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RESEARCH ARTICLE

Designing a Protected Area Network for Conservation Planning in *Jhum* Landscapes of Garo Hills, Meghalaya

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Abstract We studied vegetation and land cover characteristics within the existing array of protected areas (PAs) in South Garo Hills of Meghalaya, northeast India and introduce the concept of protected area network (PAN) and methods to determine linkages of forests among existing PAs. We describe and analyse potential elements of a PAN, including PAs, reserved forests, surrounding buffers as zones of influence, and connecting forest corridors, which collectively can provide old-forest habitat for wildlife species linked across a landscape dominated by *jhum* (shifting cultivation) agriculture. ANOVA and Chi-square analyses of patch characteristics and forest tree diversity suggested the presence of equally species-rich and diverse old forest cover (tropical evergreen, semi-evergreen and deciduous forest types) in portions of unprotected private and community owned land, which could be designated as additions to, and network linkages among, existing PAs. Such additions and linkages would help provide for conservation of elephants and existing native forest biodiversity and would constitute a PAN in the region. Most (80%) of the total forest cover of the region belongs to private or community owned land. Therefore, such additions could be formally recognized under the aegis of the 2003 amendments of the Wildlife (Protection) Act 1972, which include provisions to designate selected forest patches within private lands as Community Reserves.

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Introduction

Designating protected areas (PAs) is an important tool for conserving biological diversity and is a cornerstone of sustainable development strategies. Globally, more than 100,000 PAs encompassing about 11.6% of earth's terrestrial surface support a wide variety of the planet's biodiversity and species richness (SCBD, 2008). PAs typically include national parks, sanctuaries and other areas designed independently to protect local resources of social and scientific value from anthropogenic disturbances. In this paper, we expand the PA concept to a landscape-scale approach of identifying a protected area network (PAN), in which the role of each PA is evaluated in spatial context of all others and the intervening matrix lands. A PAN approach goes beyond the focal PA approach by evaluating the needs and opportunities for linking individual PAs with habitat corridors (Rouget *et al*., 2006), complementing existing PAs to meet various broad-scale conservation objectives (e.g., redundancy, complementarity, and uniqueness of habitats and resources within PAs), and addressing human activities in the intervening matrix lands to help maintain selected habitat elements and conditions.

One PAN architecture capable of achieving the joint targets of biodiversity conservation and providing for sustainable development can use, in part, the core-buffer strategy of the biosphere reserve system (Dyer and Holland, 1988) that includes strictly protected core areas as well as buffer areas of moderate resource use. Such an approach can be applied to conservation of wildlife habitat in fragmented landscapes also used by people for resource extraction (e.g. Heijnis *et al.,* 1999) within a landscape-scale PAN approach.

Planning for conservation of wildlife habitats at the broad landscape scale has many advantages over focusing only on specific, smaller, and disjunct and isolated parcels of land. Landscapes provide the big picture perspective at appropriate scales of ecological relationships among species, ecological communities, populations and ecosystems of wild plants, animals, and human activities (Marcot *et al*., 2002a). Our study landscape includes a mosaic of natural forest and human induced non-forest patches in the southern portion of Garo Hills in Meghalaya, north-east India. The few PAs currently designated in Garo Hills provide source populations for many wildlife species associated with undisturbed, older native forest conditions. Such wildlife typically disperse into the surrounding disturbed areas which generally serve as sinks where populations can exhibit low recruitment and high mortality rates. To help ensure the future of wildlife associated with undisturbed, older native forests of Garo Hills, we suggest a strategic planning approach involving broadening the concept and designation of a PA network to include designated wildlife habitat corridors among the PAs and between protected and unprotected areas. We use the Asian elephant (*Elephas maximus*) as an 'umbrella' species for designing such a network, under the assumption that forest habitat conserved or restored for elephants will also provide for a wide variety of other wildlife species also associated with older, undisturbed forest environments.

Elephants perform vital ecological functions such as creation and maintenance of forest paths and pools, used in turn by many other species including ungulates; and dispersal of fruits and seeds through dung deposition. Conserving elephants also serves to conserve many other wildlife species. Marcot *et al*., (2002b) analysed elephant populations and landscape characteristics and demonstrated a landscape scale conservation strategy for managing elephants in South Garo Hills. However, so far, little work has been done to evaluate the efficacy of existing PAs in Meghalaya (or north-east India). Khan *et al*., (1997) assessed their effectiveness using non-spatial databases, and suggested expanding PA coverage to better represent those biodiversity elements of Garo Hills occurring outside boundaries of existing PAs including reserved forests (RFs). The objective of our study was to critically examine existing PAs in Garo Hills and suggest an effective PAN design that can help conserve the elephant and associated biodiversity in the tropical forest ecosystem of this region.

Materials and methods

Study area

Meghalaya state in north-east India has five PAs, four of which occur in Garo Hills and represent more than 90% of state's PA coverage. Our study area (2,459 km^2) included South Garo Hills district and the adjacent Nokrek ridge in the adjoining west Garo Hills (Fig. 1). Our study area landscape holds all the PAs in Garo Hills, i.e. Balpakram National Park (BNP; 220 km^2), Nokrek National Park (NNP; 47.48 km^2, later extended to 80 km^2 to make a Biosphere Reserve), Siju Wildlife Sanctuary (SWS; 5.18 km^2) and Baghmara Pitcher Plant Sanctuary (BPPS; 0.03 km^2). Also, we considered as PAs four RFs due to absence of dependent native Garo community and management of RFs as protected forests (Kumar et at. 2002). These RFs included Baghamara (BRF; 44.29 km^2), Rewak (RRF; 6.48 km^2), Emangiri (ERF; 8.29 km^2) and Angratoli (ARF; 30.11 km^2) Reserved Forests (Fig. 1).

The PAs, including the RFs support various forest types such as tropical moist evergreen forest (TMEF) representing undisturbed primary forests; tropical semi-evergreen forest (TSEF) or old secondary forests, i.e. 30 years or older forest growth; and tropical moist deciduous forest (TMDF) or disturbed and relatively new secondary forests, i.e. younger to 30 years old forest growth; and grasslands that provide excellent habitats to many wildlife species (Kumar et al. 2006). Altogether the PAs and RFs constitute only 15% of study area landscape, whereas the rest belongs to the local Garo

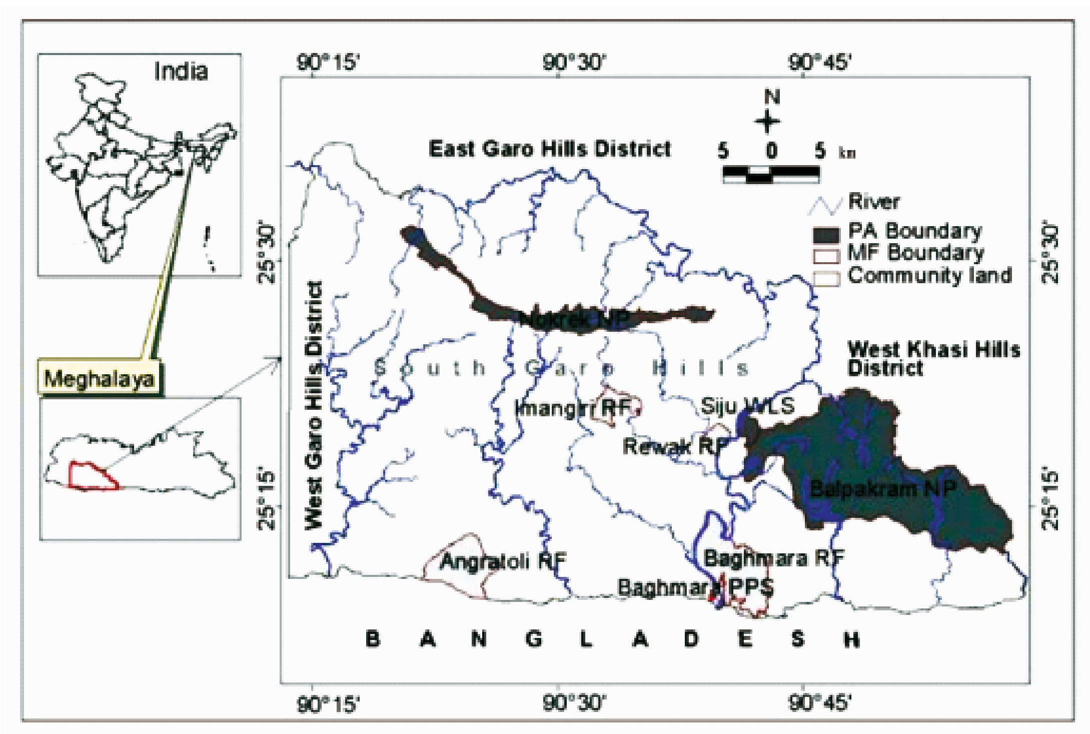

Fig. 1 Location map of study area. PA= Protected area, MF= Managed forests, RF= Reserved forests, NP= National park, WLS= Wildlife sanctuary, PPS=Picher plant sanctuary

community who commonly practice shifting cultivation (*jhum* or *jhumming*). Due to mass scale practice of *jhumming* over centuries, the larger tracts of primary forest cover (i.e., TMEF) in this region have been fragmented into a number of secondary forest patches.

Data used and methdology

We reviewed information (spatial and non-spatial data) on the Garo Hills landscape, including forest cover and existing protected areas, presented by Kumar *et al*., (2002) and other sources. This dataset includes maps and thematic layers representing important geographic features, land use activities, forest and vegetation cover categories and maps of vegetation fragmentation and forest corridors. We procured maps of PA boundaries and other spatial and non-spatial information from the State Forest Department of Meghalaya and Survey of India toposheets at 1:50,000 scale (Fig. 1).

The land use and landcover map (Fig. 2) used in the present study was generated from IRS-P4 LISS-3 satellite data of February 2000 (23.5 m resolution) by following standard mapping techniques of Lillesand and Kiefer (1994). We used this land use and land cover map to further evaluate forest fragmentation and to delineate potential wildlife habitat corridors among PAs (Fig. 3) with the Bio_CAP landscape analysis program (IIRS, 1999). Forest fragmentation

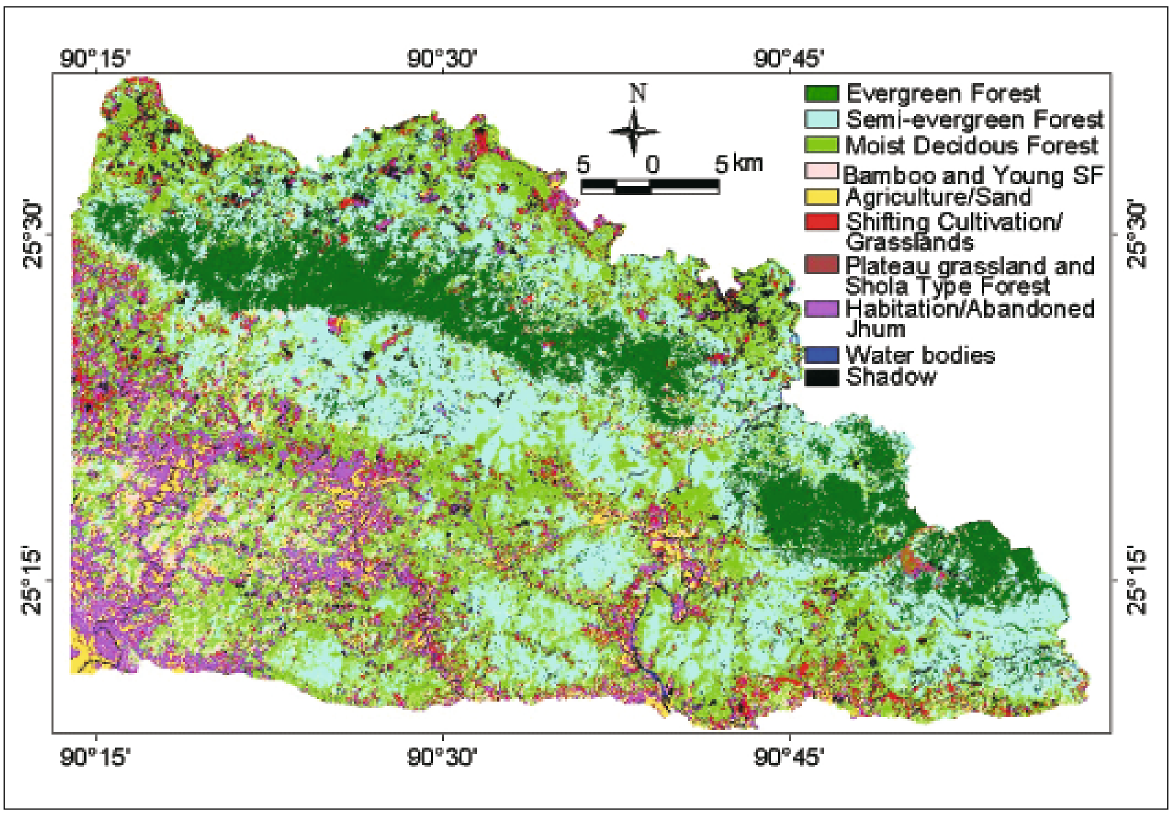

Fig. 2 Land use landcover and forest type map of study area (Source: Kumar *et al*., 2002)

was defined as the number of forest and non-forest patches per unit area, and was measured as the density of all types of vegetation patches (Romme, 1982; Roy and Tomar, 2001). We applied the Landscape Analysis Programme (LAP) in Bio_CAP using Borland C++ to evaluate forest fragmentation with a moving window analysis following methods of Roy and Tomar (2001) and Kumar *et al*. (2002). Areas of low fragmentation of native forest that linked PAs were delineated as potential wildlife (elephant habitat) corridors.

The patch indices, which we used for landscape level spatial analyses, included mean patch size, patch size standard deviation, mean patch edge length, standard deviation of patch edge length, patch density and edge density (Kumar *et al*., 2002). We mapped and analyzed conditions within two buffer distances around PAs of 2 and 5 km. These two buffer distances were selected because most Garo people inhabiting villages near PAs wander up to 2 km and 5 km for non-timber forest products collection and jhumming purposes, respectively. These two buffers divided community land into three zones, referred to as zones of influence (ZIs) in the present study. Zones ZI1, ZI2 and ZI3 represented areas within the 2 km buffer from PAs' boundaries, areas within the 5 km buffers (including between 2 km), and areas beyond the 5 km buffer (within community land), respectively (Fig. 4).

Tree species were surveyed using 1ha belt-transects (1000m × 10m) and phyto-sociology (among all n=35 belt-transects) was analyzed following Misra

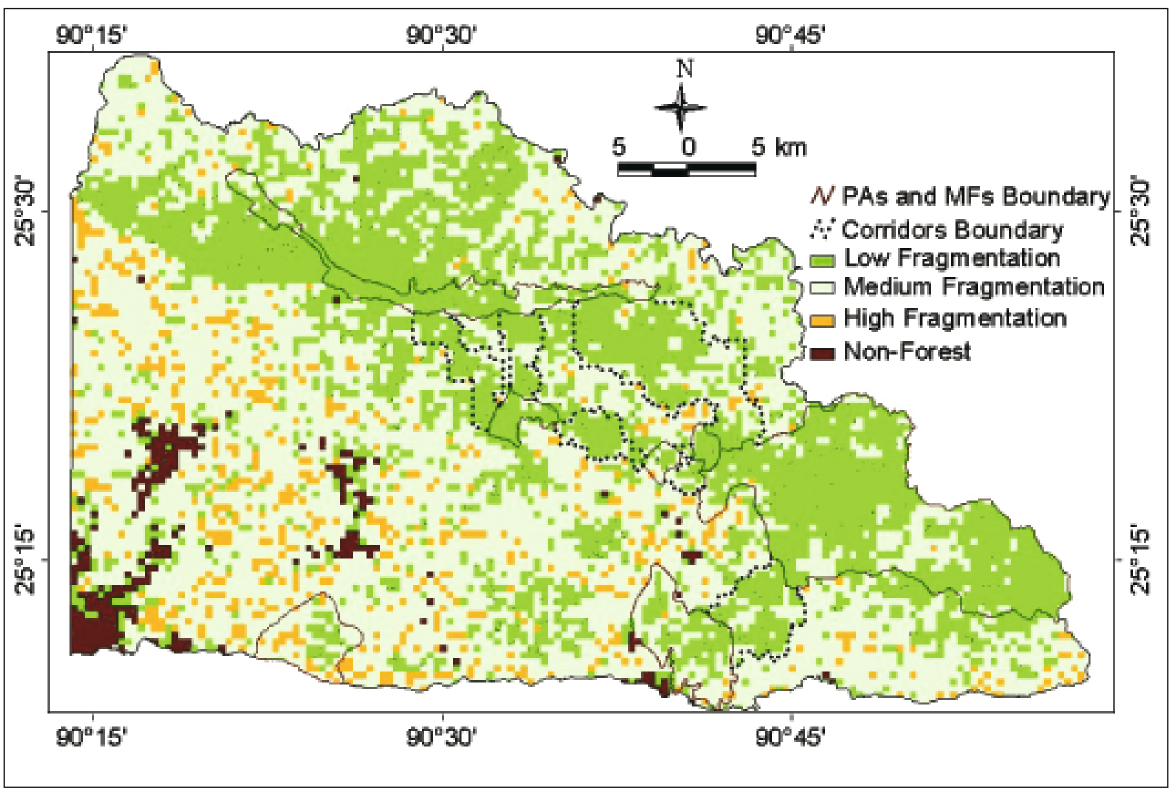

Fig. 3 Fragmentation and potential wildlife habitat corridors (Source: Kumar *et al*., 2002)

(1968). Non-spatial variables computed from the tree data included species importance value (SIV), number of tree species, mean tree density, mean basal area per ha, Menhinick index of species richness, Shannon-Wiener index of species diversity and modified Hill's ratio of species evenness (Ludwig and Reynolds 1988). We conducted further analysis of this spatial and non-spatial data to compare protected and non-protected areas using above mentioned spatial and non-spatial indices using analysis of variance (ANOVA) and Chi-square analysis ($\alpha = 0.05$).

Results and discussion

Forest cover and tree community

Forest cover including TMEF, TSEF and TMDF types comprised 68% of the study area (Fig. 2; Table 1). TMEF (14% of the study area) was confined mainly within the PAs which were typically adjoined by larger patches of TSEF (25% of the study area). TMDF, consisting of young forest, occurred mostly along the fringes of human settlements. PAs (including RFs) covered 366 km^2 of the study area; 90% of the PAs occurred as national parks (BNP and NNP) and sanctuaries (SWS and BPPS). Forest cover within PAs constituted 20% of the study area's forest cover and 12% of the entire study area.

***Patterns within protected areas**:* In PAs, the mean patch size (± 1SD) of TMEF, TSEF and TMDF were 0.62 ± 5.20, 0.17 ± 0.95 and 0.06 ± 0.19 km^2, respectively; and mean edge lengths (± 1SD) were 6 ± 3, 4 ± 14 and 2 ± 4 km, respectively. Patch densities of TMEF, TSEF, and TMDF were 2, 6, and 16 patches per km^2, respectively, and edge densities were 10, 22 and 32 km per km^2, respectively. The 10 most important tree species within PAs (decreasing order of SIV) were *Polyalthia simiarum, Schima wallichii, Castonopsis purpurella, Grewia microcos, Walsura tubularis, Macaranga denticulata, Syzygium cuminni, Syzygium operculatum, Aphanamixis polystachya,* and *Aporusa dioica*, and the 10 tree species with least importance values (SIV in increasing order) were *Anacardium occidentale, Cassia fistula, Bauhinia* sp., *Hodgsonia macrocarpa, Ochna integerrima, Disoxylum hamiltonii, Garuga pinnata, Aristolochia tagala, Bredelia tomentosa* and *Glycosmis arborea.* TMEF was absent from RFs. Mean patch size (± 1SD) of TSEF and TMDF were 0.31 ± 1.02 and 0.21 ± 0.69 km^2, respectively, and their mean edge lengths (± 1SD) were 6 ± 18 km for both TSEF and TMDF. Patch densities of TSEF and TMDF were 3 and 5 patches per km^2, and edge densities were 19 and 28 km per km^2, respectively. The 10 most important species (decreasing order of SIV) were *Shorea robusta,*

Table 1 Forest cover and non-forest areas (km^2) within existing protected areas and the entire study area in South Garo Hills

Existing Protected area	Tropical Moist Evergreen Forests	Tropical Semi-evergreen Forests	Tropical Moist Deciduous Forests	Non-forest area
Balpakram National Park	115	72	21	16
Nokrek National Park	26	14	4	4
Siju Wildlife Sanctuary		4	1	
Baghmara Reserved Forests		15	19	10
Angratoli Reserved Forests		10	13	7
Emangiri Reserved Forests		7	3	
Rewak Reserved Forests		2	2	1
All Garo Hills	353	624	703	778

Castonopsis purpurella, Schima wallichii, Tectona grandis, Syzygium cuminni, Grewia microcos, Aporusa dioica, Glycosmis arborea, Sapium baccatum, and *Dillenia pentagyna,* and the 10 species with least importance values (SIV in increasing order) were *Polyalthia* sp., *Phoebe* sp., Aesculus assamica, Ardisia sp., *Citrus* sp., *Vitex glabrata, Wendlandia excelsa, Ficus lamponga, Abrus precatorius,* and *Syzygium operculatum*.

Patterns within community land: Forest cover constituted 80% of community land (ZI3), and community land constituted 55% of the total study area (Table 2). Mean patch size (± 1 SD) of TMEF, TSEF and TMDF were 0.26 ± 3.19, 0.19 ± 2.24 and 0.13 ± 0.94 km^2, and mean edge lengths (± 1SD) were 3 ± 28, 4 ± 36 and 4 ± 23 km, respectively. Patch densities of TMEF, TSEF, and TMDF were 4, 5 and 8 patches per km^2, and edge densities were 13, 23 and 32 km per km^2, respectively. Anthropogenic land uses (habitation, permanent agriculture and *jhum*) and bamboo patches occurring primarily within community land covered 343 and 99 km^2, respectively. The 10 most important species (decreasing order of SIV) were *Shorea robusta, Schima wallichii, Castonopsis purpurella, Eurya accuminata, Dillenia pentagyna, Diospyros variegata, Castonopsis* sp., *Syzygium cuminni, Macaranga denticulata,* and *Sapium baccatum*, and the 10 species showing least importance values (SIV in increasing order) were *Polyalthia* sp., *Phoebe* sp., *Aesculus assamica, Ardisia* sp., *Citrus* sp., *Vitex glabrata*, *Wendlandia excelsa*, *Ficus lamponga, Abrus precatorius,* and *Syzygium operculatum*. Mean patch size (± 1SD) of habitation, permanent agriculture and *jhum* were 0.07 ± 0.39, 0.06 ± 0.16 and 0.03 ± 0.04 km^2, and mean edge lengths (± 1SD) were 2 ± 10, 4 ± 36 and 1 ± 1 km, respectively. Patch densities of habitation, permanent agriculture and *jhum* were 4, 5 and 8 patches per km^2, and edge densities were 34, 28 and 48 km per km^2, respectively.

Table 2 Land use and land cover in various Zones of Influences (ZI), i.e. ZI1 (2 km ZI), ZI2 (5 km ZI) and ZI3 (beyond 5 km ZI within community land).

Land use and land cover category	Area in ZI1 (km^2)	Area in ZI2 (km^2)	Area in ZI3 (km^2)
Tropical Moist Evergreen forests	9	178	25
Tropical Semi-evergreen forests	52	327	121
Tropical Moist Deciduous forests	42	248	350
Habitation/Scrub/Abandoned *jhum* fields	5	37	186
Permanent Agriculture	4	21	68
Shifting Cultivation/ grasslands	9	66	91
Bamboo/Secondary Forests (6-10 years)	8	49	118
Waterbodies	1	2	4

Comparisons among land areas: ANOVA results comparing the tree communities between PAs, (with RFs) and non-protected forest cover from community land were statistically in significant for any of six variables used for analysis (Table 3), suggesting that forests in community land are equally rich and tree diverse as those in PAs. The higher tree density and basal area within community forest land is mainly because all sample plots (transects) from this category of land occurred in virgin primary forests or very old secondary forests. Little medium-aged or younger secondary forests occurred in community land because of excessive *jhumming*.

Higher mean patch size and lower patch density of forests within PAs compared to community land suggested lower fragmentation levels within PAs, although most forest cover occurred within community land. Forest fragmentation analysis revealed that 21% of the overall study area was under high fragmentation (Fig. 3), likely due to habitation, permanent agriculture and *jhum* in community land. A study by Talukdar (2004) revealed that forest cover (including evergreen, semi-evergreen and deciduous types) in Garo Hills recently has been in steep decline, as 51% was lost between 1980 and 2000.

Protected areas and zones of influence

ZI1 (total area 135 km^2) contained substantially more forest (79% of total area ZI1) than non-forest (habitation, permanent agriculture and *jhum*), which suggested lower anthropogenic pressures than in community land. Likewise, within ZI2 the overall forest area was much greater (81% of total area ZI2) than that of non-forest. Total area within ZI2 was seven times that of ZI1, although the proportion of forest and non-forest were nearly identical. However, ZI3 contained only 55% forest cover and the proportion of TMEF was substantially low (Figs. 4 and 5).

Results of chi-square analysis revealed that TMEF, TSEF and TMDF cover differed significantly among the landscape segments of (inclusive of RFs; Fig. 5), corridors, ZI1, ZI2 and ZI3 (likelihood Chi-square ratio = 411.472, df = 8, $p << 0.05$). The forest cover varied significantly with the highest proportion of area within ZI2. Degree of anthropogenic land use differed significantly among the three ZIs with the highest per cent cover in ZI3, where habitation was the most prevalent activity followed by *jhum* and permanent agriculture. ZI1 and ZI2 supported higher proportions of forest cover with almost negligible areas under anthropogenic land use, and ZI3 had the lowest proportion of old forest cover. Thus, forest conservation efforts in ZI3 could focus more on restoration activities, which may be coupled with additional measures to help protect the remaining, larger forest tracts within the community land. In contrast, in ZI1, ZI2 and corridors, forest conservation could focus more on protection of the existing, extensive TMEF, TSEF and TMDF cover, particularly for establishing forest network connections among PAs of the region. Our findings also suggested that conservation of forest biodiversity within ZI2 could be largely achieved by just protecting existing forests and, as well, discouraging the native community from mass scale clear-felling. High priorities for protecting existing forests may include ZIs around RFs, particularly Angratoli RF and Emangiri RF, because forests in these areas are most apt to be felled in the near future for habitation, permanent agriculture, or *jhum*.

Potential wildlife (elephant) habitat corridors

Some larger tracts of primary or very old secondary forest occur within the community land, providing an opportunity to establish habitat linkages for wildlife

Table 3 Vegetation characteristics in protected areas (including reserved forests) and community forest land among belt transects (each 1000×10m).

Vegetation characteristics	Protected Areas (n = 28 belt transects)	Community Forests (n = 7 belt transects)
No. of tree species per transect	26 – 84	37 – 87
Mean tree density (n/ha, ± 1SD)	829 ± 177	946 ± 124
Mean tree basal area (m^2/ha, ± 1SD)	49 ± 31	84 ± 54
Tree species richness (Menhinick) index	0.97 – 3.22	1.24 – 3.26
Tree species diversity (Shannon) index	1.72 – 3.69	2.26 – 3.72
Tree species evenness (modified Hill's ratio) index	0.25 – 0.70	0.29 – 0.71

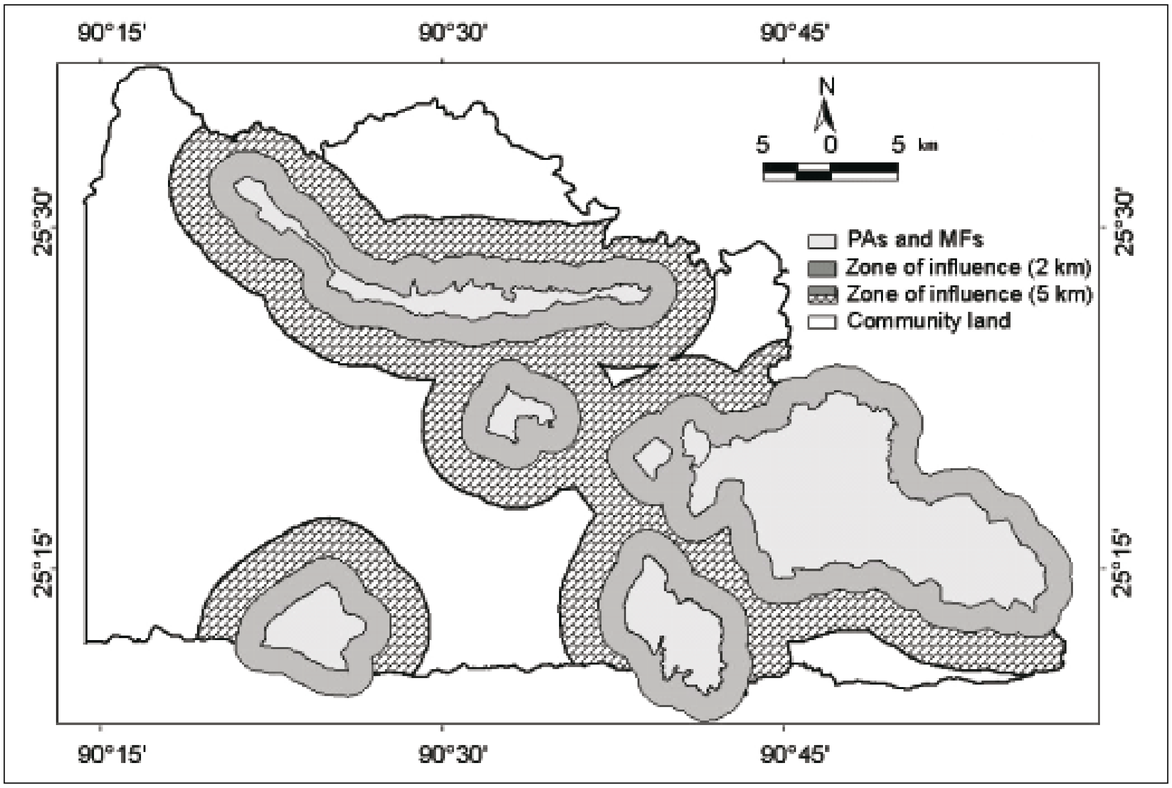

Fig. 4 Specified zones of influences (ZI); PAs = Protected areas, & MFs = Managed forests which are designated as reserved forests in the Garo Hills

Table 4 Distribution of forest types (km^2) within the potential corridors

Corridors	TMEF	TSEF	TMDF	Total
BNP/SWS-NNP	49	81	35	167
BNP-BRF	1	19	10	30
ERF-NNP	1	17	4	22
ERF-NNP	7	7	1	15
RRF-ERF	0	10	4	14
BNP/SWS-RRF	0	0	4	4
SWS-RRF	0	0	0	1
Total	58	136	58	253

ARF = Angratoli Reserved Forest, BRF = Baghmara Reserved Forest, ERF = Emangiri Reserved Forest, RRF = Rewak Reserved Forest, BNP/SWS = Balpakram National Park and Siju Wildlife Sanctuary: NNP = Nokrek National Park, TMEF= Tropical Moist Evergreen Forest, TSEF= Tropical Evergreen Forest; and TMDF= Tropical Moist Deciduous Forest.

to move among protected habitats within the more disturbed *jhum* community landscape. We identified seven potential wildlife (elephant) habitat corridors, which collectively covered 274 km^2, of which 92% is under forest cover (Table 4). We delineated the corridors on the basis of their containing high proportions of forest cover, large forest patches, and low forest fragmentation, and that could serve to link PAs of the region. One set of corridors link BNP with adjoining SWS in the south-east to NNP in the north along with two RFs (Imangiri and Rewak) via two or more routes. Another corridor links BNP with BPPS in the south along with an RF (Baghmara). At present, Angratoli RF remains unconnected with corridors to other PAs because of its relative isolation in the southwest among largely disturbed landscapes of habitations, agriculture, *jhum*, and medium to high levels of forest fragmentation.

The actual use of most corridors by native, wide-ranging wildlife needs to be evaluated in the field, although Williams and Johnsingh (1996) had earlier identified three elephant habitat or elephant travel corridors in the study area based on a short-term field survey. Their corridors were named as Siju-Rewak, Balpakram-Baghmara and Emangiri-Nokrek covering 8, 31 and 48 km^2, respectively. The seven corridors identified in present study encompass these three corridors identified by Williams and Johnshingh (1996). Angratoli RF likely was once connected with Emangiri RF, which helped facilitate movement of elephants between Nokrek Ridge in the north and the plains of Bangladesh in the south. Such migratory

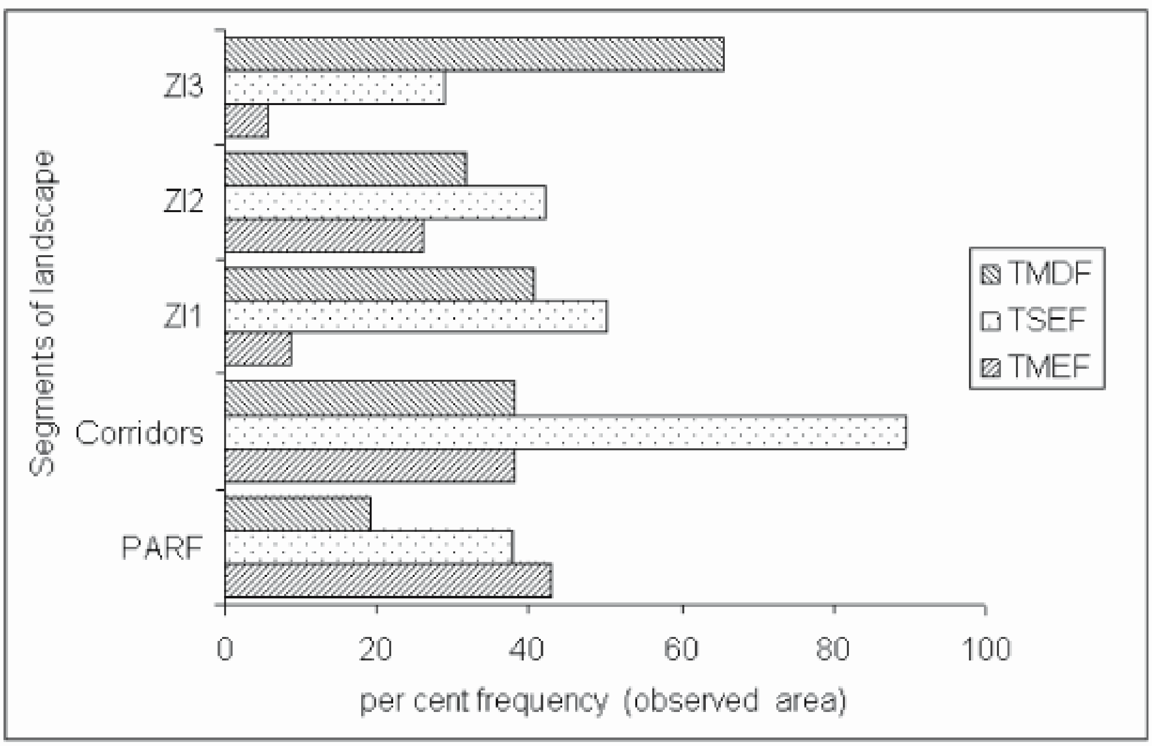

Fig. 5 Observed per cent area of various forest types among various landscape segments. TMEF = Tropical Evergreen Forests, TSEF= Tropical Semi-evergreen Forests, TMDF= Tropical Moist Deciduous Forests

routes could be restored with timely management interventions. Additionally, Angratoli RF is situated along the sensitive and porous international border, which makes this comparatively large RF vulnerable to habitat disruption, unauthorized timber removal, and illegal take of animals.

Conclusions

We refered to existing national parks, wildlife sanctuaries and RFs of west and south Garo Hills of western Meghalaya collectively as PAs. We identified a series of 7 potential forest corridors that could help link the PAs and, as such, would constitute a true PA network or PAN. To date, most PAs are identified and designated independent of other PAs, the broader landscape, and major conservation goals. The PAN approach also focuses on conditions among the PAs within the broader landscape, and delineates corridors based on high proportion of native forest cover, large average forest patch size, low levels of forest fragmentation, and low occurrence of anthropogenic land use, principally habitations, permanent agriculture and *jhum*. The PAN approach also provides clear delineation of lands more suited for human activities outside PAs and connecting corridors. As part of the PAN framework, we also evaluated forest conditions with three zones of influence surrounding PAs, and suggested potential restoration or preservation priorities within each zone, that would significantly add to the effective area of PAs and likely enhance the functionality of the connecting corridors.

Expanding the traditional conservation focus on PAs to include landscape-wide assessments and delineations of zones of influence and networks of connecting corridors could be usefully applied to other parts of the country where isolation of parks and wildlife reserves are proving problematic to maintaining at-risk species. The biodiversity within PAs in Garo Hills is influenced not only by the forest conditions protected within the PAs, but also by the traditional practice of shifting cultivation or *jhumming* in their surrounds. Our spatial analysis revealed that a substantial proportion of old native forest is still present outside existing PAs. However, unless such sites are brought within the modified and improved framework of PAN, it would be difficult to conserve biodiversity in the actively-managed community or privately-owned forest land in Garo Hills.

The Forest Rights Act of 2006 provides immense authorities to native tribal communities, empowering them to exploit natural resources including forests and wildlife to such extent that can gravely compromise native forest cover and associated biodiversity. The corridor system in our proposed PAN framework would likely provide for at least some successful, continued interchange, among PAs, of native, wide-ranging wildlife of the region including elephants, tigers, ungulates, and other large predators and herbivores. The PAN approach could include protection of selected, intact forests within zones of influence (ZI1, ZI2) and active restoration of selected sites (ZI3). From a regulatory perspective, the 2003 amendments of the Wildlife (Protection) Act of 1972 provide the basis by which state governments could be empowered to declare ‘Commmunity Reserves’ of such sites within zones of influence or connecting network corridors, by designating selected forests of high value for biodiversity conservation on non-government private or community lands. Additions to the PAs of the region, or designations of corridors and linkages to serve as a PAN, should also account for social and economic issues and resource needs of the Garo people (Mathur and Sinha 2008).

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