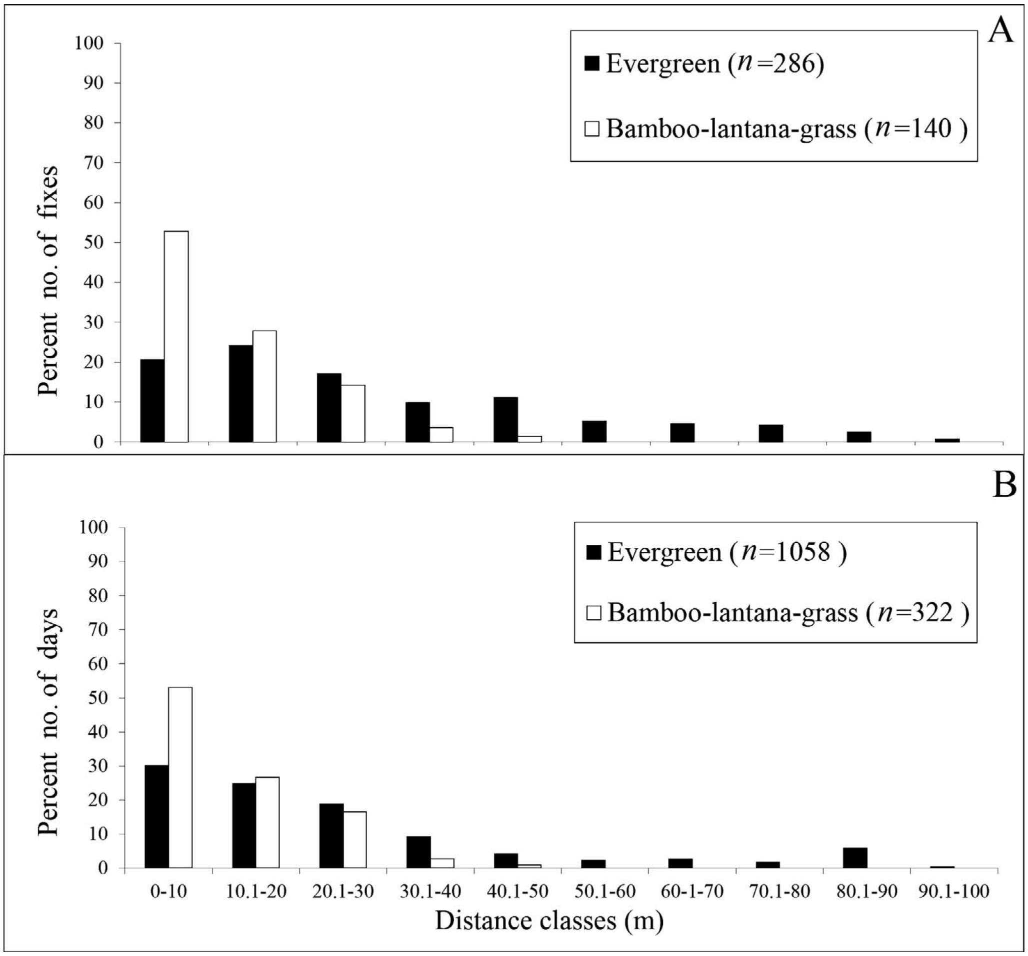

FIG. 2. Pattern in activity levels denoted by: (A) percentage of locations; (B) percentage of days spent by Travancore Tortoises from the edge of two different habitat types. 0 corresponds to the edge. Note: longest distance from the edge to the center of bamboo–lantana–grass habitat is ~50 m.

directions and averaged for each quadrat; 7) distance to water, measured from the center of the cell to the nearest water body with a map; 8) distance of the edge between evergreen and BLG habitats from the center of the grids, measured with a map; and 9) coefficient of variation in the elevation in each grid, calculated from the elevation contours mapped in the study area. Variables were tested for multicollinearity using Variance Inflation Factor (VIF) in statistical package R version 2.14.2 (R Core Team, 2012). A threshold level of five for VIF has been used to measure multicollinearity (Heiberger and Burt, 2004) and was adopted in this study. The data were tested for normality using a Kolmogorov–Smirnov test. All variables were tested for correlation using Pearson correlation test ($\alpha = 0.05$). Significantly correlated variables were removed before performing the logistic regression analysis. Species movement data often are spatially autocorrelated because locations in close proximity to one another exhibit more similarity in habitat attributes than those farther apart. To minimize the effects of spatial autocorrelation, we used logistic and autologistic model analysis in Program 145 SAM (Rangel et al., 2006); tolerance value was set at 0.75, and the autologistic model parameter alpha (α) was set at 1, a parameter that regulates the relationship among spatial units and usually improves the performance of the model (Davis, 1986, cited in Rangel et al., 2006). We performed the analysis using α-values from 0.1 to 1, where α-value of 1 indicates the best model. Three logistic regression models were built, and the model selection was done based on the lowest Akaike Information Criterion (AIC) values. We used the program SAM to perform a Chi-square goodness-of-fit test on the models to demonstrate that habitat variables explained the use of space by the tortoises.

Because there was a distinct edge habitat between the evergreen and the BLG habitats, we quantified the use of edge habitat by the tortoises. The intensity of habitat use by the tortoises within the BLG, evergreen habitats, and their edges was explored using GIS tools. All locations of tortoises were pooled and plotted as point shape files. A buffer (polyline) at 10-m interval was created around the edge between the BLG and the evergreen habitat, a process that was repeated 10 times with buffers until there was 100 m on either side of the edge. Because BLG habitat was linear in shape along streams, the buffers extended up to only 50 m within this habitat.

RESULTS

Radiotelemetry and Home Range.—Tortoises were tracked 215 and 633 days for the two males and 89 to 728 days for the two females (a total of 1,576 locations) between February 2008 and March 2010. Female #1 had the largest MCP home range (34.7 ha) encompassing > 90% of the two males home ranges (Table 1). Kernel home ranges were 9.8 ha and 3.5 ha for females #1 and #2, respectively, and 5.9 ha and 1.0 ha for males #1 and #2, respectively. We recorded 120 different locations over 409 days

TABLE 1. Overlap of 100% MCP home ranges of four radio-tagged Travancore Tortoises, two each of females (F) and males (M).

Individual (home range in ha)	F1	F2	M1	M2
F1 (34.7)	–	0	91.4	99.8
F2 (9.0)	0	–	0	0
M1 (9.3)	24.5	0	–	0
M2 (5.2)	15	0	0	–

for female #1, and 120 different locations over 485 days for male #1.

Bamboo–lantana–grass habitat constituted 12.1 ha (11%) of the study area and comprised variable amounts of area within the home ranges of our tortoises. Of the available BLG habitat, female tortoises used 0.78 to 7.4 ha (8.7–21.5% of the MCP home ranges), and males used 1.2 to 3.2 ha (22.5–34.4% of MCP home ranges). The remainder of the habitat in the home range of tortoises was represented by evergreen forest with rocky outcrops.

Spatial Movement Pattern.—Total distances moved by males were 10.37 km and 17.12 km and 31.59 km and 30.74 km for females. Maximum linear distances moved in one day by the tortoises were 425 m and 412 m by males and 665 m and 245 m by females. The average linear distances moved by the tortoises were 46.80 m and 15.14 m for males and 15.23 m and 19.68 m for females.

Tortoises most frequently used edge habitat. On average, tortoises spent 87% of their time in, and 82% of their locations were obtained within, habitat that was < 50 m from the edge habitat between the BLG and evergreen forest (Fig. 2). A single female was located within a termite mound burrow on three occasions between 2008 and 2010, spending 455 days in different parts of the study area but always returning to the same burrow. Male #1 frequented a rock crevice three times in 2008 and revisited the same refuge after 249 days in 2009.

Canopy cover was correlated with leaf litter cover ($r = 0.56$; $P < 0.01$) and with the number of trees with buttresses ($r = 0.58$; $P < 0.01$), and as a consequence, canopy cover was removed from the regression analysis. The VIF values of eight explanatory variables ranged from 1.13 to 2.47 and were well within acceptable limits. Among the three competing models, a combination of distance to edge and autocovariate function parsimoniously explained 83% of the variation in the data set (Table 2). A tortoise's distance from the edge habitat influenced its movements, such that grids closer to the edge habitat had a greater probability of occupation by tortoises (Table 3; Fig. 3) than did grids located farther away from the evergreen forest edge. The distance from the BLG-evergreen forest edge habitat along with the autocovariate function explained more variation in habitat use by the tortoises than did all other variables combined.

DISCUSSION

Home Range.—We expected home ranges to differ among sexes, because adult males show aggressive interactions and mate with several females during a breeding season (Deepak et al., 2011); however, the role of gender on home range in the present data set is unclear. Gender, size, and reproductive condition are known to influence ranging in several species of turtles, such as *Gopherus polyphemus* (McRae et al., 1981; Diemer, 1992) and *Gopherus berlandieri* (Rose and Judd, 1975). In contrast, home-range size

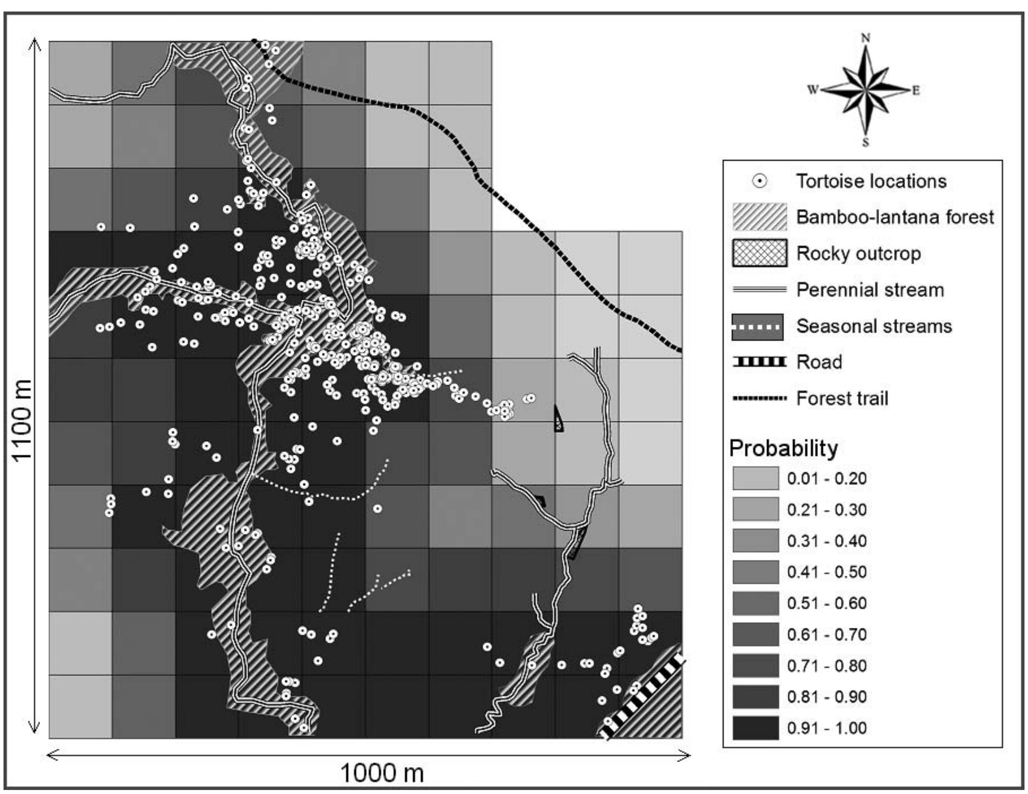

FIG. 3. Gradient in the probability of occurrence of Travancore Tortoises, based on autologistic regression model, with an overlay of habitat and terrain features in the intensive study area.

TABLE 2. Models of fine-scale habitat selection in Travancore Tortoises ranked based on AIC-value. Overall accuracy is the proportion of cells classified correctly. Chi-square goodness-of-fit test is the differences in likelihood ratios (−2 logliklihood or deviance) between the overall model (model 2 and 3) and the constant, where β = 0. Model 1 is the difference between the overall model (model 2) and the reduced model (model 1). *P <0.0001

Rank	Model	Chi-squre	df	AIC	Overall model accuracy
1	Distance to edge + autocovariate	71.28*	1	67.43	0.83
2	No. of logs + no. of liana + no. of trees with buttress + rockiness + leaf-litter cover + distance to water + distance to edge + autocovariate	77.64*	8	75.06	0.85
3	No. of logs + no. of liana + no. of trees with buttress + rockiness + elevation+ leaf-litter cover + distance to water + distance to edge	54.73*	7	95.98	0.78

was not related to body size, sex, or season in *Geochelone carbonaria* (Moskovits and Kiester, 1987). Individual variation in home-range sizes and distances moved is typical of most terrestrial turtles, such as, *Terrapene carolina carolina* (Stickel, 1950; Schwartz and Schwartz, 1974), *Terrapene ornata ornata* (Legler, 1960), *Gopherus agassizii* (Burge, 1977) *G. berlandieri* (Judd and Rose, 1983), *Manouria emys phayrei* (Wanchai, 2007), *Manouria impressa* (Wanchai et al., 2012) and *Indotestudo elongata* (Tharapoom, 1996). Furthermore, we determined that a minimum of 180 locations (~490 radio telemetry days) are required to determine home-range size in *I. travancorica,* highlighting the need for intensive data collection to understand the spatial ecology of this species.

Interactions between animal movements and environmental features contribute to home-range size and shape (Börger et al., 2006). In *I. travancorica*, interactions between individual behavior and spatial context likely are strong. From our data set, repetitive use of refuges and foraging sites by *I. travancorica* provides evidence for memory-based animal space use patterns that has important consequences for future studies.

Fine-Scale Habitat Use.—We expected *I. travancorica* to show no difference in use of habitats at a fine scale. The tortoises had considerable proportions (22–34%) of their home range within BLG habitat. Tortoises intensively used BLG habitat (only 11% of the entire study area), which served as an important foraging ground for the tortoises, because plant matter forms an important constituent in the diet of the species (Deepak and Vasudevan, 2012). Because *I. travancorica* is crepuscular (Vijaya, 1983; Deepak et al., 2011), use of the edge habitat could facilitate feeding within the BLG habitat during the morning and evening while in close proximity to the evergreen forest where refugia from midday temperatures could be used. Terrestrial tortoises, such as *Kinixys erosa* and *K. Kinixys homeana* from tropical Africa, actively thermoregulate by seeking refugia in the forest to avoid overheating (Luiselli, 2005).

We suspect that selection of edge habitat would be favored as a consequence of the trade-off between benefits from food intake and thermoregulatory costs. This idea needs to be tested by future studies on thermoregulation in the species. Through this study, we demonstrate that Travancore Tortoise show remarkable specialization for use of woodland–grassland edges. Their long-term survival pivots on maintenance of these natural edges that mosaic of habitats offer in the landscape. The BLG habitat is referred locally as *vayal* and they serve as important foraging grounds for several large herbivore species (Balakrishnan and Easa, 1986). In the southern Western Ghats, vayals are embedded within the mosaic of vegetation types, and they are crucial for the long-term persistence of Travancore Tortoises in the region. As vayals play a crucial role in supporting several species, we suggest that mapping, monitoring, and improving forage quality by eradicating exotics be practiced in the protected management area.

TABLE 3. Coefficients of autologistic regression of the best model showing significant influence of variables on the probability of movement by Travancore Tortoises.

Variables	Coefficients	SE	*P*-value
Constant	−14.07	3.90	< 0.001
Distance to edge	−0.02	0.005	< 0.001
Autocovariate	25.24	6.10	< 0.001

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