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Conservation planning in the Nepal Himalayas: Effectively (re) designing reserves for heterogeneous landscapes

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Landscapes consisting of heterogeneous environmental conditions (e.g. elevational gradients) are richer in species diversity than more homogeneous landscapes. Furthermore, the importance of heterogeneous landscapes has been widely acknowledged in biodiversity conservation due to expected elevational shifts in ranges as a result of climate change. This is especially important in mountainous landscapes. There is as yet no protocol that conservation planners can use to integrate landscape heterogeneity in the design of protected area (PAs) systems. In this study, we tested whether Nepal, as a whole, consists of highly heterogeneous landscapes in term of elevation, and whether heterogeneity of PAs is correlated with their size and species diversity. We developed a conservation index of elevational zones within Nepal to evaluate their representativeness in the protected area system. The results showed that, in Nepal's PAs, indices of elevational heterogeneity were strongly associated with species richness. However, heterogeneity indices were not strongly associated with sizes of PAs despite the fact that Nepal is a highly heterogeneous country. The same is true for national parks and conservation areas based on IUCN-The World Conservation Union's categories of PAs. The conservation index of elevation zones suggested a bias in reserve selection towards higher elevations. There is an urgent need to rectify past biases in reserve design so as to ensure protection of elevational heterogeneity during conservation planning, especially in these times of human-induced climate change.

Introduction

Protected Areas (PA) are the cornerstone for conserving most important biodiversity in the face of rapid environmental change (Heinen, 2010). However, designing effective protected areas for preserving representative samples of ecosystem and species diversity is difficult in the face of global climate change (Margules & Pressey, 2000). To date, it is estimated that more than 12% of the global land area is preserved in the global network of approximately 100,000 internationally-recognized categories of PAs (Chape, Harrison, Spalding, & Lysenko, 2005), and many countries have significant lands set aside in sub national reserves (e.g. state and county parks in the United States), that increase this total substantially (Heinen, 2012). However, the performance of existing networks of protected areas in representing biodiversity is far from expected (Chape et al., 2005; Hannah et al., 2007; Margules & Pressey, 2000). This is because most of the protected areas have focused either on protecting areas that encompass vulnerable and endangered species, and landscapes (Margules & Pressey, 2000; Peterson, Cumming, & Carpenter, 2002), or on finding the minimum set of areas that maximize the representation of biodiversity (Cabeza & Moilanen, 2001), or on finding appropriate areas that maximize probabilities of species persistence (Bonn, Rodrigues, & Gaston, 2002; Rodrigues, Tratt, Wheeler, & Gaston, 1999; Williams & Araujo, 2000). Such reserve design approaches are inadequate to ensure long term security of the representative biodiversity (Beier, Spencer, Baldwin, & Mcrae, 2011). Furthermore, studies have shown that current protected areas will fail to ensure species' long-term persistence if climate changes as projected because climate change may cause species to move out of protected areas (Araújo, Alagador, Cabeza, Nogués-Bravo, & Thuiller, 2011; Araújo, Cabeza, Thuiller, Hannah, & Williams, 2004). What would be an effective strategy to conserve biodiversity under climate change?

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Some authors have emphasized protecting areas beyond reserve boundaries with the aim of creating networks of reserves connected by buffers and habitat corridors (Heinen & Mehta, 2000; Noss & Harris, 1986; Roberge & Angelstam, 2004; Smith, Ahern, & McDougal, 1998; Timilsina & Heinen, 2008). However, corridors are often designed for particular species in question and the extent to which such corridors might facilitate dispersal of species and connectivity is questionable (Higgs, 1981). Therefore, they do not substitute for core reserves.

Two hypotheses explaining species–area relationship have been used to guide PA size: the habitat diversity hypothesis and the area *per se* hypothesis (Connor & McCoy, 1979; MacArthur & Wilson, 1967). Williams (1944) argued that large areas contain more species because of high habitat diversity. The concept of habitat heterogeneity, or the ecological heterogeneity hypothesis, supposes that structurally complex habitats may provide more niches and diverse ways of exploiting environmental resources and thus increase species diversity (Shmida & Wilson, 1985). The most extreme cases are high mountain regions at low latitudes where heterogeneous topography and climatic gradients contribute to unusually high biodiversity (Ruggiero & Hawkins, 2008). Therefore, it may be prudent to incorporate environmental diversity to capture representative biodiversity during reserve design (Bonn & Gaston, 2005).

Elevation is the most important determinant of the climate gradient because it influences average temperature, evapotranspiration rate (PET), length of the growing season, humidity, air pressure, ultraviolet radiation and rainfall (Funnell & Parish, 2001). In mountainous regions, climatic gradients support high biodiversity and also provide buffers for certain species and communities in cases of climate change inducing upward range shifts (e.g., Chen, Hill, Ohlemüller, Roy, & Thomas, 2011). Therefore, small reserves consisting of homogeneous landscapes are predicted to face rapid rates of extirpation (Allouche, Kalyuzhny, Moreno-Rueda, Pizarro, & Kadmon, 2012). In response to such potential threats, the PA designs based on the capacity to provide environmental gradients are well discussed, but as yet have not been integrated into reserve design protocols (Bonn & Gaston, 2005; Kati et al., 2010).

In this paper, we applied an assessment of environmental gradients to the Nepal Himalaya, a country with the largest elevational gradients (67–8848 m) in the world over rather small horizontal distances (200 km). Such an exceptionally large elevational variation has provided a unique assemblage of habitats and very high alpha, beta and gamma diversity within a small geographical area (Fig. 1). For example, Nepal makes up less than 0.1% of global landmass but boasts 3.9% of the world's mammals, 8.9% of the world's birds and 3.7% of the world's butterflies (Paudel, Bhattarai, & Kindlmann, 2012). Nepal is included among the earth's biodiversity hotspots (Mittermeier, Myers, Mittermeier, & Robles Gil, 1999; Fig. 1). The region includes two endemic bird areas (Stattersfield, Crosby, Long, & Wegge, 1998), several World Wildlife Fund (WWF) focal ecoregions (Olson & Dinerstein, 1998) and centres for plant diversity (WWF/IUCN, 1995). However, Himalayan biodiversity, in particular, is sensitive to climate change and other human-caused modifications (Mittermeier et al., 1999; Xu et al., 2009). The most widely reported effect is upward shift of tree line species (Telwala, Brook, Manish, & Pandit, 2013). Reserve design in Nepal has been done targeting either flagship species or on mountain peaks having cultural and aesthetic significances (Heinen & Yonzon, 1994; Hunter & Yonzon, 1993; ICIMOD, 2007; Paudel et al., 2012). Although previous work has concluded that the protected area system of Nepal is biased toward high elevation areas (e.g. Heinen & Yonzon, 1994; Hunter & Yonzon, 1993; Shrestha, Shrestha, Chaudhary, & Chaudhary, 2010), such information has not been used systematically in PA system design. This study provides the first detailed quantitative analysis of landscape heterogeneity and its inclusion into conservation planning in the Himalayan region. Specifically, we hypothesized that: (1) reserves in Nepal are not heterogeneous with respect to their area; (2) highland habitats are protected disproportionally and lower elevational habitats are underrepresented in the current network of protected areas Nepal.

Materials and methods

Study area

The study covers Nepal, a mountainous country in the central Himalayas (26°22′–30°27′ N, 80°4′–88°12′ E) (Fig. 1). Nepal has an impressive network of 20 protected areas (average size: 1429 km^2), that includes ten national parks (average size 1085 km^2), 3 wildlife

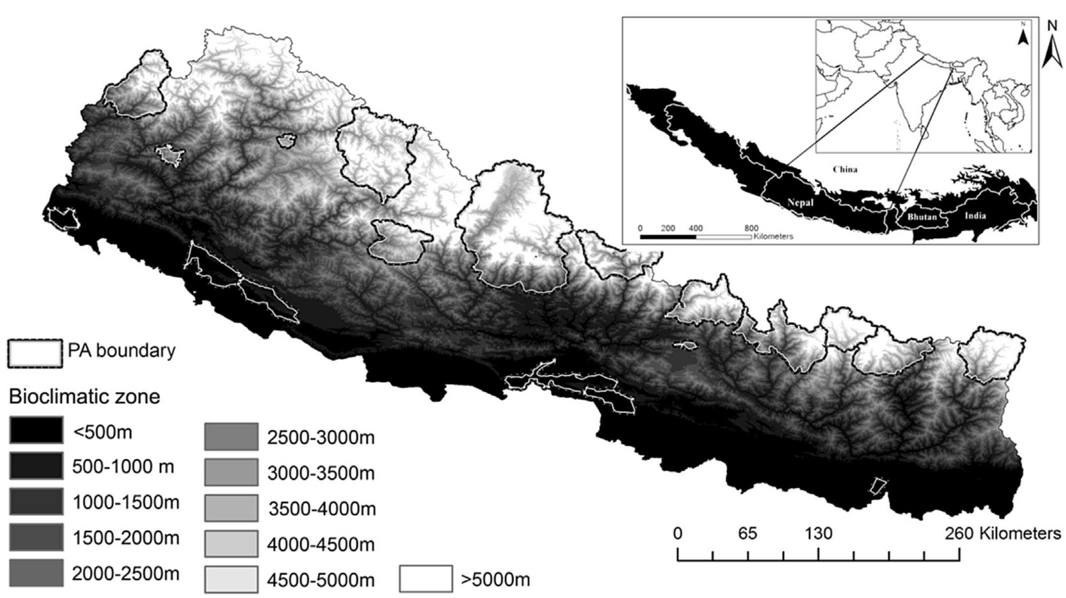

Fig. 1. The protected areas of Nepal overlaid with bioclimatic zones. There are five bioclimatic zones: tropical (<1000 m), subtropical (1000–2000 m) temperate (2000–3000 m), subalpine (3000–4000 m) and alpine (4000–5000 m). Each bioclimatic zone is further divided into two zones (upper and lower) with a 500 m elevation interval. (Inset: Himalayan biodiversity hotspot (Mittermeier et al., 1999). Nepal occupies about one third of the Himalayan range)

reserves (average size 326 km^2), 6 conservation areas (average size 2571 km^2) and one hunting reserve (1325 km^2).

Heterogeneity indices

There are several ways to measure environmental heterogeneity (e.g., Kati et al., 2010; Wiens, 2000), most of which use indices describing landscape pattern. We calculated two types of indices to quantify elevational heterogeneity: (1) a pixel-based elevational heterogeneity of Nepal, and (2) an elevational zone-based heterogeneity of PAs. We calculated the pixel-based elevational heterogeneity of Nepal using a moving window algorithm, which classifies each elevational zone pixel based on the number of unique elevational zones within a surrounding square window (e.g., Riitters et al., 2002). To calculate the pixel based elevational heterogeneity, we obtained geo-referenced digital elevation (DEM) data (ASTER GDEM) from the project page: http://www.gdem.aster.ersdac.or.jp. The data are in raster format with a resolution of 30 m. Using a map of Nepal, we resampled DEM data to a lower resolution (500 m) to make the dataset comparable with the bioclimatic zones of the country. Each of Nepal's five bioclimatic zones (tropical, subtropical, temperate, subalpine and alpine) covers 1000 m in elevational range (e.g. tropical <1000, subtropical 1000–2000 m, temperate 2000–3000 m, subalpine 3000–4000 m, alpine 4000–5000 m; Fig. 1). We further categorized each bioclimatic zone into two regions, with a 500 m interval (e.g., lower tropical: <500 m and upper tropical: 500–1000 m, see Fig. 1) to make it a representative aggregation resolution. Secondly, we used a moving window algorithm implemented in a 'Variety' function in the focal statistics tool of ArcGIS with window sizes of 3 × 3 pixels (2.25 km^2), 4 × 4 pixels (4 km^2), 5 × 5 pixels (6.25 km^2) and 6 × 6 pixels (9 km^2) to generate maps of the elevational heterogeneity of Nepal at four spatial resolutions. Here, we used different window sizes to see whether the heterogeneity indices would differ significantly at higher spatial resolutions. The function calculates the total number of unique values of the cells (e.g., unique elevational zones) in the neighbourhood. A 3 × 3 km grid (equivalent to the window size of 6 × 6 pixels) was superimposed on a map of Nepal using ArcGIS 9.2 (Environmental Systems Research Institute, Redland, CA). We excluded grid cells that do not fall completely within Nepal. We generated one point in each grid randomly and extracted pixel values corresponding to the four layers of elevational heterogeneity.

We calculated the elevational heterogeneity of PAs using a map of elevational gradients of Nepal with a 100 m interval between 0 and 4900 m. Regions above 4900 m are devoid of life (i.e. the approximate snow line — Heinen & Kattel, 1992) and therefore we grouped together elevation zones above 4900 m. For each of 20 PAs, we calculated the area occupied by the elevation zones using the spatial analyst function in ArcGIS (version 9.2, Environmental Systems Research Institute, Redland, CA). We calculated a Shannon's Diversity Index of elevation zones as an index of elevational heterogeneity of each protected area (Magurran, 2004). It is defined as: $H = \sum_{i=1}^{S} - (P_i * \ln P_i)$, where H is the Shannon diversity index of the protected area, P_i is the proportion of area occupied by elevational zone i within the protected area ($i = 1, \ldots, S$), S is the number of elevation zones, $\sum$ is the sum of elevation zone from 1 to S. A high value of H would indicate a highly heterogeneous PA in term of elevational zones. This is an appropriate index for the spatial data used here and it has been widely used in ecology for both species and habitat diversity studies. A PA with only one elevational zone has an H value of 0 whereas a large PA with high but similar sizes of elevation zones would have a high H value. Therefore, there is a maximum theoretical value of the heterogeneity index of each protected area depending on the number of elevational zones and their sizes. The heterogeneity index of Nepal based on elevational zones was also calculated to aid comparison with the heterogeneity index of protected areas.

Species richness of protected area

We obtained species data for mammals and birds in 16 of 20 PAs of Nepal from the Biodiversity Resource Book (ICIMOD, 2007). The reason for exclusion of four PAs is the lack of species presence data. Similarly, data for many other life forms (e.g. plants, insects, etc.) are incomplete and they are not included in the analyses.

Conservation indices of elevational zones

For each of 49 elevational zones of Nepal, we calculated the total area covered in Nepal, and the area covered by PA. We used a conservation index (CI) modified after Hazen and Anthamatten (2004): $\mathrm{CI} = P_i/P_{\mathrm{ar}} - 1$, where P_i is the percentage of Nepal's landmass occupied by elevation zone (i) and P_{ar} is the percentage of elevational zone (i) preserved in the protected areas ($i = 1, 2, 3, 4, \ldots$ 49). If an elevation zone is protected in the same proportion of its national coverage, a CI value would be 0. Thus, a negative value indicates under-representation and a positive value represents over-representation, of a given elevational zone in Nepal's PA system relative to their national proportion.

Statistical analyses

We used indices of elevational heterogeneity obtained at four spatial resolutions to test whether the elevation index differed significantly at high spatial resolutions. We hypothesized that as area increases, indices of heterogeneity would increase significantly in a country with a high elevational gradient. We used Friedman's rank-sum tests to compare indices of elevational heterogeneity at four spatial resolutions. This test is appropriate for diverse variables because it is not based on assumptions of normality, homoscedasticity, or equal-interval scales of measurement (Lowry, 2010). Here we used multiple comparison procedures that allow identification of variables that are different from others. Nemenyi's procedure was used as a post-hoc test and the Bonferroni correction was used to allow multiple comparisons among four spatial resolutions.

IUCN – The World Conservation Union defines six PA categories according to their management objectives: (I) — Strict Nature Reserve/Wilderness Area, (II) — National Park, (III) — Natural Monument or Feature, (IV) — Habitat/Species Management Area, (V) — Protected Landscape/Seascape and (VI) – Protected Area with sustainable use of natural resources. Using this criteria, we divided Nepal's PAs into two categories (1) national park (category II), and (2) conservation area (category VI). We further divided PAs into three categories based on elevation: (1) lower mountain PAs (more than 50% of the area below 2000 m), middle mountain PAs (more than 50% of the area between 2000 m and 4900 m), and high mountain PAs (more than 50% of the area above 4900 m). We used linear regressions to quantify the association between PA heterogeneity indices as response variables and PA size as explanatory variables for: (1) all protected areas; (2) national parks; (3) lower mountain PAs; (4) middle mountain PAs; and (5) high mountain PA.

Linear regression was also used to investigate to what degree elevational heterogeneity explained the variation in species richness of PAs. Both the elevational heterogeneity index and species richness of PAs were standardized by area to control this influence. Linear regression is appropriate in both cases because heterogeneity indices of PAs are expected to increase linearly with their sizes, especially in Nepal Himalaya.

Results

There were significant differences among the indices of elevational heterogeneity of Nepal obtained at four spatial resolutions (Friedman test statistics 17,829, df 3, $P < 0.001$). Post-hoc comparisons using Nemenyi's procedure showed that indices of elevational heterogeneity differed significantly from each other. There were no significant relationships between the size of PAs and elevational heterogeneities within them for all PAs ($R^2 = 0.17$, $n = 20$, $P = 0.069$; Fig. 2a), national parks ($R^2 = 0.055$, $n = 10$, $P = 0.52$; Fig. 2b) and conservation areas ($R^2 = 0.13$, $n = 6$, $P = 0.48$; Fig. 2c).

Indices of elevational heterogeneity of PAs and their sizes were significantly associated for lower mountain PAs ($R^2 = 0.72$, $n = 7$, $P = 0.016$; Fig. 3c) and middle mountain PAs ($R^2 = 0.83$, $n = 7$, $P = 0.005$; Fig 3b), but no such relationship was found for high mountain PAs ($R^2 = 0.068$, $n = 6$, $P = 0.62$; Fig. 3a). The heterogeneity index of Nepal was 3.65, which was close to the theoretical value (3.91). Observed heterogeneity indices of all PAs were significantly lower than expected (one-way ANOVA, $F = 5.25$, $P = 0.001$; Fig. 4). Species richness of PAs was significantly associated with heterogeneity indices when the influence of area was adjusted in the model ($R^2 = 0.81$, $n = 16$, $P = 0.001$).

Overall, this research showed that elevational zones overall were well protected, with an average conservation index of 0.17. However, the average conservation index for lower elevations (0–2000 m) was negative (−0.70, SD = 0.25; ranging from −0.93 to −0.020). Middle and higher elevations (2000–4900) were very well protected with an average conservation index of 0.72 (SD = 0.74; Fig. 5).

Discussion

This study has shown that conserving heterogeneous elevational zones supports high biodiversity. This agrees with several studies that have shown that heterogeneity is positively associated with high diversity of birds (Rahbek & Graves, 2001), mammals (Kerr & Packer, 1997) and plants (Jimenez, Distler, & Jorgensen, 2009). We are aware that limited data (birds and mammals) used in our analyses might not be representative to justify the needs of integrating environmental gradients for conservation planning. However, an extensive body of published works on birds, mammals and plants throughout the world reinforces our argument (Jimenez et al., 2009; Kati et al., 2010; Kerr & Packer, 1997; Rahbek & Graves, 2001). Bonn and Gaston (2005) found that surrogate species alone are insufficient to protect other components of biodiversity but that environmental heterogeneity represented diversity of multiple groups (e.g., woody plants, orchids, orthopterans, aquatic and terrestrial herpetofauna and passerine birds, also see Kati et al., 2010). Landscapes with large elevational gradients are therefore important not only for protecting biodiversity but also for helping to make ecosystems resilient to global climate change by providing avenues for range shifts (Rahbek & Graves, 2001) and for conserving species that are seasonal migrants along gradients in elevation.

Heterogeneous landscapes are also important for supporting high species richness and endemism, maintaining ecological and evolutionary processes (Heller & Zavaleta, 2009), and generating more stable population dynamics (Hodgson, Thomas, Wintle, & Moilanen, 2009; Oliver, Roy, Hill, Brereton, & Thomas, 2010). This is a very important finding regarding conservation in mountainous

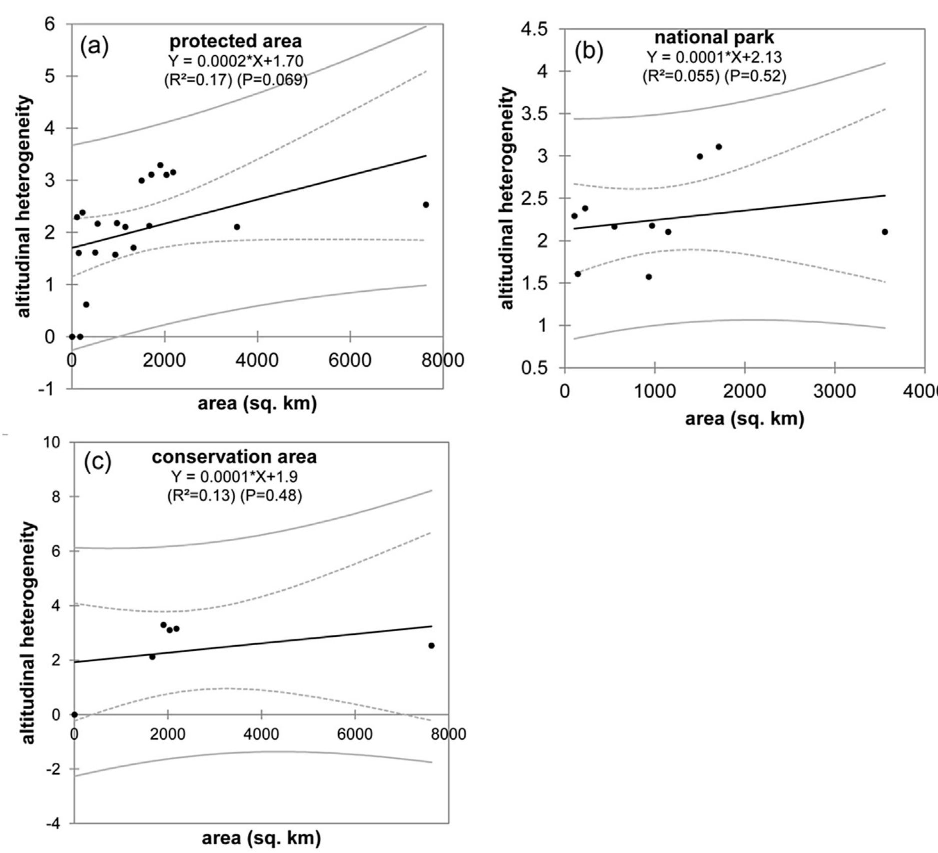

Fig. 2. A liner regression between indices of elevational heterogeneity of protected areas and their sizes for (a) all protected area, (b) national parks (IUCN category II protected area), (c) conservation area (IUCN category VI protected area).

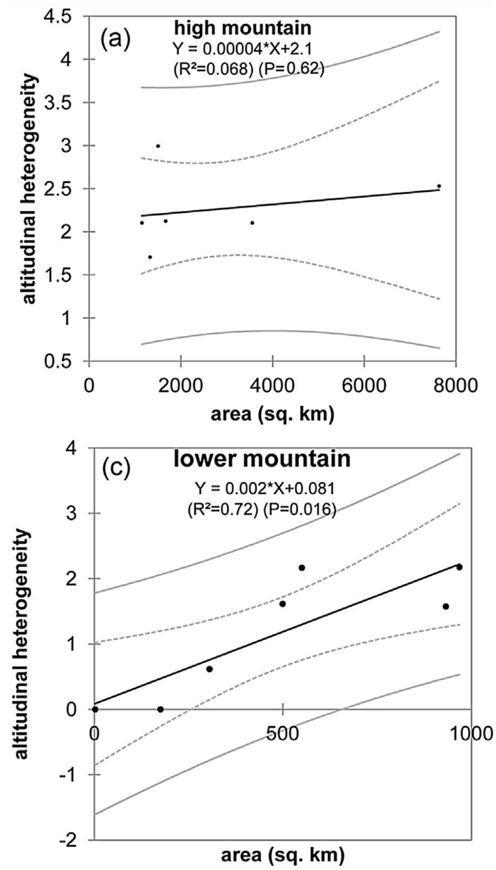

Fig. 3. A liner regression between altitudinal heterogeneity of protected areas and their size for (a) high mountain protected areas, (b) middle mountain protected areas, and (c) lower mountain protected areas.

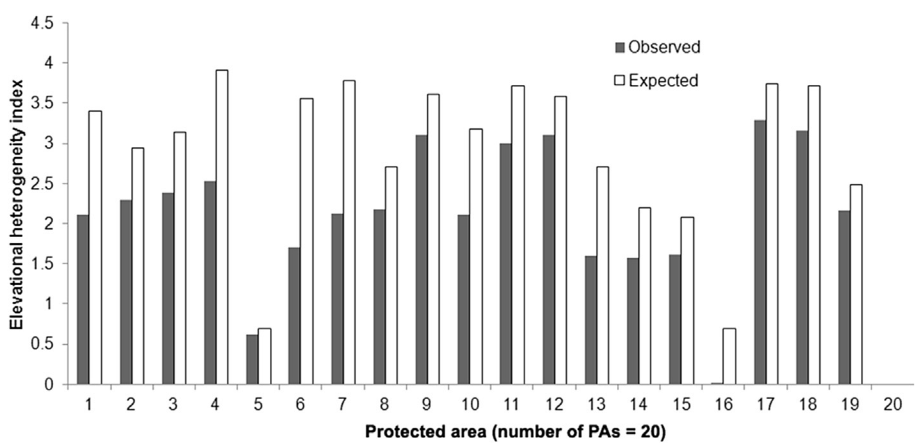

Fig. 4. Observed and expected elevational heterogeneity index of Nepal's protected areas. Expected heterogeneity index was calculated assuming that elevational zones are of same size.

countries, such as Nepal, with highly heterogeneous landscapes in terms of elevation. In such places, PAs are expected to contain heterogeneous landscapes with respect to their areas, but according to our results, this does not hold true for Nepal. Although PAs locating at lower and middle elevations had heterogeneous elevational zones relative to their areas (Fig. 3), those at higher elevations were less heterogeneous, and the conservation index of elevational zones shows a strong bias of reserves at high elevations (Fig. 5), as described in older work (e.g. Hunter & Yonzon, 1993; Shrestha, Shrestha, Chaudhary, & Chaudhary, 2010). This is in spite of many additional PAs created in Nepal, and others extended in area, over the past several decades (e.g., Heinen & Shrestha, 2006). This is also in agreement with several national studies that have shown that PAs are disproportionately at high elevations on unproductive lands in many countries (Heinen, 2012; Joppa & Pfaff, 2009; Oldfield, Smith, Harrop, & Leader-Williams, 2004; Scott et al., 2001).

Two of the most heterogeneous PAs relative to their sizes (Rara NP—106 km^2 and Khaptad NP—225 km^2) are situated in the middle mountains, but they are very small (average size 165 km^2)

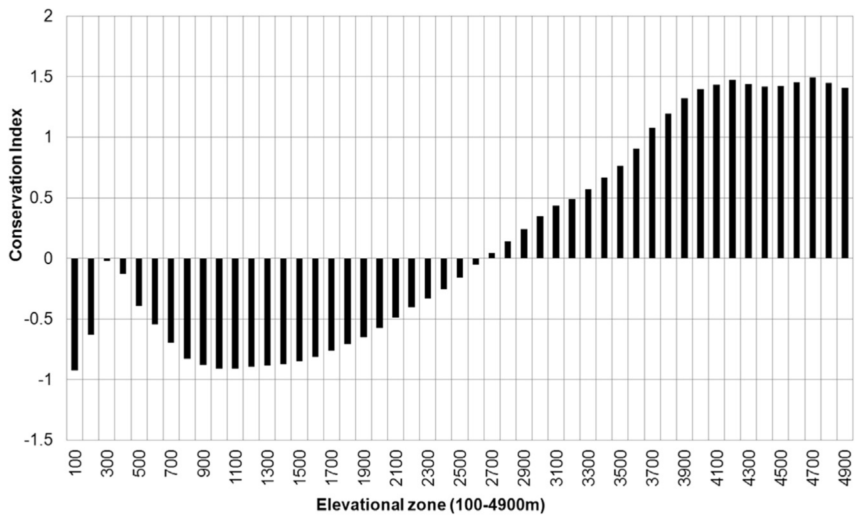

Fig. 5. Conservation index for Nepal's elevational zones.

compared to the national average (1429 km^2). The middle mountains are poorly represented in the PA system despite having the highest ecosystem diversity in the country (Hunter & Yonzon, 1993). Here we show that large PAs (>1429 km^2) tend to have small heterogeneity indices ($R^2 = -0.13$). Among the 20 PAs of Nepal, categories II and IV PAs (national parks and wildlife reserves) are smaller in size than category VI PAs (conservation areas). It is worth noting that category II PAs also receive more management efforts and are more strictly protected; thus they may be differentially important for conservation.

Our results also show that, PAs are far less heterogeneous than the country as a whole, despite covering nearly 20% of its land area. No protocol of which we are aware focuses on elevational gradients as a component of reserve planning. However, in some parts of the Andes, corridors along elevational gradients have been proposed to provide potential corridors for climate-induced displacement of species (Killeen & Solórzano, 2008). We suggest that the focus should be directed toward the inclusion of landscapes that are as heterogeneous as possible in reserve design, rather than establishing elevational corridors between isolated PAs. This is analogous to the SLOSS debate (a single large or several small conservation areas) debate of older conservation literature (e.g. Baz & Garcia-Boyero, 1996; Higgs, 1981). A large body of recent literature shows strong support for conservation at very large scales in a number of different contexts (Edward, May, & Webb, 1994; Hole et al., 2011).

In some studies, the functional relationships between elevational heterogeneity and species diversity are also reported to be negative, unimodal or flat, depending on the species and the spatiotemporal scale of the analysis (see Tews et al., 2004 for review). Kadmon and Allouche (2007) and Allouche et al. (2012) have argued that increasing heterogeneity may limit dispersal abilities of species because of a reduction in suitable habitat. However, studies have shown that as available area increases, negative effects of heterogeneity diminish, which indicates positive relationships between species richness and heterogeneity (Allouche et al., 2012).

Jones et al. (2013) highlights some key aspects of landscape planning for sustainable ecosystem services. This approach requires detailed analyses of landscape pattern gradients and their relationships with ecosystems to derive adaptive management plans. We would argue that such an approach is possible when the landscape under investigation is known for biodiversity. However, Himalayan biodiversity is, in some ways, *terra incognita*. If the ultimate goal is to sustain multiple ecosystems especially under conditions of climate change, conservation planners must seek strategies to incorporate more heterogeneous landscapes as a surrogate for conservation of multiple aspects of biodiversity.

Implications for conservation

Designing reserves in such a way that would successfully protect biodiversity is a central part of conservation planning. Generally, size, shape and configuration are the most important aspects of reserve design (see Laurance & Bierregaard, 1997; McCarthy, Thompson, Moore, & Possingham, 2011; Reed, 1983; Schelhas & Greenberg, 1996; Shafer, 1990). These aspects have traditionally been tailored based on the particular species or ecosystems of concern. However, many studies suggest that even well planned conservation targeting multiple species (e.g., umbrella and/or keystone species) and ecosystems often fails to protect less conspicuous but critically important biodiversity (Roberge & Angelstam, 2004). It is now important to ask: what should be done next in Nepal?

Although the PA system of Nepal covers about 20% of its land area, conservation of Himalayan biodiversity in the face of climate change remains a formidable challenge. Past conservation approaches were driven by the need to conserve habitat for charismatic flagship species such as Bengal tiger (*Panthera tigris. tigris*), one-horned rhinoceros (*Rhinoceros unicornis*), Asiatic elephant (*Elephas maximus*) and snow leopard (*Uncia uncia*; Heinen & Yonzon, 1994). Reserve designs targeting endangered species are reasonable for the short term given burgeoning anthropogenic threats (Brooks et al., 2006). But there is a growing consensus that conservation of heterogeneous habitats over large areas is the prerequisite for the long-term conservation of species and ecosystems (Krosby, Tewksbury, Haddad, & Hoekstra, 2010). Our results indicate that the bias of PAs toward high elevations still persists in spite of a much larger PA system, and, furthermore, that many PAs incorporate relatively homogeneous landscapes. Consequently, many species previously distributed throughout wide elevational zones are now confined to much smaller ranges, mainly within the PAs of high mountainous regions (e.g., Paudel & Kindlmann, 2012). Similarly, the synergetic impact of climate change (e.g., habitat shifts) and habitat loss and fragmentation will affect persistence of many flora and fauna. The Nepalese Himalayan region is warming and its mean annual temperature increased by

0.6 °C per decade during period between 1977 and 2000 (Shrestha, Wake, Mayewski, & Dibb, 1999). Various climate model projections for Himalaya suggest temperature increases of 2.0–3.2 °C by the 2050s and 2.6–3.5 °C by the 2080s (Shrestha & Devkota, 2010). Montane species and ecosystems are among the most vulnerable to climate change due their geographical isolation, limited range, and highly specific environmental adaptations (Cruz et al., 2007; La Sorte & Jetz, 2010). This is true for the Nepal Himalaya. Forrest et al. (2012) predict that about 30% of snow leopard habitat in the Himalaya may be lost due to a shifting tree line and shrinking of the alpine zone. Similarly, serow *Capricornis thar* and Himalayan tahr *Hemitragus jemlahicus*, for example, that have been extirpated from many intermediate elevational zones (Green, 1979; Paudel & Kindlmann, 2012) might be unlikely to persist under climate change. Most importantly, trends in new species discoveries from Himalaya (22 species per year during 1998–2008) suggest that there are many additional species – particularly of amphibians, reptiles, fish, invertebrates and plants – that have not yet been described by science (Thompson, 2009). Therefore, large PAs encompassing large elevational gradients would be more likely to encapsulate less conspicuous, still unknown and climate sensitive species.

Heterogeneity-based reserve selection is a novel approach that could assist in making a rapid conservation decisions. Therefore, we provide some key recommendations for redesigning conservation priorities in Nepal. (1) A large heterogeneous landscape chosen either while designing new PAs or expanding existing ones, especially in the middle hills of Nepal. (2) Interconnectedness of lowland and upland areas of the of Himalaya is necessary to improve altitudinal connectivity for seasonal migrations of fauna (Paudel et al., 2012) and therefore elevational heterogeneity must be taken into account in corridor design. Nepal is extreme in terms of the extent of elevational gradients, but none-the-less an example of many other mountainous regions at lower latitudes. Results of this study thus have broad implications.

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