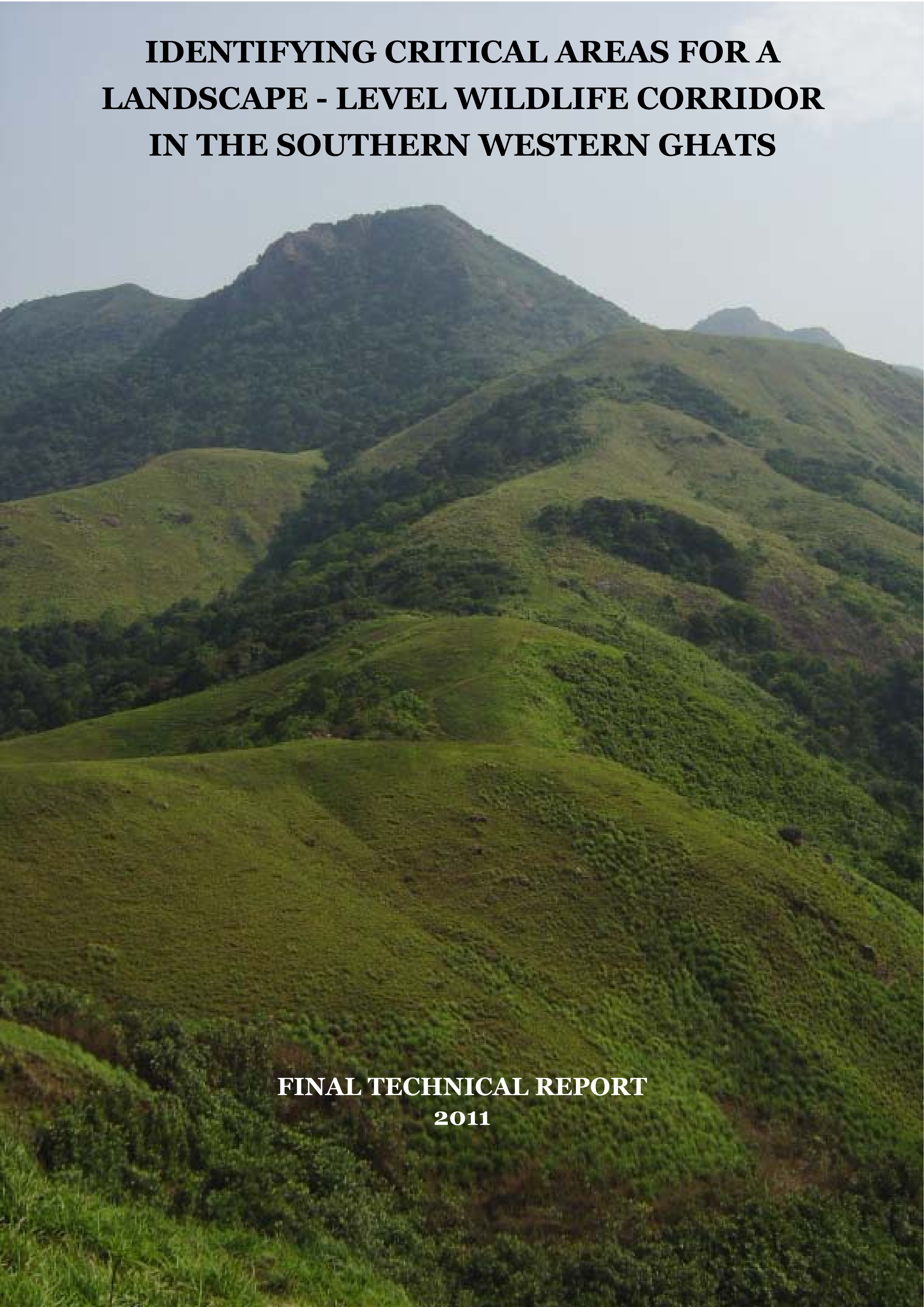
IDENTIFYING CRITICAL AREAS FOR A LANDSCAPE - LEVEL WILDLIFE CORRIDOR IN THE SOUTHERN WESTERN GHATS



FINAL TECHNICAL REPORT

2011

Foundation for Ecological Research, Advocacy and Learning
No. 27, 2nd cross, Appavou Nagar,
Vazhakulam, Pondicherry 605 012
website: www.feralindia.org

Identifying critical areas for a landscape - level wildlife corridor in the southern Western Ghats
Final technical report
Project period: November 2008 - June 2010

Citation*:

Aditya Gangadharan, Srinivas Vaidyanathan and Sunita Ram (2011). Identifying critical areas for a landscape - level wildlife corridor in the southern Western Ghats. Final technical report. Published by Foundation for Ecological Research, Advocacy and Learning (FERAL), Pondicherry.

Photocredits:
Aditya Gangadharan
Gopinath S
Srinivas Vaidyanathan
Sunita Ram

Cover: *A view along the Kerala-Tamil Nadu border from Kottavasal, Achenkovil.*

Institution involvement:

Tamil Nadu Forest Department

* *Authors listed alphabetically*

IDENTIFYING CRITICAL AREAS FOR A LANDSCAPE - LEVEL WILDLIFE CORRIDOR IN THE SOUTHERN WESTERN GHATS

FINAL TECHNICAL REPORT

2011

FERAL

Executive Summary

Among the major challenges inherent in the conservation of large mammals is the necessity to maintain connectivity between disjunct populations, which can buffer them from the negative effects of demographic stochasticity and inbreeding. In the Periyar – Agastyamalai landscape of the southern Western Ghats, tiger (*Panthera tigris*) and elephant (*Elephas maximus*) populations were historically connected through a contiguous stretch of prime habitat. However, Periyar and Agastyamalai are now separated by the Shencottah Gap: a complex mix of land use types, human settlements and linear barriers. Restoration of landscape-level connectivity is a conservation necessity; consequently, there has been increasing interest over the past few years in corridor restoration in this landscape.

Despite recognition of the importance of connectivity, however, actual conservation planning and implementation of corridors has been hampered by the lack of fundamental scientific information critical to corridor design. The primary goal of this study was to provide a quantitative, scientific basis for connectivity restoration by empirically identifying corridors for seven focal large mammal species. We collected data on animal distribution and occurrence, related these to a wide range of habitat variables, and modeled potential corridors across the Shencottah Gap at a coarse scale. We also collected a wide range of socio-economic data to characterize settlements in this area, thus developing a profile of local communties and their relationship with wild habitat.

Our results show several gaps in connectivity for all focal species as a result of variation in habitat quality. Nevertheless, empirical data shows two regions through which animal movement can potentially be restored over the long term, given adequate institutional support. These occur in the western and eastern parts of the study area, and we have named them the MSL and Kottavasal corridors respectively (after the settlements near which they pass). Each corridor has its own advantages and disadvantages in terms of biological value and human presence. From the conservation perspective, restoration of both corridors would be most beneficial, because it would provide multiple movement routes for large mammals and hence stabilize the system as a whole. However, both of them pass through, or close to, a

variety of land use types, including forest patches, forestry plantations, private landholdings and settlements. Thus, restoration of these corridors will of necessity involve setting aside forest patches and engaging with local landowners to encourage wildlife-friendly practices on private land. Further, the presence of active community based groups (such as Vana Samrakshana Samithi, VSS and Eco-Development Committee, EDC) in the landscape can potentially be used to improve wildlife habitat in multiple-use areas within Reserve Forests.

Acknowledgements

We thank the Kerala and Tamil Nadu Forest Departments particularly the Chief Wildlife Warden and the Principal Chief Conservator of Forests for providing requisite permissions for fieldwork. In particular, we wish to thank the following officers for their help through the course of the study: the late Shri. V.S. Varghese, Shri. A.K. Bhardwaj, Shri. K.J. Varughese, Shri. K.I. Pradeep Kumar, Shri. K.P. Ouseph, Shri. H. Malleshappa, Shri. A. Ramkumar, Shri. Rampati and Shri J. S. Ambrose. We acknowledge the support of the Range Officers of Thenmala, Shendurney, Achenkovil and Tirunelveli Divisions, particularly, Shri. Sreekumar, Shri. Anwar, Shri. Koshy, Shri. Mayil and Shri. Solomon Rajan. We are grateful to the Rufford Small Grants Foundation, University of Gothenberg and Critical Ecosystem Partnership Fund for funding support. We thank local field staff for their participation in field surveys and following researchers who provided assistance and inputs during the course of the study: Ignatius Peliyas, Dr. E. Somanathan, Dr. Rauf Ali, Dr. Peter Bardsley, Gary Stonehman, Dr. H. S. Sushma, Rohini Mann, Siddharth Rao, T. Karthik and S. B. Shanthakumar. We thank the management of Ambanaad Estate, particularly Shri. R. Sharma, Shri. Venkatesan and Shri. T. Thomas for permission to rent accommodation there.

Introduction

In a densely-populated country like India, the conservation of landscape species such as the tiger (*Panthera tigris*) and elephant (*Elephas maximus*) present several unique challenges. Among the most significant of these challenges is that such species require large, well-protected blocks of natural habitat in order to obtain the resources necessary for their survival. For example, individual tiger home ranges in evergreen forest can be as large as 300 km^2 (Karanth *et al.*, 2009), and elephants may range over as much as 600 km^2 (Baskaran *et al.*, 1995, Vidya et *al.*, 2005). Yet, Protected Areas (PA's) in India average only 300 km^2 (Karanth *et al.*, 2010), and even the largest are relatively small when compared to the requirements of species such as these. Consequently, population sizes of large mammals within PA's in India are often relatively low.

Historically, such low animal abundance within PA's was of little conservation concern, because wildlife still occurred widely in the intervening Reserve Forests (RF's) between PA's. Practically speaking, therefore, animal populations were contiguous over very large areas. Such was the case in the southern Western Ghats, which contains two main complexes of PA's: Periyar (consisting of Periyar Tiger Reserve PTR and Srivilliputhur Wildlife Sanctuary) to the north, and Agastyamalai (consisting of Kalakkad-Mundanthurai Tiger Reserve KMTR and Shendurney, Peppara and Neyyar Wildlife Sanctuaries) to the south. Historical accounts (Travancore Administration Report, 1937) suggest that this entire landscape once formed a contiguous swathe of high-quality habitat from the perspective of a large mammal, such that an elephant or a tiger in Periyar could easily disperse to Agastyamalai (or *vice versa*) without much anthropogenic interference to its movement.

This situation, however, has changed substantially over recent decades. Human interference has greatly decreased animal densities in the region separating the two PA complexes, and also impacted the ability of animals to move between them. As a result, many of the large mammal species in Periyar and Agastyamalai are believed to be functionally isolated from each other. The isolation of such populations into well-protected 'islands' within a 'sea' of hostile habitat has significant implications for their survival and long-term persistence. Both theoretical and empir-

ical studies show that small, isolated populations are more vulnerable to extinction (Crooks and Sanjayan, 2006), because:
a) chance stochastic events (such as the failure of rains, or a disease outbreak) are more likely to drive a small population extinct than a large population;
b) small populations are more liable to inbreeding, which decreases genetic diversity and hence impacts their capacity to adapt to changing environmental conditions.

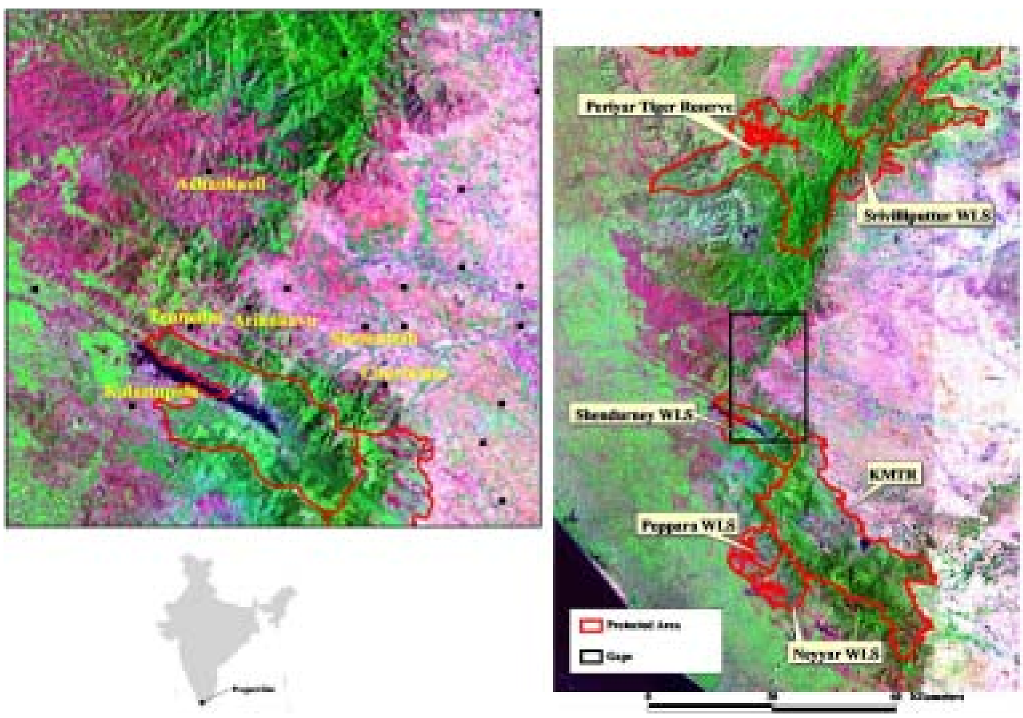
Such adverse effects, however, can be mitigated if animals are able to move between isolated populations (Haddad *et al.*, 2003) through corridors or other forms of connectivity. These distinct populations ('sources') can then exist as a stable, interconnected network. In such situations, stochastic decreases in animal abundance in one source population, or even local extinction, can be compensated by the immigration of fresh individuals from other sources. Further, if animals that disperse from their natal sources are able to establish themselves and breed in another source population, they can increase the genetic diversity of their adopted population. For these reasons, corridors have become a central part of large mammal conservation throughout the world (Beier and Noss, 1998) and in India as well (Project Tiger Directorate 2004).

In the southern Western Ghats, the Periyar and Agastyamalai landscapes are separated by the Shencottah Gap, which consists of a complex mix of habitats, land uses and linear barriers (Figure 1). Much of the original natural vegetation has been replaced with plantations of teak (*Tectona grandis*), acacia (*Acacia spp.*), eucalyptus (*Eucalyptus spp.*), and rubber (*Hevea brasiliensis*), and are managed in ways that are not conducive to large mammal use or movement. The remaining natural vegetation consists of patches of moist and dry deciduous forest, scrub and grassland. Over 30 human settlements are spread within the Shencottah Gap, resulting in significant pressure on natural resources. Finally, a busy inter-State highway (NH 208), a railway line (connecting the towns of Punalur and Shencottah) and a 400 KV power line form significant linear barriers. The proliferation of all the above human impacts has greatly affected large mammal movement across the Shencottah Gap; for example, elephants are not thought to have moved between Periyar and Agastyamalai since the 1980's (Johnsingh and Williams, 1999).

Such movement, however, may be critical to the long-term viability of large mammals in this region. Connectivity is of particular concern for tigers, which are estimated at no more than 23-30 and 9-15 in the Periyar and Agastyamalai landscapes respectively (Jhala *et al.*, 2008). In the case of elephants, the Periyar population is relatively large (1400-1900; Menon *et al.*, 1997), but is still recovering from poaching of tuskers in the 1970's and 80's, which greatly decreased mature tusker numbers (Sukumar *et al.*, 1998). The smaller Agastyamalai population (150-200; Menon *et al.*, 1997) could help redress this genetic imbalance by acting as a source for mature males, and itself be stabilized demographically through connectivity with the much larger Periyar population. Restoration of elephant and tiger corridors, therefore, has been recognized as a conservation priority in the southern Western Ghats by several authorities (*e.g.*, Menon *et al.*, 2005; Johnsingh *et al.* 2008; Elephant Task Force, 2010).

Despite this widespread recognition, however, the on-ground implementation of corridors across the Shencottah Gap has been hampered by the lack of systematic, quantitative data on animal distribution and movement. As a result, several questions that are critical to corridor design remain unanswered. For example, which large mammal species are most affected by the lack of connectiv-

Figure 1. Location of study site within India, with the region of immediate conservation concern marked. Forested areas appear in dark green, and forestry/cultivated areas in different shades of pink.



ity? Where exactly should corridors be located? Which land-use types enhance animal use, and which ones inhibit animals? How can corridors be made to work effectively over the long term in this human-dominated landscape?

Such questions require urgent answers for successful restoration of connectivity across the Shencottah Gap. Further, corridors must be identified keeping in mind the following generalisations made from the worldwide scientific literature:

a) Corridors must be based on a direct understanding of the habitat-selection processes used by animals in their movement (i.e., functional criteria), rather than structural measures of connectivity from the human perspective (Belisle, 2005). Thus, simple visual studies based on forest contiguity may not necessarily reflect an animal's perception of connectivity (Chetkiewicz et al., 2006). Instead, corridors must be designed on the basis of the locations that animals are actually found in, versus those locations where they are absent.

b) Corridors are often species-specific (Beier et al., 2008); therefore, a corridor that is suitable for one species may not necessarily work for another. A multi-species approach is therefore required for broad scale connectivity planning.

c) Corridors may function at multiple scales, ranging from short daily foraging movement to large scale dispersal and migration (*e.g.*, Chetkiewicz *et al.*, 2006). Therefore, corridor dimensions must be chosen based on site-specific conservation requirements. In the current context, corridors must be planned at the landscape level - *i.e.*, at a scale that will ensure connectivity between large mammal populations of the Periyar and Agastyamalai complexes, rather than small corridors covering just the region of the highway.

To meet the need for such a scientific study, Foundation for Ecological Research, Advocacy and Learning (FERAL) initiated a long-term research and conservation project on large mammal connectivity across the Shencottah Gap in 2008. This final technical report summarizes two years of research under research permit number WL 12-4012/2008 dated 19 July 2008 in Kerala, and WL5/49230/2008 dated 30 October 2009 in Tamil Nadu.

Objectives

The overall goal of this study was to identify landscape-level wildlife corridors for multiple large mammal species, and hence lay the scientific foundations for the restoration of these corridors across the Shencottah Gap. The specific objectives of this study were to:

a) identify areas that large mammals currently use, and intensity of this habitat use across the landscape;

b) identify areas they could potentially use in the long term, as part of a landscape level wildlife corridor; and,

c) evaluate the socioeconomic profile and relationship of local communities with forests and wildlife.

The main target species of this study were tiger, elephant, gaur (*Bos gaurus*) and lion-tailed macaque (*Macaca silenus*), based on their 'umbrella species' characteristics. However, we also collected data on ten other large mammal species during the course of our field work. Of these, we present here data on the following conservation-dependent species: leopard (*Panthera pardus*), dhole (*Cuon alpinus*) and Nilgiri langur (*Semnopithecus johnii*).

A panoramic view of the landscape within the Shencottah gap showing a mix of plantations, homesteads, remnant patches forests and grasslands.

Study Area

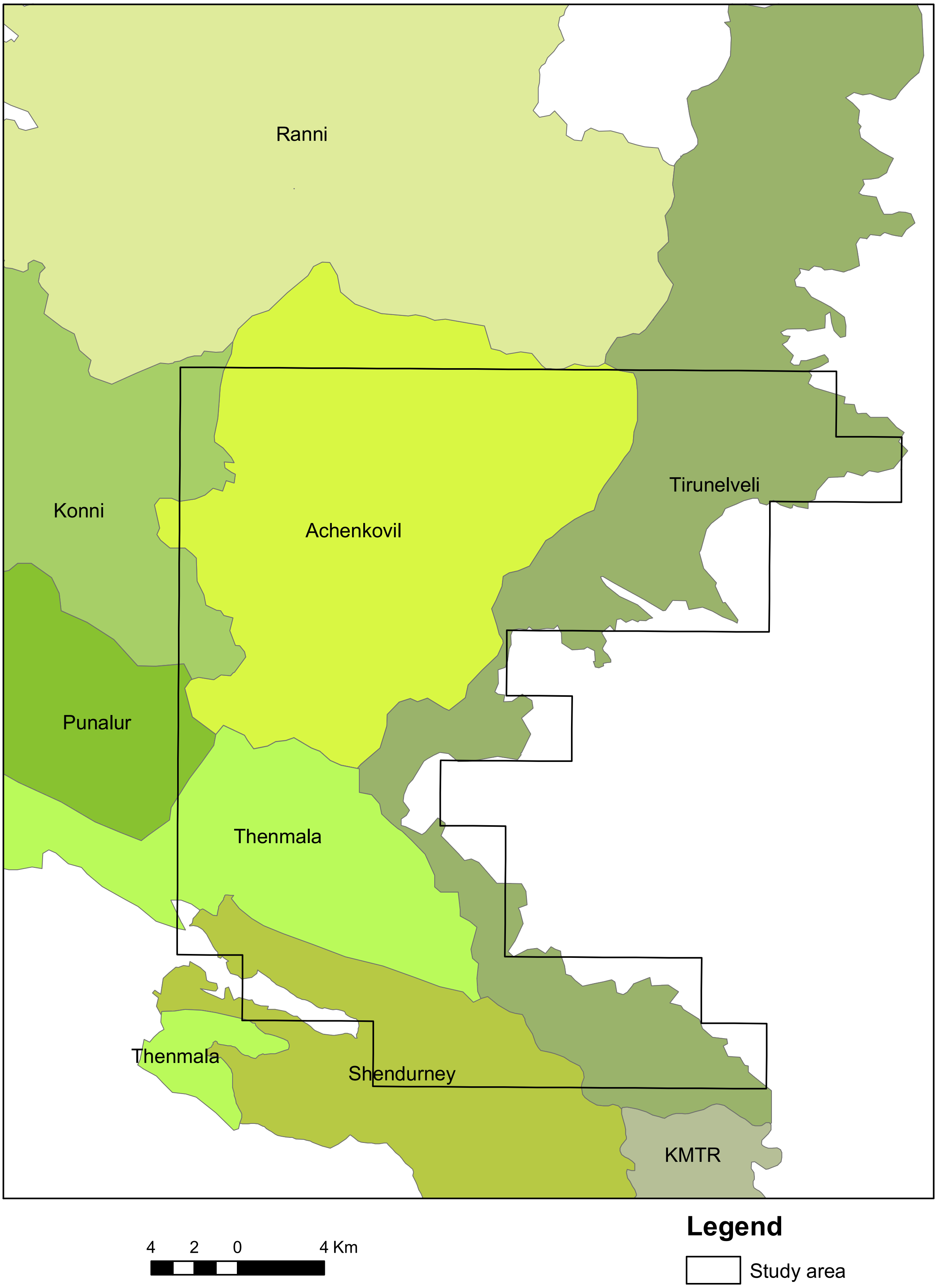
The study area (Figure 2) is the landscape along the hill ranges on either side of the Tamil Nadu-Kerala border between Ranni Division in the north and Shendurney Wildlife Sanctuary in the south. It incorporates (in whole or part) the following forest divisions and PAs of Kerala: Ranni, Konni, Achenkovil, Punalur, Thenmala and Shendurney. In Tamil Nadu, the study area covers the Tirunelveli division.

The original vegetation on the windward slopes of the study area was dominated by wet forests of the West Coast Tropical Evergreen Forest (1A/C4) and Southern Moist Mixed Deciduous Forests (3B/C2) types. The rain shadow areas along the leeward slopes were covered by the Southern Dry Mixed Deciduous Forest (5A/C3) and the Tirunelveli Semi-Evergreen Forest (2A/C3) types, along with small patches of the above wet forests (Champion and Seth, 1968). This landscape is home to a diverse array of fauna, including 225 species of birds, 17 species of amphibians and 32 species of large mammals (>3 kg body weight). These include the following threatened or endangered mammals: elephant, tiger, gaur, dhole, lion-tailed macaque, Nilgiri marten (*Martes gwatkinskii*) and Nilgiri tahr (*Nilgiritragus hylocrius*).

The forests within the study area come under some of the oldest forest divisions in the country, and have been managed for more than a century now. Historically, the primary focus of management efforts was on maximising timber pro-

Leopard (Panthera pardus) among tea bushes, they are known to use all kinds of habitats.

Figure 2: Location of study area along with administrative boundaries of forest divisions.



duction. As a result, large swathes of the original vegetation have been replaced by soft and hard wood plantations, and more recently, private holdings of rubber and mixed crops. Increased cultivation, expansion of rubber estates, construction of dams and improvement of road networks have contributed to an increase in human populations over the last three decades. Private enclosures within forest areas in the study region are listed in Appendix 1.

In the 1980's, the management focus began to gradually shift from timber production to water and biodiversity conservation, with the formation of Shendurney Wildlife Sanctuary. Soon after, a paradigm shift in policy from exclusionist forest management to joint management with local communities also began. As a result, communties began to be involved in conservation-related activities and in sustainable use of forest resources through Vana Samrakshana Samithis (VSS) and Eco-Development Committees (EDC). Despite considerable progress in management practices, however, little past attention has been paid to the importance of these areas for large mammal movement. Nevertheless, this situation has been changing over the past few years, and there now appears to be increased recognition that this landscape needs to be managed as a critical wildlife corridor between Periyar and Agastyamalai.

Habitat destruction and poaching have endangered the Lion-tailed Macaque (Macaca silenus), these macaques are know to inhabit dense tropical evergreen forests.

Methods

Biological Surveys

Overall approach

There exist several methodological approaches for the identification of wildlife corridors. A simplistic approach involves using remotely-sensed data in a Geographic Information System (GIS) to identify structural connectivity between sources (*e.g.*, Vogt *et al.*, 2007). More reliable studies are based on dividing the study area into gridded cells, and estimating the 'resistance' of each cell to animal movement. Resistance signifies the degree to which a cell hinders animal movement; thus, low-resistance cells enhance animal movement, while high-resistance cells inhibit movement. The resistance of a cell to the movement of a particular species is a function of the habitat characteristics within that cell. Thus, estimating resistance values in relation to habitat characteristics is the key to empirical methods of corridor identification.

Once resistance values are estimated, a number of different algorithms can be used to identify a corridor design that minimizes the cumulative resistance encountered by an animal moving between two sources. Least-cost path analysis (Beier *et al.*, 2008) is the simplest way to identify corridors based on resistance values, and results in the identification of a single 'best' corridor. However, increasingly sophisticated algorithms enable multiple potential pathways between source populations to be modeled. Such models are much more realistic than simple least cost methods, because they do not rely on the assumption that a dispersing animal will necessarily use the 'best' route. Specific analytical frameworks for identifying movement routes include individual-based movement simulations (*e.g.*, Hargrove *et al.*, 2005), graph theory (Urban and Keitt, 2001) and circuit theory (McRae *et al.*, 2008).

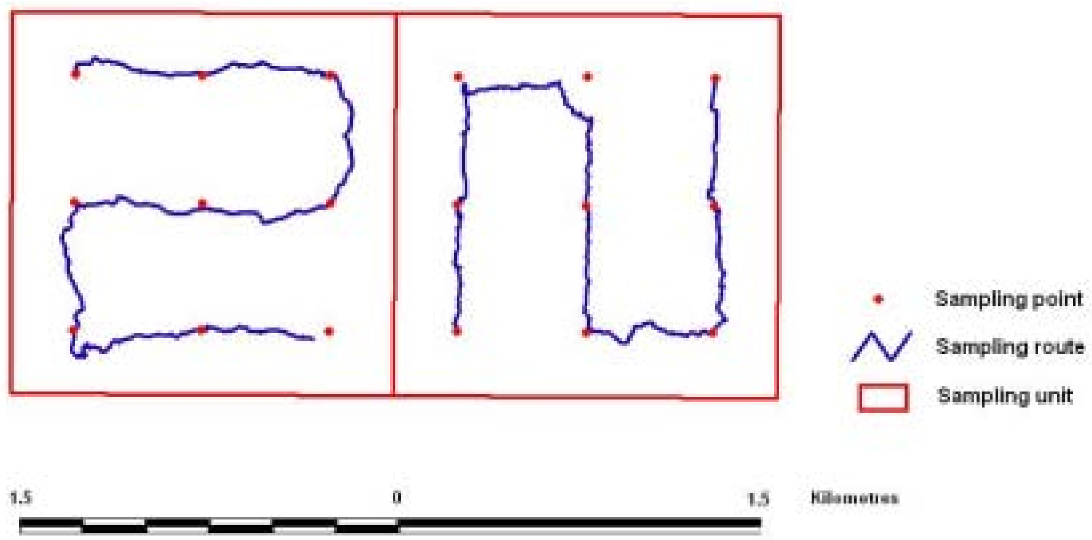
For our analysis, we used habitat occupancy models (MacKenzie *et al.*, 2006) to estimate resistance. Habitat occupancy models are a significant improvement over most regression-based frameworks (such as resource selection functions; Boyce *et al.*, 2002 and habitat suitability models; Engler *et al.*, 2004) because they account for an extremely important factor: incomplete detection of animals and their signs during surveys. If a species is not detected in a given area during a survey, it could either mean that it was genuinely absent, or that it was present but not detected by the surveyors. Ignoring this reality can lead to incorrect inferences being made when estimating animal distribution and use of the landscape (Gu and Swihart, 2004). Once resistance values were estimated using habitat occupancy methods, we modelled corridors over the study area using circuit theory. We describe below our specific field and analytical protocols.

Field methods

We superimposed a grid of 1.5 x 1.5 km cells for herbivores and 3 x 3 km cells for carnivores over the study area. We arrived at these cell sizes based on several simulations, trading-off finer detail against the need to collect data at a scale that is meaningful for multiple landscape species. We then carried out surveys for herbivore and carnivore signs in each cell, following two different sampling protocols for each group. We note that our data is amenable to future resampling and analysis at smaller scales (upto a resolution of 500 m).

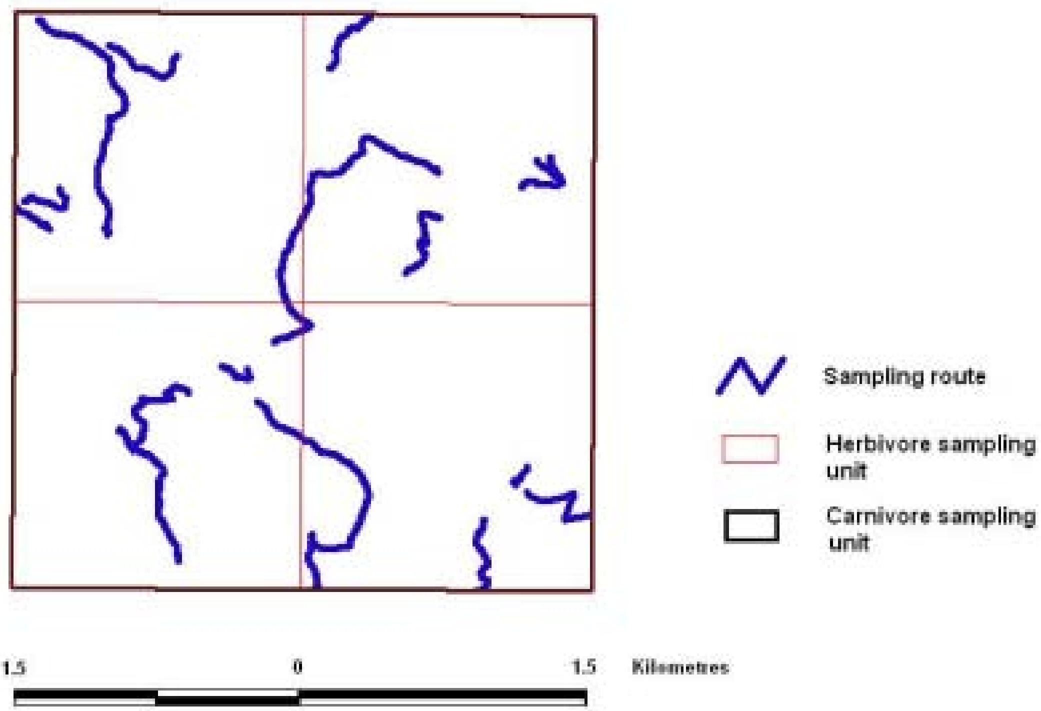
For herbivores, we systematically placed nine points within each cell, such that each point was 500 m away from its nearest neighbors. We then carried out surveys by starting at one of the corner points, and walking to the next point in as straight a line as possible, forming an S-shaped pattern overall as we walked

Figure 3: Herbivore sampling design, showing the placement and coverage of 500-m spatial replicates.



from point to point (Figure 3). We attempted to walk along animal paths and trails that were oriented in the desired direction of sampling to increase detection probability, although in most cases we did not find such paths and walked directly through the forest instead. The start point and orientation of the 'S' was based on logistical convenience. Each 500-m segment walked between two points was treated as a replicate survey within a cell. Field teams recorded both animal sightings and signs such as tracks, dung, scat and calls once every 100 m as they walked along each segment. Coordinates of each detected sign, as well as movement tracks of field teams were recorded using hand-held GPS units (Garmin EtrexTM; Garmin Ltd.). Deviations from the straight line connecting any two points were kept to the minimum, except in unavoidable circumstances (for example, when the line passed along steep rock faces). In addition to animal signs and sightings, we recorded variables (covariates) expected to influence both the detectability of animal signs, and probability of cell use by the focal species. For each 500-m segment, we collected these covariates at five equally spaced points. At each of these five points, we laid out a $1m^2$ quadrat, and recorded the following detectability covariates:

Figure 4: Carnivore sampling design, showing the placement of sampling routes.



a) visual estimates of the percentage of ground covered by soil, rock, ground vegetation and leaf litter;
b) leaf litter depth at four locations within the quadrat; and,
c) soil moisture classified into three categories.

We also measured the following biological covariates as indicators of habitat quality:
a) evidence of any human disturbance activities including poaching, extraction of non-timber forest produce, logging, and presence of fires;
b) presence of *Lantana camara* and *Eupatorium odoratum*, two invasive species associated with disturbed habitat;
c) visual estimates of canopy height; and,
d) visual estimates of the number of distinct canopy stories.

For carnivores, we followed similar sampling protocols as above, with one major difference (Figure 4): we carried out sign surveys along roads and trails (hereafter, trails), because these offer a higher probability of detecting carnivores if they are present in the area (Karanth and Nichols, 1998). Similar to the herbivore surveys, we considered 500 m of sampling to constitute a spatially replicated segment, and we recorded animal signs and covariates using the same protocols as described above.

Estimating probability of habitat use

Under the habitat occupancy models of MacKenzie *et al.*, 2006, the probability of detecting a species in a cell (p) can be estimated using replicated detection-non detection data, and as a function of appropriate covariates. We used the spatially replicated 500-m segments within each cell to estimate cell-specific detection probabilities. Similarly, we modeled the probability of use (Ψ) for each cell as a function of cell-level covariates (see Mackenzie *et al.*, 2006 for a detailed statistical formulation of this model). We used a combination of physical, biological and anthropogenic covariates to describe probability of use. Candidate covariates differed for herbivores and carnivores, because of their fundamentally different life history traits as well as the difference in the spatial resolution of their data (different cell sizes). The covariates used for modeling detectability and probability of use are described below.

Detectability covariates

a) Segment length: As it was not always

possible to walk in a straight line between two sampling points, segments were not exactly 500 m in length. As detection probability can vary with segments lengths (*i.e.*, more sampling effort), we used segment length as a detectability covariate.

b) Ground cover: Because the detectability of signs such as tracks and scats may vary depending on the proportion of the ground that is covered by leaf litter or grass, we calculated the percentage of ground cover within our quadrats as a detectability covariate.

Habitat covariates (herbivores)

a) Elevation: A majority filter was used on a 30-m ASTER Digital Elevation Model to characterize the elevation for each cell.

b) Wetness index: The DEM was used to derive a wetness index (Ambroise, 1996) as surrogate for water availability (Zhu *et al.*, 2001). The average value for each cell was used as a covariate for analysis.

c) Terrain ruggedness: Using the slope derived from the DEM, we estimated the ruggedness of the terrain as the co-efficient of variance of slope within each cell.

d) Urbanization rate: We used a time series of night light images from 1992-2004 (Elvidge *et al.*, 2009) to calculate an index of population growth/ urbanization rates. The avarage rate of change

Dhole (Cuon alpinus) are known to restrict themselves entirely to forests but are occasionally seen ranging in plantations abutting forest patches.

for every cell was used for analysis.

e) Eco-climatic distance: This index represents the Mahanolobis distance of the vegetation in a particular cell from a reference category of wet evergreen forest. 16-day Enhanced Vegetation Index (EVI) layers from MODIS 250-m data were used to derive three bands: maximum EVI for the dry season, maximum EVI for the late dry season, and co-efficient of variance for the entire dry season.

f) Minimum distance to human settlement: Using the centroids for all human settlements within a 5-km radius of the study area, the distance from a cell centroid to the nearest settlement was calculated.

g) Road index: All public access roads within a 5-km radius of the study area were mapped and classified into categories based on their level of traffic density. Each category was assigned a weight (based on field observations of vehicular traffic). The distance of a cell from the nearest road, weighted by vehicular usage of that road, was used to estimate an index of road impact on each cell.

h) Primary productivity: As a surrogate of net primary productivity within a cell, we used the EVI layer from MODIS data to calculate mean of the maximum EVI attained during the study period.

i) Human disturbance: We modeled data on the detection of human disturbances using the methods of Royle and Nichols, 2003, and hence developed a cumulative, ground-based index of human disturbance.

k) Ground-based covariates: On-ground covariates collected during the course of surveys (canopy cover, canopy storeys and grass cover) were directly used as habitat quality covariates.

l) Land-use: Each cell was assigned to simple land-use classes, which included natural vegetation, forestry (timber plantations), and intensive human use (commercial crops).

Habitat covariates (carnivores)

a) Prey index: We summed the probabilities of use (derived from the herbivore habitat use models) to calculate a prey index for each carnivore cell, dividing them into small prey (muntjac *Muntiacus muntja*k and mouse deer *Moschiola indica*), medium prey (sambar *Rusa unicolor* and wild pig *Sus scrofa*) and large prey (gaur).

b) Forest cover: We estimated the proportion of forest in each cell based on EVI data.

c) Minimum distance to human settlement: as above.

d) Road index: as above.

e) Human disturbance: as above.

We carried out the habitat use analyses in the statistical software R (R Development Core Team, 2010), using the library *unmarked* (Fiske *et al.*, 2010). We first tested all covariates for correlation using Spearman's Rank Correlation, and did not use covariates that were highly correlated ($r > 0.6$) in the same model. Because of the huge number of potential candidate models possible with all the above covariates, we first modeled detectability, chose the best detectability model, and then modeled probability of use. We modeled detectability as a function of segment-level covariates using a forward selection procedure based on the Akaike Information Criterion (AIC; Burnham and Anderson, 2002). The AIC score is a measure of the explanatory power of the model, and it trades off model complexity with parsimony. Lower AIC scores indicate a better model. We began with univariate models, and chose the model that minimized AIC. For every step of this procedure, we then fitted each of the remaining covariates in turn and added the one that resulted in the greatest drop in AIC to the model. We continued this procedure until it yielded no further decrease in AIC.

After accounting for detectability, we modeled habitat use by keeping the selected detection covariates constant across all models. We followed the same stepwise procedure described above for selecting covariates influencing habitat use. We ranked models based on the difference in AIC between them (ΔAIC). We also calculated the AIC weight for each model, which is proportional to the AIC score and describes the strength of each model out of the entire model set. To incorporate uncertainty in model selection, we used a model averaging procedure (Burnham and Anderson, 2002) for our final estimates of detectability and habitat use. Using this procedure, parameter estimates from each model are weighted by their AIC weight, and then averaged to derive robust parameter estimates. We summed the AIC weights of the top five models in which the covariate occurred to estimate the importance of each covariate in determining animal use. We also compared modeled estimates of probability of use with naive estimates derived directly from encounter rates, to assess the importance of accounting for detectability in estimating habitat use.

Corridor identification

The analytical procedure described above resulted in cell-specific estimates of probability of use. To convert these estimates to resistance, we subtracted probability of use from 1:

Resistance = 1 – Ψ

Thus, we obtained a resistance surface over the Shencottah Gap for each species. We then incorporated this surface into a circuit theory algorithm to estimate levels of animal flow across the study area, and hence identify potential movement corridors. We used the statistical program Circuitscape (McRae *et al.*, 2008) for this purpose.

We first identified the locations of the source populations, which consist of well-protected areas with high level of animal use. We chose Gudrikal Range of Ranni Division and the southern half of Shendurney Wildlife Sanctuary as the northern and southern large mammal sources respectively. We used a pairwise algorithm with eight neighboring cells to incorporate spatial correlation in resistance value between cells. The output from this analysis resulted in a current density map, with higher current densities indicating cells with higher net passage probabilities between sources. Areas with higher net passage probabilities indicate potential movement corridors. Once these maps were developed for each species, we overlaid them within a GIS, and took the common corridor areas (union function) to identify potential multi-species corridors.

Socio-economic surveys

Distinct settlements as recognized by the local populace were first identified and mapped using a hand-held GPS, following which socio-economic surveys of all settlements were conducted through structured interviews and focus group discussions. The objective of these exploratory surveys was to obtain a snapshot of each settlement with respect to demography, occupation, landholding, land use, land costs and the presence of civil society groups. A sample-based household questionnaire survey, covering 30% of the households in each settlement, was then carried out to obtain the following specific information:

a) Crop profitability: To estimate net profits derived from different crops, we collected information on input costs (including labour), and yield per acre of land.

b) Human-wildlife conflict: We collected information on the existance of human-wildlife conflict in terms of crop raiding by wild animals, the main conflict species and perceived solutions to this problem.

c) Resource use: We identified the resources collected by local residents from forests, as well as spatial variation in resource use between settlements.

d) Conservation attitude and motivation: We asked respondents to rank their concern about the loss of wild plant species, wild animal species and wild habitat. We then identified the motivation for these attitudes by classifying responses into four categories: (i) utilitarian: economic importance or use to the resource; (ii) moralistic: a creationist view to the importance of the resource; (iii) aesthetic: appreciation of beauty and nature; and, (iv) ecological: role played by the resource in ecological functioning. We also assessed whether concerns about biodiversity loss and motivation to conserve varied with three drivers: location of settlement, exposure to conservation issues (through membership in VSS or EDC) and economic status (size of land holding).

Data collection in progress.

Results

Biological surveys

A total of 332 herbivore and 99 carnivore cells within an area of 891 km^2 were surveyed in the dry seasons between November 2008 and June 2010, with a total sampling effort of 1193 km for herbivores and 452 km for carnivores. This resulted in a total of 2471 segments in which we detected the focal species, of which detections per unit effort were lowest for lion-tailed macaque and highest for elephants (Table 1).

Probability of use and covariates affecting use

Detection probability of herbivore signs was influenced by sampling effort (i.e., distance walked per segment) and amount of ground cover, whereas carnivore detection probability was influenced by sampling effort. The resulting mean estimates of detection probability for the entire study area were lowest for lion-tailed macaque and highest for elephants (Table 2).

Once encounter rates were corrected by the above detectability parmeters, resultant mean estimates of habitat use for the study area ranged from 0.18 for tigers to 0.82 for elephants (Table 2). We note that correcting for detectability resulted in substantial increases in estimates of habitat use; for example, the mean probability of use for tigers increased by 50% once detectability was incorporated into estimates. Cell-specific estimates of habitat use (Figure 5) indicate wide spatial variation in probability of use across the Shencottah Gap for all species.

Table 2: Summary statistics of the number of segments in which each species was detected out of the total segments surveyed.

Species	Detections	Surveyed
Elephant	1055	2106
Gaur	842	2106
Lion-tailed macaque	22	2106
Nilgiri langur	255	2106
Tiger	15	877
Leopard	173	877
Dhole	109	877

Covariates affecting habitat use also varied widely between species (Table 3), and included physical, biological and anthropogenic variables. For the megaherbivores and carnivores, human-related covariates formed the majority of the variables affecting habitat use, whereas the additive/ correlational effect of these covariates along with biological and physical attributes were more important for the primates. For elephant, gaur and Nilgiri langur, land-use played a role in determining probability of use; intensive human use had a negative effect, forestry had a small positive effect, and natural vegetation had a large positive effect. Prey species use was a major determinant of cell use by all three carnivores.

Corridor identification

Analysis of connectivity under a circuit theory framework indicated that the strengths of potential movement pathways varied across species, reflecting differences in dispersal probabilities across the gap. Potential movement corridors for most species tend to concentrate towards the eastern edge of the Shencottah Gap (Figure 6). However, a secondary corridor occurs on the western edge of the study area, which is particularly evident for elephants and the primates. For all species, however, the eastern corridor had higher passage probabilities than the western corridor.

Superimposition of corridors for all the focal species resulted in the identifica-

Table 3: Summary statistics of model-averaged estimates for each species, giving detection probability (p), naïve estimate of habitat use (naive ψ) and modelled estimates of habitat use (ψ), along with standard errors for modelled estimates. All estimates are averaged over the entire study site.

Species	p (SE)	naïve ψ	ψ (SE)
Elephant	0.62 (0.02)	0.8	0.82 (0.06)
Gaur	0.54 (0.02)	0.71	0.73 (0.06)
Lion-tailed macaque	0.07 (0.03)	0.06	0.23 (0.14)
Nilgiri langur	0.31 (0.02)	0.37	0.46 (0.06)
Tiger	0.11 (0.002)	0.09	0.18 (0.01)
Leopard	0.23 (0.13)	0.69	0.77 (0.01)
Dhole	0.19 (0.12)	0.48	0.62 (0.04)

Table 4: Covariates selected for each species (consisting of those in the top 5 models), covariate weights (consisting of cumulative AIC weights of the respective models in which these covariates occur) and effect direction. For a given species, higher covariate weights indicate greater influence, while low variation in weights between covariates indicate similar levels of influence. Land-use effects are for natural vegetation, intensive human use and forestry. Although natural vegetation and forestry had positive effect on use, the effect size for natural vegetation was higher than forestry.

Species	Habitat covariate	Covariate weight	Effect
Elephant	Grass cover	0.96	-
	Distance to settlement	0.96	+
	Land-use	0.85	+-+
	Elevation	0.81	+
	Human disturbance	0.64	-
	Urbanization rate	0.21	-
Gaur	Road index	0.90	+
	Urbanization rate	0.90	-
	Grass cover	0.73	-
	Eco-climatic distance	0.20	+
	Land-use	0.11	+-+
Lion-tailed macaque	Canopy storeys	0.32	+
	Eco-climatic distance	0.32	-
	Terrain ruggedness	0.25	-
Nilgiri langur	Canopy cover	0.97	+
	Eco-climatic distance	0.97	-
	Elevation	0.96	+
	Distance to settlement	0.73	+
	Canopy storeys	0.28	+
	Land-use	0.24	+-+
Tiger	Medium prey use	0.21	-
	Forest cover	0.12	+
	Human disturbance	0.09	-
Leopard	Small prey use	0.3	+
	All prey use	0.1	+
	Road index	0.08	+
	Forest cover	0.08	+
	Human disturbance	0.08	-
Dhole	Medium prey use	0.8	+
	Human disturbance	0.46	-
	Distance to settlement	0.18	+
	Forest cover	0.08	+

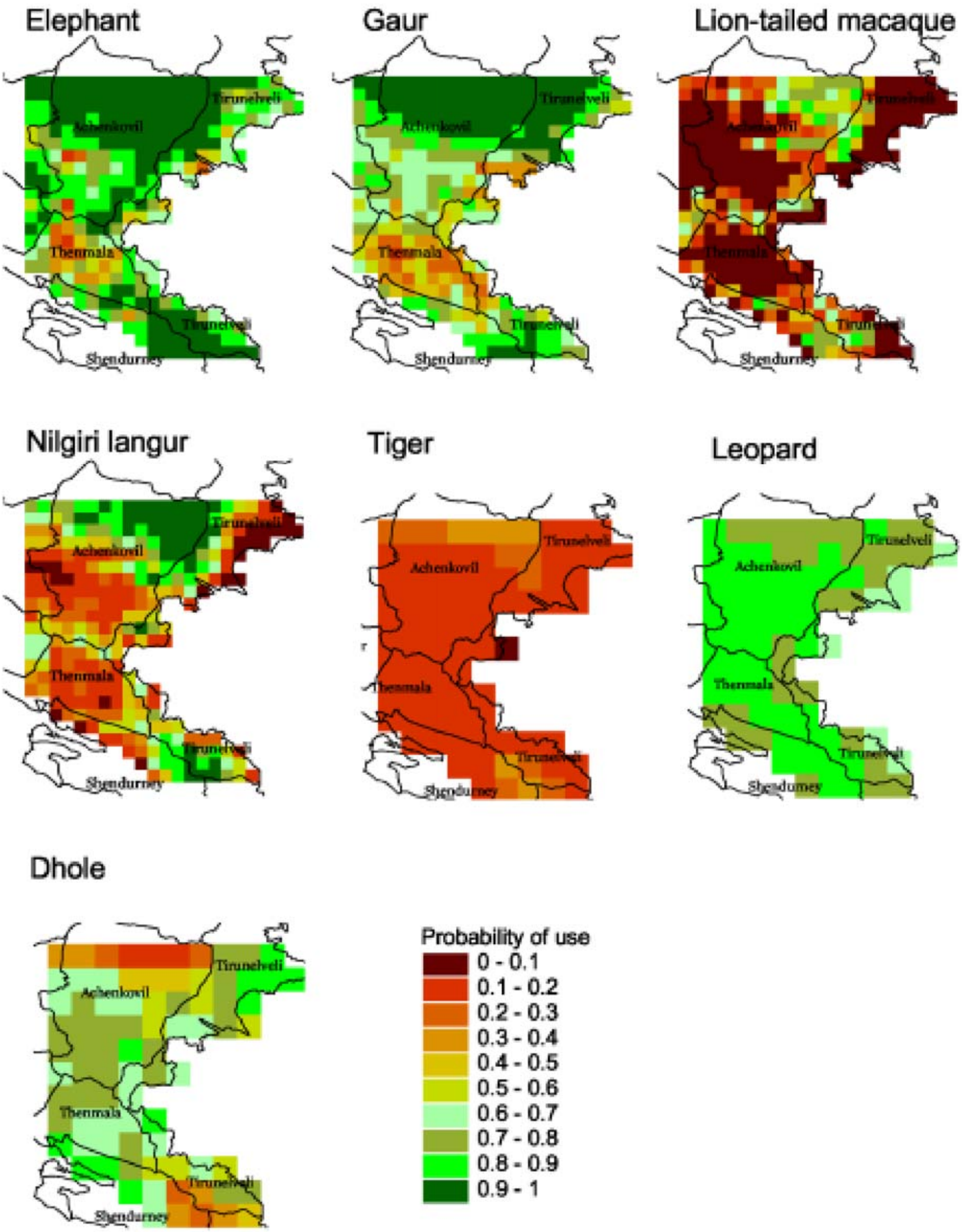


Figure 5. Spatial distribution of focal species habitat use.

Figure 6. Modeled movement pathways indicating potential north-south corridors over the Shencottah Gap for each focal species. Higher current densities (positive values, indicated by darker shades of green) denote cells with higher net passage probabilities.

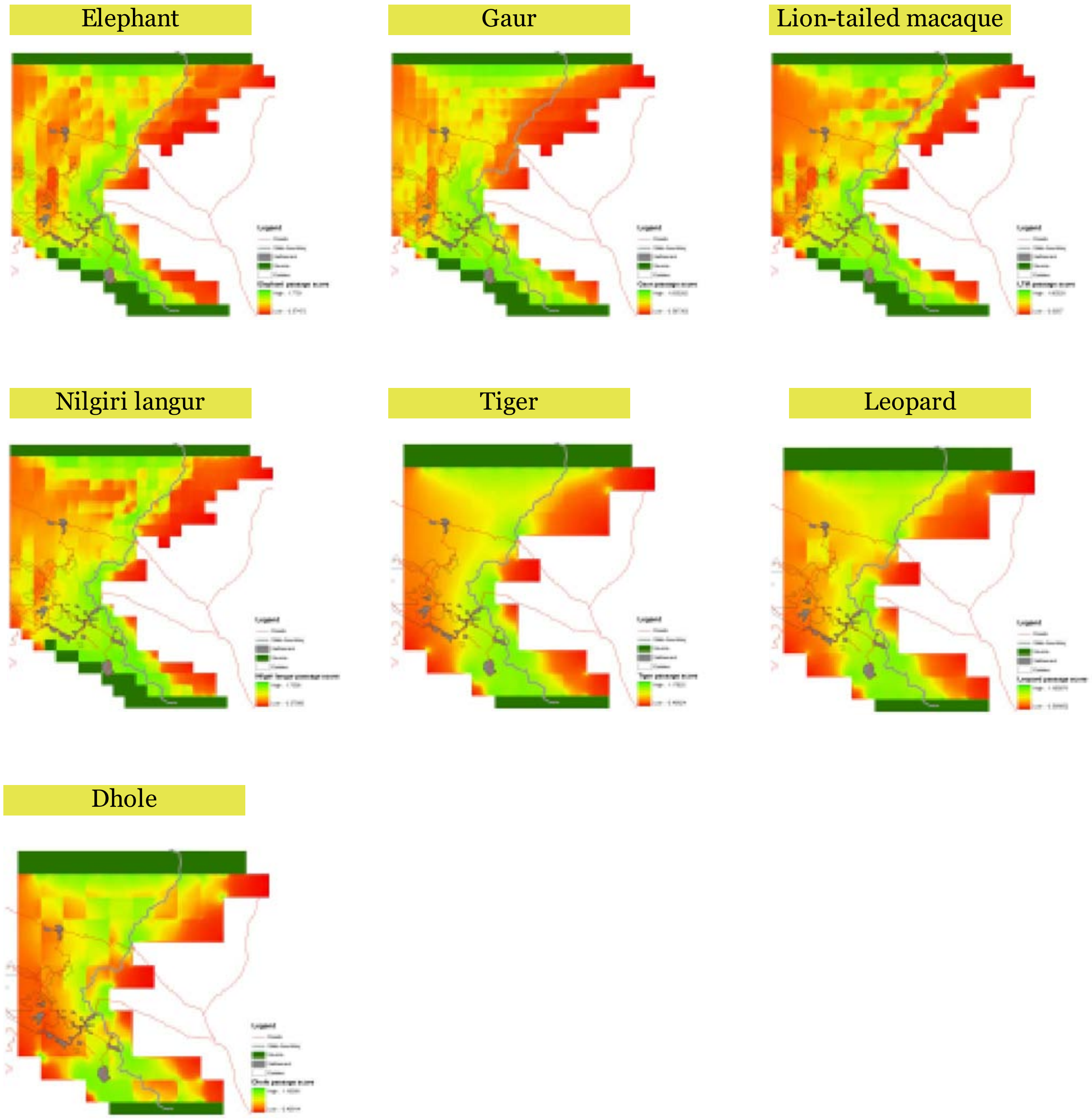


Figure 7. Potential locations of multi-species corridors across the Shencottah Gap, overlaid on forest divisions and settlements/ estates.

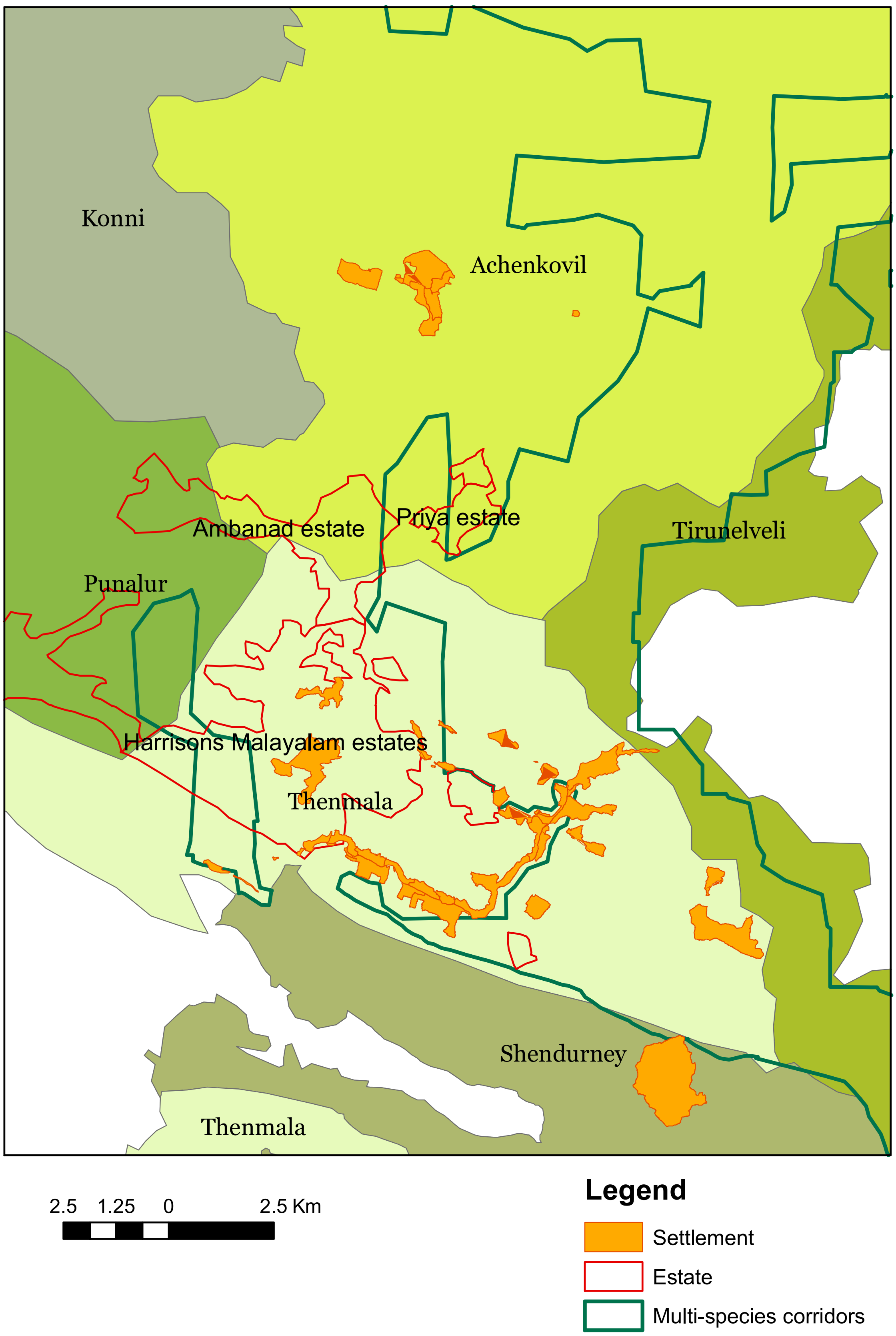
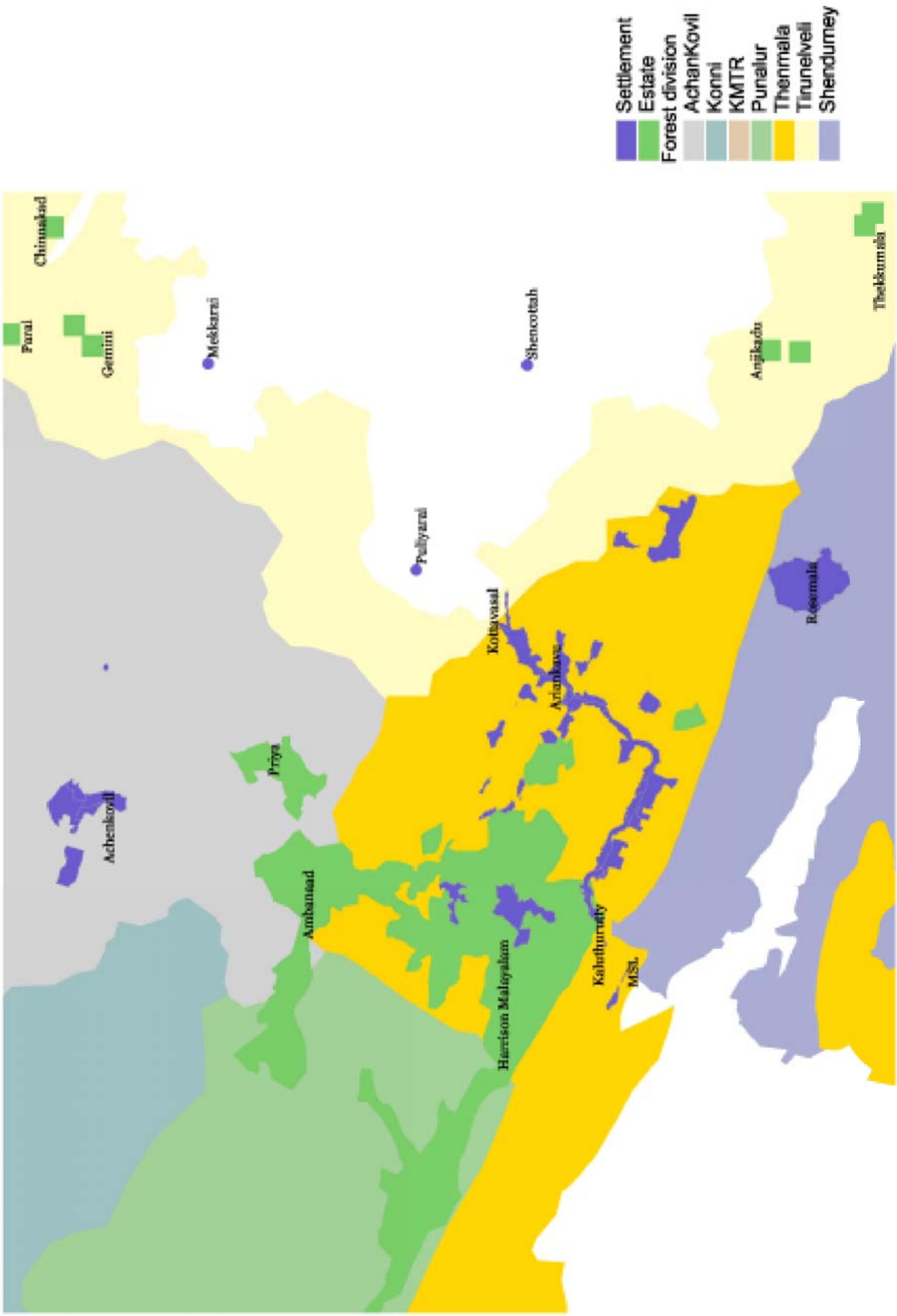


Figure 8: Locations of all settlements and estates within the study area, with major ones labelled.



tion of two potential multi-species corridors over the Shencottah Gap, located close to the western and eastern edges of the study area (Figure 7).

Socio-economic surveys

A total of 38 settlements (Figure 8) lie within the study area, of which all except Rosemala are part of Thenmala and Ariankavu Grama Panchayats in Kerala (Rosemala is part of Kulathupuzha Panchayat, although access to this settlement is from Ariankavu). There are no human settlements within the forested areas in Tamil Nadu. However there are 9 private estates in various stages of functionality. Demographic and land holding patterns of each settlement are described in Appendix 2.

Occupation and profitability

Land costs in the settlements varied from Rs. 30,000 to 20,00,000 per acre (Appendix 2), and was influenced by proximity to the National Highway and Ariankavu/Thenmala towns, and clear ownership titles. The primary occupation in these settlements is agriculture, followed by agricultural labour, with a small fraction of people working in the service sector. The primary crop is rubber, followed by pepper and coconut. Results from the crop productivity surveys shows that rubber yielded maximum profits per acre in the year 2009 (Table 4).

Table 5: Mean annual profit per acre for all cash crops in the study area.

Crop	Average annual profit (Rs./acre)
Rubber	90,000
Banana	30,000
Coconut	25,000
Pepper	20,000
Clove	7,000
Pineapple	400

Human-wildlife conflict

Crop raiding by wild animals was common in all settlements, and problematic animals included porcupine (*Hystrix indica*), wild pig, sambar, bonnet macaque (*Macaca radiata*) and elephant. A large majority of respondents (Figure 9) perceived fencing as the best solution to crop raiding, followed by habitat improvement around settlements. Resettlement was suggested only by a small number of respondents overall, but all respondents from Palaruvi, 8 Acre and 20 Acre settlements suggested resettlement as the best solution to crop raiding.

Resource use

Local communities depend on the forest for various resources including firewood, water, fodder and non timber forest produce (NTFP). People from all settlements collect fire wood. Fodder was collected only by residents of Kadamanppara, Pandiyanppara and Kottavasal, while NTFP was collected by residents of Achenkovil Harijan Colony and the Karippinthottam Harijan Colony. NTFP was the only forest resource being collected for commercial purposes, and the income from the sale of NTFP contributed around 20-25% of total annual income of respondents. Fire wood was

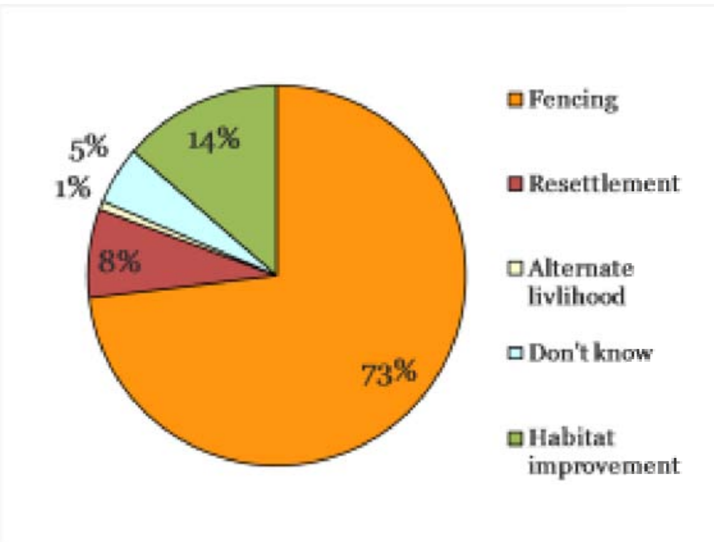


Figure 9: Summary of suggested solutions to crop raiding by respondents.

primarily collected from forest areas (Figure 10), and for personal consumption. On average, households that were entirely dependant on forests for firewood consumed about 33 kg per week.

Conservation attitude and motivation

Respondents appeared to be primarily concerned about the loss in plant species, with loss of habitat being secondary, and only 1% being concerned about loss of animal species in their surrounding areas (Figure 11). However, membership of VSS/ EDC (and hence exposure to conservation issues) appeared to influence their level of concern (Table 5) for both animal and habitat loss.

When the motivation of respondents to conserve biodiversity was classified, utilitarian motives emerged as the main reasons for the willingness to conserve plants and wild habitat (Figure 12). These concerns were influenced by settlement location, but not by exposure to conservation issues or economic status (Table 6) indicating the need for additional awareness generation programmes. However, 91% of the respondents were willing to participate in conservation initiatives, given adequate incentives.

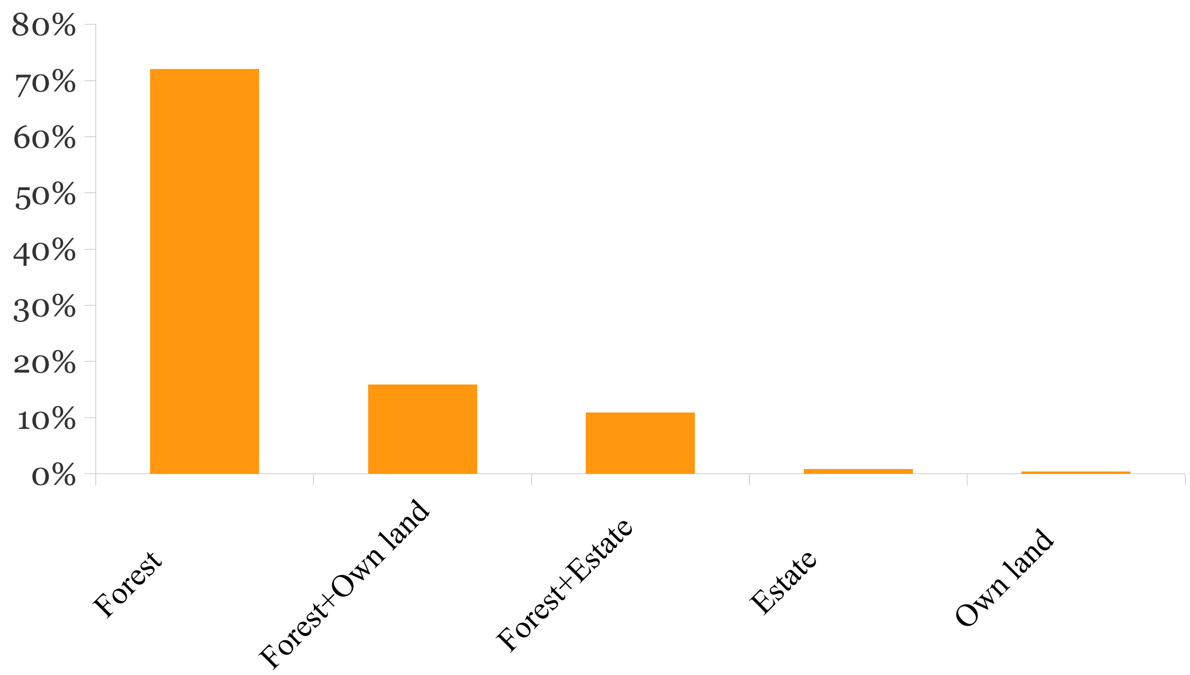


Figure 10: Sources of firewood collected by respondents.

Figure 11. Attitude of respondents to loss of plant species, animal species and habitat.

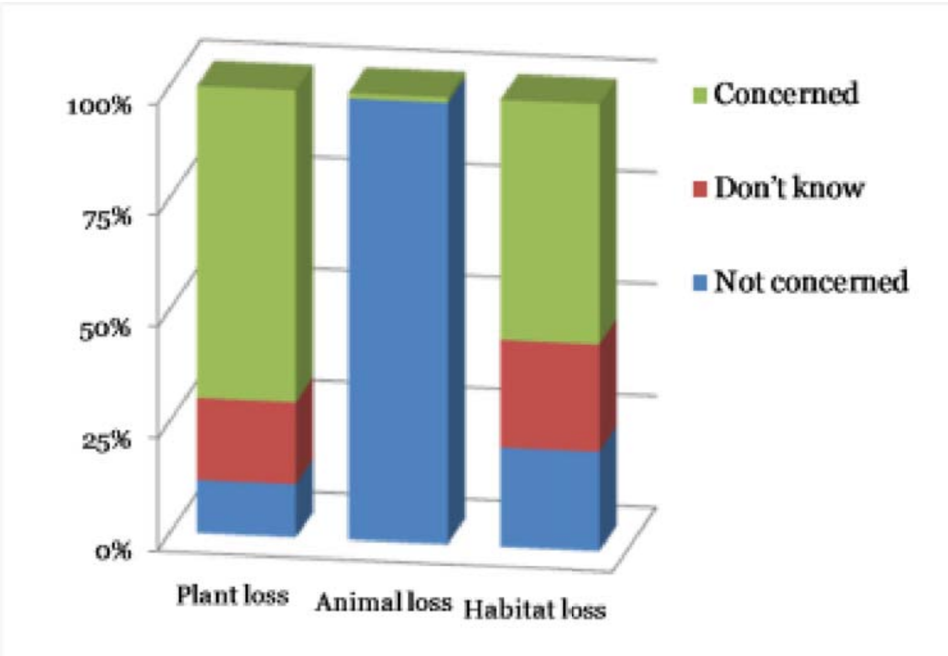


Table 5: Results of chi-squared tests comparing the influence of settlement location, exposure to conservation issues and economic status towards biodiveristy loss.

Variable	Plant loss			Animal loss			Habitat loss		
	χ^2	df	p	χ^2	df	p	χ^2	df	p
Settlement location	33.245	4	1.06E-006	1.8093	2	0.4047	37.7909	4	1.24E-007
Exposure to conservation issues	7.3769	2	0.02501	9.7404	1	0.001803	12.5197	2	0.001912
Economic status	11.1117	4	0.02534	0.3161	2	0.8538	9.7044	4	0.04571

Figure 12: Drivers influencing motivation of local communities to undertake biodiversity conservation.

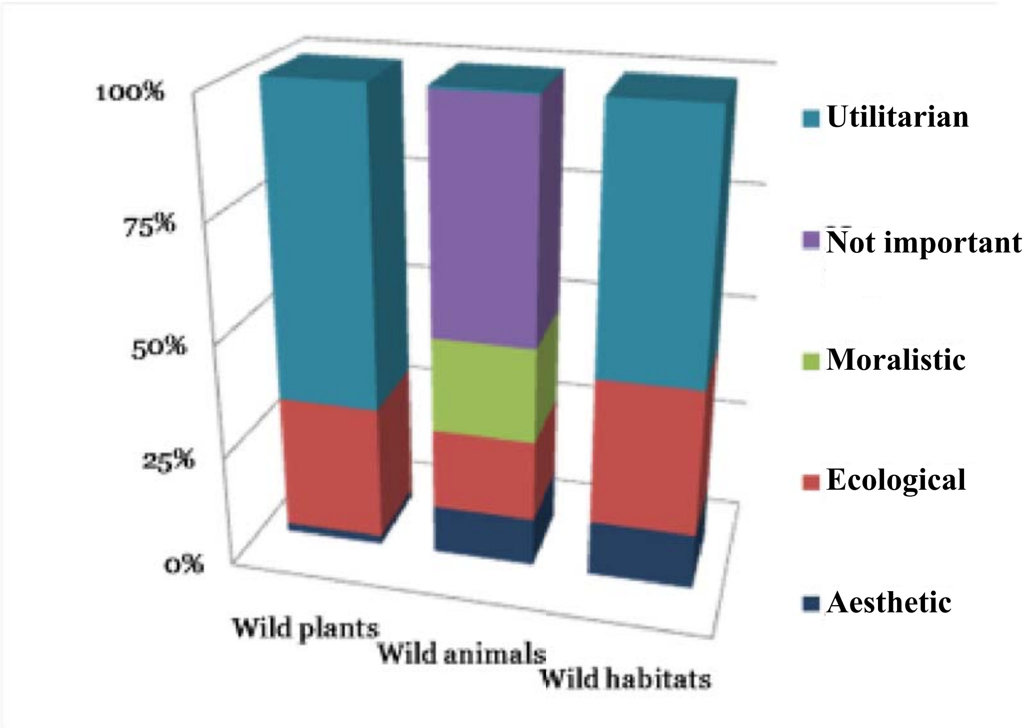


Table 6: Results of chi square tests on factors influencing motivation for biodiversity conservation.

Variable	Plant importance			Animal importance			Habitat importance		
	χ^2	df	p	χ^2	df	p	χ^2	df	p
Settlement location	14.3937	6	0.02553	49.0439	10	4.00E-007	42.3681	6	1.56E-007
Exposure to conservation issues	3.71	3	0.2939	5.47	5	0.3608	6.05	3	0.1091
Economic status	6.00	6	0.4231	10.84	10	0.3701	9.21	6	0.1622

Discussion

We surveyed an area of 891 km^2 in Kerala and Tamil Nadu over a two-year period for multiple large mammal species. We accounted for incomplete detection of animals and their signs, and used this information to derive cell-specific and species-specific maps of habitat use as a function of a range of covariates. We then converted these estimates into resistance values, and hence identified potential movement pathways for the seven focal species across the Shencottah Gap. We have presented here the results from our initial data analysis. We note that the finer details of these results are sensitive to the resolutions used for analysis. Therefore, this analysis should be viewed as an initial coarse-level identification of corridors and variables influencing animal use, which will be refined as we undertake more detailed analyses in the near future.

Our results indicate that endangered and charismatic large mammal species are present outside the PA network in the southern Western Ghats, and use the intervening habitat to a considerable extent. Significantly, many species occur adjacent to highly productive human-use areas, such as forestry plantations and cash crops. Thus, opportunities do exist for restoration of large mammal movement across the Shencottah Gap, but are threatened by a large and growing human footprint, which needs to be addressed immediately. We discuss below the influence of various factors on animal habitat use and movement, and the challenges that need to be overcome in restoring large mammal movement between Periyar and Agastyamalai.

Habitat use and covariates affecting use

Habitat use over the Shencottah Gap varied spatially and between species, and probability of use was influenced by physical, biological and anthropogenic factors. For both the megaherbivores, anthropogenic variables (especially location of settlements and land use) appeared to be major drivers of habitat use. Despite their sensitivity, however, both species ranged relatively widely over the study area, and elephants had the highest mean probability of use among the focal species. For lion-tailed macaques, physical and biological covariates were the most important determinants of habitat use; probability of use was highest in evergreen forests with complex canopies in less rugged areas. Because of the relatively low availability of such prime habitat in the study region, lion-tailed macaques had a low mean level of use and a very patchy distribution. The more adaptable Nilgiri langur was influenced by all three classes of covariates, and showed a wider distribution over the landscape than the lion-tailed macaque. Habitat use of all three carnivores was influenced mostly by prey use patterns, in combination with anthropogenic variables.

If animal use of unsuitable areas is to increase, modification of variables to more favourable types is required. Although physical factors (such as terrain) are clearly not modifiable, it is possible to improve habitat by focusing on the key biological and anthropogenic variables identified in this analysis. We emphasize that different variables affect different species to different extents; therefore, restoration of multi-species connectivity will require appropriate management and modification of all of these relevant variables over the long term.

Corridor identification

At the current resolution (1.5 km for herbivores and 3 km for carnivores), our corridor models indicate major gaps in connectivity for all focal species. We have identified two areas where corridor restoration has the best potential: the MSL corridor in the west, and the Kottavasal corridor in the east (named after the settlements near which they pass). We note that a separate GIS-based study (Johnsingh *et al.* 2008) has also suggested the Kottavasal area as a potential corridor for large mammal movement. For all focal species, particularly the carnivores, passage probability through the Kottavasal corridor was higher than the MSL corridor. For the megaherbivores and primates, however, movement may possibly occur through the MSL corridor if habitat can be appropriately restored.

Large mammal movement through the MSL corridor, however, is likely to be severely hindered by the private estate areas that it passes through. We consider the practical aspects of corridor restoration in private lands in the next section. From the biological perspective, we note that the MSL corridor occurs at the edge of our study area, and that contiguous forest (under the Forest Department) does exist to the west in Punalur and Konni Divisions. Thus, if it possible to involve private landowners in conservation, restoration of this corrridor may not be as difficult as it appears at first sight. Further, connectivity between Periyar and Agastyamalai would be stabilised if there are two dedicated movement routes rather than just one.

Requirements for corridor restoration

If connectivity between the Periyar and Agastyamalai landscapes is accepted as a conservation goal (as it is by a wide range of conservationists and governmental agencies in India), corridors must be urgently restored before large-scale changes in land use prevent any future prospects of restoration. Corridor restoration is best achieved through science-based management of the interface between moving animals and humans, backed up by appropriate economic incentives to local communities for their verifiable actions towards conservation. We discuss each of these requirements below.

Developing appropriate economic incentives

It is well acknowledged in India that landscape-level corridors can be as important as PA's for the long-term conser-

© Gopinath S, www.photoessays.net

Our surveys during the dry seasons of 2008-2010 indicate that the northern and southern populations of Asian elephant (Elephas maximus) are separated by a linear distance of just 4 km.

vation of large mammals (*e.g.*, Gopal *et al.*, 2007; Elephant Task Force, 2010). Further, because such corridors are likely to pass though multiple-use areas and private land, it is critically important that local communities are involved in their protection and management (Gopal *et al.*, 2007). Unfortunately, these communities are often hostile to conservation initiatives because of the high opportunity costs they incur through restrictions on their activities. Voluntary participation in co-management of wildlife areas is best achieved when these opportunity costs are paid, and when it is profitable (economically and holistically) for people to involve themselves in conservation activities.

The general situation described above is well exemplified by the Shencottah Gap. Both of our identified corridors pass through a mixture of land ownership types, and are close to several settlements. Setting aside areas that are already under the control of the Forest Department for the purpose of coridors is a relatively easy task. However, conservation on private land will require a more nuanced approach. Outright purchase of such land is likely to be prohibitively expensive (as suggested by land costs; see Appendix 1). Further, resettlement of people is likely to be unacceptable due to socio-political reasons. Therefore, conservation in this region may be better achieved through long-term economic incentives that encourage both small and large landowners to manage their land in a more wildlife-friendly manner. Critically, accrual of economic benefits must be directly linked to the accrual of conservation outcomes, quantified through changes in relevant biological parameters compared to baselines. For example, the estimates of habitat use from this study can be treated as baselines, and habitat improvement carried out through conservation activies can be measured through increases in probability of animal use. Further, quantification of both conservation attitudes and economic well-being of project participants before, during and after project implementation can be used to determine the success of conservation interventions.

Thus, there is potential in India for novel and innovative approaches to the co-management of corridors (Gopal *et al.*, 2007). However, these initiatives must be supported over the long term through dedicated funding. Governmental agencies involved in conservation are key to providing such funding; these funds can then be bolstered through contributons from donors, corporates and even the general public. Establishing a framework to bring these key elements together can help ensure that such co-managed connectivity conservation initiatives are successful.

Managing the spatial interspersion of humans and wildlife

A significant barrier to undertaking participatory conservation action in this landscape, is the current lack of concern, intolerance and occassional hostility, to wildlife among local residents. Our socio-economic data suggests that crop-raiding plays a significant role in driving this hostility. Further, a large majority of respondents are willing to participate in plant, animal and habitat conservation activities if they do not suffer economic losses as a consequence. Thus, management and mitigation of human-wildlife conflict must go hand in hand with corridor restoration in this landscape. In particular, conservation efforts must ensure that increasing animal movement over the landscape does not increase the potential for conflict with people.

This objective can be achieved if moving animals can be 'funnelled' into designated corridor areas and away from human-use zones. A fundamental requirement for this is fine-scale zonation of land into corridor and non-corridor areas. Through intensive habitat management combined with fencing, large mammals can be simultaneously attracted into corridors and deterred from adjacent human-use zones. Implementation of such measures requires a fine-scale understanding of animal behaviour in the context of their movement, which is best achieved using GPS collars. Unfortunately, telemetry studies do not currently receive much governmental support in India. As an alternative, methods that employ intensive camera-trapping and genetic markers need to be developed to quantify fine-scale animal movement. Further, all these methods are required to quantitatively monitor and evaluate the efficacy of the conservation activites.

Fine-scale movement & linear barriers

The resolution that we have used for this analysis reflects the scale of landscape-level connectivity between two disjunct populations, whose re-connection is the ultimate conservation goal. Thus, the multi-species corridors that we have identified are fairly diffuse (Figure 7). Within these coarse-scale corridors, however, more fine-scale movement routes need to be identified, particularly in areas close to settlements. The three major linear barriers in this region are: National Highway-208, the Punalur-Shencottah Railway line, and a 400 KV power line. These constitute significant barriers for two reasons: a) their physical characteristics inhibit large mammal movement, and b) they serve as focal areas for human activity.

Physically, the highway has vertical embankments and the railway line passes through deep gullies at several locations, which are virtually impossible for animals such as elephants to cross. We have identified only two locations that are free of physical barriers on the highway and railway. These are located within the identified Kottavasal and the MSL corridors. Previous studies have also suggested potential locations for highway mitigation structures, among which Kottavasal figures prominently (Johnsingh *et al.*, 2008). Heavy traffic along this highway, especially at night, needs to be regulated if animals are to have any chance of crossing. Currently the railway line is being upgraded and all possible efforts to enhance connectivity should be undertaken. An even more serious threat to connectivity, however, derives from the fact that these linear barriers serve as focal areas for human activity. Several settlements run along their length, which include illegal encoachements. The proliferation of these settlements needs to be contained if corridor restoration is to be achieved. We are curently in the process of analyzing data to model connectivity at a scale that will better incorporate the effects these linear barriers.

Conclusion

Our empirical data on large mammal occurrence and habitat use over the Shencottah Gap give cause for cautious optimism. There exist several major gaps in connectivity, particularly for the specialists among our focal species. However, it is potentially possible to restore large mammal movement across this landscape, if corridor management is science-based and economic realities are taken into account. The current conservation paradigm, which emphasises co-management of natural areas outside the PA network, provides a conducive framework in this regard. It is therefore an appropriate time to bring together managers, local residents and the conservation community to implement a comprehensive connectivity conservation initiative in the southern Western Ghats.

References

Ambroise B, Beven K, Freer J. 1996. Towards a generalization of the TOPMODEL concepts: topographic indices of hydrological similarity. Water Resources Research 32(7): 2135– 2145

Baskaran, N., Balasubramanian, S., Swaminathan, S. and Desai, A. A. 1995. Home range of elephants in the Nilgiri Biosphere Reserve, south India. In Daniel JC, Datye HS (eds). A Week with Elephants. Bombay Natural History Society. Oxford University Press, Bombay.

Beier, P. and Noss, R. F. 1998. Do corridors provide conectivity? Conservation Biology 12: 1241-1252.

Beier, P., Majka, D. R. and Spencer, W. D. 2008. Forks in the road: choices in procedures for designing wildland linkages. Conservation Biology 22:836-851.

Belisle, M. 2005. Measuring landscape connectivity: the challenge of behavioral landscape ecology. Ecology 86: 1988-1995.

Boyce, M. S., Vernier, P. R., Nielsen, S. E. and Schmiegelow, F. K. A. 2002. Evaluating resource selection functions. Ecological Modelling 157: 281-300.

Burnham, K. P. and Anderson, D. R. 2002. Model selection and multimodel inference: A practical information theoretic approach. Second edition. Springer-Verlag, New York, USA.

Champion, H.G and Seth, S.K. 1968. A revised survey of the forest types of India. Natraj Publishers, Dehradun, India.

Chetkiewicz, C.L., St. Clair, C. C. and Boyce, M. S. 2006. Corridors for conservation: integrating pattern and process. Annual Review of Ecology, Evolution and Systematics 37: 317-342.

Crooks, K. R. and Sanjayan, M. 2006. Connectivity conservation: maintaining connections for nature. In Crooks, K. R. and Sanjayan, M. (eds). Connectivity conservation. Cambridge University Press, New York.

Elephant Task Force. 2010. Gajah: Securing the future for elephants in India. Ministry of Environment and Forests, New Delhi, India.

Elvidge, C.D., Sutton, P. C., Tuttle, B.T., Ghosh, T., and Baugh, K. E. 2009. Global urban mapping based nighttime lights. In Gamba, P. and Herold, M. (eds). Global mapping of human settlements. Francis and Taylor, New York.

Engler, R., Guisan, A. and Rechsteiner, L. 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. Journal of Applied Ecology, 41, 263–274.

Fiske, I., Chandler, R. B., and Royle, A. 2010. unmarked: Models for Data from Unmarked Animals. R package version 0.8-9.

Gopal, R., Sinha P. R., Mathur, V. B., Jhala, Y. V. and Qureshi, Q. 2007. Guidelines for preparation of Tiger Conservation Plan. A technical document of the National Tiger Conservation Authority, Ministry of Environment and Forests, Government of India. NTCA/01/07

Gu, W. and Swihart, R. K. 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife-habitat models. Biological Conservation 116: 195-203.

Haddad, N.M., Bowne, D.R., Cunningham, A., Danielson, B.J., Levey, D. J., Sargent, S. and Spira, T. 2003. Corridor use by diverse taxa. Ecology 84: 609-615.

Hargrove, W.W., Hoffman, F.M., and Efroymson, R . A . 2005. A practical map-analysis tool for detecting potential dispersal corridors. Landscape Ecology 20: 361-373.

Jhala, Y.V., Gopal, R. and Qureshi, Q. 2008. Status of tigers, co-predators and prey in India. TR 08/00, National Tiger Conservation Authority, Government of India, New Delhi and Wildlife Institute of India, Dehradun, India.

Johnsingh, A. J. T. and Williams, A. S. C. 1999. Elephant corridors in India: lessons for other elephant range countries. Oryx 33: 210–214.

Johnsingh, A. J. T., Pillay, R., Raghunath, R., Anand, M. O., and Madhusudan, M. D. 2008. Opportunities and challenges for tiger conservation in the southern Western Ghats, India. Paper presented at 'National Seminar on People and Tigers: Shifting trajectories of Ecology and Coexistence'. Periyar Foundation, Periyar Tiger Reserve, Kerala.

Karanth, K. K., Nichols. J. D., Karanth. K. U, Hines. J. E, and Christensen.N.L. 2010. The shrinking ark: patterns of large mammal extinctions in India. Proceedings of the Royal Society B: Biological Sciences. doi:10.1098/rspb.2010.0171.

Karanth, K.U. and Nichols, J. D. 1998. Estimation of tiger densities in India using photographic captures and recaptures. Ecology 79: 2852-2862.

Karanth, K. U., Goodrich, J. M., Vaidyanthan, S., and Reddy, G.V. 2009. Landscape-scale, ecology-based management of wild tiger population. Global Tiger Workshop – Defining Strategic Actions to Save the Wild Tiger from Extinction, Kathmandu, Nepal.

MacKenzie, D. I, Nichols J. D., Royle, J. A., Pollock, K. H., Bailey, L. A., and Hines, J. E. 2006. Occupancy Modeling and Estimation. Academic Press, San Diego, USA.

McRae, B. H., Dickson, B. G., Keitt, T. H. and Shah, V. B. 2008. Using circuit theory to model connectivity in ecology, evolution and conservation. Ecology 89: 2712-2724.

Menon, V., Tiwari, S. K., Easa, P. S., and Sukumar, R. 2005. Right of passage: Elephant corridors of India. Widllife Trust of India, New Delhi.

Menon, V., Sukumar. R., and Kumar, A. 1997. A God in Distress: Threats of poaching and ivory trade to Asian Elephant in India. Technical Report No. 3, Asian Elephant Conservation Centre, Bangalore.

Project Tiger Directorate. 2004. Compendium of guidelines and circulars issued by the Director, Project Tiger. Ministry of Environment and Forests, Government of India, New Delhi.

Royle, J. A. and Nichols, J. D. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84: 777-790.

Sukumar, R., Ramakrishnan, U., and Santosh, J. A. 1998. Impact of poaching on an Asian elephant population in Periyar, southern India: a model of demography and tusk harvest. Animal Conservation 1: 281-291.

Travancore Administration Report. 1937. Travancore Government Press, Trivandrum, India.

Urban, D. and Keitt, T. 2001. Landscape connectivity: a graph theoretic perspective. Ecology 82: 1205-1218.

Vidya, T.N.C., Sukumar, R. 2005. Amplification success and feasibility of using microsatellite loci amplified from dung to population genetic studies of the Asian elephant (Elephas maximus): a field study from southern India. Current Science 88: 489-491.

Vogt, P, Riitters, K. H., Iwanowski, M., Estreguil, C., Kozak, J., and Soille, P . 2007. Mapping landscape corridors. Ecological Indicators 7: 481-488.

Zhu, A.X., Hudson, B., Burt,J., Lubich, K., and Simonson, D. 2001. Soil mapping using GIS, expert knowledge, and fuzzy logic. Soil Science Society of America Journal 65: 1463-1472.

Appendix 1

Division	Private enclosures	Area (ha)	Status
Konni	-	-	
Achenkovil	Ambanaad Rubber & Tea Estate	382.44	Functional
	Priya Rubber & Tea Estate	177.99	Non-functional
Thenmala	Bedford Estate	37	Functional
Shendurney WLS	Kallar Estate	538	Functional
	Rockwood Estate	63	Functional
	Thenginthoppe	14	Functional
Tirunelveli	Anjilkaddu Estate	17	Functional
	Chinna Ramakal Estate	25	Functional
	Chinnakadu Estate	80	Functional
	Elatheri Estate	40	Functional
	Gemini Estate	258	Functional
	Kallakadai Estate	35	Non-functional
	Kallimalai Estate	200	Functional
	Kuliratti Estate	-	Abandonded
	Myilodai	50	Non-functional
	Panchantangi Estate	-	Abandonded
	Parai Estate	283	Functional
	Shenbagavalli	12	Abandonded
	Thekkumala	283	Non-functional
	Udumbutheri	30	Abandonded
	Vakkil Estate	97	Functional
	Vasanthi Estate	42	Functional

Appendix 2

Name	No. of households	Area (acres)	Primary crop	Secondary crop	Tertiary crop	Approximate land price (lakhs/acre)	VSS name
20 acres	18	20	Rubber	Arecanut	Pepper	3-4	Kariyalamith VSS
47 acres	14	47	Pepper	Rubber	Coconut	7-8	Rajathottam VSS
8 acres	11	23	Rubber	Pepper	Tapioca	8-10	Kadamanppara VSS
9 acres	68	120	Pepper	Rubber	Coconut	2.5-3	-
Achenkovil 4 cent colony	50	3	-	-	-	15-20	West VSS
Achenkovil Adivasi Colony	114	112.5	Rubber	Banana		15-20	Adivasi VSS
Achenkovil town	150	50	Rubber	Banana	Mixed	15-20	West VSS
Ariankavu town	45	50	Rubber	Coconut	Arecanut	10-12	Kariyalamith and Palaruvi VSS
Chempuvilla	100	120	Rubber	Pepper	Coconut	9-10	Kariyalamith VSS
Depot Railway station	26	8	Mixed	Rubber	Coconut	5-6	10 Acre VSS
Edapalayam	70	60	Rubber	Pepper	Coconut	9-10	Edapalayam VSS
Edapalayam forest quarters	100	100	Rubber	Pepper	Coconut	10-12	Edapalayam VSS
Edapalayam pallimukh	70	100	Rubber	Coconut	Pepper	10-11	Edapalayam VSS
Edapalayam pallipadi	50	30	Rubber	Pepper	Arecanut	10	Edapalayam VSS
Hospital junction	100	80	Rubber	Pepper	Coconut	7-8	Palaruvi VSS
Irulamkadu	200	250	Arecanut	Pepper	Coconut	5-6	-
Kadamanpara & Pandianpara	27	27	Rubber	Pepper	Tapioca	8-10	Kadamanppara VSS
Kaluthurutty	35	40	Pepper	Rubber	Coconut	12-15	-
Kaluthurutty (Thenmala part)	4	1	Mixed	-	-	5-6	-
Kaluthurutty junction	34	8	Rubber	Pepper	Coconut	9-10	-
Karippinthottam	70	80	Rubber	Pepper	Coconut	7-8	Kottavasal VSS
Karippinthottam Harijan colony	38	2	-	-	-	-	Kottavasal VSS
Kariyalamith	70	60	Rubber	Pepper	Coconut	8-10	Kariyalamith VSS
Kariyalarthottam	60	70	Rubber	Coconut	Pepper	8-10	Kariyalarthottam VSS
Kottavasal	45	30	Pepper	Tapioca	Coconut	5-6	Kottavasal VSS
Kuzhibhagam	90	40	Rubber	Mixed		15-20	West VSS
Lakshamveedu 4 cent colony	40	16	-	-	-	-	Edapalayam VSS
Moonumukku junction	450	200	Rubber	Arecanut	Banana	15-20	West and Kanayar VSS
MSL	16	12	Mixed	Rubber	Arecanut	5-6	-
Palaruvi	18	70	Rubber	Pepper	Coconut	0.3	Palaruvi VSS
Palaruvi junction	50	50	Rubber	Pepper	Coconut	10	Palaruvi VSS
Pallivasal	9	5	Coconut	Cashew nut	Pepper	15-20	Kanayar VSS
Pathimoonuu Kannarapalam	8	1	Mixed	-	-	3-4	-
Pudukupathuvayal	25	20	Rubber	Pepper	Coconut	12-15	Palaruvi VSS
Rajacholai	50	120	Rubber	Pepper	Coconut	2-3	-
Rajacoupe	45	277	Rubber	Clove	Coconut	3-3.5	Rajathottam VSS
Road purampokku kizhakebhakam	50	15	Rubber	Banana	Mixed	15-20	West VSS
Road purampokku padinjarebhagam	32	3	-	-	-	15-20	West VSS
Rosemala	350	619	Rubber	Coconut	Tapioca	2-2.5	Rosemala EDC

Supported by

Rufford Small Grants for Nature Conservation (RSGs) are aimed at small conservation programmes and pilot projects. Please visit http://www.ruffordsmallgrants.org/rsg/ for details.

University of Gothenburg, Sweden. Please visit http://www.gu.se/ for details.

The Critical Ecosystem Partnership Fund is a joint initiative of l'Agence Française de Développement, Conservation International, the Global Environment Facility, the Government of Japan, the MacArthur Foundation and the World Bank. A fundamental goal is to ensure civil society is engaged in biodiversity conservation. Please visit http://www.cepf.net for details.