

Project

## Biodiversity and livelihood in land-use gradients in an era of climate change – outline of a Nepal-Swiss research project

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### Abstract

The Swiss National Science Foundation has recently granted a project where we propose to study how different levels of land-use intensity (from primeval forests to arable fields) and climate do affect biodiversity on the southern slope of the Nepalese Himalayas. We will investigate replicated land-use gradients at various altitudes in three regions with a different regional climate, and in particular, different levels of seasonal precipitation. Our core study region will be the Manaslu Conservation Area characterized by an oceanic climate and this region will be compared to a hyper-oceanic region in Annapurna Conservation Area and a semi-oceanic region of the Sagarmatha (Everest) region. By using a quasi-experimental landscape approach organisms will be investigated in six valleys covering different precipitation regimes, altitudinal gradients over 1600 m representing different temperatures, and four land use types ranging from closed forests to open landscapes. These organisms will include plants, lichens, mushrooms, butterflies and birds. Population data of Red Listed mammals (flagship species) will be collected during the project by local authorities. The functional connectivity of forest fragments along land-use and climate gradients will be assessed for two intensively studied species, the epiphytic lichen *Lobaria pindarensis* and the tree species *Taxus wallichiana*.

### Introduction

There is general agreement among the scientific community that maintenance of natural levels of biodiversity is necessary for proper ecosystem functioning and the provision of sound ecosystem services to humankind (Schulze and Mooney 1994; Sala *et al.* 2009), constraints on infectious disease (Patz *et al.* 2005; Vittor *et al.* 2006), medicinal and genetic resources, and quality of life (Sala *et al.* 2009). The most important direct driver of biodiversity loss and change in ecosystem services is habitat transformation, particularly from conversion to agriculture. Tropical moist forests are amongst the most diverse ecosystems on earth (UNEP 2001), but are currently experiencing more extensive deforestation and forest degradation than in the rest of the world (Millennium Ecosystem Assessment 2005). However, deforestation is recognized to contribute

with important benefits to society, opening economic opportunities and the availability of a number of ecosystem goods, at least in the short term. Thus, there is a trade-off balance to find between realizing short-term gains in selected ecosystem goods, while potentially degrading ecological function and other ecosystem services in the long term (Foley *et al.* 2005; Foley *et al.* 2007). Recent assessments of the ecological impacts of land-use practices have focused on the need to balance the tradeoffs resulting from human actions (Foley *et al.* 2005; Millennium Ecosystem Assessment 2005) where multifunctional systems at the landscape level could probably provide the best scenario (Foley *et al.* 2005).

### Biodiversity in Mountain Environments

The personal safety and well-being of one fifth, and water supply for almost half of all people depend directly or indirectly on the functional integrity of mountain ecosystems,

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the key component of which is a robust vegetation cover (Körner 2004). Our continuing dependence on organismal diversity within healthy ecosystems is clear. However, much more research is needed to characterize all the species involved and to discover their complex interactions, impacts on humans, and responses to change (Mindell 2009).

As stated by Körner *et al.* (2006), mountains are inhabited by more species as one would estimate from their land area and have therefore been called “hot spots” of biodiversity (Körner 2004). Biodiversity in mountain environments often shows a mid elevation peak in species richness, i.e. highest numbers or densities of species occur at a certain range of mid elevations, whereas species richness or density declines towards mountain tops or lower altitudes. This effect has been shown worldwide for several mountain ranges and taxa, including vascular plants in Norway (Grytnes 2003), India/the Himalayas (Oommen and Shanker 2005), or Switzerland/the Alps (Wohlgemuth *et al.* 2008); ants in Colorado, Nevada, and Utah (Sanders 2002); litter invertebrates in Panama (Olson 1994); small mammals in Madagascar (Goodman and Carleton 1996), Philippines (Heaney 2001), Mexico (Sanchez-Cordero 2001), Nevada and Utah (Rickart 2001), or Costa Rica (McCain 2004); or birds in South America (Rahbek 1997), or Colombia/the Andes (Kattan and Franco 2004).

Such peaks in species richness at mid elevations have also been described from Nepal – especially for the southern slope of the Himalayas: Vetaas and Grytnes (2002) found a mid elevational peak for vascular plants and Baniya *et al.* (2010) presented corresponding results for lichens. As an important finding, richness of endemic species consistently differed from the overall richness patterns. The peak of endemics is shifted to higher altitudes and demonstrates different history and causation behind these biodiversity patterns.

Conventional explanations for the mid elevation peak include:

- o *Habitat diversity*: Habitat diversity in mountains is primarily based on topographical diversity including strong gradients in exposure, steepness of slope, variation of substrate, disturbance and microclimate over short distances. Gravity is the primary force behind this geodiversity (Körner *et al.* 2006).
- o *Compression of climatic zones*: Due to the elevation range covered, mountains encapsulate several

climatic life zones that would otherwise be separated by thousands of kilometres at low elevation (Barthlott *et al.* 1996). This is linked to the idea that elevational gradients mirror to some extent latitudinal gradients (Stevens 1992). The compression of climatic zones as well as habitat diversity also contributes to a high local diversity by mass effects, when species establish in sites where a self-maintaining population cannot exist (Shmida and Wilson 1985; Grytnes 2003).

- o *Geometrical constraints*: Constraints due to boundaries of species distributions result in greater overlap of species ranges in the middle of sample domains, leading to an emergent *mid-domain* peak in richness (Colwell and Lees 2000). Because *area* decreases along the elevational gradient in general, area has to be considered as an additional geometric constraint, and adequate null models have to be applied for the analysis of species richness (Rahbek 1995; Grytnes and Vetaas 2002).
- o *Historical factors*: If the montane zones are both isolated and large enough to allow population persistence and divergence over evolutionary time, they may represent hotspots due to speciation and endemism (Lomolino 2001). This is amplified by distributional disjunctions and different refugia due to climate change in former times and sympatric speciation along steep environmental gradients. On the other side, mountain species pools should have relatively high extinction rates and low immigration rates, while lower elevational zones with larger areas having greater potential for serving as a target for immigrants (Lomolino 2001). As a result, widely distributed species in general decline monotonically with elevation, whereas mountain species and especially mountain endemics exhibited a mid-elevation peak (Kattan and Franco 2004). Against this background, montane ecosystems are simply a special case of the island paradigm (MacArthur and Wilson 1967).

However, the causation behind richness patterns may change with spatial scale and grain and a hierarchical view is needed how factors affect biological diversity at different scales (Shmida and Wilson 1985; Mackey and Lindenmayer

2001; Soberon 2007). While clear and significant results at broader scales are common, the contribution of drivers at local scales remains often unclear. As an example, the distinctive mid elevational peaks of species richness in Nepal (Vetaas and Grytnes 2002; Baniya *et al.* 2010) derived from compilations of national floras with upper and lower elevation limits. They do not cover local elevation gradients, and thus the transferability to local scales and conditions is largely unknown.

### Effects of Habitat Loss and Fragmentation on Populations

Deforestation and degradation of old-growth forests has the potential to cause catastrophic species extinctions (Groom *et al.* 2006). Natural habitat has been displaced by human disturbance by at least 50% of the global land's surface (Hannah *et al.* 1994; Sanderson *et al.* 2002; Turner 2002); and it is predicted, that the pressure on land use and habitat conversion will still increase in future (Sala *et al.* 2000; Tilman *et al.* 2001). On the other hand, biodiversity in terms of species richness is often linked to high habitat diversity – that itself is often the results of loss and fragmentation of a single or few dominant habitat types.

Increasing biodiversity loss is expected with progressing habitat loss that typically starts with gap formation or perforation of the habitat. At later stages the gaps are getting more extended and numerous and eventually the non-habitat patches become the dominant part in the landscape. As a result, the structural connectivity between the original habitat patches has been broken and depending on the species' ability to move across this mosaic the fragmented landscape gradually ceases to support more and more species.

### Effects of Climate Change on Biodiversity

Networks of protected areas are a most valuable resource for conserving global biodiversity (Bruner *et al.* 2001). The majority, however, have been established on a static, present-day snapshot of species distributions, greatly increasing their susceptibility to anthropogenic drivers of global change (Gaston *et al.* 2006). Climate change in particular represents a key potential threat to their future effectiveness (Burns *et al.* 2003; Hannah *et al.* 2007). Evidence from the paleo-

ecological record of past climate change (Graham and Grimm 1990), together with recent documented changes in species phenology and distributions (Parmesan and Yohe 2003; Jonzen *et al.* 2006), and modelled simulations of species future range shifts (Erasmus *et al.* 2002; Huntley *et al.* 2008), indicate that species responses to projected climatic change over the coming decades could substantially alter present-day patterns of biodiversity (Hole *et al.* 2009).

One clear effect of climate warming in mountain environments is the upward shift of species distributions (Parmesan and Yohe 2003). Elevational shifts have been found for several taxa including vascular plants, bryophytes, butterflies, or birds (Hickling *et al.* 2006; Lenoir *et al.* 2008). For many taxa these dynamics are quite consistent with an upward shift in mean annual isotherms, but species restricted to mountain habitats seems to be more affected (Lenoir *et al.* 2008). These shifts have not only been found at distributional margins, but also at the spatial core or elevational optimum of species (Lenoir *et al.* 2008). Additionally, at lower altitudes of mountains the colonization by specialized low-elevation species may fail to compensate for the loss of high-elevation species (Wilson *et al.* 2007). Thus, climate warming combined with habitat loss and other drivers of biological change may lead to significant losses in biological diversity especially in mountain environments.

Since last few decades, several modeling approaches have been developed to predict the impact of climate change on biodiversity. Results from these models have suggested some alarming consequences of climate change for biodiversity. However, caution may be required in interpreting results, not least because their coarse spatial scales fail to capture topography or "microclimatic buffering", because they often do not consider the full acclimation capacity of plants and animals (Botkin *et al.* 2007), often assume equilibrium, or do not distinguish between the realized and fundamental niche of species (Hutchinson 1957) – a concept that has anyway to be rephrased in time of global change (Araujo and Guisan 2006; Soberon 2007). Several recent studies indicate that taking such aspects into consideration can seriously alter the model predictions (Hole *et al.* 2009; Willis and Bhagwat 2009).

Basic research on ecological responses of high-elevation species to climatic variables is notably lacking in the Greater Himalayas, but it is generally expected that rapid responses by individual species to climate change may disrupt interactions and may include potential ecological cascading effects with secondary extinctions triggered by losses of key

species in the alpine ecosystems. The endemic-rich Himalayas include many plant species that may not respond successfully to projected rates and magnitude of climate change (Salick *et al.* 2009; Xu Jianchu *et al.* 2009).

Varying drivers of biodiversity at different spatial scales are common. While climate is usually the most important factor at global to regional scales land cover including land use is in general a dominant local driver – with combinations at intermediate scales. This holds not only for species richness, but also for functional or trait diversity or other measures of biodiversity. In this regard, different traits like flowering phenology has recently gained increased attention, especially in the context of climate warming. Based on data of the Biodiversity Monitoring of Switzerland Kühn *et al.* (2009) showed that phenology of vascular plants within assemblages at an intermediate landscape scale are – quite similar to species richness – mainly driven by climate (temperature), followed by substrate type and land cover with forest cover as the most important land-cover type.

Beside the applicability of statistical modeling to reveal and test important covariates of species richness or traits, or to predict such measures of biodiversity in space, these methods can also be used for projections in time based on environmental change scenarios. In a recent publication the Swiss partner analyzed changes in the species richness of neophytes, i.e. non-native plant species introduced to Switzerland since 1500 (Nobis *et al.* 2009). By using different scenarios for land cover (urban sprawl) and climate (climate warming) we showed that neophyte species richness is basically driven by climatic conditions, and urban areas additionally modulate small-scale differences upon a coarse-scale pattern. According to our projections, climate warming will contribute to the future increase in neophyte species richness much more than ongoing urbanization, with highest gains at lower altitude. However, small-scale differences at low altitudes will be strongly affected by urban areas. Again, while the overall diversity pattern is primarily driven by climate conditions, strong small-scale differences at local conditions are controlled by land use.

### **Consequences of Biodiversity Change for Human Health and Well Being**

The loss of biodiversity by global change, most immediately affects the world's poor, who depend on wild plants, animals

and wild habitats for basic goods such as food, shelter and medicines. Because of this link between biodiversity loss and human well-being, conserving and managing ecosystem and species in a sustainable way become more and more important (Millenium Ecosystem Assessment 2005; Fuentes 2008). Himalaya Mountains are rich in medicinal plants and mountain dwellers have long tradition of using these medicinal and aromatic plants for their health care. The great majority of people in the Himalayas rely primarily on herbal medicine. Folk medicine is widely used and the region is home to four of the world's great medical traditions – Ayurveda, Chinese, Tibetan and Unani. Additionally, many people outside the Himalayas use medicines derived from Himalayan plants, generating large-scale trade in certain species.

In highlands of Nepal, collection of these plants from wild for sale in market is an integrative part of mountain peoples' livelihood and has significant share in local household as well as national economy (Olsen and Larsen 2003). Due to socio-economic transformation, urban people rely mostly on modern allopathic medicine but mountain people still use selected medicinal plants and formulations prepared from them. Ethnomedicinal knowledge can provide a lead for this venture (Hamilton 2003; Shrestha *et al.* 2007).

## **Research Plan**

### **OVERALL GOAL AND MAIN OBJECTIVES**

The overall goal of this research collaboration is to identify and analyze how land-use and climate change affect biodiversity in high-elevational landscapes in the Himalayas. We will analyze the consequences of biodiversity change for (1) species richness of plants, mushrooms, lichens, butterflies and birds, the two latter groups being assessed by regional parataxonomists, (2) plant functional groups, (3) rare, endangered and red-listed mammal and bird species (documented by staff of National parks and local parataxonomists), (4) selected ecosystem goods and services including medicinal and aromatic plants, edible fungi and lichens used for incense and spices on the Indian and Nepali markets (Upreti *et al.* 2005; Scheidegger and Werth 2009).

Besides the expected rise in mean temperature in the Himalayas, climate change leads to more intense rainfall events while the number of rainy days and total amount of precipitation has decreased (Cruz *et al.* 2007). This will (1)

**Table 1.** Study regions.

Parameters	Sagarmatha	Manasalu	Annapurna
Conservation Type	Outside Park	Conservation Area	Conservation Area
Location	Eastern Region	Central Region	Western Region
Districts	Solukhumbu	Gorkha, Manang, Lamjung	Manang, Mustang, Kaski, Myagdi, Lamjung
Major ethnic groups	Sherpa, Rai, Tamang, Newar	Gurung, Thakali, Thakuri, Lama	Gurung, Magar, Thakali, Brahmin,
Area (sq.km)	Not applicable	1663	7629
Altitude (m)	2843-6957	600-8163	790-8091
Average Annual Precipitation (mm)	1000	1900	3650

have a direct effect on biodiversity because temperature is the main limiting ecological factor in humid mountain regions, and (2) influence the way and intensity how local population will manage their land. Current and future biodiversity change is the combined consequence of climate- and land-use change.

In our project we therefore propose to study how different levels of land-use intensity, from primeval forests to arable fields will affect biodiversity in temperature and precipitation gradients. We will study replicated land-use gradients at various altitudes (temperature gradient) in three regions with different regional climate, i.e. different levels of seasonal precipitation (precipitation gradient). This approach will allow to quantify the effects caused by climate and land-use, respectively, and to provide the necessary scientific data for the development of land-use and conservation strategies for a sustainable use of natural resources in times of climate change. This information will be made available to regional and national stakeholders.

#### STUDY DESIGN

Our project will be carried out in three regions covering different precipitation regimes in the southern slope of the Himalayan Mountains in Nepal (Table 1). According to the main objectives the design of this study considers both climate and land use gradients in Nepalese Himalayas and will be carried out at three different spatial levels: (i) between regions, (ii) within regions, and (iii) at local conditions (Fig. 1).

The “between regions level” will enable the comparison of regions with different climates with respect to precipitation. These regions include (1) hyper-oceanic climate in the region around Lumle in Annapurna Conservation Area, (2) oceanic climate in the Manasalu Conservation Area, and (3) semi-

oceanic climate in the Sagarmatha region (Everest region). Within each region we will select two independent valleys (sub-drainage basins) as replicates for the region.

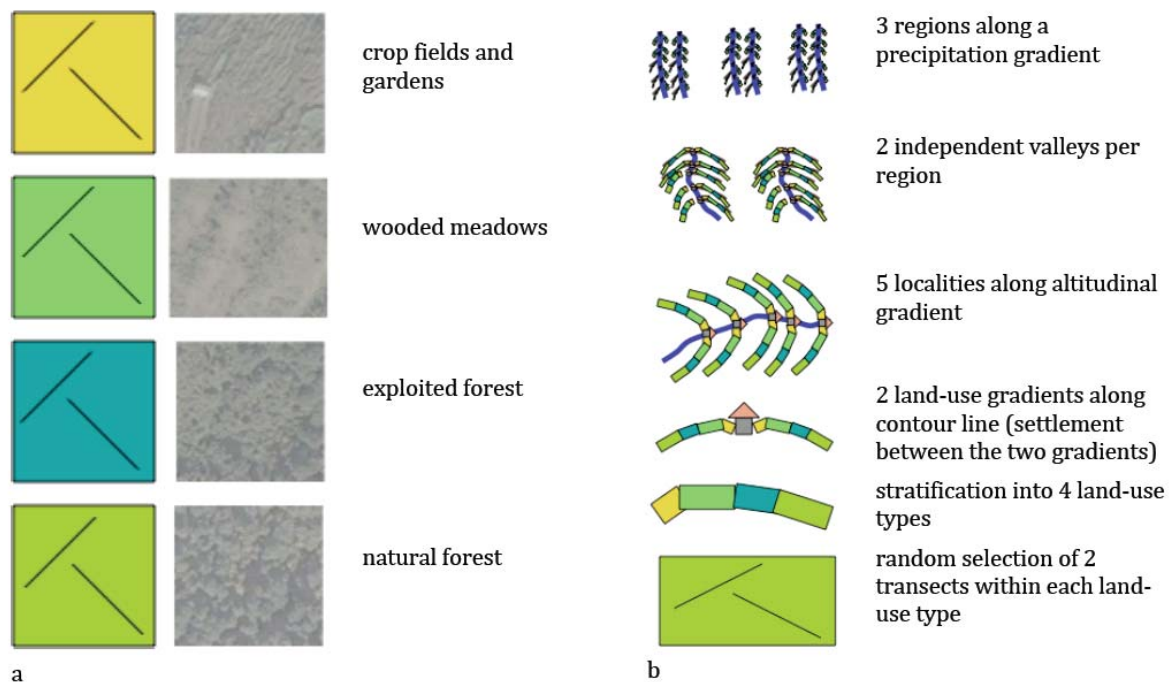
The “within region level” will focus on different temperature conditions and therefore considers different altitudes. Because species richness – especially for species endemic to Nepal or Himalayas and at larger scales – is highest in high mountain areas, this study will be carried out in the upper forest zone up to the timber line (about 2400 – 4000 m a.s.l.). In each region, five localities at different altitudes (around 2400, 2800, 3200, 3600 and 4000 m a.s.l.) including the highest settlement at or close to the timber line will be investigated. The altitudinal steps between each site will be about 400 m, thus the whole elevational gradient will span about 1600 m in total.

At the “local level”, in each region and at each of the five altitudes two land-use gradients will be established along a contour line with one gradient on each aspect/slope of the valley. Beside different land use, this local level is also designed to compare differences in (micro-)climate within short distances between both sides/slopes of the valleys.

Each land-use gradient will include four different types of land-use:

(1) **Natural forest** areas with either pristine character or with a low anthropogenic influence that include low levels of tree harvest that does not alter the forest stand structure and tree species composition. In this forest villagers cannot go for one-day round trip collection because of the distance. With natural forest stand (mainly pine forests and mixed broad-leaf temperate forests), also the resources include rocks and pastures that have not been grazed or which have been abandoned for more than a decade. Normally forest stands far





**Figure 1.** Land-use type with two randomly selected transects (left) and example from satellite (a) and study design to identify and analyze how land-use and climate change affect biodiversity in high-elevation landscapes in the Himalayas (b).

from human settlements are reported to have this kind of forest.

(2) **Plantation and exploited forests** with average tree age >20 years and revealing a relatively closed canopy but with an altered stand structure and tree species composition compared to natural forests, either because of intensive exploitation for agriculture, livestock, and collection of fodder and fuel woods or plantation after intensive domestic or commercial forest management. Due to limited lands suitable for living and farming in and around this type of forest, the land resources are heavily exploited.

(3) **Wooded meadows and meadows** with less than 20% tree coverage. Domestic livestock including goats, buffalos, cows, yaks and horses graze or browse the vegetation, which have seen a great impact on resources. Trees are largely treated by various lopping regimes.

(4) **Crop fields and gardens** are intensively managed, fertilized, sometimes irrigated and yearly ploughed. On slopes

fields are often terraced and soil erosion is the main problem. Main crops include maize, wheat, and finger millet, rice, beans, potato, barley, oat and buckwheat. Vegetables are mainly cultivated in gardens in home yards and in close vicinity of the settlements. Similarly, varieties of non-timber forest products (NTFPs) and medicinal and aromatic plants (MAPs) are also cultivated either for commercial purpose or for daily uses.

The land-use gradient will be stratified into the four land-use types along a contour range of  $\pm 50$  m. In each land-use type two transects will be randomly selected within the contour range. The length of one transect is 50 m. Thus, in total 240 land-use units from 60 land-use gradients from 30 localities will be sampled. The transect method has been widely tested in the Swiss biodiversity monitoring program and is thus applicable also in steep mountain regions. Nevertheless, the protocol will be tested and possibly adapted before the training courses for the PhD students and parataxonomists.

Beside different land use, this local level is also designed to compare differences in (micro-)climate within short

distances between both sides/slopes of the valleys. For this purpose the orientation of all valleys have to be more or less the same.

#### WORKPACKAGES

The project is subdivided into six workpackages (WP). The detailed description of the study areas at the regional and local levels will be carried out in WP 1. The assessment of biodiversity along the land-use gradients will be carried out in WP2 and in WP 3 local and regional gene flow will be studied for two species in order to assess functional connectivity of the studied areas within and between land-use gradients. Data analyses are assigned to two different work packages: in WP4, all present-day data will be prepared and analyzed, whereas significant effects between biodiversity and environment will be used in WP5 to develop biodiversity scenarios under different future environmental changes. The outcomes of the research project will be summarized and the consequences for sustainable land-use and appropriate conservation measures to mitigate climate change effects in the study region will be discussed with stakeholders and appropriate documentations will be elaborated in WP6.

#### **WP 1:** Implementation of the sampling design and site description.

We determine landscape-level structural parameters from satellite images and aerial photographs (if available) with GIS methods across land-use gradients. Land-use types will be classified according to crop systems, disturbance frequency and intensity. Landscape metrics such as patch size, fragmentation and structural connectivity will be calculated for the land-use gradients. Meteorological data (temperature, precipitation, air humidity, photosynthetic active radiation and sun light, wind speed and direction) according to standard protocols will be measured for 12 localities, i.e. the lowest and highest locality in each valley studied. Topsoil temperature (daily average, min and max) will be measured with data loggers for all 240 transects. Canopy disturbance will be classified according to Vetaas (1997), and canopy openness will be assessed for all land cover types by digital, hemispherical photographs (fisheye photographs). This well established method (Anderson 1964; Frazer *et al.* 2001) is not only suitable for assessing light indirectly and describing canopy structures; in addition, this method enables an excellent

documentation of the sites and plots (Nobis and Hunziker 2005). The locations for data-loggers and hemispherical photographs will be directly spatially linked to the species assessment and placed along the same transects as described in the following workpackage. Current Land-use will be described for each site and land-use history of the last 50 years documented based on interviews with the land-managers. Disturbance intensity, frequency as well as irrigation and fertilizer regime will be noted based on information given by the land-managers. The protocols have been developed in the framework of the project BioAssess (Watt *et al.* 2007) and will be adapted for this project.

#### **WP 2:** Assessment of species diversity.

We will assess species occurrences of selected higher taxa including plants, birds, butterflies, mushrooms and epiphytic lichens. All PhD- and Masters students of the project will contribute to the data collection in the field. Plants and lichens will be assessed during one field visit but mushrooms, birds and mammals need bi-weekly observations during the relevant parts of the year. Bi-weekly observations can best be done by local people that are already associated with national parks or conservation NGO's. In the framework of this project, we will thus involve parataxonomists with sufficient faunistic experience in birds and mammals and train parataxonomists in wild mushrooms. For the biodiversity assessment, higher taxa have been selected because of their low levels of inter-taxon correlations, and because the quality of taxa capture and identification is relatively easy and reliable (Watt *et al.* 2007).

The assessment of the species lists will be carried out with standardized protocols on randomly selected transects of 50 m within land-use types. In comparison to more compact plot shapes, transect sampling will better consider and compensate for nearby heterogeneity within the community level, i.e. changing species combinations and vegetation structures, which are not the focus of our project. Thus, transect sampling is used to characterize the biodiversity of a given land-use unit as a whole.

This information will be complemented by time-restricted observational data collected on each land-use type. This approach will add information about rare and possibly endangered species that would otherwise be neglected in the transect observation. The amount of time to be spent on each land-use type will be fixed (e.g. 1.5 hours). Based on the experiences from the EU framework project BioAssess and

the Swiss Biodiversity Monitoring Program (BDM) the biodiversity assessment will be carried out by standardized transect sampling. In each land-use unit two separate transects with a length of 50 m each will be investigated and sampling will follow a strict protocol. Each species of the selected taxa that occurs within a strip of defined width will be recorded. The width of the strip is 2.5 m for plants, lichens, mushrooms and butterflies, but 25 m for birds and mammals. The protocols will be tested for each taxonomic group. Replicates at the levels of transects, land-use units, and land-use gradients will be used to enable the control of data quality.

**WP 3:** Effects of land use and climate change effects on gene flow.

We investigate how patch size and the spatial isolation and fragmentation of habitats affect dispersal and gene flow of two selected forest-dwelling species with different dispersal potential. One species, *Lobaria pindarensis* Räsänen requires bark surface of old trees as habitat and depends on a relatively moist forest stand microclimate (Joshi and Awasthi 1982), whereas the second species, *Taxus wallichiana* Zucc. is a generalist species under the canopy in mountain forests (Polunin and Stainton 1984).

*Taxus wallichiana* is one of the most important medicinal tree species of the Himalayan region. It is dioecious and wind pollinated, with seed dispersal by animals (Zhang *et al.* 2009). Recently, microsatellite markers have been developed for *Taxus wallichiana* (Yang *et al.* 2009), and Zhang *et al.* (2009) have investigated effects of forest fragmentation on genetic diversity based on intersimple sequence repeat (ISSR) markers.

*Lobaria pindarensis* is a foliose lichen species associated with the green algal photobiont *Dictyochochloropsis reticulata*. It has been described from, and is widespread in the Himalayas. It has a similar ecology as *L. pulmonaria* and according to preliminary fieldwork carried out by the Swiss partner *L. pindarensis* mainly disperses with vegetative propagules, which are rather large. They are presumably splash and wind dispersed and seem to be strongly dispersal limited. The lichen is widely distributed and locally frequent in mountain forests and open woodlands in Nepal (Miehe 1990). Preliminary analyses have shown that 7 photobiont specific microsatellite markers work for *L. pindarensis* (Devkota *et al.*, in prep.). Mycobiont-specific-microsatellite markers are available for *L. pulmonaria* (Walser *et al.* 2003; Widmer *et al.* 2010).

**WP 4:** Analyses of the present-day biodiversity

This workpackage will statistically describe and test the present-day variation of various biodiversity aspects in Nepalese Himalayas in a multivariate environmental space defined by land use, temperature and precipitation. Besides the distributions of single species, different biodiversity measures including species richness, functional diversity based on species traits as well as beta-diversity (Pielou 1975; Magurran 2004) will be analyzed for all combinations of spatial and environmental levels of the project, i.e. between regions/precipitation, altitudes/temperature, and land-use types including micro-climates.

**WP 5:** Expected biodiversity change under different climate change and land-use change scenarios.

Based on significant present-day covariation of climate and land use with biodiversity measures found in the previous workpackage, WP5 will investigate expected changes in future biodiversity using climate and land-use change scenarios. We will use IPCC scenarios, representing different sets of assumptions regarding the future development of human activities and corresponding climate trajectories (IPCC 2007). Land-use change scenarios will reflect expected dynamics due to changes in climate and socio-economic drivers for the land use types of our study design. Both climate and land-use scenarios will consider low- and a hi-scenarios representing strong and moderate future changes, respectively. Our present-day data and the environmental scenarios will be linked within a modeling framework by using methods like generalized linear models (GLM; McCullagh and Nelder 1989).

Since our projections in time will be based on present-day covariation in space, this is a classical space-for-time substitution approach that always has to be applied with caution. This holds especially when projections are restricted to changes in a single factor only – as often done with climate warming in the global change debate. However, our sampling design is developed to measure simultaneously the covariation of biodiversity with precipitation, temperature and land use. Furthermore, it is designed to reduce potentially confounding effects between these well known drivers of biodiversity. Thus, we will be able to apply space-for-time substitution in a well defined multivariate environmental space of precipitation, temperature and land use.



**WP 6:** Consequences of climate change on land use and biodiversity conservation.

The purpose and outcome of the project will be widely disseminated at local, regional, national and international levels by various means. The objectives and results and relevant issues of the project will be published in the daily newspapers, magazines, national and international journals, booklets and books as well. Moreover, emphasis will be given at community level by organizing public awareness programs, conducting training/workshop programs, etc. The local school students and teachers, mother groups, community-based organizations will be mobilized to disseminate the information. The project information will be effectively and widely disseminated through a project website, jointly run by the collaborating institutions in Nepal and Switzerland.

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