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Prioritisation of conservation areas in the Western Ghats, India

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A B S T R A C T

Areas of high conservation value were identified in the Western Ghats using a systematic conservation planning approach. Surrogates were chosen and assessed for effectiveness on the basis of spatial congruence using Pearson's correlations and Mantel's tests. The surrogates were, threatened and endemic plant and vertebrate species, unfragmented forest areas, dry forests, sub-regionally rare vegetation types, and a remotely sensed surrogate for unique evergreen ecosystems. At the scale of this analysis, amphibian richness was most highly correlated with overall threatened and endemic species richness, whereas mammals, especially wide-ranging species, were better at capturing overall animal and habitat diversity. There was a significant relationship between a remote sensing based habitat surrogate and endemic tree diversity and composition. None of the taxa or habitats served as a complete surrogate for the others. Sites were prioritised on the basis of their irreplaceability value using all five surrogates. Two alternative reserve networks are presented, one with minimal representation of surrogates, and the second with 3 occurrences of each species and 25% of each habitat type. These networks cover 8% and 29% of the region respectively. Seventy percent of the completely irreplaceable sites are outside the current protected area network. While the existing protected area network meets the minimal representation target for 88% of the species chosen in this study and all of the habitat surrogates, it is not representative with regard to amphibians, endemic tree species and small mammals. Much of the prioritised unprotected area is under reserve forests and can thus be incorporated into a wider network of conservation areas.

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1. Introduction

In the uphill battle to preserve increasingly threatened species and habitats with scarce resources, (Pimm and Raven, 2000; Brooks et al., 2002) scientists have identified areas that deserve high priority for conservation (Olson and Dinerstein, 1998; Stattersfield et al., 1998; Myers, 2003). One prioritisation approach has led to the delineation of 34 global hotspots of biodiversity (Myers, 2003; Mittermeier et al., 2004). Twenty of the 34 biodiversity hotspots identified by Myers lie in tropical countries, which for the most part, face the gravest threats to their natural resources and have the most limited resources for conservation. Subsequent studies have corroborated the importance of these areas as global priorities (Rodrigues et al., 2004a). Hotspots cover tens of thousands of square kilometers. Thus, there is an urgent need to conduct further prioritisation exercises within hotspots. Few exercises have been undertaken within the tropical hotspots, especially in Asia, where the resources for conservation are meagre and the need for prioritisation is the greatest (Rodrigues et al., 2004a).

This study presents a fine scale prioritisation effort for a tropical biodiversity hotspot in Asia: the Western Ghats of India. It represents the first such exercise based on the principles of systematic conservation planning (Margules and Pressey, 2000) for a tropical hotspot. While a considerable amount of work has already been done on identifying areas of conservation value in the Western Ghats, (Gadgil and Meher-Homji, 1986; Karanth, 1986, 1992; Rodgers and Panwar, 1988; Daniels et al., 1991; Nair, 1991; Ramesh et al., 1997c; Prasad et al., 1998; Venkatraman et al., 2002; Rodgers et al., 2002), most studies do not set explicit conservation targets, and lack a replicable and scaleable approach that is applicable to the entire hotspot. Many of the studies that have adopted biogeographic or ecosystem criteria are based on subjective evaluations by expert consultants (Rodgers and Panwar, 1988) and are therefore heavily biased towards areas for which some survey-based or other ground information already exists. Studies, such as the ones conducted by Ramesh et al. (1997c) and Prasad et al. (1998), that use a combination of species and ecosystem surrogates and apply uniform, quantitative criteria across the entire study area, are restricted to smaller sub-regions within the Western Ghats and no such objective prioritisation exists for the entire region.

Prioritisation exercises conducted in other regions have used a number of different methods including iterative heuristic algorithms, optimization algorithms or scoring. The latter has been found to be less efficient than iterative heuristic approaches (Pressey and Nicholls, 1989). Additionally, scoring techniques do not take into account the actual composition of various sites in terms of their surrogates. This precludes the application of principles such as complementarity, irreplaceability and flexibility, which have emerged as major considerations in conservation planning (Vane-Wright et al., 1991; Pressey et al., 1993; Ferrier et al., 2000; Margules and Pressey, 2000; Margules et al., 2002). Iterative approaches while suboptimal, offer the advantage of flexible, interactive solutions that are better suited to actual planning situations (Pressey et al., 1996).

This study identifies areas of high conservation value based on the distribution of threatened and endemic biodiversity. It uses an iterative approach founded on the principle of irreplaceability (Pressey et al., 1993; Ferrier et al., 2000; Tsuji and Tsubaki, 2004). The irreplaceability value of a given site is determined by its contribution towards meeting the specified conservation goal for a region (e.g. 10% of a certain habitat type or one representation of every threatened species), relative to other available sites. Irreplaceability accounts for how complementary a site is to existing reserves, in terms of maximizing the number of unrepresented features. It also facilitates flexibility in conservation planning by presenting the planner with a range of options for meeting the stated conservation goals (Ferrier et al., 2000).

The main objectives of this study are: (1) to identify and assess effective surrogates to represent the threatened and endemic biodiversity of the Western Ghats; (2) to identify areas of high irreplaceability using a combination of the most effective species and habitat surrogates, and (3) to examine the representativeness of the protected area network with regard to the species and habitat surrogates used.

2. Methods

2.1. Study area

The Western Ghats cover an area of approximately 160,000 km^2, with an elevational range of 300–2700 m, and a latitudinal extent of 12° (8°N–20°N) (Fig. 1). The presence of these hills creates major precipitation gradients that strongly influence regional climate, hydrology and the distribution of vegetation types and endemic plants (Pascal, 1988; Gadgil and Meher-Homji, 1990). A latitudinal gradient in duration of the dry season, determined by the rapid advance and gradual withdrawal of the southwest monsoons, is characterized by a decrease in the number of dry days from north to south. A longitudinal rainfall gradient is also generated, where rainfall decreases rapidly from west to east, in some instances from over 7000 mm to 4000 mm within 15 km (Gadgil, 1996; Ramesh et al., 1997b). This decrease also varies across latitude, with the transition being more rapid at higher latitudes (Ramesh et al., 1997b). Additionally, a temperature-elevation gradient gives rise to structural and floristic differences in forests at higher altitudes (Ramesh et al., 1997b). In general, the mean temperature of the coldest month ranges from 25 °C at sea level to 11 °C at 2400 m (Daniels, 2001). Variation in the degree of endemism in the Western Ghats is affected by these latitudinal and temperature gradients, with a greater number of endemics found in the southern parts of the Western Ghats, which have a shorter dry season and higher elevations (Ramesh et al., 1997b), with plant species diversity and endemism increasing from east to west (Ramesh et al., 1997b; Gadgil, 1996).

The study area comprises the major portion of the Western Ghats and Sri Lanka biodiversity hotspot (Myers et al., 2000). The Western Ghats contains more than 30% of all plant and vertebrate species found in India, in less than 6% of India's landmass. It is estimated that there are four thousand species of flowering plants known from the Western Ghats and 1500 of these are endemic (Nair and Daniel, 1986). The major forest types are moist deciduous forests, evergreen and dry deciduous forests. The evergreen forests contain

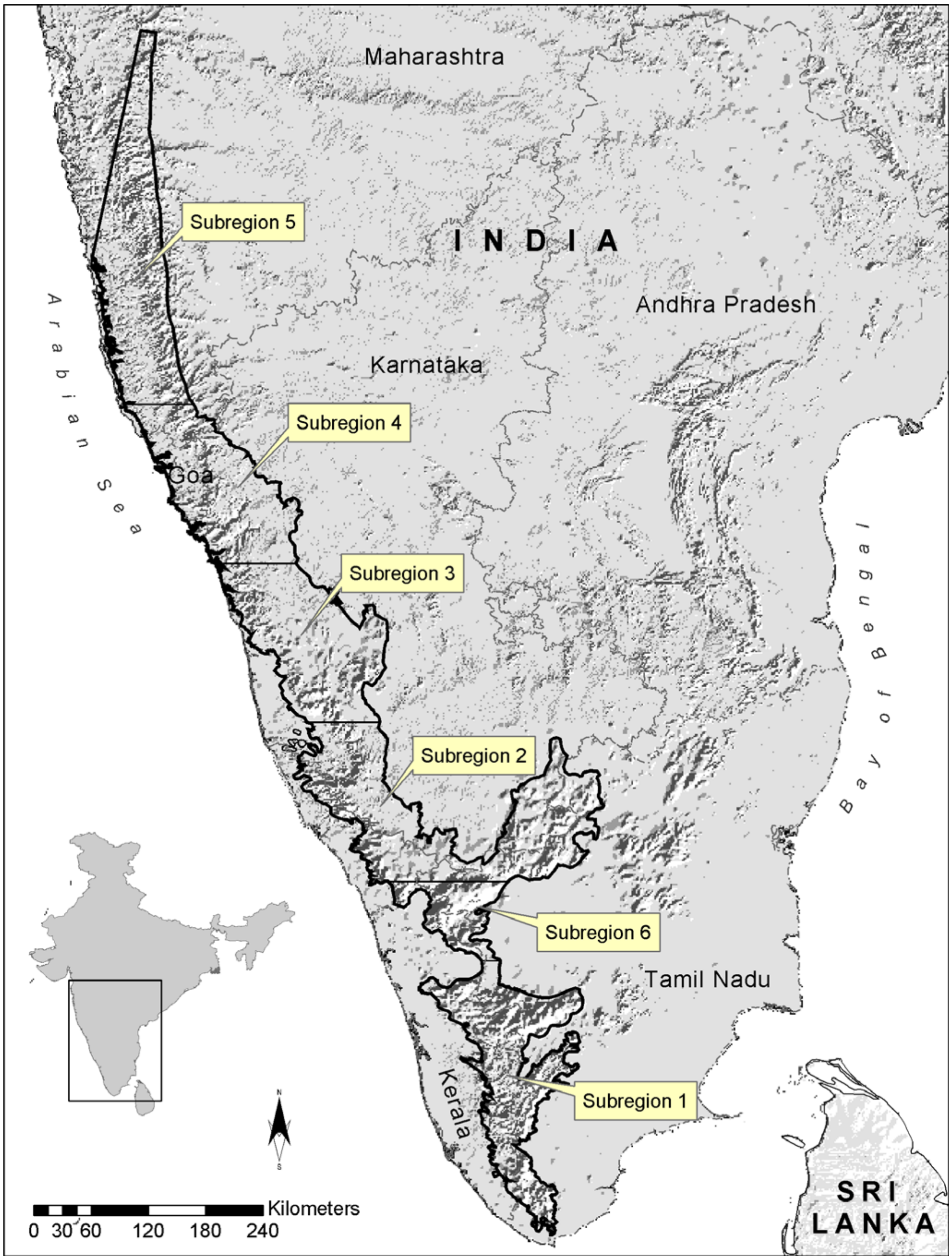

Fig. 1 – Study area map showing division into subregions for analysis.

the highest number of endemics. Levels of endemism within this forest type are not uniform as there are many localized centers of endemism and speciation (Blasco, 1970; Nair and Daniel, 1986). The dry forest types, though poor in plant endemism and diversity (Daniels, 2001), provide crucial habitats for wide ranging animals such as tigers (*Panthera tigris*) and the Asian elephant (*Elephas maximus*) (Sukumar, 1989; Wikramanayake et al., 1999).

The Western Ghats supports a diverse fauna. Among the vertebrates, the largest number of known species is among birds (508 species), followed by fishes (218), reptiles (157), mammals (137), and amphibians (126). The highest rate of endemism is to be found among amphibians (78% of all Western Ghats species) followed by reptiles (62%), fish (53%), mammals (12%), and birds (4%).

2.2. *Identification and assessment of surrogates for representation of threatened and endemic biodiversity*

A combination of species and habitat surrogates were selected to represent the threatened and endemic biodiversity (Pressey, 2004) of the Western Ghats. The surrogates were: presence records for globally threatened and endemic vertebrates and plant species, area of the rarest habitat type by sub-region, area covered by unique evergreen ecosystems, area covered by dry forest habitats, and finally, area of relatively unfragmented or low edge forest habitat. The analysis focused on threatened and endemic species rather than total species, as this group is the most vulnerable and most in need of conservation action (Eken et al., 2004). Similarly, the choice of unique evergreen ecosystems and the rarest habitat class by sub-region attempted to capture rarer forest types as the faunal elements associated with these rare habitats are likely to be under greater threat. Most of the species surrogates used for this study are endemic to evergreen forests. Dry forests were therefore specifically targeted to include species of birds and mammals that are endemic or threatened within this habitat type. Forest areas with low edge were chosen as a surrogate to target large, intact forest patches where the probability of persistence of threatened forest interior species is likely to be highest. Together, these habitat surrogates also encompass the elevational gradient of the Western Ghats.

2.2.1. *Mapping of species surrogates*

The distributions of species surrogates were mapped by imposing a 1:25,000 scale grid (0.125° longitude by 0.125° latitude) on site polygons for each of the species and recording whether the species was present within each grid. This was done using ArcGIS software (Environmental Systems Resource Institute, 2003). A geographic projection with a WGS 84 datum was used for all the spatial layers in this study. Plant species were mapped to grids based on their respective point occurrences. For animal species, sites included reserve forests, protected areas, private lands, and in some instances, entire forest divisions. Reserve forests are nested within forest ranges, which are in turn nested within forest divisions. These categories have fewer restrictions on human use than protected areas (Wildlife Sanctuaries, Tiger Reserves and National Parks).

IUCN (2002) Red Listed animal species of the Western Ghats and endemic tree species of evergreen and semi-evergreen forests were used as the species surrogates. The IUCN Red List provides quantitative, standardized criteria to identify and assess globally threatened species. Only species classified as critically endangered, endangered and vulnerable were used. As the IUCN Red List from 2002 contains insufficient information on threatened amphibians in the Western Ghats, information compiled by the Global Amphibian Assessment was also included to identify and map threatened and endemic amphibian species (IUCN, Conservation International, and NatureServe, 2004). All of the amphibian species considered in this study are endemic to the Western Ghats. Mammal data were compiled from published literature. Information on Important Bird Areas in the Western Ghats (Islam and Rahmani, 2004) was used to map the distribution of bird species. The lack of consistent site-level information on reptiles, fish and invertebrate species in the Western Ghats prevented the incorporation of these groups in the analysis. For plant data, the comprehensive information provided on 352 endemic tree species by Ramesh et al. (1997b) was used. These records are in the form of point locations based on data gathered from herbaria, published literature and field surveys. Up to 49% of these species are also globally threatened (IUCN, 2002). The animal species databases were reviewed by experts at a workshop and further revised based on the information they provided.

2.2.2. *Mapping of habitat surrogates*

Two scenes of Indian Remote Sensing satellite WiFs sensor (pixel resolution 188 m), acquired for three dates between December 2000 and March 2003, were used to map habitats. The dates were chosen to capture seasonal variability, from the end of the wet season to the middle of the dry season. Images were geocoded using 1:250,000 scale Survey of India topographic maps. The study area was divided into 6 sub-regions corresponding to the French Institute vegetation maps (Pascal et al., 1982a,b, 1984, 1992; Ramesh et al., 1997a; Franceschi et al., 2002), (Fig. 1). These maps were used as the reference data for the vegetation classification. Forest cover classification was done separately for each sub-region using IDRISI Kilimanjaro (Clark Labs, 2003). Multi-date Normalized Difference Vegetation Index (NDVI) was used to classify forest and habitat types through a classification and regression tree approach (Krishnaswamy et al., 2004). The forest types mapped were: evergreen forest, moist deciduous forest, dry deciduous forest, scrub forest and grasslands. The rule-based vegetation sub-class that covered the least area within each sub-region was identified as the rarest class. Only one such vegetation sub-class was chosen from each sub-region.

A distance measure, hereafter referred to as remotedist, was defined, which is a Mahalanobis distance (Mahalanobis, 1930) of every pixel in multi-date NDVI space to a reference evergreen class. The remotedist measure ranged from 0.749 to 175,000. Smaller values imply similarity to wet evergreen, high canopy biomass habitats and larger values span a gradient of increasing deciduousness and lower canopy biomass. Pixels with a remotedist value less than 1 were identified as unique evergreen ecosystems. In a visual comparison, these pixels were found to coincide with the presence of distinctive evergreen communities such as *Myristica* swamps, *Ochlandra* reed ecosystems and *Nagea wallichiana* facies as defined by the French Institute vegetation maps for South India (Ramesh et al., 1997a; Franceschi et al., 2002).

In order to obtain a quantitative index of low edge forest, multi-date NDVI based measures of spatial variability, including a local fractal dimension (Clark Labs, 2003), were defined on WiFs pixels nested within a 1 km^2 grid for the entire study area. A Principal Component Analysis generated three components, of which the third component was related to heterogeneity caused by edges, both natural and anthropogenic. Evergreen forests are the least "edgy" and dry deciduous and scrub forests are more "edgy". For a given forest type, especially evergreen, the third component was found to be useful in quantifying edges caused by human induced disturbance and degradation. Maps of the third component were shown to experts familiar with specific forest areas, and they verified the usefulness of this index in quantifying anthropogenic edge.

Only grids with a minimum 50% natural forest cover were retained. The third component values were classified into low, medium and high "edge" using quartiles. The area of low edge forest cover within each grid cell was calculated and used as a surrogate for relatively unfragmented forest areas. The use of this surrogate in the prioritisation de-emphasizes representation of habitats that are naturally "edgy" such as montane evergreen-grassland (*shola*) habitats. However, other habitat surrogates used in this study compensate for this effect.

2.2.3. Analysis of spatial congruence between various taxa and habitat surrogates

The surrogates identified for this study should provide complementary information about the distribution of threatened and endemic biodiversity (Vane-Wright et al., 1991). In order to assess this, a set of tests for spatial congruence was applied.

First, sets of grids were selected, on the basis of irreplaceability, to meet conservation targets (one occurrence for species surrogates and 10% area for habitat surrogates) for: (a) habitat surrogates only, (b) individual taxa and (c) combinations of taxa. Each set of grids was then examined to see whether it also met the conservation targets for surrogates that were not used in the selection of those grids (Beger et al., 2003; Warman et al., 2004).

The number of occurrences or extent in grids of each surrogate was also plotted against the other to check for non-linearity. For the surrogates that were related in a linear fashion, a pair-wise Pearson's correlation test was applied to assess the correlations between number of occurrences of various taxa or extent of habitat surrogates across grid cells. Mantel's tests (Mantel, 1967), using Bray Curtis distances (Urban et al., 2002), were conducted to assess whether grids that were similar in terms of their mean $\log_{10}$ remotedist measure were also alike in terms of their species' components. The Mantel's test answers the question of whether pair-wise differences between grids for a particular biodiversity component are correlated with pair-wise differences in another biodiversity component. Since these pair-wise differences are not independent, this non-parametric test, which uses permutations to assess significance, is particularly appropriate. Additionally, significance in the Mantel's r_M is achieved at a lower value than in the corresponding Pearson's correlation obtained using the original data.

2.3. Prioritisation of conservation areas

The study area was divided into 713 grid cells to correspond to Survey of India 1:25,000 scale topographic maps (0.125° latitude by 0.125° longitude), with each grid covering an area of about 180 km^2. Each grid cell was taken to correspond to one conservation area. The average size of protected areas in the Western Ghats is 243 km^2, while the average size of a reserve forest, the smallest forest administrative unit, in the region is approximately 69 km^2. Therefore the chosen grid size falls well within the range of areas for relevant management units in the Western Ghats.

Irreplaceability was selected to assign conservation value to these grids, as it is a measure of how important a given area is to achieving the conservation targets for the surrogates (Ferrier et al., 2000). Since the surrogates that the irreplaceability measure is based on are essentially endemic and globally threatened species and rare habitats, this study also accounts for vulnerability in the process of prioritisation. Additionally, one of the surrogates, low edge forest area, targets the most intact forest areas, especially evergreen forests, in the Western Ghats where viable populations of threatened and endemic species are most likely to occur.

The conservation planning software C-Plan (New South Wales National Parks and Wildlife Service, 2001) was used to calculate site irreplaceability and summed irreplaceability for each grid. The site irreplaceability measure multiplies across all surrogate irreplaceability values to produce an index for each grid, ranging from 0 to 1. A site irreplaceability of one indicates that the grid is critical in terms of meeting conservation targets for one or more of the surrogates contained within it. A grid with a low site irreplaceability value has many possible substitutes for reaching conservation targets for the surrogates it contains. Grids with an irreplaceability of 0.8–1 were prioritized iteratively, followed by grids with irreplaceability value greater than 0.2 that were adjacent to existing protected areas (Appendix). Grids with irreplaceability of 0.8 or greater had very few replacements and were therefore critical to meeting the conservation targets for one or more of the surrogates. Summed irreplaceability is calculated by adding across all the feature irreplaceabilities in a grid. Values range from zero to large numbers, with higher values indicating that the grid is important for achieving targets for several surrogates. Summed irreplaceability can be used to distinguish between grids that have a site irreplaceability of 1. The summed irreplaceability values were ranked and grids with summed irreplaceability values in the top 1% were prioritised.

Two levels of conservation targets were set for the prioritisation exercise. The first level aimed at a minimal total area of reserves, which captured only one occurrence of every species, and 10% of each of the habitat-based surrogates for the Western Ghats. The second level consisted of the following targets for the study area: (i) 3 occurrences of all targeted species (with each one in a different grid) (ii) all occurrences of the critically endangered species, (iii) 25% of the area under each of the habitat-based surrogates.

2.4. Evaluation of the representativeness and efficiency of the protected area network

The prioritisation analysis was first run with the assumption that none of the grids were protected and then re-run incorporating existing protected area boundaries (digitized at 1:250,000 scale). This was done to assess the representativeness and efficiency of the existing reserve network (Pressey and Nicholls, 1989) with regard to the chosen surrogates and targets. The steps used to create these reserve networks are detailed in the Appendix.

3. Results

3.1. Assessment of surrogates and their spatial congruence

The globally threatened flora and fauna in the Western Ghats are represented by 229 plants, 31 mammals, 15 birds, 52 amphibians, 4 reptiles and 1 fish species. Of these, 55 are critically endangered, 148 are endangered and 129 are vulnerable. Four hundred and ninety eight grids or 70% of the study area contained one or more species presences. Sites could not be identified for four mammal species, as adequate information on location could not be obtained.

Preliminary analysis revealed that most of the targeted species have restricted distributions, with 21% of the animal species occurring in less than 1% of the grids and 91% in less than 5% of the grids. Twenty-two of the globally threatened amphibian species in this hotspot are highly restricted; they are known only from one or two locations. Similarly, 39% of the plant species were found to occur in less than 1% of the grids and 86% in less than 5% of the grids. The most common species (only 2% of the total) were found to occur in 10–19% of the grids.

The greatest concentration of unique evergreen ecosystems is in sub-region 1, followed by sub-region 2 (Table 1a). These habitats have very localized distributions and are relatively rare throughout the Western Ghats. Overall, sub-region 6 had the highest proportion of low edge forests (Table 1a). Proportionally, sub-region 6 also had the most low edge evergreen forests, followed by sub-region 1. Sub-region 5 had the greatest proportion of high edge evergreen forest.

Table 1b identifies the rarest rule-based vegetation sub-class in each sub-region of the Western Ghats.

The grids selected on the basis of their irreplaceability towards meeting the conservation target of 10% of each habitat surrogate, served to capture one occurrence each for 57% of the species surrogates. Specifically, these grids represented 86% of the birds, 77% of the mammals, 61% of the amphibians and 55% of the plants. When the conservation targets were increased to 25% of each habitat type, 78% of the species surrogates were represented once, as follows: 93% of the birds, 91% of the mammals, 78% of the plants and 73% of the amphibians. Grids selected on the basis of irreplaceability for relatively unfragmented forest area were more effective at representing bird, mammal and amphibian species compared to grids selected on the basis of the other habitat surrogates. Grids selected to meet conservation targets for the unique evergreen ecosystems surrogate were most effective at representing endemic tree species.

Table 1a – Area under unique evergreen ecosystems and low edge forests in the sub-regions of the Western Ghats

Sub-region	Unique evergreen ecosystems (km^2)	Proportion	Low edge forest area (km^2)	Proportion
1	70	0.005	2312	0.165
2	28	0.001	2788	0.101
3	13	0.001	1533	0.116
4	7	0.001	1764	0.243
5	0.07	<0.001	1169	0.072
6	2	0.001	554	0.248

Table 1b – Identity of the rarest rule-based vegetation sub-class (Krishnaswamy et al., 2004) in each sub-region of the Western Ghats

Sub-region	Rarest rule based sub-class	Class area (km^2)	Proportion of sub-region
1	Evergreen sub-class	74	0.005
2	Open dry deciduous with grass and thickets	233	0.011
3	High elevation grasslands	16	0.002
4	Moist deciduous sub-class	48	0.004
5	Moist deciduous sub-class	49	0.003
6	Open moist deciduous sub-class	15	0.004

With regard to the species surrogates, it was found that grids selected on the basis of irreplaceability towards meeting the conservation target of one occurrence for each of the endemic trees captured 83% of the animal species surrogates. Those not captured included birds, mammals and amphibian species that are endemic to evergreen forests. Similarly, grids that met conservation targets for both mammals and amphibians captured 80% of the other species surrogates each, while birds captured 68% of other species surrogates. Grids selected for endemic trees and amphibians captured 92% of the threatened and endemic bird and mammal species, while the grids selected to meet conservation targets for threatened and endemic trees, amphibians and mammals captured at least one occurrence of all the bird species. However, it was found that these grids failed to capture all the occurrences of some critically endangered bird species (e.g. *Gyps bengalensis* and *Gyps indicus*). Therefore it was decided that the bird species data should be retained in the final prioritisation.

Results of the Pearson's pair-wise correlations between the distributions of threatened and endemic species of various taxa show that the strongest correlation is between the distributions of threatened birds and mammals ($r = 0.739$, $p < 0.01$), followed by that of endemic amphibians and endemic mammals ($r = 0.668$, $p < 0.01$) (Fig. 2). Among the animal taxa, mammalian richness showed the highest correlation with richness of other animal taxa combined ($r = 0.785$, $p < 0.01$), followed by birds ($r = 0.702$, $p < 0.01$) and then amphibians ($r = 0.637$, $p < 0.01$). Amphibian richness was the most highly correlated with overall threatened and endemic species richness, including trees ($r = 0.586$, $p < 0.01$), followed closely by mammals ($r = 0.581$, $p < 0.01$). The correlation between endemic tree species richness and that of threatened and endemic animals was also relatively strong ($r = 0.543$, $p < 0.01$). However, the correlation between endemic tree species and amphibian richness ($r = 0.515$, $p < 0.01$) proved to be weaker than that between endemic trees and endemic mammals ($r = 0.576$, $p < 0.01$). When all mammals were included, this relationship weakened ($r = 0.497$, $p < 0.01$). Finally, the correlation between the distribution of the unique evergreen ecosystems and endemic tree species richness was $r = 0.524$ ($p < 0.01$).

The results of the Mantel's tests also showed a significant positive correlation between the Bray Curtis distance for endemic tree species and the mean $\log_{10}$ remotedist ($r_M = 0.267$, $p < 0.002$), indicating that grids that were more similar in terms of remotedist values were also more similar in terms of their endemic tree species composition. The results for individual animal taxa varied with mostly small but significant correlations: amphibians ($r_M = 0.102$, $p < 0.002$), mammals ($r_M = 0.056$, $p < 0.002$) and bird species ($r_M = 0.058$, $p < 0.002$). Finally, the results using combinations

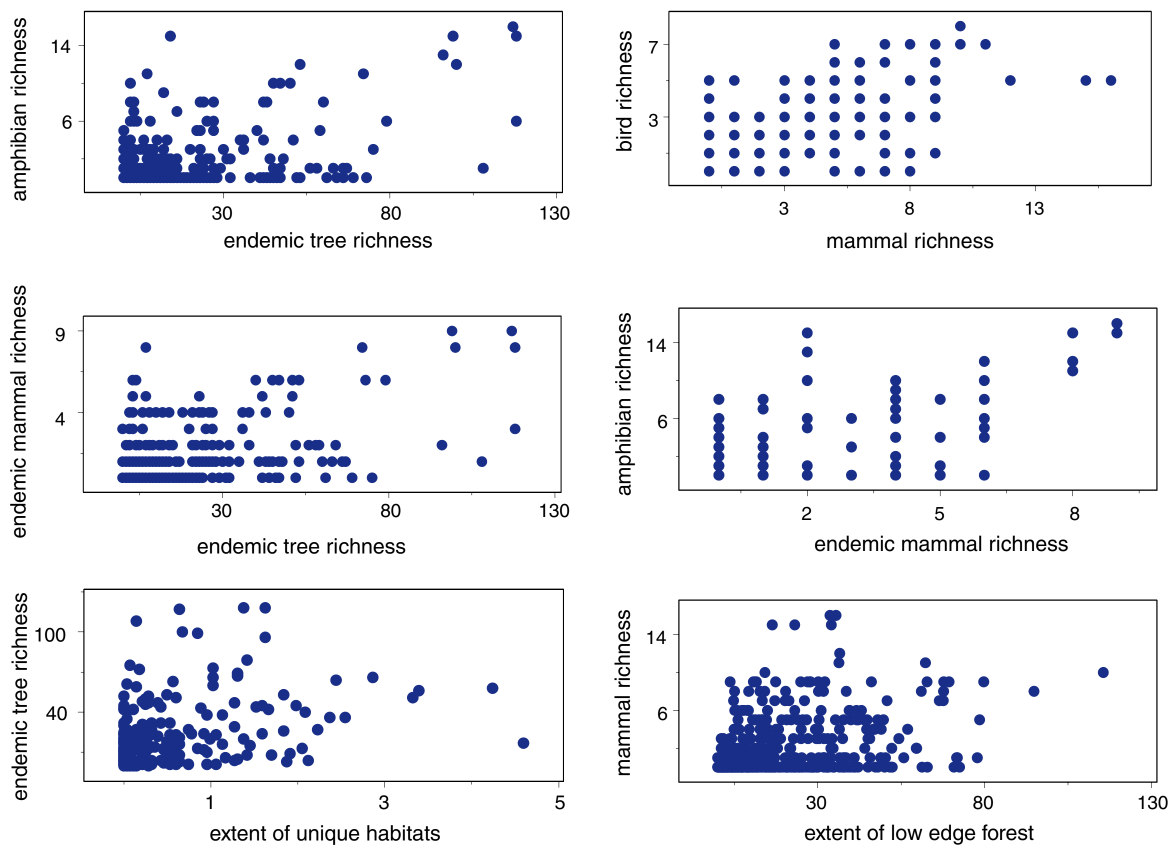

Fig. 2 – Pair-wise scatterplots of surrogates that show significant correlations across grid cells in their species richness/ habitat extents.

of taxa indicated that the remotedist measure performs best in the case of birds, endemic trees and amphibians combined ($r_M = 0.23$, $p < 0.002$).

The results of the surrogate testing suggest two main points; first that the use of remote sensing based habitat surrogates was justified as there was evidence of their ability to detect areas with high diversity of threatened and endemic species, and second that while there were significant overlaps in the distributions of certain taxa, using combinations of taxa was far more effective than using any single taxa. Therefore, it was decided that the prioritisation of conservation areas should be based on all five surrogates as each one was able to bring new information to bear on the prioritisation process.

3.2. *Areas of high conservation value in the Western Ghats*

The high irreplaceability sites in the Western Ghats are depicted in Figs. 3a and 4a. Out of the total of 713 grids in the study area, 49 were eliminated from the analysis, as they did not contain representations of the species or habitat surrogates. These grids were located along the edges of the study area and in the Palghat Gap, which has been largely deforested. There were a total of 21 completely irreplaceable grids (site irreplaceability = 1), only six of which (29%) happened to fall within the current protected area network (Fig. 3a and Table 2). All of these grids except for 48 I/6/SW (Barpede Cave) and 58 G/6/SW (Periyar Tiger Reserve) are globally irreplaceable as they cover sites that contain the only recently recorded, and in some cases, the only recorded occurrence of an endemic species. Eleven of these grids are also irreplaceable for species listed as critically endangered, while 10 are irreplaceable for endangered species (Table 2). In all, 57 grids (approximately 8% of the study area) had an irreplaceability score between 0.8 and 1 (Fig. 3a). A total of 60 grids were prioritised to meet the first level of conservation targets (Fig. 3b). When the second level representation targets (i.e. 3 occurrences of all species and 25% of habitats) were set for the surrogates, a total of 207 grids (29% of the study area) were selected on the basis of their summed irreplaceability scores (Fig. 4a). The distribution of the additional 147 grids, largely coincided with existing protected areas in the northern and central Western Ghats (Figs. 3b and 4a). Proportionally, a larger area was added in the southern Western Ghats, where the additional grids included protected areas as well as large tracts of contiguous reserve forests, such as in the Ranni and Konni Divisions (south of Periyar Tiger Reserve), and in one case, reserve forest interspersed with private lands (Palni Hills).

3.3. *Evaluation of the existing protected area network in the Western Ghats*

The existing reserve network in the Western Ghats meets the minimal representation target of one occurrence each for 88% of the 423 species chosen in this study. Among the species

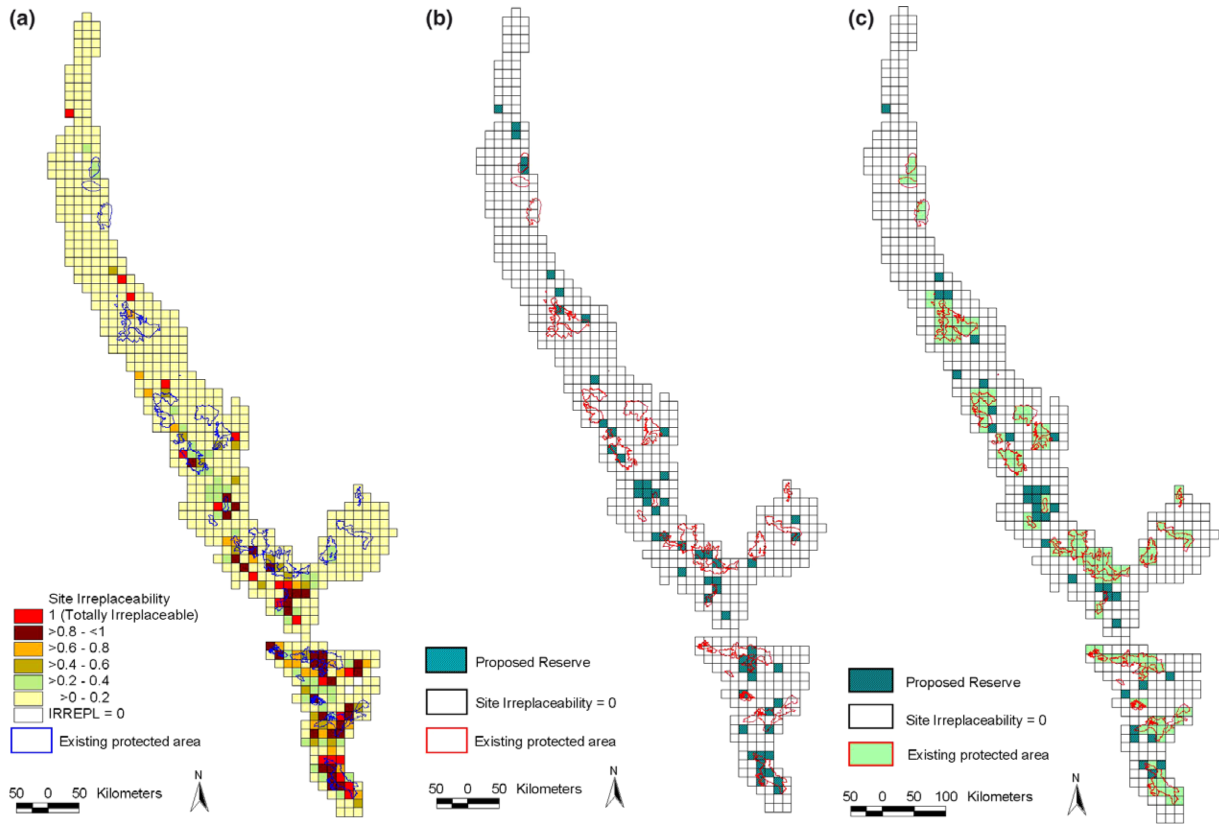

Fig. 3 – Panel (a) indicates the initial site irreplaceabilities for achieving the minimal reserve network targets. Panel (b) is a minimal reserve scenario where sites were prioritized first on the basis of their irreplaceability, then on the basis of whether they fell within the boundaries of an existing protected area, then on their adjacency to a protected area and finally on the basis of their complementarity and diversity (see Algorithm 1 in Appendix). Panel (c) is a minimal reserve network with existing protected areas accounted for in the calculation of site irreplaceability (see Algorithm 2 in Appendix).

considered, the existing reserve network has the highest representations of tiger (*Panthera tigris*), dhole (*Cuon alpinus*) and Asian elephant (*Elephas maximus*), all wide-ranging large mammals. Ninety three percent of the protected area grids contained representations of one or more of these species. The current reserve network also meets and exceeds the 10% minimum area target for all the habitat-based surrogates.

There are however, important gaps in the network. Of the 47 species not currently represented, 38 are trees, 7 amphibians, and 2 are small mammals. All of these species, with the exception of Wroughton's free-tailed bat (*Otomops wroughtonii*), are endemic to the Western Ghats.

It was found that with the first level representation targets (i.e. one occurrence of each species and 10% of each habitat), only 40% of the grids with the highest site irreplaceability scores (0.8–1) fell within the current protected area network (Fig. 3a). In the first minimal reserve network (Fig. 3b and Appendix), 34 grids (57%) fell outside the current protected area network. The network depicted in Fig. 3b is designed to be practical and allow for greater connectivity between prioritised grids (Appendix). It is also more efficient (Pressey and Nicholls, 1989) than the second minimal reserve network (Fig. 3c), which accounted for existing protected areas in the calculation of irreplaceability. This network covers a total of 166 grids, 36 (22%) of which were selected from outside the existing protected areas in order to meet conservation targets.

The networks designed on the basis of the second-level representation targets (see Section 2.3), met the targets set for all but 61 species, as these species have only one or two recorded occurrences in the dataset. They also met or exceeded the targets for all the habitat surrogates. After overlaying the protected area polygons, it was found that 114 (55%) of the grids with the highest summed irreplaceability fall outside the current protected area network (Fig. 4a). The second network, which accounts for existing reserves (Fig. 4b, Appendix), has a total of 230 grids prioritized on the basis of their summed irreplaceability (32% of the study area). Of these, 100 (43%) grids lie outside the protected areas (Fig. 4b). The difference in the number of grids prioritized between these two networks (Fig. 4a and b) indicates that the current protected area network in the Western Ghats does not maximize efficiency, in that it does not meet the targets set for the species and habitat surrogates in the minimum possible area (Pressey and Nicholls, 1989).

When human demographic data (Fig. 5) was overlaid on the proposed reserve grids, it was found that all reserve grids, except four, had a human population density of less than 200 people/km^2, suggesting that most people in this densely populated landscape live outside Forest Department land.

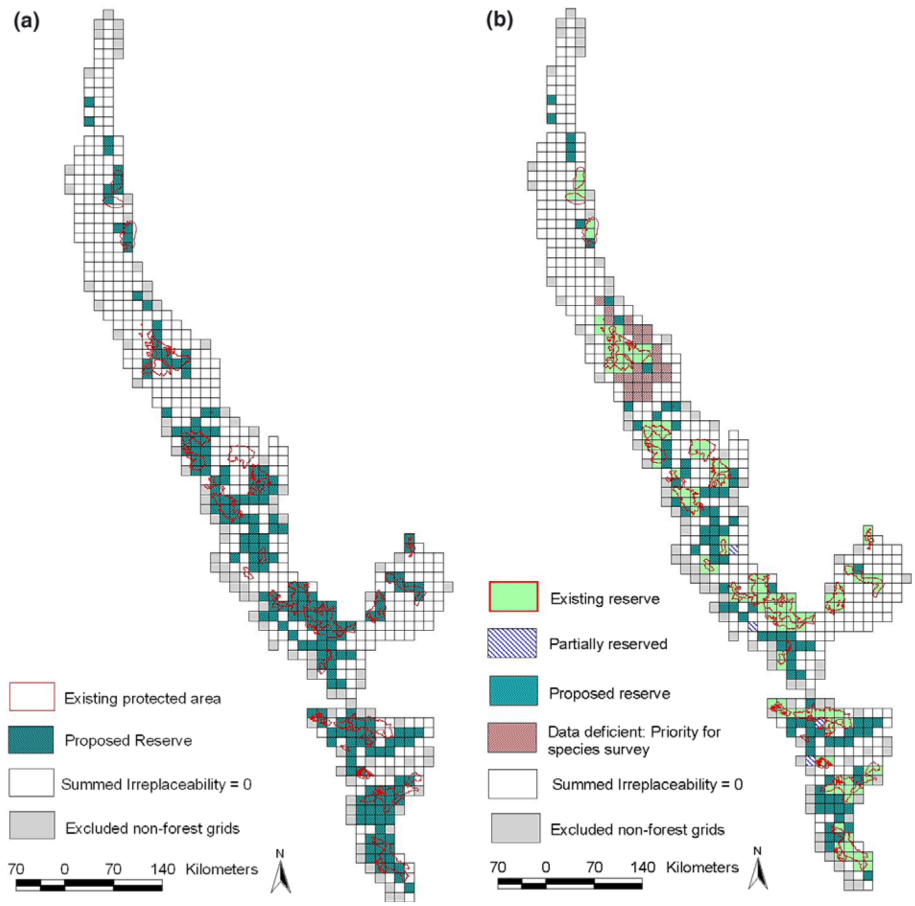

Fig. 4 – Panel (a) is a reserve network with grids prioritized iteratively on the basis of their summed irreplaceability using second level conservation targets, not accounting for existing protected areas in the analysis (see Algorithm 3 in Appendix). Panel (b) is a reserve network with grids prioritized iteratively on the basis of their summed irreplaceability values using second level conservation targets and taking into account the existing protected area network at the beginning of the analysis (see Algorithm 4 in Appendix).

The four reserve grids with a density of greater than 200 people/km^2 were retained in the proposed reserve network as partial reserves, since these grids had high irreplaceabilities for at least one of the species surrogates. Partial reservation indicates that some form of conservation action other than strict protection, such as targeted management intervention, is required. This can be used for sites that have high irreplaceability for a particular species, but where strict protection is not feasible. Of the four partially reserved grids, one was in northern Kerala in Vyittiri *taluka* of Wayanad district (Table 2) and another was east of the Pushpagiri Wildlife Sanctuary in Somvarpet *taluka* of Kodagu district (high irreplaceability for *Eugenia cotonifolia*). The third was in the Valparai plateau in Pollachi *taluka* of Coimbatore district and the fourth lies just west of the Idukki Wildlife Sanctuary in Todupulai *taluka* of Idukki district. The Valparai Plateau grid was partially reserved for *Pseudoglochidion anamalayanum* and *Indirana phrynoderma*. The Todupulai grid was partially reserved for *Anacolosa densiflora*.

4. Discussion

This study is directed at making conservation planning more explicit in the Western Ghats by defining surrogates, quantifying targets and evaluating the irreplaceability of sites with respect to meeting those targets. The implications of the results presented here for conservation planning are discussed below. Further, additional analysis is suggested and information needs highlighted.

There are some major considerations in interpreting the results of this analysis: first, that presence only data was used for the species without accounting for detection probability; second, there is a paucity of data on the distribution of several taxa; third, the data are affected by unrepresentative sampling effort with respect to habitats in protected areas and those in unprotected areas. Lastly, apart from the distribution of elements of biodiversity, future prioritisation efforts should also consider ecological processes, which are important in ensuring persistence (Gaston et al., 2002; Pressey et al., 2003).

4.1. *Assessment of surrogates and their spatial congruence*

This analysis provides support for the use of habitat surrogates based on remote sensing data. In particular, the unique evergreen ecosystems surrogate, which represents areas with the lowest remotedist values, showed significant correlation

Table 2 – Totally irreplaceable grids in the Western Ghats, their corresponding sites, and the species for which they are irreplaceable

No.	Survey of India (1:25,000 grid number)	Corresponding site(s)[a]	Species for which it is irreplaceable
1	58 H/7/NE	Virapuli RF	*Homalium jainii* (EN)
2	58 H/6/NW	Kalakkad Mundunthurai TR	*Cinnamomum walaiwarense* (CR), *Eugenia singampattiana* (CR)
3	58 H/6/SE	Kalakkad Mundunthurai TR	*Symplocos pulchra* (EN)
4	58 H/5/NW	Kuttalam RF	*Litsea nigrescens* (EN), *Nothopegia aureo-fulva* (CR)
5	58 H/1/NE	Puliyarai RF and Kuttalam RF	*Drypetes travancorica* (EN)
6	58 H/1/NW	Kulathapuzha RF (part) – Thenmala Range	*Canthium pergracilis* (EN)
7	58 G/6/SW	Periyar TR	*Syzygium chavaran* (EN)
8	58 F/8/NE	Amburuvi RF and Shingalvariyar RF – Periyakulam Range	*Elaeocarpus blascoi* (EN)
9	58 F/4/SW	Munnar area	*Philautus chalazodes* (CR), *Philautus griet* (CR)
10	58 B/9/NE	Palghat Division	*Syzygium palghatense* (CR)
11	58 A/8/NE	Southern Old Amarambalam RF, northern Silent Valley NP, southwestern Mukurthi WLS, northern Attapadi RF	*Actinodaphne lanata* (CR), *Ilex gardneriana*, *Glochidion sisparense* (EN), *Microtropis densiflora* (EN)
12	58 A/7/NE	Low elevation evergreen forest in Gudalur taluka – west of Naduvattam RF	*Atuna indica* (EN), *Pittosporum viridulum* (CR)
13	58 A/11/NW	Naduvattam RF	*Fejervarya murthii* (CR)
14	58 A/2/SW	Chedaleth FR, Kozhikode FD	*Cynometra beddomei*, *Eugenia argentea*
15	48 P/10/SW	Kilarmale RF and Sampaji RF	*Cinnamomum heyneanum*, *Hopea jacobi* (CR)
16	48 O/3/SW	Kudremukh NP	*Hopea canarensis*
17	48 O/14/SW	Bababudan hills	*Croton lawianus* (CR)
18	48 J/14/SW	Siddapur FR – RF no. 63	*Syzygium utilis*
19	48 I/6/SW	Barpede cave	*Otomops wroughtonii* (CR)
20	48 I/1/SE	Degraded semi-evergreen forests in Kalasgade RF and Parle RF, Changadh range and NE of Dodamarg	*Cinnamomum goaense*, *Nothopegia castanaefolia* (CR)
21	47 F/8/NE	Sinhagad RF	*Millardia kondana* (EN)

a RF – Reserve forest; FR – Forest Range; FD – Forest Division; WLS – Wildlife Sanctuary; TR – Tiger Reserve; NP – National Park.

with endemic tree species richness and composition, indicating that this surrogate has the potential to identify areas that are rich in evergreen and semi-evergreen forest endemics. It should be further tested at different scales and across sites with a greater number of species to determine its true potential. The remotedist measure itself, which is a Mahalanobis distance of every pixel in multi-date NDVI space to a reference evergreen class, was moderately successful as a surrogate for threatened and endemic vertebrate species in the Western Ghats.

With regard to the species surrogates, there was some evidence of spatial congruence, particularly between the distributions of threatened birds and mammals. Prasad et al. (1998) report a similar result in their assessment of conservation areas in Kerala. At the scale of this analysis, amphibians emerged as the most effective surrogate for all the study species combined, whereas mammals, especially wide-ranging species, were better at capturing overall animal and habitat diversity. These relationships are likely to change as the scale of analysis becomes finer.

Grids selected to meet conservation targets for amphibians and endemic trees species captured at least one occurrence of almost all threatened and endemic birds and mammals. The exceptions were two mammalian species and one bird species, all found outside evergreen and semi-evergreen forests. The relatively weak correlation between amphibian and endemic tree diversity in this study could be explained by the fact that amphibian diversity and endemism is highest between altitudes of 800–1000 m, while endemism among angiosperms is particularly high above 1700 m (Daniels, 1992). The use of amphibians and endemic trees therefore increased the complementarity of grids selected in the prioritisation.

Most studies have found low congruence between the species richness patterns of different groups (Gaston et al., 1995; Van Jaarsveld et al., 1998; Meijard and Nijman, 2003; Grand et al., 2004; Roberge and Angelstam, 2004; Kati et al., 2004). However, there is evidence of higher spatial congruence between taxa in the tropics (Howard et al., 1998). The results from the study presented here provide some support for this finding. Studies on congruency and the effectiveness of indicator taxa vary widely in scale of analyses, location and methods of association and no conclusive evidence has been provided so far of the effectiveness of certain taxa to act as indicators for others. Therefore the continued use of multiple taxa that are varied in their phylogeny and ecology in future prioritisation exercises is recommended (Grand et al., 2004), with emphasis on taxa that have higher rates of endemism, such as trees and amphibians in the case of the Western Ghats.

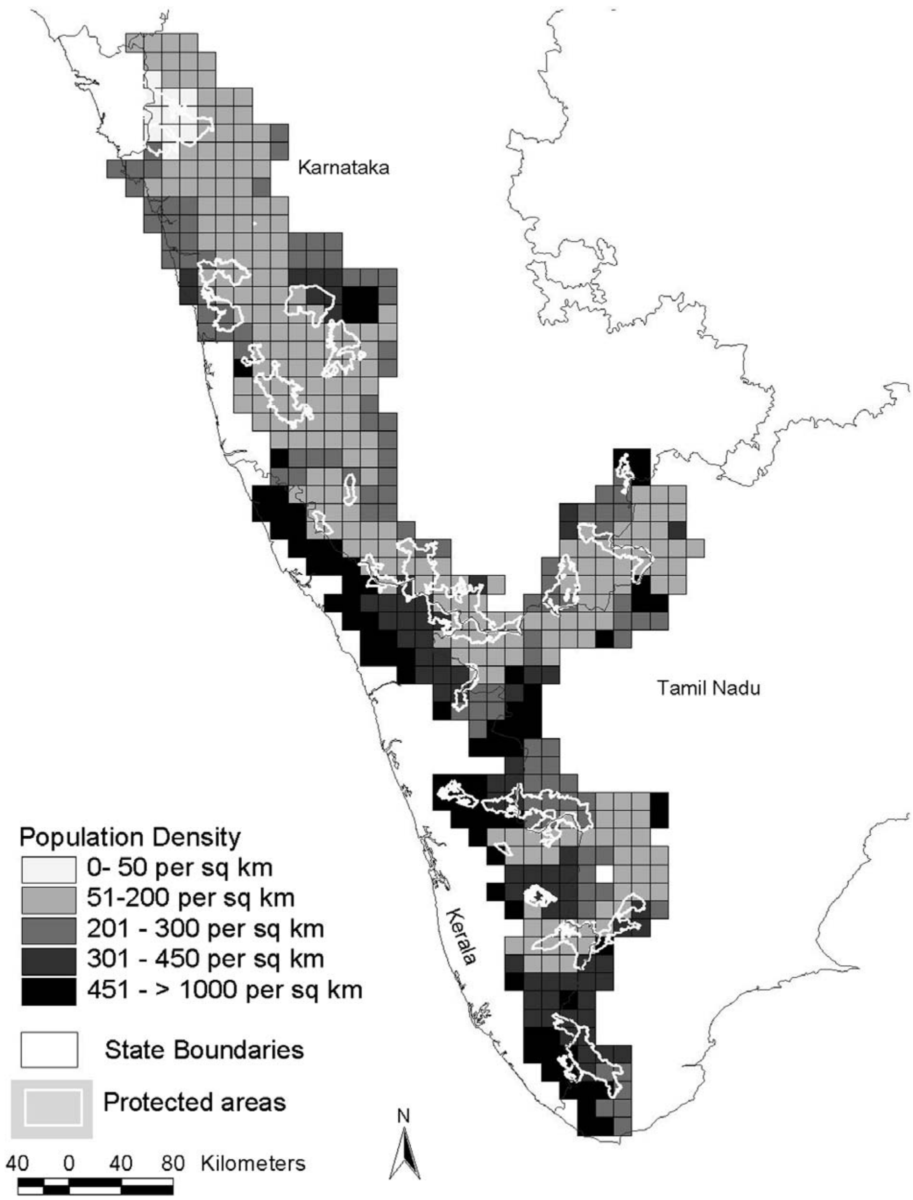

Fig. 5 – Population density in the southern Western Ghats based on 2001 census (Census of India, 2001).

The species surrogates used for this analysis are relatively rare within the study area. It is not known how well they capture other components of biodiversity in the Western Ghats. Lawler et al. (2003) found that at-risk species performed well as an indicator group in the middle Atlantic United States, covering about 84% of all other species used in their study. Given the uncertainty regarding the effectiveness of the rare and threatened surrogates used with regard to other elements of biodiversity, representativeness of priority areas could be increased in further analyses by adding broader environmental surrogates such as land types defined by biotic and abiotic factors like climate, topography and geology (Belbin, 1993; Pressey et al., 2000; Sarkar et al., 2005). However, the classification system used for land types should be guided by observed patterns of species distribution in environmental space instead of untested assumptions (Brooks et al., 2004).

4.2. *Assessment of the protected area network in the Western Ghats and identification of priority areas for future conservation action*

The results show that there are important areas of high conservation value outside the current protected area network – including private lands. More than half of the prioritised grids lie outside the current protected area network (Figs. 3 and 4). While the existing network of protected areas in the Western Ghats has a good representation of the ranges of several threatened and endemic species, it does not effectively conserve certain taxa, particularly amphibians, tree species of evergreen and semi-evergreen forests and small mammals. These groups have high rates of endemism and must be adequately conserved within this region for their chances of persistence to be assured at a global level.

This pattern could be the result of actual species distributions as well as the fact that there is not only a paucity of data on several taxa, but also a sampling bias with regard to the protected area network for certain taxa. A review of the existing protected area network undertaken by the authors revealed that no systematic or intensive sampling surveys are available for most protected areas with regard to small mammals, amphibians or trees.

The current reserve network, which covers approximately 12% of the study area, may not be sufficient to ensure the persistence of all endemic and globally threatened species in the Western Ghats, even wide ranging mammals. The latter tend to occur at very low densities and ensuring the viability of their populations and meta-populations is a bigger challenge than for other species of which several thousand individuals can persist in a relatively small area. As shown in Fig. 4a and b, up to about 30% of the Western Ghats could be targeted for conservation action.

Rodrigues and Gaston (2001) found that the minimum percentage area required to represent species within a region increases with the number of species targeted, the size of the planning units and the level of endemism. Thus the 30% figure is specific to the Western Ghats, at the scale of this analysis, and is based mainly on conservation of threatened and endemic trees and vertebrate species. Rodrigues et al. (2004b) noted that globally the percentage of "gap" species is correlated with levels of endemism, independent of the proportion of area that is protected. They too conclude that the Western Ghats reserve network is not adequately representative and needs to be expanded (Rodrigues et al., 2004a). This study corroborates their findings while identifying sites for further conservation action at a much finer geographic scale.

There is immense scope for enlarging the area over which conservation action can be implemented in the Western Ghats. An analysis of land use patterns and population density in grids with the highest conservation values (site irreplaceability value of 0.8–1, Tables 2, 3 and Fig. 3) revealed that, on average, reserve forests cover 61% of the land area under the unprotected high irreplaceability grids. Plantation crops such as coffee, tea and rubber cover approximately 25%, while 14% is open or agricultural land. The average population density for these grids is 291 people per km^2, which is comparable to the average population density for the study area. In addition, prioritised grids with lower irreplaceability values (Fig. 3b and c) lie mostly in reserve forest areas. Thus some form of conservation action can be implemented in a vast majority of the prioritised grids. A diversity of conservation approaches – ranging from strict protection to alteration of existing land use patterns to targeted management interventions for a particular species – would be necessary across the prioritised area.

Several of the high conservation value grids contain reserve forests adjoining existing protected areas. The feasibility of including these forests in the respective protected area should be examined. Strict protection may not be practical within some of these lands, owing to large numbers of forest-dependent communities. The recently constituted Community and Conservation reserves (Wildlife Protection Act, 1972 amendment 2002) should be considered as conservation options in these areas in order to stop further habitat degradation.

Areas such as Somwarpet, Bababudan Hills, Munnar, Valparai Plateau, Palni Hills and parts of the High Wavy mountains have a large proportion of privately owned commercial estates that can play a very important role in ensuring the persistence of threatened and endemic species in the region. Coffee and cardamom estates in particular, provide refuge and act as corridors for several species ranging from mammals to birds and amphibians (Shahabuddin, 1997; Umapathy and Kumar, 2000). Approximately 18% of the grids with high site irreplaceability value (Fig. 3a) have 5% or more of their area under coffee estates, while 23% lie adjacent to grids with 10% or more of their area under coffee plantations (Fig. 6). It would not be feasible or even necessary to convert all of these

Table 3 – Reserve forest areas of high conservation value (irreplaceability value > 0.8 to < 1) in the Western Ghats

Name	Forest areas included[a]
Periyar – Agasthyamalai	Kulathapuzha-Palode forests west of Kalakkad Mundunthurai TR Ranni and Konni reserve forests south of Periyar TR
Anamalai hills and Palni hills	Reserve forests to the west of Eravikulam NP Southwestern part of Palni Hills
Nilgiri – Wayanad area	New Amarambalam RF Forest areas between Coonoor and Mukurthi WLS Evergreen forests between Nilambur FD and Brahmagiri WLS in the Wayanad and Kozhikode FDs of Kerala
Kodagu area	Kerti RF Pattighat RF
Malnad area	Gundia forests around Pushpagiri WLS Agumbe and Balahalli RFs east of Someshwara WLS
Sahyadri – Konkan region	Bhimgad forests Amboli RF Forests of Mahabaleshwar

a RF – Reserve forest; FD – Forest Division; WLS – Wildlife Sanctuary; TR – Tiger Reserve; NP – National Park.

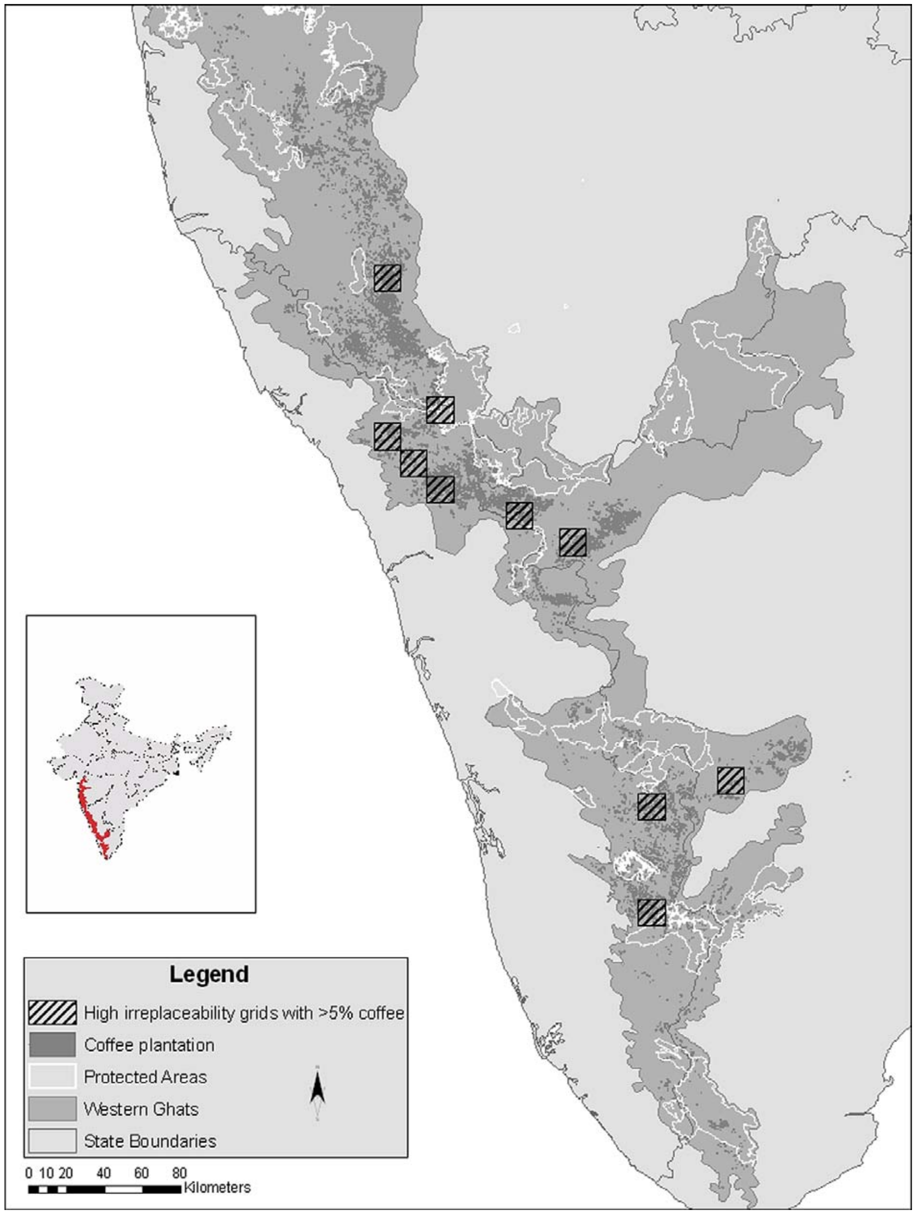

Fig. 6 – Map of high irreplaceability grids that also contain greater than 5% area under coffee plantation.

areas to strict reserves (Margules and Pressey, 2000). Instead, options for targeted conservation action and management of biodiversity should be explored with private landowners, including reducing further encroachment into remaining natural areas and promoting native trees over exotic species.

Several of the prioritised grids have been identified by previous studies as having high conservation value, especially the reserve forests of Kodagu, Upper Nilgiris, Anamalais and Periyar-Agasthyamalai regions (Rodgers and Panwar, 1988), and for the Kerala Western Ghats (Nair, 1991), the Kulathapuzha–Palode forests west of Kalakkad–Munduthurai (Ramesh et al., 1997c) and parts of the Ranni Forest Division in Kerala (Prasad et al., 1998). This study, while supporting the findings of previous work, identifies additional high conservation value areas outside Forest Department land, such as Somwarpet, Bababudan Hills, Munnar, Valparai Plateau and parts of the High Wavy mountains.

4.3. *Further analysis and information needs*

Further analysis should be undertaken to incorporate persistence and vulnerability more comprehensively in reserve design for the Western Ghats (Cabeza and Moilanen, 2001; Gaston et al., 2002). This study has attempted to incorporate vulnerability by targeting features that have the most restricted distributions and which are considered to be most at risk (Eken et al., 2004). The IUCN Red Data Lists are one way of identifying vulnerable species, however other regional and national level lists of threatened species exist which should also be taken into account in future efforts. In this case, use of IUCN species' data has been complemented with habitat surrogates.

Persistence could be incorporated by defining conservation targets in terms of abundances and proportion of range (Pressey et al., 2003) instead of number of occurrences, particularly for wide-ranging species, as the required data on population status and distribution are made available. Collecting consistent information on population status and distribution of threatened species, both within and outside protected areas, and on the sources and impacts of threats (Reyers, 2004), particularly for the areas identified in this study, should be a major priority for further conservation planning in the Western Ghats. This is especially important in light of decisions regarding the 'scheduling' of conservation action (Pressey et al., 2004) within these areas. The authors are currently gathering information on threats to species and habitats of high conservation value identified in this study.

Certain land use types such as coffee and cardamom plantations should be quantitatively assessed for their biodiversity values. In addition, there are areas that support intact forest habitats but for which very little species data exist, such as the forests south of the Kali river (Fig. 4b) and some of the proposed reserves. These areas should be systematically surveyed so that they can all be incorporated in future conservation planning and priority setting projects.

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Appendix

The first minimal reserve network was created through the following steps:

Algorithm 1

Step 1: selected grids iteratively with irreplaceabilities from 1 to 0.8.
Step 2: overlaid polygons of the existing protected area network on study grids and all grids inside a protected area, with an irreplaceability value greater than 0.2 were included in the reserve network.
Step 3: iteratively selected grids with irreplaceability greater than 0.2 adjacent to an existing protected area.
Step 4: iteratively selected any remaining grids with an irreplaceability greater than 0.2.
Step 5: iteratively selected grids on the basis of their ability to meet targets for the maximum number of remaining under-represented surrogates till all targets were met.

Algorithm 2. A second minimal reserve network was created taking into account the existing protected areas at the beginning of the analysis. If over 50% of the grid fell within a protected area, then the grid was considered to be within the existing reserve network.

Step 1: selected grids with irreplaceabilities of 1 after accounting for existing reserves.
Step 2: iteratively selected grids with irreplaceabilities of just less than 1–0.8.
Step 3: iteratively selected grids with irreplaceabilities from 0.4 to 0.8.
Step 4: iteratively selected grids adjacent to existing or proposed reserves with an irreplaceability greater than 0.

Algorithm 3. In the case of the reserve networks with second level conservation targets, areas with less than 10% forest cover were excluded. Next, grids were prioritized iteratively on the basis of their summed irreplaceability score till all achievable targets were met.

Algorithm 4. Algorithm 3 was re-run taking the existing protected areas into account, as follows:

Step 1: grids with less than 10% forest cover were excluded.
Step 2: summed irreplaceabilities were calculated taking the existing protected areas into account and grids with values in the top 1% were iteratively selected till all targets were met.
Step 3: prioritised grids not under ownership of the Forest Department that were found to have human population densities of above 200 people per square kilometer at the sub-district or *taluka* level (Census of India, 2001), were assessed with regard to their irreplaceability value. In cases where these densely populated grids were found to be irreplaceable for one or more features, they were recommended as partial reserves for those features.

REFERENCES

Beger, M., Jones, G.P., Munday, P.L., 2003. Conservation of coral reef biodiversity: a comparison of reserve selection procedures for corals and fishes. Biological Conservation 111, 53–62.
Belbin, L., 1993. Environmental representativeness: regional partitioning and reserve selection. Biological Conservation 66, 223–230.
Blasco, F., 1970. Aspects of flora and ecology of the savannas of the south Indian hills. Journal of the Bombay Natural History Society 67, 522–534.
Brooks, T.M., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Rylands, A.B., Konstant, W.R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., Hilton-Taylor, C., 2002. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology 16, 909–923.
Brooks, T., da Fonseca, G.A.B., Rodríguez, A.S.L., 2004. Species, data and conservation planning. Conservation Biology 18, 1682–1688.

Cabeza, M., Moilanen, A., 2001. Design of reserve networks and the persistence of biodiversity. Trends in Ecology and Evolution 16, 242–248.
Census of India, 2001. Office of the Registrar General and Census Commissioner, India.
Clark Labs, 2003. IDRISI Kilimanjaro. ©1987–2003 Clark University. Clark University, Worcester, MA. Available from: http://www.clarklabs.org.
Daniels, R.J.R., 1992. Geographical distribution patterns of amphibians in the Western Ghats, India. Journal of Biogeography 19, 521–529.
Daniels, R.J.R., 2001. National Biodiversity Strategy and Action Plan: Western Ghats Eco-region. Report submitted to Ministry of Environment and Forests, Government of India.
Daniels, R.J.R., Hegde, M., Joshi, N.V., Gadgil, M., 1991. Assigning conservation value: a case study from India. Conservation Biology 5, 464–475.
Eken, G., Bennun, L., Brooks, T.M., Darwall, W., Fishpool, L.D.C., Foster, M., Knox, D., Langhammer, P., Matiku, P., Radford, E., Salaman, P., Sechrest, W., Smith, M.L., Spector, S., Tordoff, A., 2004. Key biodiversity areas as site conservation targets. Bioscience 54, 1110–1118.
Environmental Systems Resource Institute, 2003. ArcGIS 9. Environmental Systems Resource Institute.
Ferrier, S., Pressey, R.L., Barrett, T.W., 2000. A new predictor of the irreplaceability of areas for achieving a conservation goal, its applicability to real-world planning, and a research agenda for further refinement. Biological Conservation 93, 303–325.
Franceschi, D., Ramesh, B.R., Pascal, J.P., 2002. Forest Map of South India: Coimbatore–Thrissur. French Institute, Pondicherry.
Gadgil, M., 1996. Western Ghats: a lifescape. Journal of the Indian Institute of Sciences 76, 495–504.
Gadgil, M., Meher-Homji, V.M., 1986. Localities of great significance to conservation of India's biological diversity. Proceedings of the Indian Academy of Sciences (Animal Sciences/Plant Sciences Supplement) November, 165–180.
Gadgil, M., Meher-Homji, V.M., 1990. Ecological diversity. In: Daniels, J.C., Serrao, J.S. (Eds.), Proceedings of the Centenary Seminar of the Bombay Natural History Society. Bombay Natural History Society and Oxford University Press, Bombay, pp. 175–198.
Gaston, K.J., Williams, P.H., Eggleton, P.J., Humphries, C.J., 1995. Large scale patterns of biodiversity: spatial variation in family richness. Proceedings of the Royal Society London B 260, 149–154.
Gaston, K.J., Pressey, R.L., Margules, C.R., 2002. Persistence and vulnerability: retaining biodiversity in the landscape and in protected areas. Journal of Biosciences 27, 361–384.
Grand, J., Buonaccorsi, J., Cushman, S.A., Griffin, C.R., Neel, M.C., 2004. A multi-scale landscape approach to predicting bird and moth rarity hotspots in a threatened pitch pine-scrub oak community. Conservation Biology 18, 1063–1077.
Howard, P.C., Viskanic, P., Davenport, T.R.B., Kigenyi, F.W., Baltzer, M.C., Dickinson, C.J., Lwanga, J., Matthews, R.A., Balmford, A., 1998. Complementarity and the use of indicator groups for reserve selection in Uganda. Nature 394, 472–475.
Islam, M.Z., Rahmani, A.R., 2004. Important Bird Areas in India: Priority sites for conservation. Indian bird conservation Network: Bombay Natural History Society and BirdLife International (UK). pp. xviii +1133.
IUCN, 2002. 2002 IUCN Red List of Threatened Species. International Union for the Conservation of Nature and Natural Resources http://www.iucnredlist.org.
IUCN, Conservation International, and NatureServe, 2004. Global Amphibian Assessment. Available from: www.globalamphibians.org.
Karanth, K.U., 1986. Status of wildlife and habitat conservation in Karnataka. Journal of the Bombay Natural History Society 83, 166–179.
Karanth, K.U., 1992. Conservation prospects for lion-tailed macaques in Karnataka, India. Zoo Biology 11, 33–41.
Kati, V., Devillers, P., Dufrene, M., Legakis, A., Vokou, D., Lebrun, P., 2004. Testing the value of six taxonomic groups as biodiversity indicators at a local scale. Conservation Biology 18, 667–675.
Krishnaswamy, J., Kiran, M.C., Ganeshaiah, K.N., 2004. Tree model based eco-climatic vegetation classification and fuzzy mapping in diverse tropical deciduous ecosystems using multi-season NDVI. International Journal of Remote Sensing 25, 1185–1205.
Lawler, J.J., White, D., Sifneos, J.C., Master, L.L., 2003. Rare species and the use of indicator groups for conservation planning. Conservation Biology 17, 875–882.
Mahalanobis, P., 1930. On tests and measures of group divergence. I. Theoretical formulae. Journal and Proceedings of the Asiatic Society of Bengal 26, 541–588.
Mantel, N.A., 1967. The detection of disease clustering and a generalized regression approach. Cancer Research 27, 209–220.
Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253.
Margules, C.R., Pressey, R.L., Williams, P.H., 2002. Representing biodiversity: data and procedures for identifying priority areas for conservation. Journal of Biosciences 27 (Suppl. 1.2), 309–326.
Meijard, E., Nijman, V., 2003. Primate hotspots on Borneo: predictive value for general biodiversity and the effects of taxonomy. Conservation Biology 17, 725–732.
Mittermeier, R.A., Robles-Gil, P., Hoffmann, M., Pilgrim, J.D., Brooks, T.M., Mittermeier, C.G., Lamoreux, J.L., Fonseca, G., 2004. Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. CEMEX, Mexico City.
Myers, N., 2003. Biodiversity hotspots revisited. Bioscience 53, 916–917.
Myers, N., Mittermeier, R.A., Mittermeier, C., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–857.
Nair, S.C., 1991. The Southern Western Ghats; A Biodiversity Conservation PlanStudies in Ecology & Sustainable Development, vol. 4. Indian National Trust for Art & Cultural Heritage INTACH, New Delhi.
Nair, N.C., Daniel, P., 1986. The floristic diversity of the Western Ghats and its conservation: a review. Proceedings of the Indian Academy of Sciences (Animal Sciences/Plant Sciences Supplement), 127–163.
New South Wales National Parks and Wildlife Service, 2001. C-Plan: Conservation Planning Software – User manual for C-Plan Version 3.06. New South Wales National Parks and Wildlife Service, Armidale, Australia.
Olson, D.M., Dinerstein, E., 1998. The Global 200: A representation approach to conserving the earth's most biologically valuable resources. Conservation Biology 12, 502–515.
Pascal, J.P., 1988. Wet evergreen forests of the Western Ghats of India: Ecology, structure, floristic composition and succession. French Institute of Pondicherry, India.
Pascal, J.P., Ramesh, B.R., Kichenassamy, K., 1992. Forest Map of South India: Bangalore–Salem. French Institute, Pondicherry.
Pascal, J.P., Shyam Sundar, S., Meher-Homji, V.M., 1982a. Forest Map of South India: Mercara–Mysore. French Institute, Pondicherry.
Pascal, J.P., Shyam Sundar, S., Meher-Homji, V.M., 1982b. Forest Map of South India: Shimoga. French Institute, Pondicherry.
Pascal, J.P., Shyam Sundar, S., Meher-Homji, V.M., 1984. Forest Map of South India: Belgaum–Dharwad. French Institute, Pondicherry.

Pimm, S.L., Raven, P., 2000. Extinction by numbers. Nature 403, 843–845.
Prasad, S.N., Vijayan, L., Balachandran, S., Ramachandran, V.S., Verghese, C.P.A., 1998. Conservation planning for the Western Ghats of Kerala: I. A GIS approach for location of biodiversity hot spots. Current Science 75, 211–219.
Pressey, R.L., 2004. Conservation planning and biodiversity: assembling the best data for the job. Conservation Biology 18, 1677–1681.
Pressey, R.L., Nicholls, A.O., 1989. Efficiency in conservation evaluation: scoring versus iterative approaches. Biological Conservation 50, 199–218.
Pressey, R.L., Humphries, C.J., Margules, C.R., Vane-Wright, R.I., Williams, P.H., 1993. Beyond opportunism: key principles for systematic reserve selection. Trends in Ecology and Evolution 8, 124–128.
Pressey, R.L., Possingham, H.P., Margules, C.R., 1996. Optimality in reserve selection algorithms: when does it matter and how much? Biological Conservation 76, 259–267.
Pressey, R.L., Hager, T.C., Ryan, K.M., Schwarz, J., Wall, S., Ferrier, S., Creaser, P.M., 2000. Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales. Biological Conservation 96, 55–82.
Pressey, R.L., Cowling, R.M., Rouget, M., 2003. Formulating conservation targets for biodiversity pattern and process in the Cape Floristic region, South Africa. Biological Conservation 112, 99–127.
Pressey, R.L., Watts, E., Barrett, T.W., 2004. Is maximising protection the same as minimizing loss? Efficiency and retention as alternative measures of the effectiveness of proposed reserves. Ecology Letters 7, 1035–1046.
Ramesh, B.R., Franceschi, D., Pascal, J.P., 1997a. Forest Map of South India: Thirvananthapuram–Tirunelveli. French Institute, Pondicherry.
Ramesh, B.R., Pascal, J.P., Nouguier, C., 1997b. Atlas of Endemics of the Western Ghats Distribution of Tree Species in the Evergreen and Semi-evergreen Forests. French Institute, Pondicherry.
Ramesh, B.R., Menon, S., Bawa, K.S., 1997c. A vegetation based approach to biodiversity Gap Analysis in the Agastyamalai region, Western Ghats, India. Ambio 26, 529–536.
Reyers, B., 2004. Incorporating anthropogenic threats into evaluations of regional biodiversity and prioritisation of conservation areas in the Limpopo Province, South Africa. Biological Conservation 118, 521–531.
Roberge, J., Angelstam, P., 2004. Usefulness of the umbrella species concept as a conservation tool. Conservation Biology 18, 76–85.
Rodgers, W.A., Panwar, H.S., 1988. Planning a Wildlife Protected Area Network in India. Wildlife Institute of India, Dehradun.
Rodgers, W.A., Panwar, H.S., Mathur, V.B., 2002. Wildlife Protected Area Network in India: A Review. Wildlife Institute of India, Dehradun.
Rodrigues, A.S.L., Gaston, K.J., 2001. How large do reserve networks need to be? Ecology Letters 4, 602–609.
Rodrigues, A.S.L., Akçakaya, H., Resit, A., Sandy, J., Bakarr, M.I., Boitani, L., Brooks, T.M., Chanson, J.S., Fishpool, L.D.C., Da Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, J., Sechrest, W., Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., 2004a. Global gap analysis: Priority regions for expanding the Global Protected-Area Network. Bioscience 54, 1902–1910.
Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Cowling, R.M., Fishpool, L.D.C., da Fonseca, G.A.B., Gaston, K.J., Hoffman, M., Long, J.S., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, J., Sechrest, W., Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., Yan, X., 2004b. Effectiveness of the global protected area network in representing species diversity. Nature 428, 640–643.
Shahabuddin, G., 1997. Preliminary observations on the role of coffee plantations as avifaunal refuges in the Palni Hills of the Western Ghats. Journal of the Bombay Natural History Society 94, 10–21.
Sarkar, S., Justus, J., Fuller, T., Kelley, C., Garson, J., Mayfield, M., 2005. Effectiveness of environmental surrogates for the selection of conservation area networks. Conservation Biology 19, 815–825.
Sukumar, R., 1989. Ecology of the Asian elephant in southern India. I. Movement and habitat utilization patterns. Journal of Tropical Ecology 5, 1–18.
Stattersfield, A.J., Crosby, M.J., Long, A.J., Wege, D.C., 1998. Endemic Bird Areas of the World: Priorities for Biodiversity Conservation. BirdLife International, Cambridge.
Tsuji, N., Tsubaki, Y., 2004. Three new algorithms to calculate the irreplaceability index for presence/absence data. Biological Conservation 119, 487–494.
Umapathy, G., Kumar, A., 2000. The occurrence of arboreal mammals in the rain forest fragments in the Anamalai Hills, south India. Biological Conservation 92, 311–319.
Urban, D., Goslee, S., Pierce, K., Lookingbill, T., 2002. Extending community ecology to landscapes. Ecoscience 9, 200–202.
Van Jaarsveld, A.S., Freitag, S., Chown, S.L., Muller, C., Koch, S., Hull, H., Bellamy, C., Kroeger, M., Endroedy-Younga, S., Mansell, M.W., Scholtz, C.H., 1998. Biodiversity assessment and conservation strategies. Science 279, 2106–2108.
Vane-Wright, R.I., Humphries, C.J., Williams, P.H., 1991. What to protect? – systematics and the agony of choice. Biological Conservation 55, 235–254.
Venkatraman, A.B., Venkatesa, K.N., Varma, S., Sukumar, R., 2002. Conservation of a flagship species: prioritizing Asian elephant (*Elephas maximus*) conservation units in southern India. Current Science 82, 1023–1033.
Warman, L.D., Forsyth, D.M., Sinclair, A.R.E., Freemark, K., Moore, H.D., Barrett, T.W., Pressey, R.L., White, D., 2004. Species distributions, surrogacy, and important conservation regions in Canada. Ecology Letters 7, 374–379.
Wikramanayake, E.D., Dinerstein, E., Robinson, J.G., Karanth, K.U., Rabinowitz, A., Olson, D., Matthew, T., Hedao, P., Conner, M., Hemley, G., Bolze, D., 1999. Where can tigers live in the future? A framework for identifying high priority areas for the conservation of tigers in the wild. In: Seidensticker, J., Christie, S., Jackson, P. (Eds.), Riding the Tiger: Tiger Conservation in Human Dominated Landscapes. Cambridge University Press, Cambridge, pp. 255–272.
Wildlife Protection Act 1972, as amended by the Wildlife (Protection) Amendment Act, 2002. Wildlife Protection Society of India, Professional Book Publishers, New Delhi.