# Spatial analysis for identification and evaluation of forested corridors between two protected areas in Central India

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**Central Indian forested lands, biologically one of the most diverse regions in India, are facing the serious problem of habitat fragmentation both at small and large scales. While the entire conservation programme in this region revolves around a network of protected areas (PAs), safeguarding the genetic exchanges amongst wildlife populations, located in spatially separated but biologically rich PAs, is a prerequisite for the longevity of these conservation areas. We present here the results of a new methodological framework that evaluates the potential of forested tracts for functioning as viable corridors between Kanha Tiger Reserve and Achanakmar Wildlife Sanctuary located in the states of Madhya Pradesh and Chhattisgarh respectively. We use 1 : 250,000 scale Indian remote sensing (IRS LISS-I) data to generate a detailed landuse map. The landscape suitability model is developed in GIS domain and is essentially based on two spatial characteristics of the landscape, viz. interspersion and juxtaposition, using landuse map. The landscape suitability model was refined by overlaying the human pressure map. The model underlines that a combination of moderate and highly suitable habitats can establish habitat connectivity between the two PAs. The model results are also substantiated by ground information collected from about 200 sample points across the forested landscape. We also identify a few forest patches and various management strategies that are critical for the viability of the entire corridor within the landscape.**

IN a domain of socio-political realities, where there are increasing protests against bringing more areas under the protected area (PA) network[1], many existing intra-PAs perform one of the most essential functions for biodiversity conservation, viz. providing genetic connectivity to spatially separated wildlife populations[2]. Unequivocally, these intra-PA habitats have greater roles for biodiversity conservation by effectively supporting the functions of 'corridors'[2–5]. However, human-induced large scale degradation and shrinkage of natural forests outside PAs, actually break the continuity of genetic exchanges amongst the spatially isolated populations and thus cause significant biodiversity loss[6–9]. Linking up existing better-quality forest patches (PAs) through strips of lands with similar habitats (corridors) offers the much needed contiguity for exchange of genetic materials and mitigates the negative biological impacts of habitat fragmentation[10].

'Landscape ecology' is largely founded on the notion that spatial patterns and arrangements of ecological units influence many ecological processes[11–13]. The effectiveness of conservation measures of an isolated population within a landscape is seriously influenced by the spatial settings of those populations[10,14,15] and often characterized by measures like size, shape, connectivity, etc. of suitable habitat patches[11,16]. Satellite imageries combined with geographic information systems (GIS) proved to be effective tools in adopting landscape-level spatial analysis[17–19] and also have high potential in evaluation of habitat corridors[20].

## Rationale of study

Central Indian states of Madhya Pradesh (MP) and Chhattisgarh, with over 25% of their combined geographical area under forest cover, provide habitat for about 13% of the world's population of wild tigers (*Panthera tigris*)[21]. Therefore, they are considered as one of the most potential regions for *in situ* conservation of tigers. Consequently, about 17,000 $km^2$ area of these two states was brought under extensive PA network comprising six National Parks, five Tiger Reserves and 33 Wildlife Sanctuaries. Nevertheless, the 1997 tiger census in these states highlighted that about 50% of the tiger population actually inhabited the forests lying outside the PA network. Ironically, these forests are vulnerable to large-scale transformations[22,23], losing important wildlife corridors and thus resulting in fragmentation of important wildlife habitats.

The forests in and around Kanha Tiger Reserve (KTR) and other nearby PAs like Bandhavgarh Tiger Reserve, Pench Tiger Reserve, Phen Wildlife Sanctuary (PWLS) in MP and Achanakmar Wildlife Sanctuary (AWLS) in Chattisgarh form one of the most extensive tiger lands of the country (Figure 1). While these PAs are situated at varying distances from each other, some degree of forest contiguity among these PAs still exists. Recognizing the importance

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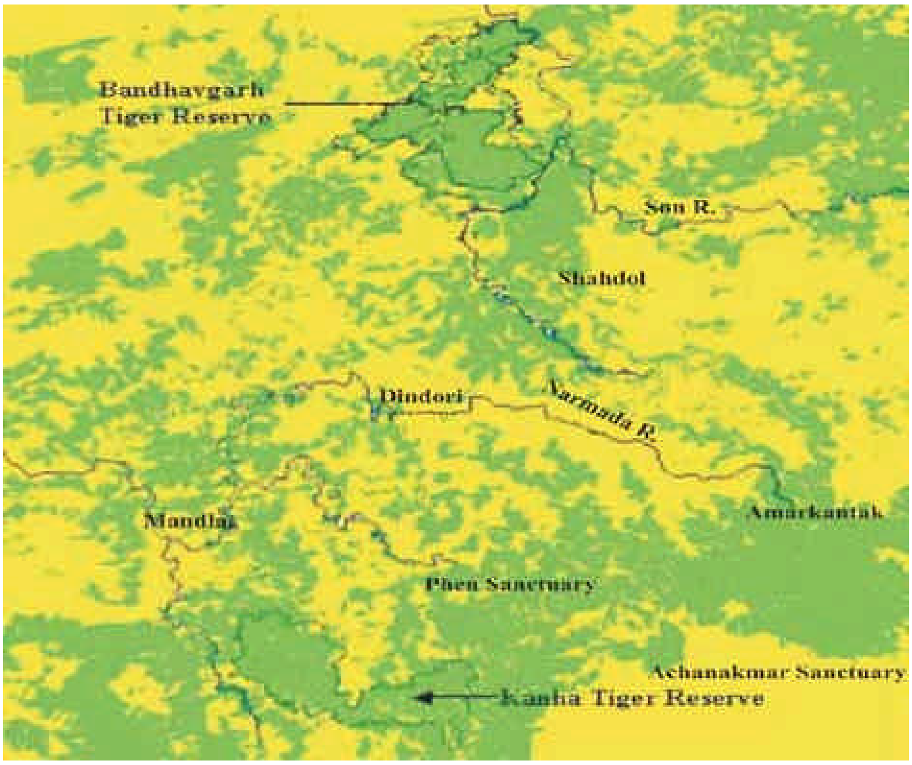


**Figure 1.** Study area showing Kanha–Bandhavgarh–Achanakmar landscape. Forested patches (green) are seen in the matrix of non-forest areas (yellow).

of the entire area for tiger conservation, a need for establishing as well as rehabilitating viable forest corridors between PAs of this region was strongly recommended[24–26].

The present study attempts to identify and evaluate the forested tract between KTR and AWLS for functioning as a viable corridor, using the tools of remote sensing and GIS within an overall framework of landscape ecology. The study also attempts to identify and prioritize the areas that need immediate management intervention for maintenance of habitat contiguity between the two PAs.

## Study area

The study area lies between 22°–23°15′N lat and 80°30′–82°E long and encompasses approximately 13,500 $km^2$ of Central Indian highlands, including about 5850 $km^2$ (~43%) of forested area. Administratively, the study area falls under Mandla, Balaghat and Shahdol districts of MP and Rajnandgaon and Bilaspur districts of Chhattisgarh.

The study area, predominantly a hilly tract, mainly supports tropical moist deciduous forests. The valleys are dominated by the sal (*Shorea robusta*) forests, while the lower and higher slopes support the bamboo (*Dendrocalamus strictus*) with sal and miscellaneous species respectively. In addition, many plateaus support extensive grasslands, commonly known as 'dadar'. The wider intermontane valleys are mostly occupied by vast stretches of agricultural fields. A good population of forest dependent Baiga and Gond tribes also occupy the study area.

These forests provide extensive habitats for a variety of wild-animal species. For example, a good population of spotted deer, sambar, hard-ground swamp deer, barking deer, black buck, four-horned antelope, gaur, etc. forms the major prey base for three main predators of the area, viz. tiger, leopard and dhol (wild dog). Sloth bears also occur in good numbers in these forests.

Recognizing the higher conservation values of the study area, about 2600 $km^2$ area falls under three PAs, viz. KTR (1945 $km^2$), PWLS (110.7 $km^2$) and AWLS (551.5 $km^2$) (Figure 1).

## Methodology

### *Ground data collection*

To assess the habitat quality of the entire forested tract between KTR and AWLS, ground surveys were conducted during the winter of 1994. It is understood that while the interior 'core' parts of the forest patch are less disturbed, the 'edge' areas near the forest boundaries are under severe biotic pressure. In addition, those severely constricted forested patches which were mainly encroached by agriculture landuse, are subjected to high biotic pressure and considered as 'bottleneck' areas. In a practical sense,

**Table 1.** Weight assignments to different landuse classes and their adjacency. Numerical values in parenthesis are weights assigned to individual landuse categories. Weights for landuse adjacencies are the sum of weights assigned to individual landuse types

| Landuse | WB (10) | CF (9) | OF (8) | GR (8) | FB (6) | SC (3) | AG (1) |
|---|---|---|---|---|---|---|---|
| Water Body (WB) | 20 | | | | | | |
| Closed Forest (CF) | 19 | 18 | | | | | |
| Open Forest (OF) | 18 | 17 | 16 | | | | |
| Grasslands (GR) | 18 | 17 | 16 | 16 | | | |
| Forest Blank (FB) | 16 | 15 | 14 | 14 | 12 | | |
| Scrub (SC) | 13 | 12 | 11 | 11 | 9 | 6 | |
| Agriculture (AG) | 11 | 10 | 9 | 9 | 7 | 4 | 2 |

'bottleneck' areas are narrow and elongated corridors that connect two larger habitat patches and are predominately more 'edgy' in nature. Subject to the positional importance in overall forest linkage between the two PAs, adequate sampling sites in each of the core, edge and bottleneck areas were marked *a priori* on Survey of India topo-sheets.

In each sampling site, a line-transect of 1 km length was laid to assess the habitat quality of the area. Sampling was done in five circular plots of 10 m radius at every 250 m interval. A total of 201 such plots were sampled in 42 transects. In each sample plot, information on important habitat parameters was collected using standard field techniques[27]. Vegetational similarity within the study area, an important criterion for corridor evaluation, was ascertained using TWINSPAN classification technique[28].

## *Corridor suitability analysis*

It is recorded that a contiguous forest with poor habitat quality can act as the 'population sink' for dispersing animals[2,29]. Therefore, in order to assess the viability of corridors, it is essential to evaluate both contiguity and habitat quality of the forested tract in the entire landscape. For this, we adopted a landscape level of habitat suitability model using different spatial variables, derived mainly from landuse/ land cover map[30].

IRS-LISS I False Colour Composites (scale 1 : 250,000, October 1994) were utilized for the preparation of landuse/ land cover map of the study area using visual image interpretation. The landuse/ land cover map was authenticated with the help of forest cover maps of Forest Survey of India. Base features like rivers, roads and village locations were mapped using Survey of India topo-sheets. GIS software GRASS was employed in creating the spatial database and used for analysing different landscape characteristics.

Landuse/land cover maps were used for studying two important metrics of landscape patterns, viz. interspersion and juxtaposition. The measure of spatial inter-mixing of different landuses is known as interspersion[29,31]. In a rasterize window of $3 \times 3$ size, interspersion is a measure of the number of surrounding cells that differ from the central cell. Put differently, interspersion value in a landscape is the 'index of habitat fragmentation'. It can also be interpreted in terms of human disturbances in the landscape matrix and thus leads to its diversity[32].

From the corridor point of view, each landuse category has its own importance within a landscape. However, in the context of habitat suitability, the adjacency of different landuse types has different ecological meaning. For example, in a rasterize map, if a forest cell (or pixel) shared its boundary with other forest cells, habitat suitability can be considered high compared to the situations where a forest cell is surrounded by agriculture or scrub cells. Similarly, presence of water bodies could enhance the habitat value of the surrounding forest area. Such a measure of relative importance of adjacency of two or more landscape elements is known as juxtaposition[29,31]. Based on discussions with conservation biologists and landuse managers, the numerical weights were assigned a priori to describe the relative importance of each landuse type and also different landuse adjacencies. Relatively higher weights were assigned to waterbodies, forests and grasslands, while scrub and agriculture types were given lower weights (Table 1). Like interspersion, the juxtaposition values were also computed using a rasterize window of $3 \times 3$ size, where the relative importance values of landuse adjacencies of all the cells were summed up and assigned to the central cell.

A network of major roads and village locations was used to understand the spatial pattern of human pressures within the landscape. Finally, the above three measures, viz. interspersion, juxtaposition and anthropogenic pressure, were used in developing a habitat suitability model. Spatial settings of the entire landscape were also evaluated by different patch characteristics, viz. density, shape, size, patchiness and porosity[11,33]. While porosity refers to the density of patches of a particular type, patchiness is a measure of density of all patches. The entire methodological framework is schematically represented in Figure 2.

## Results and discussion

## *Landuse and field data analysis*

Visual interpretation of satellite imagery identified seven landuse classes, including open and closed forests (Figure 3;

Table 2). About 42% of the study area is covered under forest and mostly surrounded by agricultural areas. TWINSPAN identifies seven major classes of vegetation, with the sal and sal-mixed types as the most commonly recorded ones covering about 68% of the total forested area (Table 3). In addition, TWINSPAN analysis recorded low measure of variance (the eigenvalue ranges between 0.19 and 0.27), suggesting quite a homogenous vegetation structure in the area. At a coarser level, this aptly fulfils one of the most important criteria for viable corridors.

Analysis of field data suggests that the habitat parameters differed significantly in core, edge and bottleneck areas. Relatively better habitat conditions and low biotic pressures represent the core parts of the forests than the other two areas (Table 4). High encounter rate of wild ungulate species in the core areas further substantiates the above observation. Also, at aggregated level, forests under PAs were found in better conditions than those outside PAs. Regeneration status of some of the major native tree species like *Shorea robusta*, *Terminalia tomentosa*, *Diospyros melanoxylon* and *Embelica officinalis* was found consistent in the entire study area.

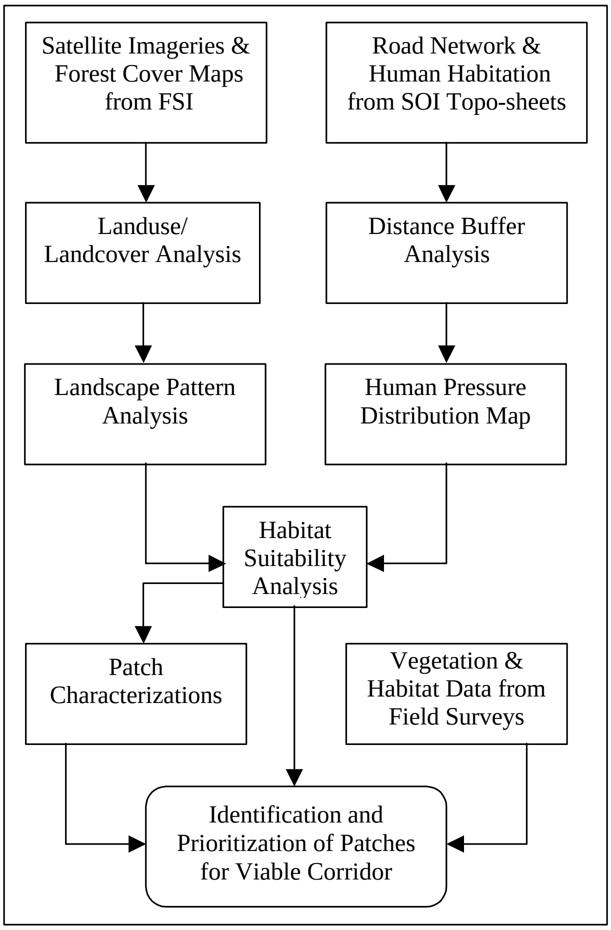


**Figure 2.** Schematic diagram depicting methodological framework adopted for the study.

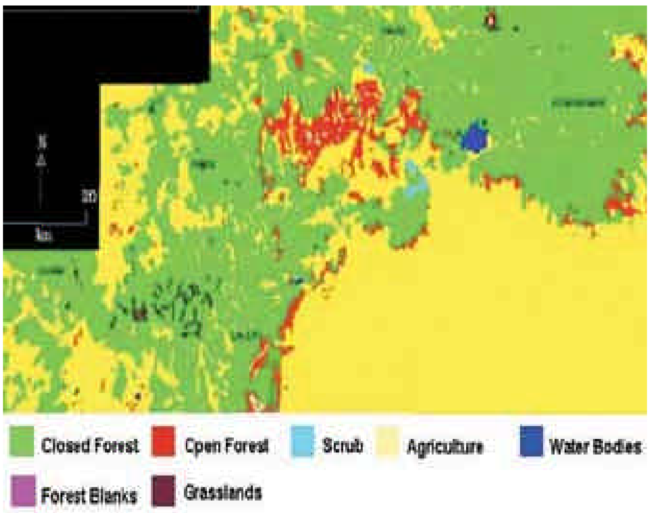


**Figure 3.** Landuse map of Kanha–Achanakmar landscape.

### *Landscape suitability analysis*

Relatively higher interspersion values were recorded for forested areas outside PAs. This observation is on the expected line, especially when forests outside PAs are open for higher degree of human-induced landuse changes, causing higher level of habitat fragmentation. Due to this behaviour of interspersion values, it is treated as a ‘pulling-down’ factor, while evaluating habitat suitability.

The juxtaposition values for the entire landscape ranged between 16 and 160 (i.e. all agriculture cells to all waterbody cells) and were regrouped into ten equal classes. The higher juxtaposition values signify better habitat suitability as defined by the spatial arrangements of different landuse classes, and directly help in accentuating those patches of landscape that have the potential for being a part of the corridor network. In other words, juxtaposition values present near-realistic habitat conditions of the patches and the landscape.

On the face of it, while both interspersion and juxtaposition values describe two vital characters of landscape mosaic, they need to be treated differently, both in terms of their importance and their role in delimiting the suitable corridor areas within a landscape. As defined earlier, juxtaposition

**Table 2.** Landuse types in the study area

| Landuse type | Area ($km^2$) | Percentage of total area |
|---|---|---|
| CF | 4941.0 | 36.7 |
| OF | 773.2 | 5.7 |
| SC | 53.9 | 0.4 |
| FB | 16.6 | 0.1 |
| GR | 56.1 | 0.5 |
| AG | 7596.8 | 56.4 |
| WB | 28.7 | 0.2 |
| Total | 13466.3 | 100.0 |

**Table 3.** Forest types recorded with TWINSPAN

| Forest type | Major species composition | Percentage of total area |
|---|---|---|
| Sal | *Shorea robusta*, *Syzigium cumini*, *Pterocarpus marsupium*, *Zizyphus xylopyra* | 14.4 |
| Sal-mixed | *S. robusta*, *T. tomentosa*, *Buchannania lanzan*, *Ougenia dalbergioides*, *Emblica officinalis* | 54.2 |
| *Terminalia tomentosa*-I | *T. tomentosa*, *B. lanzan*, *Lagerstroemia parviflora* | 3.0 |
| *T. tomentosa*-II | *T. tomentosa*, *E. officinalis*, *L. parviflora*, *Diospyros melanoxylon* | 5.0 |
| Mixed with sal | *Anogeissus latifolia*, *O. dalbergioides*, *B. lanzan*, *T. tomentosa*, *S. robusta* | 13.9 |
| Mixed without sal-I | *E. officinalis*, *Bridelia retusa*, *Kydia calycina*, *T. tomentosa* | 6.0 |
| Mixed without sal-II | *T. tomentosa*, *O. dalbergioides*, *Cleistanthus collinus*, *Lannea coromandelica* | 3.5 |

**Table 4.** Indicators of habitat conditions at different disaggregated levels

| Parameter | Bottleneck area | Edge area | Core area | Protected area | Outside protected area | Entire area |
|---|---|---|---|---|---|---|
| No. of sample plots | 82 | 67 | 52 | 43 | 158 | 201 |
| Tree density (no./ha) | 809 | 729 | 979 | 1024 | 772 | 826 |
| Percentage sample plots in canopy cover (%) classes | | | | | | |
| 20–40 | 34 | 36 | 20 | 16 | 35 | 31 |
| 40–60 | 44 | 43 | 40 | 37 | 44 | 43 |
| >60 | 22 | 21 | 40 | 47 | 21 | 26 |
| Mean canopy cover (%) | 49.7 | 49.1 | 58.3 | 60.7 | 49.3 | 51.7 |
| Mean stand height (m) | 17.2 | 15.1 | 17.2 | 17.2 | 16.3 | 16.5 |
| Mean shrub cover (%) | 26.7 | 17.8 | 26.9 | 29.4 | 22.3 | 23.8 |
| Mean grass cover (%) | 7.1 | 13.1 | 25.3 | 18.7 | 12.5 | 13.8 |
| Shannon diversity index | 1.98 | 2.14 | 2.27 | – | – | – |
| Species richness | 6.47 | 6.06 | 5.62 | – | – | – |
| Percentage sample plots in regeneration classes | | | | | | |
| Poor | 6 | 11 | 6 | 2 | 9 | 7 |
| Medium | 26 | 43 | 23 | 16 | 35 | 31 |
| High | 68 | 46 | 71 | 82 | 86 | 62 |
| Percentage sample plots in water distance (m) classes | | | | | | |
| <100 | 26 | 49 | 33 | 40 | 34 | 35 |
| 100–200 | – | 10 | 8 | 9 | 5 | 6 |
| 200–500 | 29 | 21 | 38 | 35 | 27 | 29 |
| 500–1000 | 16 | 21 | 6 | 7 | 12 | 11 |
| >1000 | 29 | 10 | 15 | 9 | 22 | 19 |
| Percentage sample plots in weed intensity classes | | | | | | |
| High | 16 | 15 | 8 | 12 | 14 | 13 |
| Low | 15 | 21 | 11 | 9 | 18 | 16 |
| Nil | 69 | 64 | 81 | 79 | 68 | 71 |
| Ungulate encounter rate (evidences/km) | | | | | | |
| Cheetal | 1.3 | 1.1 | 5.6 | 7.0 | 1.1 | 2.4 |
| Muntjac | 0.7 | 0.2 | 2.1 | 2.5 | 0.4 | 0.9 |
| Sambar | 0.0 | 0.4 | 0.4 | 0.5 | 0.2 | 0.2 |
| Total | 1.9 | 1.7 | 8.1 | 10.0 | 1.7 | 3.5 |
| Livestock dung (no./km) | 11.2 | 12.3 | 7.9 | 2.8 | 47.2 | 10.7 |
| Tree cut (no./ha) | 302 | 254 | 102 | 96 | 272 | 232 |

values identified suitable habitat patches for the corridor by considering the adjacency of critical habitats and play a stronger and direct role in corridor identification. On the other hand, the interspersion values represent the degree of breaks in the corridor (or fragmentation) and thus reduced its functional value. Due to their relative importance, the juxtaposition values were given four times higher weightage than the interspersion values. Finally, in order to obtain a more realistic landscape suitability model, interspersion values were subtracted from the weighted juxtaposition values (i.e. landscape suitability = 4*J*–*I*). This composite map embodied the entire landscape into four suitability classes (nil, low, moderate and high) and was considered as the 'preliminary suitability map' (PSM).

Proximities to human habitation and road networks are known to have pulling-down effect on habitat quality[34]. Therefore, in the present study four distance buffers of 0.5, 1, 2 and >2 km were generated along the village boundaries and road networks. These buffer areas were assigned with appropriate numerical weights in increasing order with decreasing proximity to the villages and roads. These were used in developing a 'biotic pressure map' and demarcate the entire landscape into four pressure classes (nil, low, moderate and high).

It is implicit that the habitat suitability of the area, as derived through spatial patterns of landscape (interspersion and juxtaposition), actually gets diminished due to biotic pressures. Therefore, the biotic pressure map was overlaid on the PSM and the 'final suitability map' (FSM) was generated, which was also categorized into four suitability classes (Figure 4). Considering that the habitat contiguity and its suitability are the two most important criteria for establishing the corridors, highly suitable patches by themselves could not establish the contiguity between the two PAs. Thus moderately suitable patches are found critical to ascertain the corridor between the two PAs (Figure 4).

### *Patch characterization*

Habitat patches with relatively larger size, less appendages and less porosity are crucial for long-term viability of corridor functions[2,11]. The FSM clearly suggested that the intervening areas between KTR and AWLS represent a patchy landscape that supports a different quality of habitat. Under such conditions, for the present study FSM was used for characterizing patches within the landscape, using parameters like patch size, patch shape, porosity and patchiness.

Structural analysis of patches was specifically conducted in three major zones that are delineated on the basis of their existing level of protection (Figure 4). Being better protected, Zone-1 has good core environment as indicated by the presence of patches of large sizes and less patchiness (Table 5). Zone-2 is predominantly a multiple use area and thus is subjected to severe biotic pressure. High degree of interspersion of agricultural lands in the forested tracts is a characteristic feature of this zone, represented by patches of small size with higher patchiness and porosity values. Most of the forests in Zone-3 are from AWLS and thus receive better protection. Consequently, the zone was characterized by large patch size and low patchiness, indicating more compact conservation area. Conversely, high porosity in this zone indicates the presence of villages and agricultural lands within AWLS and adjacent forest areas. Interestingly, the patch characteristics across zones recorded a concurrence with the quality of habitat in the respective zones. Accordingly, around 32, 11 and 25% of total area of the respective zones were found under highly suitable areas (Table 5).

### *Management prospects*

Around 45% of the total forest area of the entire landscape is under the PA system and is located at two opposite ends of the study area (i.e. Zone-1 and Zone-3). Central part of the study area (i.e. Zone-2) is unprotected. Different spatial and field parameters clearly highlight that the forests in this part of the landscape are under severe biotic pressure and therefore, highly vulnerable to large-scale habitat transformations. Hence, the role of this zone becomes critical in restoring viable habitat contiguity between the KTR and AWLS. Upgrading the legal status of forests in Zone-2 could be one measure to prevent further degradation of these crucial habitats. Keeping this in view, our study suggests raising the conservation status of four patches of reserve forest (RF) to that of four satellitic sanctuaries.

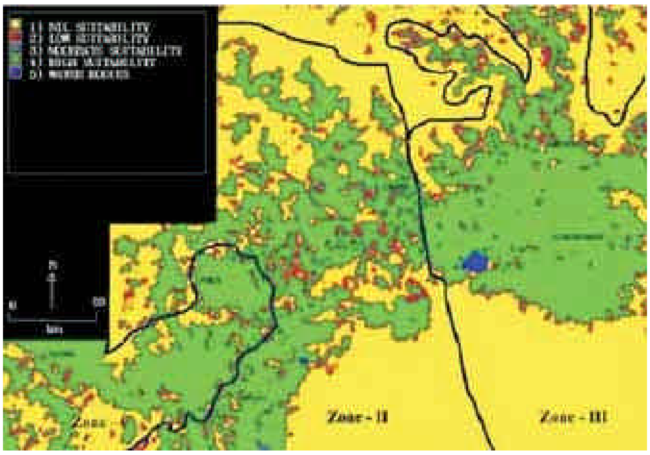


**Figure 4.** Final suitability map. For the description of zones, see text.

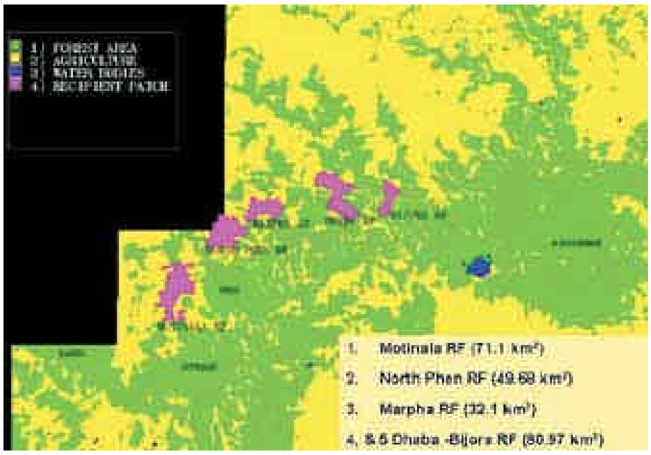


**Figure 5.** Location of forest patches identified for satellitic sanctuaries.

**Table 5.** Landscape characteristics in different zones. Zones are defined on the basis of current conservation status

| Parameter | Zone-1 (Kanha and Phen) | Zone-2 (Reserve Forests) | Zone-3 (Achanakmar) |
|---|---|---|---|
| Average patch size ($km^2$) | 205.9 | 102.8 | 164.7 |
| Average patch shape (1 for any circle) | 2.3 | 2.5 | 2.4 |
| Patchiness | 0.6 | 2.4 | 1.6 |
| Patch porosity | 2.7 | 13.3 | 10.0 |
| Suitable area (%) | | | |
| High | 32.1 | 10.8 | 25.1 |
| Moderate | 25.5 | 24.0 | 17.0 |
| Low | 7.3 | 8.7 | 5.9 |
| Nil | 35.0 | 56.5 | 51.6 |

These patches, due to their size and strategic location in the corridor, are crucial in providing refuge as well as habitat contiguity to different dispersing wild animals. These forest patches include Motinala RF (71.1 $km^2$), North Phen RF (49.68 $km^2$), Marpha RF (35.1 $km^2$) and Dhaba–Bijora RF (80.97 $km^2$; Figure 5).

Although the present study identifies the potential of establishing the forested corridor between the two PAs, it also recorded that at several locations the connectivity exists only through narrow forest strips. Loss of these critical forest patches could seriously impair the viability of the corridor between the two PAs. Therefore, some phase-wise management interventions are needed in these forest areas. Packages of community-centred conservation programmes with eco-development measures in the villages lying in such forested tracts are a prerequisite for the viability of this corridor.

More importantly, the entire study area is spread over different districts, divisional administration and even states, which might cause serious administrative complications in coordinating and implementing any holistic conservation and management plan for the area. To provide an institutional backing for the landscape level management, the setting up of an apex coordinating body with the representatives from the Forest and Revenue Departments of MP and Chhattishgarh is felt important.

## Conclusion

Given that the natural patchiness of Central Indian forests is increasingly being fragmented by human activities, the present study to evaluate the possibilities of a corridor for biodiversity conservation of the region is timely. While this study does not attempt to pass final judgments on corridor capabilities as such, it actually provides a synoptic view of the area and its potential for corridors, using some of the most commonly used concepts of landscape ecology. Methodologically, this study is also able to provide a framework where there is a balance between contemporary field ecological methods and modern analytical tools like remote sensing and GIS. Such complementarities of different analytical approaches clearly enhance our power to evaluate wildlife habitats for identifying the key conservation areas within a large, highly fragmented and differentially managed landscape. We, therefore, advocate extensive use of such methodological framework in other biodiversity-rich areas of the country, for restorative management and conservation planning. At the same time, we also felt that the results from such approach could be significantly improved if (i) better resolution satellite data are used to prepare more detailed landuse maps, (ii) topographical information is used in the form of terrain models and (iii) more detailed field-base information is collected on habitat and biotic pressure parameters.


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ACKNOWLEDGEMENTS. We thank all the officials in the MP and Chhattisgarh Forest Departments who shared valuable information and their experiences about the area and also provided full logistic support during the entire survey period. We thank Shri H. S. Panwar and Shri S. K. Mukherjee, Wildlife Institute of India (WII), Dehra Dun, for motivating us to take up this study. Thanks are also due to the entire technical team in the GIS Cell of WII for inputs at various stages of the study.

Received 15 December 2003; revised accepted 16 December 2004