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DOI:10.1016/j.ancene.2014.05.004

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Abstract
High altitude Himalayan regions are geo-dynamically active and sensitive to natural disturbances. Nonetheless, even in this remote region, human pressure is often most important in influencing forest and landscape structure. In the last decades, fuelwood demand has risen due to increasing numbers of tourists and mountaineers. To understand human interactions with forest resources, stand structure and composition were examined at the landscape scale in the Sagarmatha National Park and its Buffer Zone in the Khumbu valley (Nepal). Using biological and historical data sources, a multi-scale approach revealed the influence of human activities on the distribution of tree species and forest structure. We sampled stand structure and environmental characteristics from 173 plots, and derived anthropogenic variables from thematic maps and satellite images for multivariate statistical analyses. Results suggest relationships among forest structure, anthropogenic influences, and topography. Low-density stands (100-150 tph) with sparse trees and rare big trees were in close proximity (0 – 36 m) to tracks and lodges. The wide variability in species diversity (0.67 at SNP and 0.58 at BZ) was strongly related to environmental factors, such as elevation, and human pressure. The frequent removal of green branches has adverse effects on tree growth, forest resistance, resilience, and regeneration capacity. We conclude that natural resources can adequately supply the local population needs, but current practices are not sustainable.

Keywords
Historical ecology; Soil erosion; Sustainability; Landscape change; Forest structure; Sagarmatha National Park

1. Introduction

Mountain landscapes are highly sensitive to natural hazards and disturbances due to their harsh geophysical characteristics and severe climatic conditions (Beniston, 2003). Their topographic complexity generates sharp gradients and abrupt climatic changes, in particular temperature and precipitation, over very short distances (Bugmann, 2001). The physical template (climate and topography) is commonly considered a principal factor in affecting vegetation structure and dynamics (Stephenson, 1990; Urban et al., 2000). Human influences play a major role, however, in shaping the structure of forest stands and landscapes even in remote mountain areas of the world.
Environmental fragility and seasonality of human activities, such as tourism, make mountain areas in developing regions particularly vulnerable to human-induced impacts (e.g. soil and vegetation trampling, disturbance to native wildlife, waste dumping) (Brohman, 1996). Tourism in mountain areas has increased in the last decades (Price, 1992) and is becoming a critical environmental issue in

many developing countries (Geneletti and Dawa, 2009). This is particularly evident in Nepal, where increased pressures of tourism-related activities on forest resources and the biodiversity of alpine shrub vegetation has already been documented (Stevens, 2003). Sagarmatha National Park and its Buffer Zone (SNPBZ), a World Heritage Site inhabited by the Sherpa ethnic group and located in the Khumbu valley (Stevens, 2003), provides an example.
The Himalaya region, which also includes the Sagarmatha (Mt. Everest), has been identified as a globally important area for biodiversity (Olson et al., 2001) and is one of the world's 34 biodiversity hotspots (Courchamp, 2013). Over the past 50 years, the Sagarmatha region has become a premier international mountaineering and trekking destination. Related activities have caused adverse impacts on regional forests and alpine vegetation (Bjønness, 1980; Stevens, 2003), with over exploitation of alpine shrubs and woody vegetation, overgrazing, accelerated slope erosion, and uncontrolled lodge building (Byers, 2005). Large areas surrounding the main permanent settlements in the region are extensively deforested, with *Pinus wallichiana* plantations partly replacing natural forests (Buffa et al., 1998).

Despite the importance of the Sagarmatha region, few studies have examined sustainable management and environmental conservation of its fragile ecosystems, where ecological and socio-economic issues are strongly linked (Byers, 2005). The lack of knowledge about forest structure and composition, as well as human impact on the ecosystems, has frequently limited the implementation of sustainable management plans (MFSC, 2007; Rijal and Meilby, 2012). This study gathered quantitative data on forest resources and assessed the influences of human activities at Sagarmatha National Park (SNP) and its Buffer Zone (BZ). Using a multi-scale approach, we analyzed relationships among ecological, historical, topographic and anthropogenic variables to reveal the effects of human pressures on forest structure and composition. Specifically, we hypothesized that: (1) tourism and other human activities cause a reduction in diversity of both forest stand structures and tree species composition; (2) topographic constraints such as elevation play a fundamental role in shaping forest structure; (3) the establishment of a protected area such as the SNP has an important role for the conservation of forest resources in the Khumbu valley.
The results of this analysis enable a new assessment of possible management options for sustainability in fragile ecosystems in this area and elsewhere in the world.

2. Methods

2.1. Study area

This study encompassed both the core area (SNP) and buffer zone (BZ) of the National Park. Elevation of the study area ranges from 2300 m a.s.l. to 8848 m a.s.l. (Mt. Everest peak). The topography features very steep slopes and deeply incised valleys. The climate is strongly influenced by the summer monsoon regime with 70-80% of precipitation occurring between June and September (Salerno et al., 2010). Winters are generally cold and dry, while summers are cool and wet. The SNP extends for 1148 km2, with rocks, glaciers, and tundra vegetation covering 69% of the total surface area (Bajracharya et al., 2010). Pastures (28%) and forests (3%) dominate the remaining area. Six vegetation zones occur along an altitudinal gradient: 1) lower subalpine forests (3000-3600 m a.s.l.) dominated by Pinus wallichiana, Abies spectabilis and Juniperus recurva; 2) upper subalpine forests (3600-3800 m a.s.l.) dominated by Betula utilis, Abies spectabilis and Rhododendron spp.; 3) lower alpine shrublands (3800-4500 m a.s.l.) dominated by Juniperus spp. and Rhododendron spp.; 4) upper alpine meadows (4500-5500 m a.s.l.); 5) sub-nival zone (5500-6000 m a.s.l.); 6) nival zone (above 6000 m a.s.l.).

Human interactions in the Khumbu region began ~ 500 years ago when Sherpa people migrated from Tibet (Byers, 2005). For five centuries, they extensively applied irregular forest thinning on southern slopes, reducing the stem density by removing small and easily harvestable trees to obtain firewood, timber and to increase pasture areas (Stevens, 1993). A common properties system and the presence of Sherpa field guards ensured a sustainable use of forest resources (Byers, 2005). The Private Forest Nationalization Act in 1957, however, together with increased tourism and local population in the period 1950-1980, caused significant land use changes due to the growing demand for timber and firewood (Byers, 1997; Byers, 2005). In the last thirty years, the number of tourists has increased further, but its impact on the SNP forest landscape is still not clear. Socio-economic, anthropological and geographic studies reported "widespread deforestation" caused by human pressure in the Sagarmatha region (e.g. Bjønness, 1980; Garratt, 1981; Hinrichsen et al., 1983; von Fürer-Haimendorf, 1984). More recent studies (Stevens, 2003; Byers, 2005) have reported different conclusions. With the establishment of the Sagarmatha National Park in 1976, whole tree felling inside the Park was prohibited. Massive green branch removal and damage to trees can still be observed, however, (Fig. 2) since the removal of deadwood is allowed. Currently, nine permanent villages and more than a hundred secondary and herding settlements are present in the Park (Stevens, 2013), with 6221 local residents and 1892 head of livestock (Salerno et al., 2010).

2.2. Sampling design

We collected data on forest structure and species composition in 173 sample plots during two field campaigns in 2010 and 2011. The plots were randomly distributed within the forest areas in a GIS and then mapped in the field. To detect forest areas, we used a land cover map obtained from a classification of a Terra Aster satellite image taken in February 2006 (Bajracharya et al., 2010). We then used square plots of 20x20 m for the tree (Diameter at the Breast Height - DBH ≥ 5 cm) layer survey, and square subplots of 5x5 m were randomly located within the tree plot for the regeneration (DBH < 5 cm and height > 10 cm) and shrub layers.

2.3. Data collection

For all trees, we recorded species, total height, DBH, and species and density for regeneration and shrubs. The following stand descriptors were computed for each survey plot to be used in the analyses: tree density, basal area, average DBH, maximum DBH, tree diameter diversity index (Marzano et al., 2012; Rouvinen and Kuuluvainen, 2005), and Shannon species diversity index (Table 2).

Topographic variables such as elevation, slope, and heat-load index were derived from the NASA/METI ASTER Global Terrain Model, with a geometric resolution of 30 m and vertical root mean square error (RMSE) of about 9 m. We calculated heat-load index (McCune and Keon, 2002) in a GIS and used it as a proxy variable for solar radiation. Anthropogenic variables (forest proximity to buildings, trails, and tourist lodges) were derived from thematic maps (Bajracharya et al., 2010) and computed using horizontal-Euclidean distance, slope distance and accessibility time, in order to assess possible effects of topographic features. Accessibility time was estimated by dividing the DEM-computed slope distance by the average walking speed (Tobler, 1993). These data allowed estimation of the effect of forest, understory vegetation, and terrain roughness in reducing off-trail walking speed for wood gathering.

2.4. Data analyses

We gathered summary statistics on tourism activities and fuelwood consumption from previous studies on the Khumbu valley (Salerno et al., 2010) for multivariate statistical analyses. These tests examined the relationships among environmental variables (topographic and anthropogenic) and forest structure and species composition. Three data sets were central for ordination analyses: (i) forest structure (6 variables×167 plots); (ii) species composition (22 species×173 plots); (iii) environmental variables (12 variables×173 plots). For forest structure, we considered 167 out of 173 plots after removing outliers using a standard deviation cutoff of 2.0. For analysis of species composition, we used 22 species out of 27 after excluding rare species. We then used Principal Component Analysis (PCA) to assess the correlation of environmental variables with the underlying gradients of stand structure (PCA axes). With a Canonical Correspondence Analysis (CCA), we explored the importance of topographic and anthropogenic underlying gradients in determining tree species composition. PCA and CCA multivariate analyses as well as the outlier analysis were run with PC-ORD 6 statistical package (McCune and Mefford, 1999). The Monte Carlo permutation method tested the statistical significance of ordination analyses based on 10,000 runs with randomized data.

3. Results

3.1. Human pressures

Trekking activities and expeditions to Mt. Everest have a relevant impact on the Khumbu valley environment. Annual visitors to this region increased dramatically from 1950, when Nepal opened its borders to the rest of the World. The number of recorded trekkers was less than 1400 in 1972-73, and increased to 7492 in 1989. Despite a significant decrease (13786 in 2002) recorded during the civil war between 2001 and 2006, the trekkers increased to more than 36000 in 2012 (Fig. 3). The increase in visitors has directly affected the forest cover because of the higher demand for firewood. One of the most important energy sources in the SNP is firewood: kerosene accounts for 33%, firewood 30%, dung 19%, liquefied petroleum gas 7% and renewable energies only 11% (Salerno et al., 2010). Furthermore, firewood is the main fuel for cooking (1480-1880 Kg/person/year), with *Quercus semecarpifolia*, *Rhododendron arboreum* and *Pinus wallichiana* being among the most exploited species (NAST, 2010).

3.2. Forest structure

A comparison between the SNP and its BZ revealed that tree density, species and structural (TDD) diversity are higher within the protected area (Table 3). BZ has a larger mean basal area and diameter, but the biggest trees (Dbh_max) are located in SNP.

A PCA biplot of the first two components (PC1 and PC2) showed that denser and more diverse stands were located farther from buildings and at higher elevations (Fig. 4). The perpendicular position of basal area, TDD, and Dbh_max vectors related to elevation and distance from buildings, indicated that living biomass and structural diversity variables were uncorrelated to environmental variables. Elevation was negatively correlated with average tree size (Dbh_av). The first component (PC1) accounted for 42.81% of the total variation and was related to basal area, tree diameter diversity and maximum diameter. The second component (PC2) accounted for 22.60% of the total variation and was related to tree density and species diversity (Table 4).

3.3. Species composition

We recorded twenty-seven woody species representing 19 genera in the whole study area: 20 species in SNP and 22 in BZ. *Abies spectabilis* and *Betula utilis* are dominant in most of the forests within the Park (78%, BA), but *Rhododendron campylocarpum* is also common among shrub species (7.6%, BA). In the BZ the dominant species is *Pinus wallichiana* (44%, BA), whereas *Abies spectabilis*, *Quercus semecarpifolia*, *Rhododendron arboreum* and *Tsuga dumosa* together reach 41% of the total basal area (Table 5).

The Canonical Correspondence Analysis (CCA) for direct gradient analysis (Fig. 5) revealed interactions among tree species composition, human activities and topography. The first axis (eigenvalue = 0.789) expressed an elevation gradient where upper subalpine forest species were clearly separated from the lower subalpine ones. The second axis (eigenvalue = 0.147) expressed a gradient of slope steepness and distance from buildings and lodges (Table 6). Along this gradient, a group of *Rhododendron* species appeared clearly distinct from the other species. In particular, *Rhododendron arboreum* and *Rhododendron campanulatum* were present only in less accessible sites with steep slopes and located far from human infrastructures.

4. Discussion

4.1 Forest structure and composition

The forests of SNP are denser and more diverse than those located in the BZ, where the prolonged and intensive thinning has altered the forest structure and composition. After the institution of the SNP (1979) the increasing demand for firewood was supplied by logging in external areas very close to the park borders (Stevens, 2003). The Pharak region included in the BZ was heavily logged due to a lack of harvesting regulations. The higher mean basal area and tree size in the BZ could be a consequence of felling practices applied by local populations. Illegal logging, especially of small trees, could be one of the main causes of the lower diversity and density in the Pharak forests.

With regard to the influence of environmental variables on forest structure, we found that less dense and poorer stands are located in close proximity to human constructions (mainly tourist lodges). Human impact in this area consists largely of severe forest degradation, due to the overexploitation of small trees from the most accessible sites. Preferred logging sites, both for timber and fuelwood, are located uphill of the Sherpa villages since wood removal downhill is easier (Stevens, 2003). Similar processes were found in the Sikkim region of India (Chettri et al., 2002), where the best-conserved forests were confined to steeper slopes and far from tourist settlements.

The negative relationship of average tree size and species diversity with elevation confirmed that in mountain regions anthropogenic pressure is generally more important at lower altitude and on more accessible sites (Garbarino et al., 2013; Castagneri et al., 2010).

The higher tree species richness found in BZ forests is probably due to their lower elevation, but the environmental trend revealed by the direct gradient analysis is common to both SNP and BZ. Rhododendron species (*R. arboreum*, *R. barbatum, R. campylocarpum, R. campanulatum*) are more abundant on less accessible sites with steeper slope and far from human infrastructures. These findings seem to confirm that local people tend to harvest small rhododendron trees, which are easily exploitable as firewood (Stevens, 2003; Byers, 2005).

4.2 Effects of human activities on forest degradation

Human pressure on forests, caused by population growth, diffused poverty and lack of alternatives, is increasing, leading to extensive forest degradation and deforestation (Rijal and Meilby, 2012). Salerno et al. (2010) assessed an average decrease of 38% in forest biomass between 1992 and 2008 in the Khumbu Valley. Nonetheless, the development of sustainable management plans, taking into account both ecological and socio-economic issues, is often limited by the lack of knowledge on forest structure and of awareness about human impact on the ecosystem (Rijal and Meilby, 2012).

The measured effects of forest exploitation on stand structure and tree species composition confirmed the recent hypothesis that forest degradation has a stronger impact than deforestation in SNPBZ (Stevens, 2003; Byers, 2005). Trekking tourism is still increasing in the SNP and is seriously affecting the Sherpas traditional use of natural resources (Byers, 2009; Spoon, 2011). Forest degradation and shrub removal (especially *Juniperus wallichiana*) are the more evident effects of this socio-cultural change. A land cover change analysis recently performed in the area (Bajracharya et al., 2010) revealed that between 1992 and 2006 the most significant shifts were the reduction of mixed forest cover, together with an increase of dwarf shrubs at 3000-4000 m a.s.l. and a reduction of shrubland at higher elevations (4000-5000 m a.s.l.). The overall change in forest and shrub communities was negligible (-4% and -9% respectively) compared to the relevant increase (47%) of dwarf shrubs at 3000-4000 m a.s.l.

Prior to 1950, the Sherpa people extensively clearcut woodlands and converted them into pastures and villages. Land use/cover change is a further driver of erosion risk in Himalaya, a region characterized by heavy rainfalls (Valdiya and Bartarya, 1989; Rawat and Rawat, 1994; Tiwari, 2000). Soil erosion and mass movement are often related to human activities such as deforestation, overgrazing and building construction in vulnerable sites (Shresta et al., 2004), but natural disturbances can sometimes override human influence (Bruijnzeel and Bremmer, 1989; Messerli and Hofer, 1992).

In the last decades excessive tree felling without any silvicultural rationale, became the most common forest practice and is still widespread. The prohibition to log living trees inside the national park has caused the increasing removal of green limbs and branches (especially of *P. wallichiana*) causing severe mechanical damage and growth and survival limitations to the trees (Gautam, 2001; Gautam and Watanabe, 2002; Bhat et al., 2000; Pandey and Shukla, 2001). In addition, since the removal of deadwood is still allowed within the park, stems are often purposely injured in order to hasten their death.

Firewood and dried manure are still the most important energy sources (49%) in the SNPBZ, mainly for cooking and heating (Salerno et al., 2010). Demand increased exponentially with the number of tourists, worsening the existing heavy pressure on forest resources. Similar processes have been observed in other Himalayan regions of India (Awasthi et al., 2003; Chettri et al., 2002), and Bhutan (Brunet et al., 2001).

The tourism boost at SNPBZ also affected the size and composition of livestock herds (Padoa-Schioppa and Baietto, 2008). Together with the traditional yak, Sherpas started to breed more Zopkyos (a yak/cow hybrid), widely used as a pack animal for trekkers and mountaineers (Stevens, 2003). The increased number of Zopkyos intensified pressure on forest regeneration and grasslands by overgrazing, mainly in the lower valleys and near villages and trekking routes. Forest grazing has been practiced in rural areas of Nepal for a long time and is currently identified as one of the most important factors of forest degradation (MFSC, 1988; UNCED, 1992; Tamrakar, 2003). Livestock trampling reduces the porosity of the soil and hampers plant establishment and growth, exposing the soil to an increasing risk of erosion and landslides (Ghimire et al., 2013).

4.3 Sustainable forest management

In the SNPBZ, the current use of forest-related resources and its effects on forests have been strongly affected by the lack of strategic management plans. Forest exploitation thus appears to be largely unsustainable and urgently needs to be regulated. After two decades of forest biomass decline, immediate restoration actions should be applied to increase forest resilience and eventually move toward sustainability. Sustainable harvesting of forest products has several ecological but also socio-economic implications, strictly related to local wood extraction and management practices, and population needs (Cunningham, 2001; Ticktin, 2004). Defining sustainable management practices implies the understanding of plant and forest ecology within the local socio-economic context and use of wood products (Rijal and Meilby, 2012). A good example of sustainable management that resulted in a reduction of wood extraction is the Annapurna Conservation Area, where a community-based forest conservation approach was introduced (Bajracharia et al., 2005; Bajracharia et al., 2006). To avoid depleting the current growing stock of the SNPBZ forests, 75% of the fuelwood should be replaced by alternative energy sources (Salerno et al., 2010). International research projects aimed at promoting the use of solar panels, small wind and hydropower plants, and waste management are ongoing (Manfredi et al., 2010; Sapkota et al., 2010). The use of adaptive silvicultural practices calibrated for improving local quality of life without degrading the forests (Carter, 1996; Malla, 1997; Stræde et al., 2002) could be a first step toward the development of effective management plans that could positively affect the sustainability of forest exploitation. Sustainable forest management should necessarily be based on the application of an appropriate silviculture. Among the goals of efficient management, guaranteeing tree recruitment should be prominent. Wherever grazing proves to be a major limiting factor for seedling survival, livestock should be banned from some regeneration areas in the forest. Reafforestation projects, establishing or expanding local nurseries for the production of high quality seeds and seedlings of native species (NAST 2010), could also be promoted with the aim of increasing the forest cover. To thoroughly assess all these issues, further field-based research investigating the interaction between vegetation and environmental factors, as modified by anthropogenic interference, is highly recommended. The establishment of permanent research plots for long-term monitoring of the effects of environmental and human-induced factors on silvo-pastoral systems should be strongly encouraged, taking into account the possible impacts of the on-going climate change in the area (NAST, 2010; Nepal, 2013; McDowell et al., 2013).

5. Conclusions

Sustainable forest management of national parks with increasing human pressure from tourism activities is currently a real challenge for land managers and scientists. In these protected areas the simplification of the forest structure is often more important than deforestation. This reduction of structural diversity, often called forest degradation, is in fact less obvious than deforestation, and for this reason more difficult to detect and manage. Research studies on the main causes and impacts of forest overexploitation should be promoted in other sensitive areas in order to contribute to increasing forest resilience and reversing the process of environmental degradation.

Forest degradation at Sagarmatha National Park has mostly resulted from the intensive thinning and overexploitation of small size rhododendron trees from the most accessible sites. Increased trekking tourism intensified shrub removal (especially *Juniperus wallichiana*) and exploitation for firewood, but the establishment of the SNP in 1976 delocalized human pressure to the Pharak forests that recently (2002) became the Buffer Zone of the SNP. In the absence of a sustainable land use policy tourism can be a major driver of forest degradation. This issue is observed globally in many other protected areas where trekking tourism is responsible for socio-cultural changes that indirectly affect the traditional use of natural resources. Nowadays unregulated logging is one of the main causes of the lower diversity and density measured in the BZ, the current use of forest-related resources thus appears largely unsustainable and needs to be planned. A sustainable management of forest resources at SNP is imperative and should integrate different management actions (e.g. reafforestation projects, adaptive silvicultural practices and regulating livestock grazing), at the same time implementing a greater use of alternative energy sources.

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Sites	Total area (ha)	Forested Area (ha)	Plots (n)	Analyzed area (ha)	Elevation mean (m a.s.l.)	Elevation range (m a.s.l.)	Slope mean (°)
SNP	113148	2627	103	41	3748	2881-4358	51.34
BZ	28065	6689	70	28	2754	2262-3705	58.89
Total	141213	9316	173	69	3363	2262-4358	54.27

Table 1. Summary statistics and characteristics of the two study sites. Total area is the total site surface; analyzed area is the portion of surveyed terrain for the forest structure analyses, and forested area is the total forest surface classified from a Terra Aster satellite image (Bajracharya et al., 2010). Elevation and slope values refer to field plots characteristics.

Variable category	Code	Description	Unit	Data source
Forest structure	BA	Basal Area	m^2/ha	Field
	Dbh_av	Average diameter at the breast high (1.3m)	cm	Field
	Dbh_max	Maximum diameter at the breast high (1.3m)	cm	Field
	De	Tree density	$\#ha^{-1}$	Field
	Diversity	Shannon index applied to tree species	-	Field
	TDD	Shannon index applied to tree diameters	-	Field
Environment	Elevation	Elevation	m a.s.l.	DTM
	Slope	Slope	°	DTM
	Hea	Heat load index	-	DTM
	Build_E	Euclidean distance from buildings	m	DTM
	Build_R	Slope distance from buildings	m	DTM
	Build_T	Accessibility time from buildings	s	DTM
	Road_E	Euclidean distance from roads and trails	m	DTM
	Road_R	Slope distance from roads and trails	m	DTM
	Road_T	Accessibility time from roads and trails	s	DTM
	Tour_E	Euclidean distance from touristic lodges	m	DTM
	Tour_R	Slope distance from touristic lodges	m	DTM
	Tour_T	Accessibility time from touristic lodges	s	DTM

Table 2. Environmental and forest structure variables included in the ordination analyses.

Descriptors	SNP		BZ	
BA (m^2/ha)	10.61	*5.92*	16.27	*10.37*
Dbh_av (cm)	16.67	*7.38*	23.61	*6.38*
Dbh_max (cm)	47.94	*20.89*	41.41	*14.11*
De (n/ha)	1172.33	*1118.11*	304.48	*123.70*
Div	0.67	*0.34*	0.58	*0.52*
TDD	1.55	*0.32*	1.42	*0.32*

Table 3. Mean values and standard deviations (in *italics*) of the 6 stand structure descriptors collected in 173 field plots at Sagarmatha National Park (SNP) and its Buffer Zone (BZ).

	PC1	PC2
BA	**0.518**	-0.131
Dbh_av	**0.517**	0.329
TDD	**0.444**	-0.259
Dbh_max	**0.414**	**-0.437**
Div	-0.085	**-0.627**
De	-0.297	**-0.473**
Eigenvalue	*2.569*	*1.356*
% Var	*42.812*	*22.597*
Cum % Var	*42.812*	*65.409*
p	*0.0001*	*0.0001*

Table 4. Principal Component loadings for the first two principal components for the SNP and BZ study area. Loadings greater than 0.4 are indicated in bold.

Site	Abi.spe	Bet.uti	Rho.cam	Jun.rec	Pin.wal	Lyo.ova	Que.sem	Rho.arb	Tsu.dum	Other species
SNP	42.2	35.8	7.6	3.1	2.0	0.7	1.3	0.4	0.2	6.8
	(1.43)	(1.27)	(0.42)	(0.16)	(0.08)	(0.04)	(0.09)	(0.15)	(0.86)	(0.01)
BZ	7.5	0.0	0.0	0.0	43.9	3.8	11.8	12.4	9.5	11.0
	(0.30)	(0.00)	(0.00)	(0.46)	(1.72)	(0.67)	(1.06)	(0.00)	(0.00)	(0.60)

Table 5. Percentage basal area and Importance Value index (in parentheses) of dominant tree species at Sagarmatha National Park (SNP) and its Buffer Zone (BZ) plots. Abi.spe=*Abies spectabilis*; Bet.uti=*Betula utilis*; Rho.cam=*Rhododendron campylocarpum*; Jun.rec=*Juniperus recurva*; Pin.wal=*Pinus wallichiana*; Lyo.ova=*Lyonia ovalifolia*; Que.sem=*Quercus semecarpifolia*; Rho.arb=*Rhododendron arboreum*; Tsu.dum=*Tsuga dumosa*.

	CCA1	CCA2	CCA3
Eigenvalue	0.789	0.147	0.115
% var in species data	10.90	2.00	1.60
Cum % var in species data	10.90	13.00	14.60
Species-Env Pearson correlation	0.93	0.48	0.46

Table 6. Axis summary statistics for 3 canonical axes in the Canonical Correspondence Analysis. The Total variance ("inertia") in the species data is 7.213 and the p value for CCA1 is 0.0001.

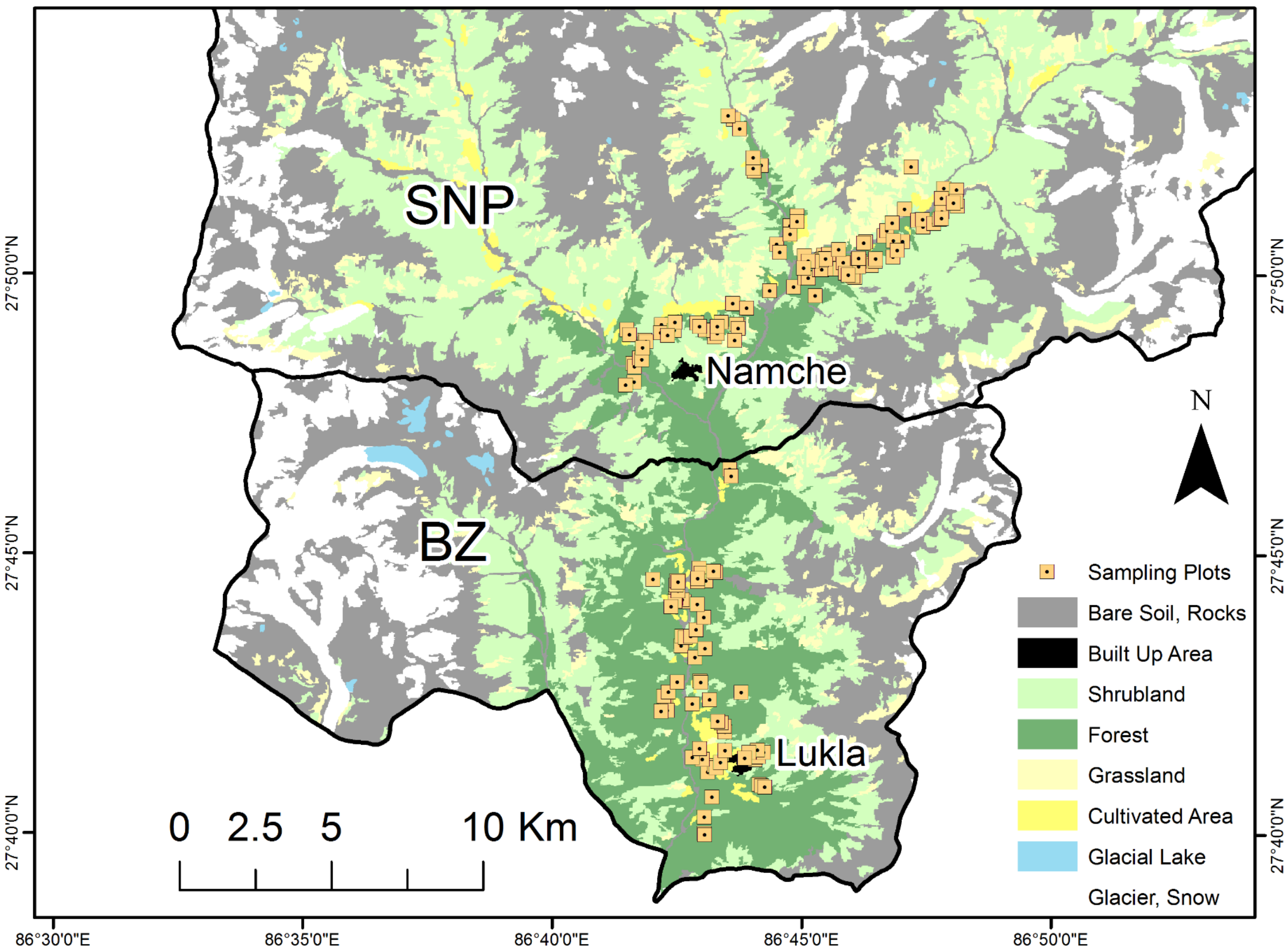

Figure 1. Land cover map of Khumbu valley divided by site (Sagarmatha National Park – SNP, and Buffer Zone - BZ) derived from satellite images (Bayracharia et al., 2010). 173 temporary field plots (red dots) were randomly located within the "forest" land cover category.

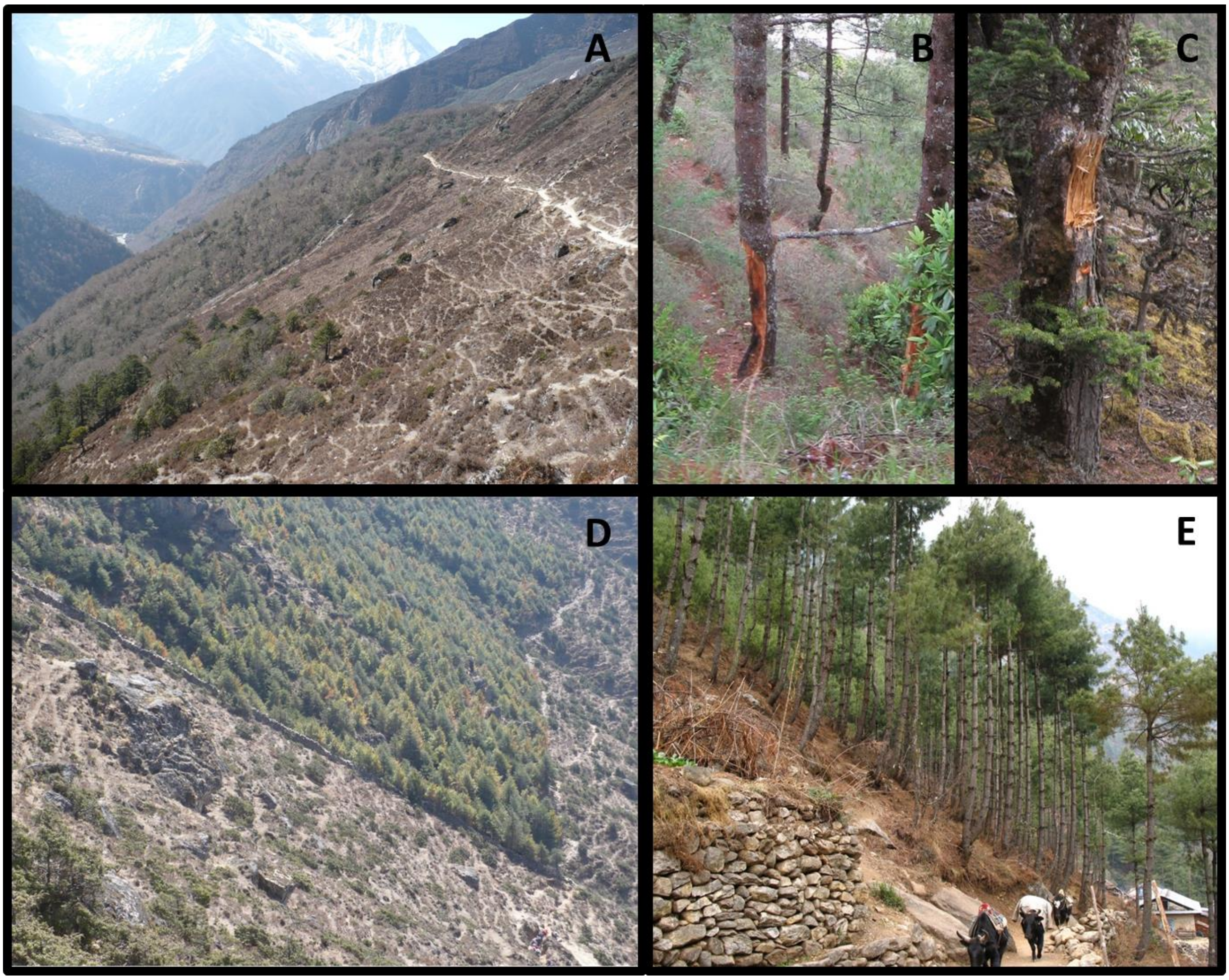

Figure 2. Visible effects of human pressure within the SNP: soil erosion by overgrazing (a), damage to tree stems (b, c), deforestation and overgrazing (d), pruning of *P. wallichiana* green branches (e).

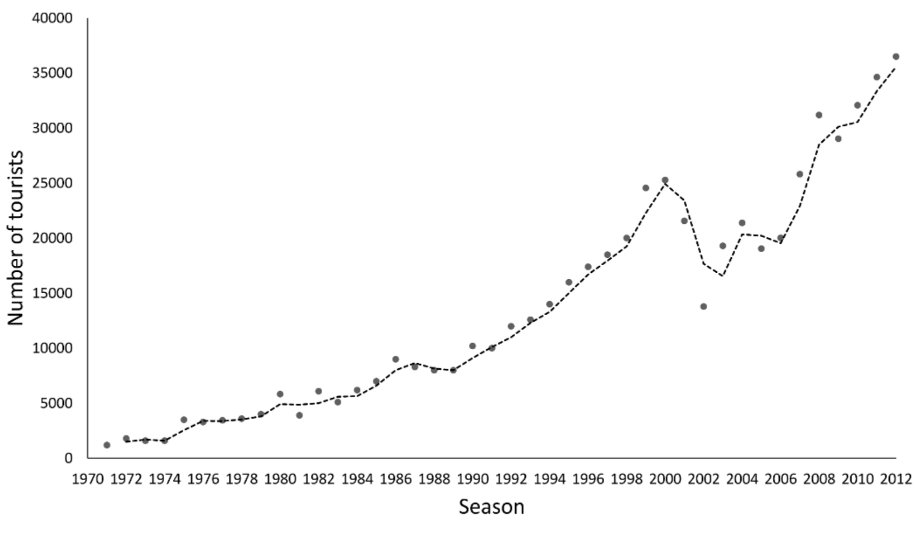

Figure 3. Annual recorded tourists at SNP: data for the 1971-2002 period were taken from Stevens (2003). Statistics for the period 2003-2007 were taken from the Park gates at Monjo (SNP) and for the period 2008-2012 from the Ministry of Culture, Tourism & Civil Aviation (2013). A moving average trend dashed line is superimposed on the seasonal data to aid interpretation of the graph.

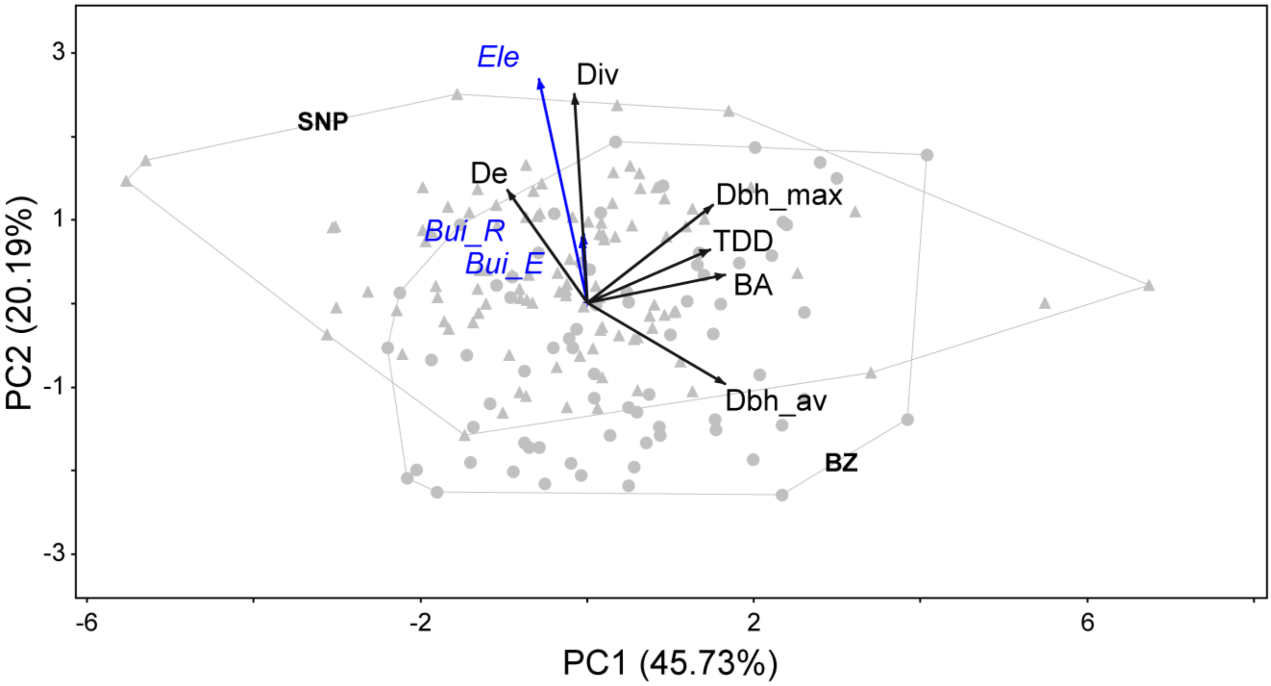

Figure 4. Principal Component Analysis of stand structure in relation to environmental variables of 173 field plots surveyed at Sagarmatha National Park (SNP) and its Buffer Zone (BZ). Black line arrows represent stand structure descriptors (De=tree density per ha; Div=Shannon diversity on tree species; Dbh_av=mean Dbh; Dbh_max=maximum Dbh; TDD=Shannon diversity on tree diameter; BA=basal area). Blue line arrows represent environmental variables (Ele=elevation; Bui_E=Euclidean distance from buildings; Bui_R=slope distance from buildings). Grey dots are sampled plots (triangles: SNP; circles: BZ). Grey polylines are convex hulls indicating the maximum surface area occupied by plots belonging to the same site. The first and second principal component were significant ($p < 0.001$, Monte Carlo test) and accounted for 45.7% and 20.2% of the total variation, respectively.

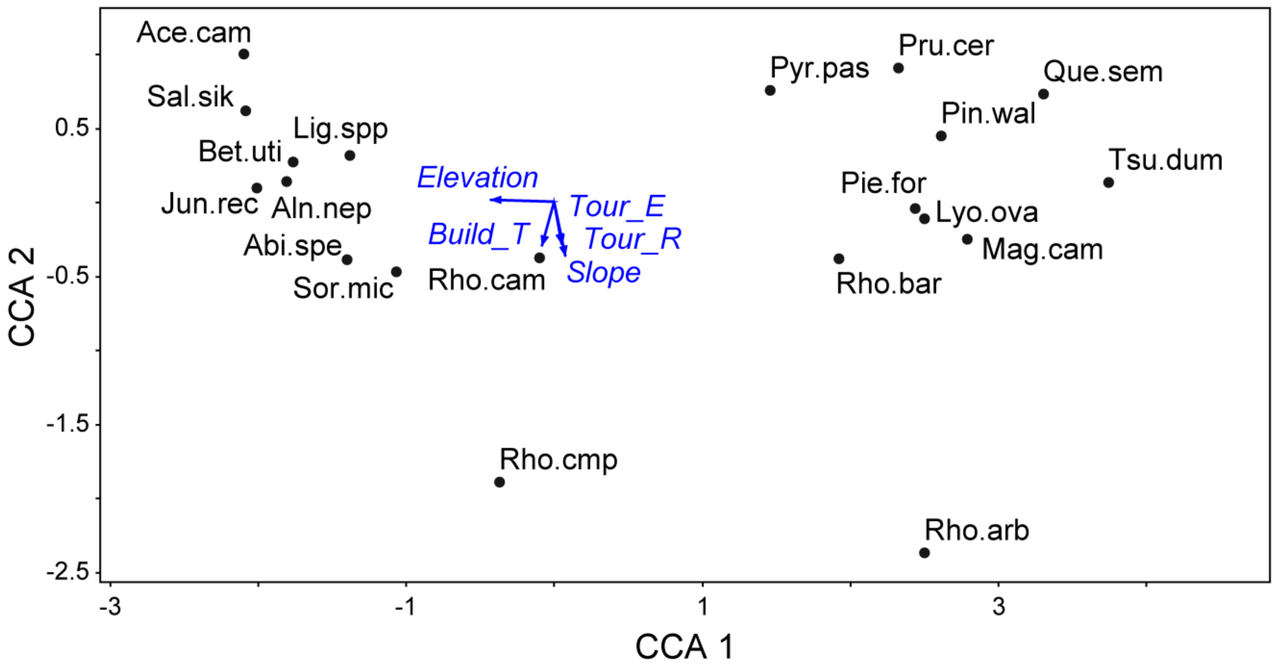

Figure 5. Canonical Correspondence Analysis (CCA) of the basal area of tree species in relation to the environmental variables (Elevation=elevation; Slope=slope aspect; Tour_E=Euclidean distance from tourist lodges; Tour_R=slope distance from tourist lodges; Build_T=time distance from buildings) expressed by vectors. Tree species are indicated by dots symbols (Abi.spe=*Abies spectabilis*; Ace.cam=*Acer campbellii*; Bet.uti=*Betula utilis*; Jun.rec=*Juniperus recurva*; Lig.spp=*Ligustrum* spp; Lyo.ova=*Lyonia ovalifolia*; Pin.wal=*Pinus wallichiana*; Rho.arb=*Rhododendron arboreum*; Rho.bar= *Rhododendron barbatum*; Rho.cam= *Rhododendron campylocarpum*; Rho.cmp= *Rhododendron campanulatum*; Sal.sik=*Salix sikkimensis*; Sor.mic=*Sorbus microphylla*; Aln.nep=*Alnus nepalensis*; Pru.cer=*Prunus cerasoides*; Tsu.dum=*Tsuga dumosa*; Que.sem=*Quercus semecarpifolia*; Mag.cam=*Magnolia campbellii*; Pie.for=*Pieris formosa*; Pyr.pas=*Pyrus pashia*).