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How Representative is the Protected Areas System of Nepal?

A Gap Analysis Based on Geophysical and Biological Features

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A protected areas system (PAS) is effective only when it adequately includes a representative sample of important geophysical and biological features, including critically endangered biota of a region. However, protected areas in Nepal, as in many parts of the world, have been established on an ad hoc basis, and thus one or more important features have been overlooked. We conducted a gap analysis and developed a comparison index to assess the representativeness of geophysical features (physiography, altitude, and ecoregions), species diversity, and endangered species listed in International Union for Nature Conservation (IUCN) and Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) by using a Geographical Information System (GIS) framework. The analysis indicated that more than two thirds (67.84%) of the total area of protected areas (PAs) is in high mountains, although this region accounts for only 23.92% of the country's total area. The hills comprise the highest proportion (29.17%) of the country's area but currently have the smallest proportion (1.33%) of PAs. The altitudinal zones between 200–400 m are well represented with PAs; however, the region between 400–2700 m is poorly represented, and representation by PAs is comparatively higher in the area above 2800 m. The ecoregions that have high conservation priority at global scale are poorly represented in protected areas of Nepal. Existing PAs include 39.62% of flowering plants, 84.53% of mammals, 95.73% of birds, and 70.59% of herpetofauna of the country. Threatened animal species are well protected, whereas a large number of threatened plant species are not represented by the current PA system.

Keywords: *Gap analysis; protected areas; comparison index; representativeness; geographical information system (GIS); Nepal.*

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Introduction

Protected areas (PAs) play a vital role in the protection of biodiversity in a given geographical area (Bruner et al 2001). A protected areas system should be comprehensive, adequate, and representative (Trisurat 2007). However, many regional- and national-level analyses have shown that existing protected areas networks are not adequate for protecting biodiversity (Margules and Pressey 2000; Rodrigues et al 2004a; Rondinini et al 2005; Catullo et al 2008). The main reason is that many conservation areas have been established on an ad hoc basis. Often socioeconomic and aesthetic rather than biological criteria have been used in choosing PA locations (Pressey 1994). Identification of a completely representative set of protected areas is a first step toward biodiversity conservation (Scott and Csuti 1997), but resource constraints generally preclude systematic data collection for multiple taxonomic groups, making it difficult to ensure maximum representation (Pawar et al 2007). Consequently, sites with higher conservation value remain unprotected, while sites of lesser conservation value are chosen for conservation areas (Catullo et al 2008).

Gap analysis has often been used to identify gaps in the network of land and water conservation areas (Jennings 2000). Gap analysis is a powerful approach for exploring the comprehensiveness of a PA system in representing local biodiversity (Scott et al 1993). Recently, gap analyses have been conducted using biological and geophysical features in different countries worldwide, such as Hong Kong (Yip et al 2004), Japan (Kamei and Nakagoshi 2006), Thailand (Trisurat 2007), England (Oldfield et al 2004), Africa (Rondinini et al 2005), Costa Rica (Powell et al 2000), Mexico (Cantu et al 2004), and Chile (Tognelli et al 2008). Chettri et al (2008) conducted a gap analysis for the entire Hindu Kush–Himalaya region using global biodiversity hotspots, global 200 ecoregions, and important bird areas. These analyses have provided important insights for conservation planning.

Nepal is situated in the central part of the world's top 20 hottest global biodiversity hotspots, the Himalayas, where the world's highest mountains, including Mount Everest, are found. It is portrayed as a biodiversity-rich country representing a significant share of global biodiversity, although it comprises only 0.09% (147,181 km^2) of the global land area (ICIMOD 2007). Floral diversity includes 465 species of lichens (2.3% of the global diversity); 1822 species of fungi (2.4%); 687 species of algae (2.6%); 853 species of bryophytes (5.1%); 534 species of pteridophytes (4.71%); 27 species of gymnosperms (5.1%); and 6391 species of angiosperms (2.7%) (ICIMOD 2007; GoN/DNPWC 2009). Faunal diversity includes 168 species of platyhelminthes (1.4%); 144 species of spiders (0.2%); 5052 species of insects (0.7%); 640 species of butterflies and 2253 species of moths (together 2.6%); 182 species of fish (1.0%); 77 species of amphibians (1.84%); 118 species of reptiles (1.87%); 867 species of birds (9.53%); and 181 species of mammals (4.52%) (GoN 2009).

Nepal's rich biodiversity is a reflection of its unique geographic position, diverse climatic conditions, complex topography, broader altitudinal range, and great habitat variation. Botanically, Nepal forms a transition zone between the plants of the western Himalaya and the eastern Himalaya (NHM 2009). It incorporates the Palearctic and the Indo-Malayan biogeographical regions and the 5 major floristic provinces of Asia (the Sino-Japanese, Indian, western and central Asiatic, southeast Asiatic, and African Indian desert) (HMG/MFSC 2002). This geophysical settlement of the country creates a unique blend of various floristic elements and makes the county's terrestrial biodiversity richer.

Climatic factors (rainfall, winter snow, temperature) and topography (aspect, altitude) have a significant influence on biodiversity and the distribution of flora and fauna in Nepal (ICIMOD 2007). Topography plays the most important role in modifying climate, weather, precipitation, distribution, and soil properties (Lillesø et al 2005b). The country has a monsoon climate; about 80% of total precipitation falls during monsoon (Lillesø et al 2005a). The average annual rainfall in Nepal is about 1600 mm, but total precipitation differs in each eco-climatic zone. The eastern region is wetter than the western region (HMG/MFSC 2002).

The Nepalese Himalayan elevation gradient is one of the longest bioclimatic elevation gradients in the world, extending from 67 m to 8848 m (the roof of the world) within 150–200 km, south to north, and it includes tropical/subtropical, temperate, subalpine, and alpine climatic zones (Vetaas and Grytnes 2002). Aspect also has an important effect on the distribution of plants and animal species, because north-facing slopes receive much less solar radiation than those facing south (NHM 2009). This variability makes the country a habitat for both tropical to alpine species of plants and animals.

Scholars have described Nepal's physiographic zones and vegetation types in different ways. Hagen (1998) divided Nepal into 7 physiographic divisions, whereas LRMP (1986) divided the country into 5 physiographic zones: Terai, Siwalik, Mid Hills, Mountains, and High Himal, which is the pattern followed in this study. The Terai is situated in the southernmost part of the country along the Nepal–India border from east to west and has a tropical climate. Siwalik is a range of foothills that has a subtropical climate and rises abruptly from the Terai to the north. The Mid Hills and Mountains are high and steep hilly regions with a temperate climate; they are situated in the middle part between Siwalik and High Himal. The High Himal zone is the northernmost part of the country bordering with Tibet; it consists of subalpine and alpine climates. Dobremez (1972, 1976) recognized 4 belts (western, northwestern, central, eastern), 11 bioclimatic zones, 35 forest types, 75 vegetation types, and 118 ecosystems.

Nepal contains 12 out of 867 terrestrial ecoregions of the world as defined by Olson et al (2001). Ecoregions, which provide a framework for assessing the representation and gaps in conservation efforts worldwide, are relatively large units of land containing distinct assemblages of natural communities and species. An assessment of the representativeness of ecoregions in PAs in Nepal will help to identify regionally and globally important areas of exceptional biodiversity and develop conservation priority at country level.

The protected areas (PA) system in Nepal

Formal conservation in Nepal started in 1973 with the passage of the National Parks and Wildlife Conservation Act (HMG 1973; HMG/MFSC 2002) and establishment of the country's first national park, Chitwan National Park. There are now 19 protected areas in Nepal, including 3 protected areas declared in December 2009 (Table 1). The total area of the PAs, including 11 buffer zones, is 33,073 km^2 (ie 22.5% of the total area of the country; GoN/DNPWC 2009). The cabinet meeting held on 8 January 2009 decided to integrate the Nagarjun forest area into Shivapuri National Park—an area that is not included in this analysis. Similarly, Gaurishankar Conservation Area (2035 km^2, representing mid- and high altitudes), Api-Nampa Conservation Area (1902.42 km^2, representing mid- and high altitudes), and Bankey Wildlife Reserve (WR) (137 km^2 of Terai area)—declared PAs in December 2009—are not included in this study, because base maps of these areas are not yet publicly available.

The proportion of total area covered by protected areas of the country is much higher than in many other countries around the world. In addition, several protected areas have been successful in meeting conservation targets. Among these are Sagarmatha National Park, with its plantation and control of illegal trade, Chitwan National

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TABLE 1 Protected areas of Nepal.

Protected areas (PAs)[a]	Latitude (°N)	Longitude (°E)	Area (km^2)[b]	Year established	IUCN categories
1. Chitwan National Park	27.49	84.38	1182	1973	II
2. Langtang National Park	28.14	85.57	1752	1976	II
3. Sagarmatha National Park	27.92	86.72	1158	1976	II
4. Rara National Park	29.49	82.07	114	1976	II
5. Bardia National Park	28.44	81.46	908	1976	II
6. Suklaphanta Wildlife Reserve	28.84	80.22	367	1976	IV
7. Koshi Tappu Wildlife Reserve	26.64	86.99	1657	1976	IV
8. Shey-Phoksundo National Park	29.40	82.82	35,627	1984	II
9. Khaptad National Park	29.37	81.10	2337	1984	II
10. Parsa Wildlife Reserve	27.34	84.84	4917	1984	IV
11. Shivapuri National Park	27.80	85.40	91	1985	II
12. Dhorpatan Hunting Reserve	28.64	83.00	1315	1987	VI
13. Makalu-Barun National Park	27.72	87.04	1515	1991	II
14. Annapurna Conservation Area	28.73	83.96	7703	1992	VI
15. Kanchenjunga Conservation Area	27.69	87.92	2026	1998	VI
16. Manaslu Conservation Area	28.53	84.83	1699	1998	VI

[a] The list includes only the PAs considered for this study.

[b] Based on the World Database on Protected Areas (2009).

Park and its one-horn rhino and tiger conservation, Annapurna Conservation Area and its ecotourism, and Kanchenjunga Conservation Area with its community-based conservation, and red panda and snow leopard conservation (ICIMOD 2007). The conservation paradigm has shifted from species conservation to the landscape conservation approach. The inception of the Terai Arc Landscape (TAL) in Terai and Sacred Himalayan Landscape (SHL) in the Mountains district has been important to conserve and monitor biodiversity at a larger scale (ICIMOD 2007; GoN/DNPWC 2009).

Despite policy-level transformation, the shift in conservation paradigm, and the many successes achieved in implementation, researchers widely agree that the current PAs are not fully representative, and many important areas, altitudinal zones, and ecosystems still remain outside protected areas (Hunter and Yonzon 1993; Chaudhary 2000; HMG/MFSC 2002; Heinen and Shrestha 2007). Nepal's PAs are highly skewed toward less productive, high-altitude regions that are not under major anthropogenic threats (Heinen and Shrestha 2007), because population density and accessibility to forests is extremely low compared to all other geographic regions. However, climate change-related threats are likely to greatly affect the region, with serious impacts on habitats and biodiversity resulting from glacial lake outburst floods (GLOF), and snow and glacial melt. Endemic species of the alpine regions of the Himalayas will be threatened as warming continues (Salick et al 2009). The forest types of the Mid Hills are poorly represented by the PAs (Chaudhary 2000). Hunter and Yonzon (1993) have pointed out incoherent distribution of parks with the distribution of birds and mammals.

The extent of the effectiveness of current protected areas for conserving the important elements of biodiversity in Nepal is largely unknown. At the time when protected areas were established, no accurate field data were available (Nepali 2006). Failure in conservation planning was also the result of poor consideration of major principles of conservation planning (eg comprehensiveness and representativeness). In addition, implementation of plans was not effective, partly because the participation of different stakeholders, including local communities, was not duly considered (Nepali 2006). Also, the major gaps in the current protected areas system have not been determined. The Nepal Biodiversity Strategy (HMG/MFSC 2002) mentions 13 different types of gaps in the existing mechanism of the protected areas, including poor representation of Mid Hill ecosystems, but it fails to address the gaps in representativeness of geophysical and biological features. Hence, it is imperative to analyze the gaps in the current protected area system of Nepal.

This assessment will be the first comprehensive analysis of the protected area system in Nepal. It aims (1) to analyze the representativeness of physiography, altitude, and ecoregions in the current PA system of Nepal; and (2) to identify gaps in representation of different life forms—flowering plants, mammals, birds, herpetofauna, as well as threatened species listed in the International Union for Conservation of Nature and Natural Resources (IUCN) Red List and protected species listed by the Convention on International Trade in Endangered Species (CITES). This study also aims to discuss the congruence of global conservation priorities with local-level representation. Moreover, it identifies priorities to address existing gaps and makes necessary recommendations, including the need for incorporating the underrepresented areas in existing PA networks.

Material and methods

Data

This study is based on secondary sources of information that are freely available. The World Database on Protected Areas (WDPA) is a foundation data set for conservation planning that provides the most updated and comprehensive information about the world's protected areas. The base maps of the protected areas were obtained from the WDPA portal (http://www.wdpa.org/AnnualRelDownloads.aspx), and physiographic zones were downloaded from the Mountain Environment and Natural Resources Information System (MENRIS) on the ICIMOD portal (http://menris.icimod.net/Downloads). Although WDPA lists 25 protected areas in Nepal, only the 16 protected areas designated by the Government of Nepal are included in this study. Global 200 ecoregions, the most crucial ecoregions of the world, are prioritized for conservation by the World Wide Fund for Nature (WWF). Global 200 ecoregions data were gathered from the WWF data portal (Olson et al 2001; http://www.worldwildlife.org/science/data/item1878.html). A digital elevation model (DEM: a digital representation of surface topography derived from remote-sensing techniques, comprising information on elevation) was downloaded from the Consortium for Spatial Information (CGIAR-CSI) GeoPortal (http://srtm.csi.cgiar.org).

The *Nepal Biodiversity Resource Book* (ICIMOD 2007) provides the most updated species-level information for the different life forms of Nepal. The reason behind the selection of only 4 life forms (flowering plants, mammals, birds, and herpetofauna) was nothing but the unavailability of comprehensive data for other groups. We used species data for flowering plants, mammals, birds, and herpetofauna from the *Nepal Biodiversity Resource Book* for this study. The IUCN Red List provides the most comprehensive record of the global conservation status of plant and animal species and conveys the urgency of conservation to the public and policy makers. Similarly, CITES is an international agreement to regulate international trade in plant and animal species. It provides a list of species to safeguard them from overexploitation. Information from the 2008 IUCN Red List of threatened species reported from Nepal was downloaded from IUCN Red List website (http://www.iucnredlist.org/), and the information about CITES-listed species from Nepal was downloaded from the CITES official website (http://www.cites.org/eng/resources/species.html) to analyze the gap in protected species representation in PAs (CITES 2008; IUCN 2008).

Gap analysis

We overlaid the protected areas map on the maps of physiographic regions, altitudinal zones derived from the DEM, and ecoregions in order to calculate the area coverage, using Arc View 9.2 (ESRI 2006). The area of physiographic regions, altitudinal zones, and ecoregions for each protected area was calculated using the "calculate geometry tool" in ArcView. The DEM was classified into 50 elevation classes: 49 classes at 100 m intervals from 0 to 4900 m and one class above 4900 m, assuming that there are no biota—otherwise little considered in this study—above 4900 m. Elevation classes were divided into 100 m intervals to make our classification conform with the previous studies of species richness patterns along elevation gradients (eg Vetaas and Grytnes 2002; Bhattarai et al 2004; Grau et al 2007). Areas for each elevation class were calculated. In addition, the total area and the area represented by PAs in each physiographic zone, elevation range, and ecoregion were calculated. Due to error in digitization and differences in map projection and scale, the total area of the country taken into account differs slightly (by 0.57%) from the exact area. It was ignored, however, because it is insignificant compared to the large area used for analysis.

The species of flowering plants, mammals, birds, and herpetofauna reported from all protected areas were combined and overlaid with the national checklists of corresponding life forms in order to identify covered species and gap species. In theory, the minimum requirement for species to be considered covered by a protected area network is inclusion within the network of at least one viable population (Rodrigues et al 2004b). However, measurements of viable populations and predictions of a species' range using the given species record data and park boundary polygon are very complex. Moreover, the range information given in the Global Biodiversity Information Facility (GBIF) and IUCN websites for the plants and animals species of Nepal is incomplete and incomprehensive. Thus, a species is considered represented or covered by a PA system if the species is reported from any of the protected areas. A

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TABLE 2 Comparison index for Nepal's protected areas (PAs) and physiographic areas.

Physiographic zone[a)]	Elevation range (m)[b)]	Total area in km² (with %)	Total PA area in km² (with %)	% PA area in physiographic zone	Comparison index (CI)
High Himal	1800–8800	35,412.28 (23.92)	17,156.31 (67.84)	48.45	2.84
Mountains (High mountains)	700–4100	30,149.70 (20.37)	3675.65 (14.53)	12.19	0.71
Mid Hills (Middle mountains)	20–3500	43,179.90 (29.17)	335.31 (1.33)	0.78	0.05
Siwalik	100–2000	19,010.20 (12.84)	3015.34 (11.92)	15.86	0.93
Terai	Below 600	20,272.02 (13.70)	1106.35 (4.37)	5.46	0.32
Total in Nepal	–	148,024.10 (100)	25,288.96 (100)	–	–

[a)] Sources: LRMP (1986), Lillesø et al (2005b), ICIMOD (2007). The figures result from the authors' own calculation using a DEM acquired for the different physiographic zones.

[b)] The altitudes are the highest and lowest points of the DEM found in the respective physiographic zone.

species not represented in any protected area is considered a gap species (Rodrigues et al 2004b). The species of plants, mammals, birds, and herpetofauna listed in the IUCN Red List of threatened species and CITES for the year 2008 were compared with the national checklist. The species of different life forms on IUCN and CITES lists were extracted. The species and infraspecific taxa listed in the IUCN and the CITES list but not found in Nepal's national checklist were excluded from this analysis. Nevertheless, the synonyms of such species were checked to ensure maximum match; 1 species of herpertofauna, 3 species of plants, and 1 species of birds were found to be listed in CITES list but not in the national checklist provided in the *Nepal Biodiversity Resource Book*.

Comparison Index (CI)

We employed the comparison index (CI) method described by Hazen and Anthamatten (2004) and Trisurat (2007) to measure representativeness in the current protected areas system. A CI index is calculated by dividing the proportion of protected areas in a particular physiographic region, elevation zone, or ecoregion by that category's share of the country's total land area. For example, the Terai region covers 13.70% of the country's total area. If the Terai were to be proportionally covered by protected areas, about 13.70% of Nepal's protected areas would have to be in the Terai region, resulting in a CI value of 1. In general, a CI value greater than 1 denotes good representation, and a CI value less than 1 represents poor representation (Hazen and Anthamatten 2004; Trisurat 2007).

Results: representativeness of Nepal's PAs

Physiographic representativeness

The representation of the physiographic zones in PAs was found to be extremely uneven and inequitable. High Himal is well represented (CI = 2.84); however, the Mid Hills are significantly underrepresented (CI = 0.05) in current PAs. The Terai (CI = 0.32) and Mountains (CI = 0.71) are fairly underrepresented. The High Himal, Mountains, Mid Hills, Siwalik, and Terai zones cover 23.92%, 20.37%, 29.17%, 12.84%, and 13.70% of the total area of the country, respectively (Table 2). Although the Mid Hills make up the largest proportion of the country's area and host the highest number of ecosystems (52 out of 118), representation of the region in the current protected area system is extremely low (only 1.33%). Only 0.78% of the total area of the Mid Hills and 5.46% of the total area in the Terai zone is under protection, whereas 48.44% of the total area of the High Himal is under protection (Table 2).

Elevational representativeness

Based on the elevation classification used in this study, regions higher than 2800 m in altitude are well represented by PAs, whereas the lower-altitudinal zones are poorly represented (Figure 1). The CI value ranged from 0.06 to 2.77. The lowest CI value was observed for the area between 800–900 m and 900–1000 m, whereas the highest CI value was observed for the area above 4000 m. The middle elevation (400–2800 m) is underrepresented, of which the area between 700–1400 m is extremely underrepresented (CI value ≤ 0.10) in current PAs. At lower elevation, the area between 200–400 m is well represented, but the area below 200 m is poorly represented. The area between 100–200 m has the highest elevational proportion in the country (9.24%), but it is underrepresented in current PAs (CI = 0.56). Our results show that middle and very low elevations are underrepresented, and the location of protected areas is highly skewed toward higher-elevation zones (Figure 2).

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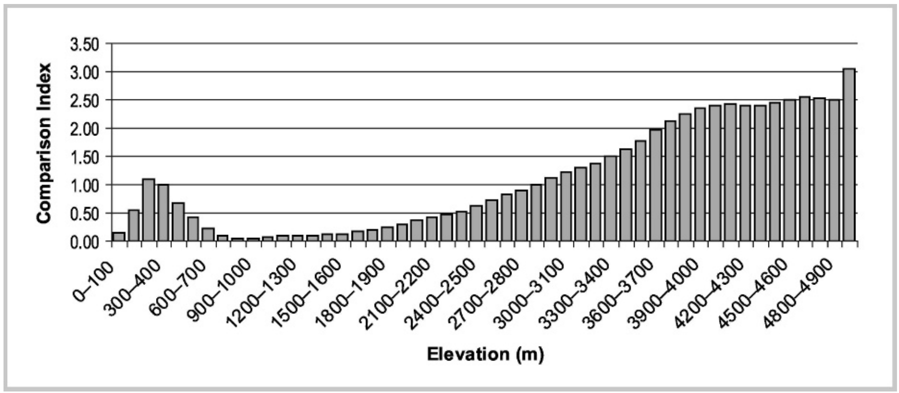
FIGURE 1 Comparison index for Nepal's protected areas and total areas by altitudinal range.



Ecoregion representativeness

Nepal has 12 of 867 terrestrial ecoregions across the globe, of which PAs encompass 10 ecoregions. The Lower Gangetic Plains moist deciduous forests, which occupy 0.13% of the country's land area, and the Upper Gangetic Plains moist deciduous forests, which occupy only 4 km^2 of the country's land area, are not represented by current PAs. The Eastern Himalayan alpine shrub and meadows ecoregion has the highest representation (CI = 4.18), whereas the lowest ecoregion representation is for Himalayan subtropical pine forests (CI = 0.18). Eastern Himalayan subalpine conifer forests, rock and ice, and Western Himalayan alpine shrub and meadows are well represented, whereas Eastern Himalayan broadleaf forests, Himalayan subtropical broadleaf forests, Terai–Duar savanna and grasslands, Western Himalayan broadleaf forests, and Western Himalayan subalpine conifer forests are poorly represented. Of these underrepresented ecoregions, three—Himalayan subtropical broadleaf forests, Terai–Duar savanna and

FIGURE 2 Protected areas overlain on elevation zones. (Map by authors)

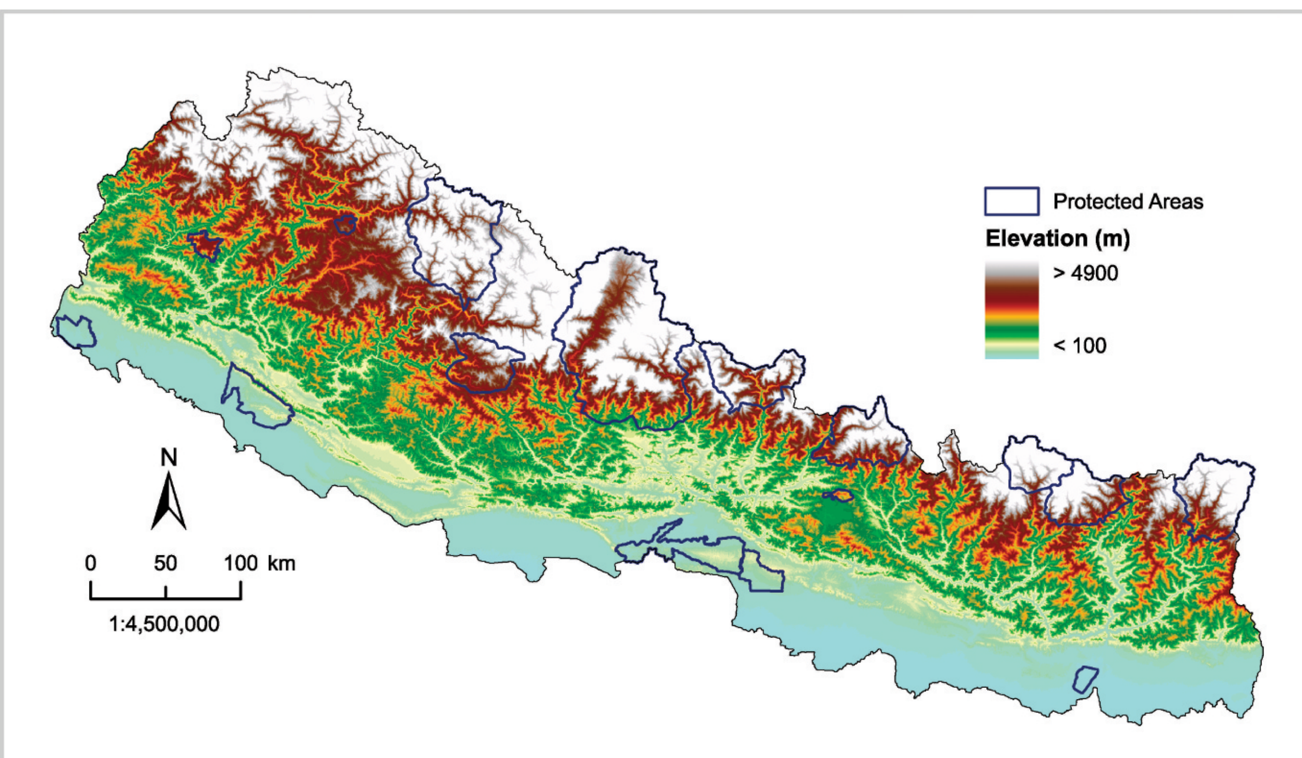


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TABLE 3 Comparison index for Nepal's protected areas and total areas by ecoregions. Not rep, not represented.

Ecoregions[a]	Elevation (m)[b]	Total area (km^2)	% of total area	Protected area (km^2)	% PA area in ecoregion	Comparison index
Eastern Himalayan alpine shrub and meadows	1822–8038	8657	5.85	6184	24.45	4.18
Eastern Himalayan broadleaf forests	270–4707	15,414	10.41	717	2.84	0.27
Eastern Himalayan subalpine conifer forests	795–6324	5020	3.39	2058	8.14	2.40
Himalayan subtropical broadleaf forests	80–2245	28,295	19.12	1946	7.69	0.40
Himalayan subtropical pine forests	249–3724	22,764	15.38	693	2.74	0.18
Lower Gangetic Plains moist deciduous forests	58–92	199	0.13	Not rep.	Not rep.	Not rep.
Rock and ice	2375–8808	6815	4.60	4492	17.76	3.86
Terai–Duar savanna and grasslands	58–999	22,506	15.20	2140	8.46	0.56
Upper Gangetic Plains moist deciduous forests	120–164	4	0	Not rep.	Not rep.	Not rep.
Western Himalayan alpine shrub and meadows	1631–8132	21,476	14.51	5600	22.14	1.53
Western Himalayan broadleaf forests	486–4236	4789	3.24	597	2.36	0.73
Western Himalayan subalpine conifer forests	1082–4457	12,084	8.16	864	3.42	0.42

[a] Derived from Global 200 ecoregions base map (Olson et al 2001).

[b] The figures are the authors' own calculation based on a DEM acquired for the different ecoregions.

grasslands, and Western Himalayan broadleaf forests—are treated as critical/endangered, and one ecoregion—Western Himalayan subalpine conifer forests—is treated as vulnerable by the WWF. A well-represented Eastern Himalayan subalpine conifer forest has vulnerable conservation status. Our results clearly show that the ecoregions that have high conservation priority at global scale have low representation in protected areas of Nepal (Table 3; Figure 3).

Species diversity representativeness

The representation of different life forms under the protected areas system is determined based on the species reported from the protected areas and the total number of species reported from the entire country. Current PAs have the highest representation of birds and comparatively the lowest representation of flowering plants. Out of 6391 species of flowering plants, 181 species of mammals, 867 species of birds, and 195 species of herpetofauna, the numbers of species under protection (reported from protected areas) are 2532 for flowering plants (39.62%), 153 for mammals (84.53%), 830 for birds (95.73%), and 130 for herpetofauna (66.67%) (Table 4).

Protected species representativeness

There are 99 species of flowering plants, 56 species of mammals, 108 species of birds, and 26 species of herpetofauna listed in the CITES appendix for Nepal (Figure 2). To make the calculation less confusing, all the species listed in CITES were considered as protected species irrespective of their appendix number. Out of 99 species of flowering plants listed in CITES, only 44 species were reported from PAs, and 55 species are still excluded. Likewise, protected areas do not cover 4 species of mammals, 6 species of birds, and 3 species of herpetofauna that are listed in the CITES appendix (Figure 4).

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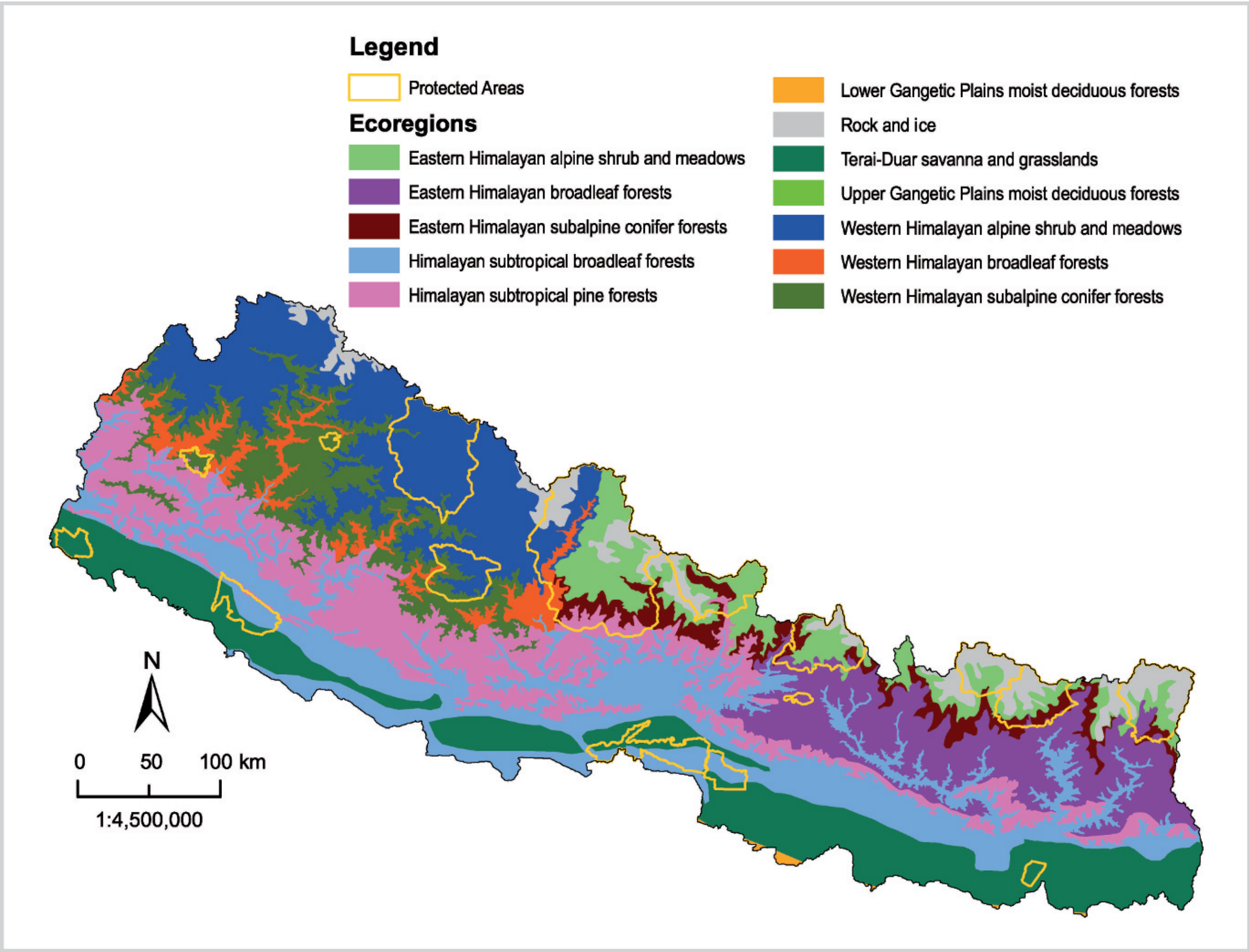
FIGURE 3 Protected areas overlain on ecoregions. (Map by authors)



The representativeness of species of different life forms designated in the different categories of the IUCN Red List of threatened species was also calculated. Thirty-four species of flowering plants, 138 species of mammals, 784 species of birds, and 39 species of herpetofauna are listed in the IUCN Red List of threatened species. Thirty-three species of flowering plants, 124 species of mammals, 750 species of birds, and 24 species of herpetofauna listed in the IUCN Red List of threatened species were reported from PAs. Two Critically Endangered (CE), 1 Vulnerable (VL), 1 Near Threatened (NT), and 30 Least Concern (LC) species of birds are not represented in PAs. Likewise, 1 Endangered (EN), 12 Least Concern (LC), and 1 Data Deficient (DD) species of mammals are not represented in PAs. One Critically Endangered (CE), 11 Least Concern (LC), and 3 Data Deficient (DD) species of herpetofauna are not represented in PAs. Similarly, 1 Least Concern (LC) species of plants is not represented in PAs (Figure 5).

Discussion

Although the history of wildlife conservation in Nepal began in the 1840s with restrictions on the hunting of certain animals like rhinos, tigers, and elephants (HMG/MFSC 2002), the effective era of conservation started in 1973 with the passage of the National Parks and Wildlife Conservation Act (HMG 1973; HMG/MFSC 2002) and establishment of the country's first national park, Chitwan National Park, in the same year. Since the establishment of the Chitwan National Park, several conservation policies have been initiated, and different conservation approaches have been adopted in Nepal.

Under the framework of national policies such as the Master Plan for the Forestry Sector (HMG 1988a), the National Conservation Strategy (HMG 1988b), the National Environmental Policy and Action Plan (IUCN 1991; HMG 1993), the draft National Conservation

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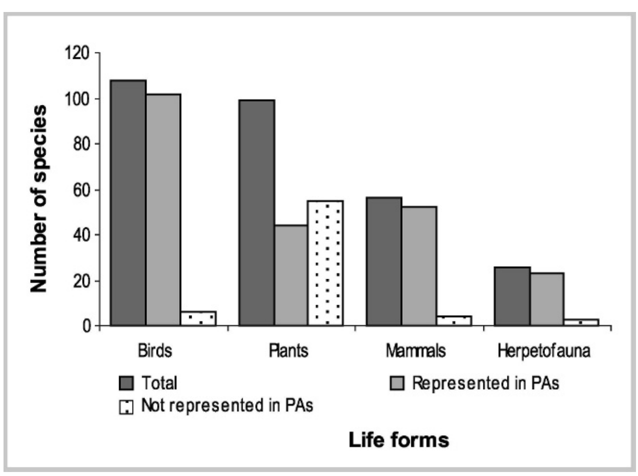
TABLE 4 Percentage of representation of species of different life forms in Nepal's PAs. (Source of data: BPP 1995; ICIMOD 2007)

Life forms	Total number of species	Number of species reported from protected areas	Percentage representation in protected areas
Flowering plants	6391	2532	39.62
Mammals	181	153	84.53
Birds	867	830	95.73
Herpetofauna	195	130	66.67

Strategy (HMG 1988b), and the National Biodiversity Conservation Strategy (HMG/MFSC 2002), the government of Nepal has prioritized conservation through the establishment of an extensive protected area system. However, systematic conservation planning has been lacking so far, and conservation areas have been expanded on an ad hoc basis. This was mentioned in the fourth National Report to the Convention on Biological Diversity (GoN 2009), with the recommendation to review priority habitats in the country that are within and outside the protected areas system, along west–east (regional) and south–north (altitudinal) axes, and consider biodiversity at biome, ecosystem, habitat, species, and genetic levels (GoN/DNPWC 2009). The current study attempts to fill the gap with a quantitative analysis of the representativeness of the protected areas system in terms of ecoregions, ecosystems, habitats, and species.

Although 22.5% (17.01% included in this study; the rest are newly declared, and base maps are not readily available) of Nepal's land area is allocated for protected areas, the protected areas system is not sufficient to represent all geophysical, ecological, and biological features. As a consequence, the system does not suffice to protect the biodiversity of the country and thus has not been able to achieve the conservation goal to its full extent. Our analysis shows that current PAs do not appropriately cover all ecosystems and species adapted to different physiographic zones, elevation gradients, and ecoregions. Representation increases with increase in elevation; CI values continuously increase from 800 m, but the rate is slower after 4000 m. As mentioned already, this shows that the distribution of the protected areas system in the country is highly skewed toward higher elevation. Previous studies have also indicated the asymmetrical distribution of protected areas, where more protected land falls in high mountain regions that are dominated by snow and rocks (Hunter and Yonzon 1993; Ramesh et al 1997; Powell et al 2000; Cantu et al 2004; Heinen and Shrestha 2007) and that are biologically less diverse (ICIMOD 2007) and too remote or unproductive to be important economically (Pressey 1994).

FIGURE 4 Representativeness of CITES listed species for different life forms in PAs.



Physiographically, the Mid Hills make up the largest proportion of the country's area and the greatest ecosystem diversity (52 out of 118 ecosystems) and species diversity in Nepal, with nearly 32% of the country's forests occurring there (HMG/MFSC 2002). Nevertheless, the representation of the Mid Hills in current PAs is lowest among all physiographic regions. Similarly, the representation of Terai and Siwalik is also low, even though the ecosystems of these areas are of international significance (BPP 1995; HMG/MFSC 2002). In addition, deforestation and biodiversity loss are high in these poorly represented areas, likely due to high population pressure, rapid agricultural expansion, and inadequate government attention in controlling overexploitation (HMG/MFSC 2002). In essence, the Mid Hills and Terai zones are not receiving adequate protection, despite biodiversity richness and serious threats. In other words, the areas that are critical and need direct attention for conservation have remained excluded.

The species richness pattern in Nepal varies significantly by altitudinal gradients, showing a strong correlation between altitude and species richness; richness increases up to a certain elevation level, reaches a plateau, and then declines (Hunter and Yonzon 1993; Vetaas and Grytnes 2002; Bhattarai et al 2004; Grau et al 2007). For instance, species richness of flowering plants increases from 1000 m, reaches a maximum between 1500 and 2500 m, peaks at 2500 m, and decreases from 2500–

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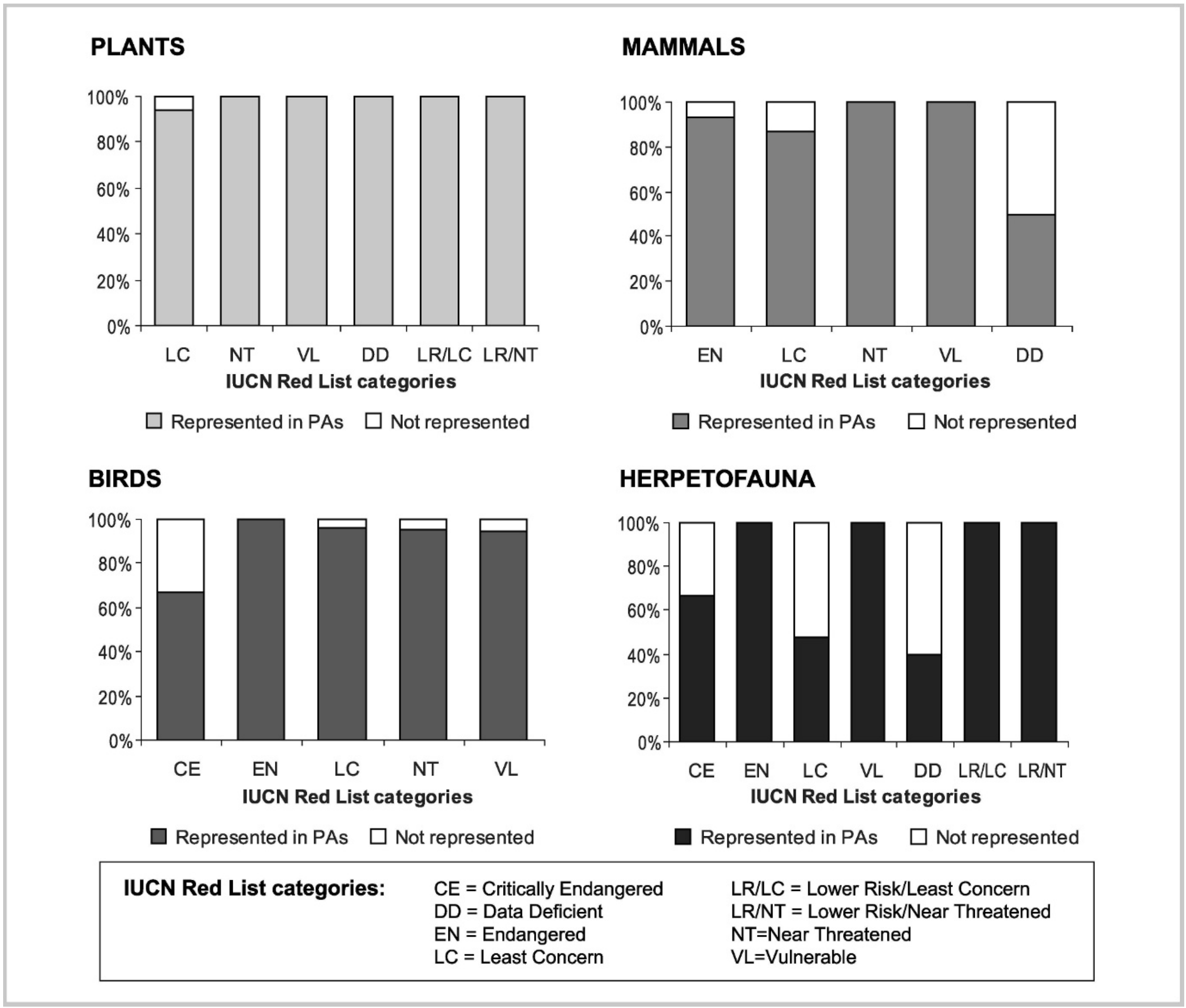
FIGURE 5 Representativeness of the IUCN Red List of threatened species for different life forms in PAs.



4000 m (Vetaas and Grytnes 2002). However, the regions between 1000–2800 m are poorly represented in the current PA system. This could be a possible reason for the underrepresentation of 39.62% of flowering plants in PAs. Inadequate data due to lack of thorough assessment of floral diversity in PAs of Nepal could be another cause of underrepresentation. This is, however, subject to more rigorous research in future.

Species richness of mammals and birds, some of the well-studied life forms in Nepal, is highest below 500 m and decreases with increasing altitude (Hunter and Yonzon 1993); thus, they are well represented in protected areas of the country. This is mainly because land areas between 200–400 m and Terai ecosystem types (10 out of 10) are very well represented in the protected areas system of the country. On the other hand, only 15% (3860 km^2 of 26,119 km^2) and 9 out of 27 Important Bird Areas (IBA) of Nepal are outside the protected area system (Chettri et al 2008).

Although the species data for ferns, mosses, and liverworts were not included in this study, we readily understood that their representation would have been poorest in the altitudes between 1000–2800 m in current PAs. It is reported that the areas between 1000–3000 m host 493 species (66.32%) of bryophytes and 272 species (71.58%) of pteridophytes (BPP 1995; GoN/DNPWC 2009). Moreover, the species richness of ferns peaks at 1900 m (Bhattarai et al 2004), mosses at 2500 m, and liverworts at

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2800 m (Grau et al 2007). A similar inference can be drawn for the endemic species of vascular plants, even though these data were not included in this study. The good representation of protected areas at higher elevation zones (above 2800 m) could be important for conserving endemic vascular plants, since endemism for them is highest in the regions between 3800–4200 m (Vetaas and Grytnes 2002). Current protected areas included only 191 species (77.64%) out of 246 species of endemic vascular plants; Annapurna Conservation Areas alone harbors 55 endemic species (Shrestha and Joshi 1996), showing that the distribution of these plant groups is not uniform.

Threatened animals (mammals and birds) are well included in the protected areas system, although current PAs fail to cover several species of animals. However, threatened flowering plants are underrepresented because the entire category of flowering plants themselves has remained poorly represented. Herpetofauna is one of the least represented species after flowering plants and needs more attention in future protected areas planning. Although butterflies are not included in this study, it can be inferred that areas between 800–2800 m, which is poorly represented in current PAs, might have high species richness of butterflies because 557 species of butterflies (88.00%) are found between 1000–3000 m (BPP 1995; GoN/DNPWC 2009). From the point of view of conservation, the inclusion or exclusion of species in the system is not as important as information about minimum viable populations of certain species protected by the system. Therefore, for a rigorous gap analysis and better conservation planning of new protected areas, a detailed distribution map of individual species and population-level analysis are essential. In addition, it is important to study small mammals, insects, and lower plants and include the information in future gap analysis so that more important ecosystems are included in the PA system (Chettri et al 2008).

The spatial distribution of PAs in Nepal seems distributed in an east–west pattern, but the altitudinal and physiographic distribution is north–south. Moreover, the species richness and distribution patterns are highly influenced by altitude. Better representation of vegetation and species can be seen in protected areas that extend from south to north and cover wider elevation zones. Annapurna Conservation Area, for example, extending from 790–8091 m, represents the highest number (16 out of 36) of vegetation types in Nepal (ICIMOD 2007).

A comparison index (CI) only measures the proportion of the land that is currently protected by comparison with the total land area and disregards distribution pattern, population viability, and ecological integrity (Hazen and Anthamatten 2004; Trisurat 2007). In reality, degrees of conservation needed in the different ecosystems are not equivalent, because threats to biodiversity vary depending on the ecosystem. It is also not pragmatic to incorporate entire biological, ecological, and geophysical features proportionally into protected areas. Nevertheless, this method is a good way of comparing the features (eg species, habitats, and ecosystems) and highlighting the critical or underrepresented areas that are important for protected areas planning and management.

Conclusion

GIS analysis and CI representativeness showed that the current protected areas system of Nepal does not adequately provide protection of geophysical and biological features, as PAs are skewed toward High Himal regions, leading to poor representation of some important ecosystems, ecoregions, habitats, and species. The poor representation of the Mid Hills and the regions between 800–2800 m poses a serious challenge, since the Mid Hills represent the highest ecosystem diversity in the country and face acute population pressure. In addition, the distribution of globally important ecoregions such as Himalayan subtropical pine forests, Eastern Himalayan broadleaf forests, and Himalayan subtropical broadleaf forests are predominately distributed in the Mid Hills and midelevation regions. To ensure adequate representation and to formulate national conservation strategies congruent with global conservation priorities, selection of new protected areas or extension of current protected areas should ensure adequate representation of the Mid Hills and midelevation regions.

Ideally, the spatial arrangement of protected areas should both ensure a full range of ecological variation of biodiversity features and sustain connectivity between reserves (Kamei and Nakagoshi 2006). In order to capture the full range of geophysical and biological features, a systematic approach to biodiversity conservation planning for Nepal is necessary that ensures a comparison index of at least 1 for each physiographic zone, elevation zone, and ecoregion, whenever possible, following recommendations made previously as well. Therefore, to improve the existing protected areas system of Nepal, special attention should be given to underrepresented or unrepresented physiographic zones, altitudinal zones, ecoregions, ecosystems, and species. All excluded lands can be protected either by classifying them as new protected areas, incorporating them within existing protected area systems, or protecting them as extended land (corridors).

The extension of current PAs or selection of new protected areas in the Mid Hills, where population pressure is high and human settlements are fragmented, is very challenging. When considering geophysical and biological features, human interests must not be ignored. Extension of current PAs in those areas could be materialized by adopting and refining the integrated conservation approach that Nepal has been practicing for decades. In order to maintain a balance between the

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conservation of globally important ecosystems and species and human needs at local level, a people-centered conservation approach that keeps both ecological and socioeconomic factors in balance is essential. This paper calls for more action research on implementing a people-centered conservation approach that maximizes representativeness with minimum impairment to people and the ecosystems.

Although this paper focuses on representation of protected areas in Nepal, it has broader significance. Not only other Himalayan countries, but also several other non-Himalayan countries that are undergoing poor conservation planning and management need to carry out similar analyses before further PA planning is done. Scientists can also benefit from the methodology employed in this study because it introduces some novel strategies to assess representation of protected areas at a national level. However, replication in other regions might require some modification or adaptation according to local situations.

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REFERENCES

Bhattarai KR, Vetaas OR, Grytnes JA. 2004. Fern species richness along a Central Himalayan elevational gradient, Nepal. *Journal of Biogeography* 31: 389–400.
BPP [Biodiversity Profiles Project]. 1995. *Biodiversity Profile of the Terai/Siwalik Physiographic Zones*. Biodiversity Profile Project Publication 12. Kathmandu, Nepal: Department of National Parks and Wildlife Conservation.
Bruner AG, Gullison RE, Rice RE, da Fonseca GAB. 2001. Effectiveness of parks in protecting tropical biodiversity. *Science* 291:125–128.
Cantu C, Wright RG, Scott JM, Strand E. 2004. Assessment of current and proposed nature reserves of Mexico based on their capacity to protect geophysical features and biodiversity. *Biological Conservation* 115:411–417.
Catullo G, Masi M, Falcucci A, Maiorano L, Rondinini C, Boitani L. 2008. A gap analysis of Southeast Asian mammals based on habitat suitability models. *Biological Conservation* 141:2730–2744.
Chaudhary RP. 2000. Forest conservation and environmental management in Nepal: A review. *Biodiversity and Conservation* 9:1235–1260.
Chettri N, Shakya B, Thapa R, Sharma E. 2008. Status of a protected areas system in the Hindu Kush–Himalayas: An analysis of PA coverage. *International Journal of Biodiversity Science and Management* 4:164–178.
CITES [Convention on International Trade in Endangered Species of Wild Fauna and Flora]. 2008. *Checklist of CITES Species 2008*. Compiled by UNEP–WCMC http://www.cites.org/eng/resources/species.html; accessed on 23 March 2008.
Dobremez JF. 1972. Les grandes divisions phytogéographiques du Népal et de l'Himalaya. *Bulletin de la Société botanique de France* 119:111–120.
Dobremez JF. 1976. *Le Népal: Écologie et Biogéographie* [Ecology and Biogeography of Nepal]. Paris, France: Centre Nationale de la Recherche Scientifique (CNRS).
ESRI. 2006. *ArcGIS Version 9.2*. Redlands, CA: Environmental Systems Research Institute (ESRI).
GoN. 2009. *Nepal Fourth National Report to the Convention on Biological Diversity*. Kathmandu, Nepal: Ministry of Forests and Soil Conservation.
GoN/DNPWC. 2009. *Protected Areas of Nepal*. http://www.dnpwc.gov.np/protected-areas.asp; accessed on 18 March 2009.
Grau O, Grytens JA, Birks HJB. 2007. A comparison of altitudinal species richness patterns of bryophytes with other plant groups in Nepal, central Himalaya. *Journal of Biogeography* 34:1907–1915.
Hagen T. 1998. *Nepal—The Kingdom in the Himalaya.* 4th edition. Lalitpur, Nepal: Himal Books.
Hazen H, Anthamatten P. 2004. Representation of ecoregions by protected areas at the global scale. *Physical Geography* 25(6):499–512.
Heinen JT, Shrestha SK. 2007. Evolving policies for conservation: An historical profile of the Protected Area System of Nepal. *Journal of Environmental Planning and Management* 49(1):41–58.
HMG [His Majesty's Government of Nepal]. 1973. National Parks and Wildlife Conservation Act 2029. *Nepal Gazette*, 2029-11-28 (Bikram Sambat).
HMG [His Majesty's Government of Nepal]. 1988a. *Master Plan for the Forestry Sector Main Report*. Kathmandu, Nepal: Ministry of Forests and Soil Conservation.
HMG [His Majesty's Government of Nepal]. 1988b. *The National Conservation Strategy for the Kingdom of Nepal*. Kathmandu, Nepal: Ministry of Forests and Soil Conservation.
HMG [His Majesty's Government of Nepal]. 1993. *Nepal Environmental Policy and Action Plan: Integrating Environment and Development*. Kathmandu, Nepal: HMG, Environmental Protection Council.
HMG/MFSC [His Majesty's Government/Ministry of Forests and Soil Conservation]. 2002. *Nepal Biodiversity Strategy*. Supported by the Global Environment Facility (GEF) and UNDP. Kathmandu, Nepal: HMG.
Hunter M, Yonzon P. 1993. Altitudinal distribution of birds, mammals, people, forests and parks in Nepal. *Conservation Biology* 7(2):420–423.
ICIMOD [International Center for Integrated Mountain Development]. 2007. *Nepal Biodiversity Resource Book (Protected Areas, Ramsar Sites, and World Heritage Sites)*. Kathmandu, Nepal: ICIMOD, MOEST, GoN.
IUCN [International Union for Conservation of Nature]. 1991. *A Legislative and Institutional Framework for Environmental Management in Nepal*. Kathmandu, Nepal: National Conservation Strategy and Implementation Project, IUCN.
IUCN [International Union for Conservation of Nature]. 2008. *2008 IUCN Red List of Threatened Species*. http://www.iucnredlist.org; accessed on 23 March 2008.
Jennings MD. 2000. Gap analysis: Concepts, methods and recent results. *Landscape Ecology* 15:5–20.
Kamei M, Nakagoshi N. 2006. Geographic assessment of present protected areas in Japan for representativeness of forest communities. *Biodiversity Conservation* 15:4583–4600.
Lillesø J-PB, Shrestha TB, Dhakal LP, Nayaju RP, Shrestha R. 2005a. Manuscript submitted to Tree Improvement and Silviculture Component (TISC), together with data for 261 Weather Stations. Kathmandu, Nepal.
Lillesø J-PB, Shrestha TB, Dhakal LP, Nayaju RP, Shrestha R. 2005b. *The Map of Potential Vegetation of Nepal: A Forestry/Agroecological/Biodiversity Classification System*. Forest & Landscape Development and Environment Series 2-2005 and CFC-TIS Document Series No. 110.
LRMP [Land Resources Mapping Project]. 1986. *Land Resources Mapping Project*. Kathmandu, Nepal: Survey Department, HMGN and Kenting Earth Sciences.
Margules CR, Pressey RL. 2000. Systematic conservation planning. *Nature* 405:243–253.
NHM [Natural History Museum]. 2008. *The Flora and Vegetation of Nepal*. http://www.nhm.ac.uk/research curation/research/projects/nepal/flora.html; accessed on 18 March 2009.
Nepali SC. 2006. *Management Effectiveness Assessment of Protected Areas using WWF's RAPPAM Methodology*. Kathmandu, Nepal: WWF Nepal.
Oldfield TEE, Smith RJ, Harrop SR, Williams NL. 2004. A gap analysis of terrestrial protected areas in England and its implication for conservation policy. *Biological Conservation* 120:303–309.
Olson DM, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GVN, Underwood EC, D'amico JA, Itoua I, Strand HE, Morrison JC, Loucks CJ, Allnutt TF, Ricketts TH, Kura Y, Lamoreux JF, et al. 2001. Terrestrial ecoregions of the worlds: A new map of life on Earth. *Bioscience* 51: 933–938.

http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00019.1

Pawar S, Koo MS, Kelley C, Ahmed MF, Chaudhuri S, Sarkar S. 2007. Conservation assessment and prioritization of areas in Northeastern India: Priorities for amphibians and reptiles. *Biological Conservation* 136:346–361.
Powell GVN, Barborak J, Rodriguez M. 2000. Assessing representativeness of protected natural areas in Costa Rica for conserving biodiversity: A preliminary gap analysis. *Biological Conservation* 93:35–41.
Pressey RL. 1994. Ad hoc reservations—Forward or backward steps in developing representative reserve systems. *Conservation Biology* 8:662–668.
Ramesh BR, Memom S, Bawa KS. 1997. A vegetation based approach to biodiversity gap analysis in the Agastyamalai region, Western Ghats, India. *Ambio* 26:529–536.
Rodrigues ASL, Akcakaya HR, Andelman SJ, Bakarr MI, Boitani L, Brooks TM, Chanson TM, Fishpool LDC, da Fonseca GAB, Gaston KJ, Hoffmann M, Marquet PA, Pilgrim JD, Pressey RL, Schipper J, et al. 2004a. Global gap analysis: Priority regions for expanding the global protected-area network. *Bioscience* 54:1092–1100.
Rodrigues ASL, Andelman SJ, Bakarr MI, Boitani L, Brooks TM, Cowling RM, Fishpool LDC, da Fonseca GAB, Gaston KJ, Hoffmann M, Long JS, Marquet PA, Pilgrim JD, Pressey RL, Schipper J, et al. 2004b. Effectiveness of the global protected area network in representing species diversity. *Nature* 428:640–643.
Rondinini C, Stuart S, Boitani L. 2005. Habitat suitability models and the shortfall in conservation planning for African vertebrates. *Conservation Biology* 19:1488–1497.
Salick J, Fang ZD, Byg A. 2009. Tibetan ethnobotany and climate change in the eastern Himalayas. *Global Environmental Change* 19:147–155.
Scott JM, Csuti B. 1997. Noah worked two jobs. *Conservation Biology* 11: 1255–1257.
Scott JM, Davis FW, Csuti B, Noss R, Butterfield B, Groves C, Anderson H, Caicco S, Derchia F, Edwards TC, Ulliman J, Wright RG. 1993. Gap analysis: A geographic approach to protection of biological diversity. *Wildlife Monographs* 123:1–41.
Shrestha TB, Joshi RM. 1996. *Rare, Endemic and Endangered plants of Nepal*. Kathmandu, Nepal: WWF Nepal.
Tognelli ME, Arellano de Ramirez PI, Marquet PA. 2008. How well do the existing and proposed reserve networks represent vertebrate species in Chile? *Diversity and Distribution* 14:148–158.
Trisurat Y. 2007. Applying gap analysis and a comparison index to protected areas in Thailand. *Environmental Management* 39:235–245.
Vetaas OR, Grytnes JA. 2002. Distribution of vascular plants species richness and endemic richness along the Himalayan elevation gradient in Nepal. *Global Ecology and Biogeography* 11:291–301.
WDPA [World Database on Protected Areas]. 2009. *World Database on Protected Areas Annual Release* (web download version). http://www.wdpa.org/Download.aspx; accessed on 3 July 2009.
Yip JY, Corlett RT, Dudgeon D. 2004. A fine-scale gap analysis of the existing protected areas system in Hong Kong, China. *Biodiversity and Conservation* 13: 943–957.