TECHNISCHE UNIVERSITÄT MÜNCHEN

Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt

Department für Ökologie und Ökosystemmanagement - Fachgebiet Geobotanik

Distribution pattern, micro-site conditions, host tree characteristics and utilization of epiphytic orchids in the central Himalayas

Yagya Prasad Adhikari

Vollständiger Abdruck der von der Fakultät Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt der Technischen Universität München zur Erlangung des akademischen Grades eines

Doktors der Naturwissenschaften

genehmigten Dissertation.

Vorsitzender: Univ.-Prof. Dr. A. Göttlein

Prüfer der Dissertation:1.

1 Univ.-Prof. Dr. A. Fischer
2. Univ.-Prof. Dr. S. Pauleit
3. Assoc. Prof. Dr. M. P. Devkota/Tribhuvan University Kathmandu, Nepal (nur schriftliche Beurteilung)

Die Dissertation wurde am 25.03.2013 bei der Technischen Universität München eingereicht und durch die Fakultät Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt am 13.06.2013 angenommen.

Table of contents

1. Introduction

1.1 Epiphytes and their habitats

Epiphytes are canopy elements, independent from ground habitats. They have specialised nutrient and water (i.e. precipitation, throughfall, and cloud water) uptake mechanisms in the canopy habitat. Epiphytes generally grow on trees or shrubs without harming them (Nieder et al. 2001). They are divided into two groups; holo-epiphytes (complete life cycle on host trees) and hemi-epiphytes (only part of life cycle on host trees). Due to their very special habitat epiphytes are generally considered as excellent indicators of ecosystem changes (Nadkarni 1994). Epiphytes are sensitive to but are responsive to anthropogenic disturbances (Wolf 2005; Song et al. 2011). Suitable host availability is important (Ackerman 1996) and therefore host species have to be considered in conservation strategies (Migenis and Ackerman 1993).

Canopies provide habitat for various species of plants, microorganisms, insects, birds, and mammals that are rarely or never encountered on the forest floor (Nadkarni 1994). Epiphytes offer numerous forest products, including medicines, foods, ornamental plants, and fibres (Acebey et al. 2010). Although epiphytes are believed to be important in maintaining the diversity, resiliency, and functioning of the forests they inhabit, they are poorly explored.

Epiphytic plants are taxonomically and ecologically diverse including vascular plants (orchids, ferns), bryophytes, algae fungi and lichens. Moisture rich and mossy habitats are especially suitable for luxuriant growth of epiphytic orchids (Koirala et al. 2010). The plant family of Orchidaceae is one of the largest and most diverse families of the flowering world. Understanding epiphytic diversity to a high degree is synonymous with understanding epiphytic orchids (Gentry and Dodson 1987). Orchid's commercial and horticultural values, as well as ethnobotanical uses (in medicine or food) support livelihood of people in different parts of the world. However, overharvesting and habitat destruction have driven many species in the wild towards extinction (Chen et al. 2012). Furthermore, the population of orchids and their habitat are decreasing throughout the world, beginning with genetic erosion and ending up with local, regional, or global species loss. The main driving forces are habitat loss due to deforestation, agricultural and industrial expansion, urbanization, and illegal collection and trade. Considering both endangering, the natural beauty of epiphytic orchids, and their important in canopy ecosystems, comprehensive efforts for their conservation are needed.

1.2 Epiphytic orchids

Epiphytic orchids comprise over two-third of all epiphyte vascular species (Gentry and Dodson 1987). Most of them occur in tropical and subtropical forests and their species richness peaks in subtropical areas in an elevation around 1,500 m (Acharya et al. 2011). The evergreen broad-leaved forest type offers excellent habitats for a large number of epiphytes during the long, rainy period in summer (Acharya et al. 2011), especially for epiphytic orchids (Adhikari et al. 2012b). Epiphytic orchids are both of the sympodial (stems of determinate growth; e.g. Dendrobium) and the monopodial (indeterminate terminal growth; e.g. Vanda) type. Epiphytic orchids are able to absorb and store atmospheric moisture. The lack of forest floor contact combined with the diversity of nutrient and water sources in the canopy life has led to specific adaptation mechanisms in epiphytes (Cardelus and Mack 2010). They have thickened stems to form a pseudo-bulb with adventitious roots. The main nutrient and water sources of epiphytic orchids are precipitation, canopy throughfall, and cloud water from which they shape their functional morphologies. For example, thick leathery leaves, water loaded pseudo bulbs; pendant orchids with velamen-coated aerial root uptake serve the double purpose of anchorage and absorption (Benzing et al. 1990). The symbiotic association between epiphytic orchids and michorrizal fungi is vital for essential nutrient supply during germination and seed establishment (Weston et al. 2005).

Therefore, epiphytic orchids are an important part of the canopy ecosystem. Their distribution pattern and environmental conditions, e.g. micro-climate, need to be studied for their long-term protection.

1.3 Host trees and abiotic variables

The diversity of epiphytic orchids and their abundance are mainly influenced by the available host trees and their micro-site conditions. Abiotic variables are host characteristics as micro-site conditions (e.g. host bark pH, bark rugosity, and water holding capacity of barks). Different abiotic substrates of the host bark play a vital role for aggregation and abundance of epiphyte species. The amount of rainfall is a good indicator of epiphyte abundance. Therefore, vascular epiphytes are largely found in tropics and subtropics (Nieder et al. 2001). However, there is no significant result for host epiphyte interactions, if there is enough water availability for epiphytes. In contrast, in increasingly xeric conditions, Callaway et al. (2002) it is predicted that host traits affecting water availability will be increasingly important and host-epiphyte interactions will be increasingly species-specific.

The distribution of epiphytes is affected by two major processes: dispersal and establishment (Hirata et al. 2009). The host tree size, the host tree as substrate for epiphytes, the chemical characteristics of host bark (Frei and Dodson 1972), the bark structure, and rugosity (Adhikari et al. 2012a; b), but a combination of the host tree traits appears to be important in determining the epiphytes presence and diversity (Laube and Zotz 2006). The natural forests (e.g. National Park) have a wider differentiated micro-climate condition compared to disturbed habitats (Barthlott et al. 2001). The knowledge of host tree species, their traits and chemical characteristics including microsite conditions as well as knowledge of their ecological formation is important for conservation of epiphytic communities in the future.

Considering reasons for the continuous depletion of epiphytic orchid habitat and their populations, the study on epiphytic orchid's distribution pattern, host utilization, and micro-site conditions in different land use intensities is important. This is the first study to include all relevant types of habitat (from natural habitats to single tree habitats in urban environments) transformation at a single study site, developed conservation perspectives, and sustainable utilization of epiphytic orchids in the tropics and subtropics. This is a local scale study but to a large degree still missing. So I am organizing to fulfil this gap by taking orchid as an example for subtropical environment with a human impact gradient in central Himalayas.

1.4 Aims and questions

The knowledge and information on basics of epiphytic communities, substrates provided by host trees, microhabitat as characteristics of host trees, and ultimately the whole canopy ecosystem is important for epiphyte conservation. This information will help to develop sustainable key elements essential for conservation of epiphytic plants as taking epiphytic orchids as an example in the central Himalayas. The main questions of this study are: What is the distribution pattern of epiphytic orchids in human influenced landscape in urban areas? And what are the driving forces? For that the relation of orchids and their site conditions (micro-climate, bark characteristics) had to be analysed.

2. Materials and Methods

2.1 Study area

Our study site is the Kathmandu Valley (Fig. 1) area in Nepal, with the four closely located cities of Kathmandu, Bhaktapur, Lalitpur and Banepa, situated in the subtropical evergreen broad-leaved forest. We selected Kathmandu Valley as our study area because (i) the valley is well known for the richness of epiphytic orchids, but (ii) it is the most urbanized place in Nepal. The Valley is bowl-shaped and located in the central region of Nepal (27° 76' ~ 62' N latitude and 85° 25' ~ 45' E longitude) in the subtropical zone at around 1,250 – 1,730 m elevation. The annual average rainfall is 1,400 mm (Pant and Dangol 2009) with the absolute maximum during summer time (monsoon climate) and 75 % annual average humidity at 1,400 m a.s.l. The temperature in general is 19 °C to 27 °C in summer and 2 °C to 20 °C in winter. Kathmandu Valley contains Nepal’s largest urban population and hosts 12 % of all households of Nepal (Zurick et al. 2005).

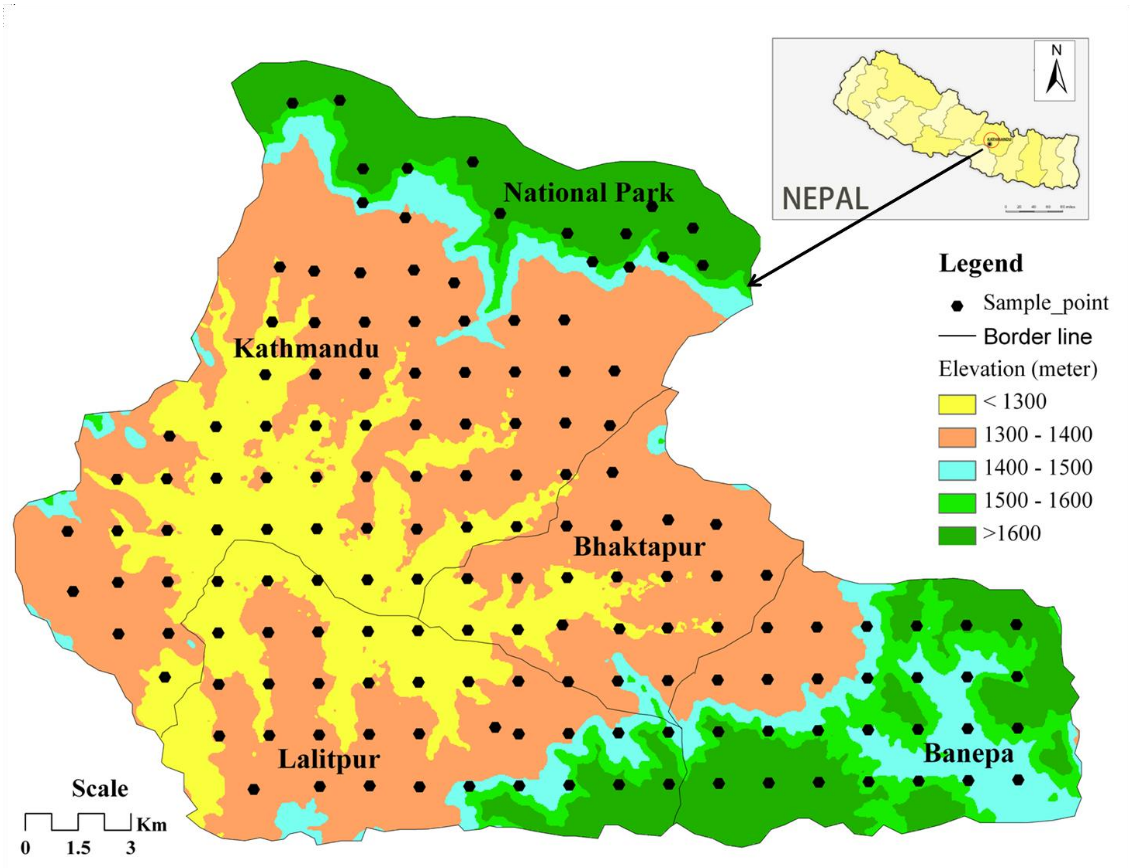

Fig. 1 The study area: Geographical differentiation (elevation) and the position of the four cities. The dots mark the (1.5×1.5 km) grid net for analysing epiphytic orchids in the Kathmandu Valley.

The natural vegetation of this Valley is subtropical evergreen broad-leaved forest, nowadays remaining in the city area in the form of a few isolated forest patches, several park areas, and temple areas with groups of trees, offering habitat for epiphytic orchids (Adhikari et al. 2012a). The single isolated trees or groups of several native trees including the religious tree, *F. Religiosa*, serve as possible habitats for epiphytic orchids in this densely populated area (Adhikari and Fischer 2011). Both the valley and its surroundings are rich in flora and have 16 endemic flowering plants. *Schima wallichii, Castanopsis indica, Pinus roxburghii,* and *Alnus nepalensis* are the dominant tree species at lower elevations. Whereas *Rhododendron arboreum* and *Quercus semecarpifolia* are the dominant tree species in higher elevations (Chaudhary 1998). Due to rapid urbanization agricultural land is rapidly converted into housing areas which poses serious problems, e.g. decreasing ground water table, air pollution, and loss of vegetation (Pant and Dangol 2009). Our study area was defined as up to about 1,700m altitude in the northern (Shivapuri- Nagarjun National Park), foot hills of the Kathmandu Valley in the west and south and up to Banepa city in the east (Fig. 1).

2.2 Remote Sensing and land use classification

To capitalize land cover classification of the study area, data originating from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) image (March 2011) was used. This image covers the 141/41 (path/ row) in the Landsat worldwide reference system and was delivered to a Universal Transverse Mercator (UTM) projection. Maximum likelihood supervised classification method was acquired. This classification differentiates the heterogeneous land-use to get information on the land-use types. This information helps to causally investigate the distribution and abundance of epiphytic orchids. The post classification result shows that the confusion matrix of the classification results for the overall accuracy is 83.34 % and kappa value is 0.78. In a first step, we identified ten types of land-use, e.g. agriculture, crop land, forest (Fig. 1b Adhikari et al. 2012a). Based on remote sensing information and using percentage of host tree coverage from field observation as a criterion, we categorised these types of land use into five land-use intensity classes from very low to very strong:

- Very low (VL): natural forest (national park, nearly untouched)
- Low (L): remnant forest patches in the city
- Intermediate (I): small forest patches, isolated single trees mixed with buildings, infrastructure, and agriculture
- Strong (S): single trees in agriculture land
- Very strong (VS): single trees in densely settled areas

2.3 Field sampling

We used a systematic (Adhikari and Fischer 2011; Adhikari et al. 2012a) and a stratified systematic sampling strategy (Adhikari et al. 2012b) for the selection of the sampling points within the study area. 156 grid points in a regular grid with 1.5 × 1.5 km distance were used in Kathmandu Valley. The points were identified in the field using Geographic Positioning System (GPS). Samples were taken on a plot less basis (Wolf et al. 2009). At each point we studied the ten individual trees (dbh > 10 cm) closest to the grid point within a 300 meters radius. To analyse land-use intensities, we chose subsets of points from these different land-use intensities. For more details, see publications (Adhikari and Fischer 2011; Adhikari et al. 2012a; b).

At each point we identified all orchid species as well as their host trees. Information on site conditions (e.g. latitude, longitude, elevation, and intensity of land-use), host tree characteristics (dbh, host bark rugosity, exposure to wind, bark water holding capacity, and bark pH) and orchid characteristics (name, sunlight intensity and number of individuals) was collected. For host characteristics and micro-site conditions measurement procedures see Adhikari and Fischer (2011) and Adhikari et al. (2012a; b). Orchid individuals were counted per tree up to 19 individuals; 20 and more are coded as ‘‘20’’ (including very young and small individuals). Each tree was examined from different points, thereby assuring a clear view of all tree parts (Migenis and Ackerman 1993). For larger trees and to collect samples of unidentified orchid specimens, the rope climbing technique was used (Mitchell et al. 2002).

Fig. 2 Left to right: Data collection using single rope climbing technique. Measuring host bark pH, *Bulbophyllum affine* on *Rhododendron arboreum* host, *Rhynchostylis retusa* on *Ficus religiosa* host tree.

2.4 Data analysis

All data were stored in a relational data base system in MS-Access. Analyses were performed using JMP® Statistical Discovery Software version 5.1.2 (SAS Institute Inc., 2009). Polynomial regression was used to analyze the relationship of the most common orchid species, *Rhynchostylis retusa*, density (number of individuals per tree) with bark pH and tree size. One-way analysis of variance was executed to compare the density of *Rhynchostylis retusa* among different light conditions and bark rugosity. However, pair-wise comparisons were conducted by using a t-test analysis (Adhikari and Fischer 2011). Analyses were performed using the statistical software R 2.12.1 package version (R Development Core Team 2010). For metric variables we used the nonparametric Wilcoxon rank sum test, for categorical variables, chi-square test was used for the inspection for differences between the categories (Adhikari et al. 2012a).

To analyse orchid distribution within different host tree species, expected frequencies of the occurrence was calculated and compared with the real frequencies. The expected frequency is the product of the relative frequency of the orchid species, the relative frequency of the host tree species, and the total number of orchid occurrences in the data set (for more details, see data analysis, Adhikari et al. 2012b). As the land-use categories slightly differ in sample size, species richness cannot be compared directly between them. To compensate the effect of sample size, we calculated sample-based rarefaction curves with the program PAST Version 2.09 (Hammer et al. 2001). According to Austin and Hux (2002), 95 % confidence intervals were calculated. The dependence of orchid abundance on land-use intensity and host tree characteristics was tested by a generalized linear model. We used the function GLM from the R-package version 2.12.1 with a poisson error distribution (Adhikari et al. 2012b).

For land-use intensity the category ‘‘very low’’ (i.e. national park) was chosen as a reference, for bark rugosity the category ‘‘medium’’, and for wind exposure the category ‘‘sheltered.’’ The percentage of deviance explained by the model was calculated as 1-(residual deviance)/(null deviance). Initially, the influence of all variables on orchid abundance individually was tested. Secondly, all host tree characteristics one by one together with land-use intensity was tested. Finally, the remaining variables in the sequence of individual explanation capacity were tested. Explained deviance as well as the Akaike Information Criterion (AIC) was used to evaluate the models (table 3, Adhikari et al. 2012b).

3. Publications

Distribution pattern of the epiphytic orchid *Rhynchostylis retusa* under strong human influence in Kathmandu Valley, Nepal

Yagya Prasad Adhikari and Anton Fischer

Geobotany, Department of Ecology and Ecosystem Management,
Technische Universität München, Hans-Carl-von-Carlowitz-Platz- 2, D- 85354 Freising, Germany

This manuscript was published in

Botanica Orientalis - Journal of Plant Science (2011) **8:** 90–99.
Open access Journal: doi: http://dx.doi.org/10.3126/botor.v8i0.5956

The focus of this paper is (i) the detailed representation of the study area and methodology as well as (ii) an analysis of the distribution of one dominant orchid in the study area. *Rhynchostylis retusa* (L.) Blume (hereafter referred to as *R. retusa*) is the most dominant epiphytic orchid species in the urban areas of Kathmandu Valley. Based on collected information on the regular 1.5×1.5 grid net points (total 100 grid points) we sought the distribution pattern of *R. retusa* in different land use types in the Kathmandu Valley. Furthermore, the site conditions for *R. retusa* were also analysed (fig. 3; unpublished).

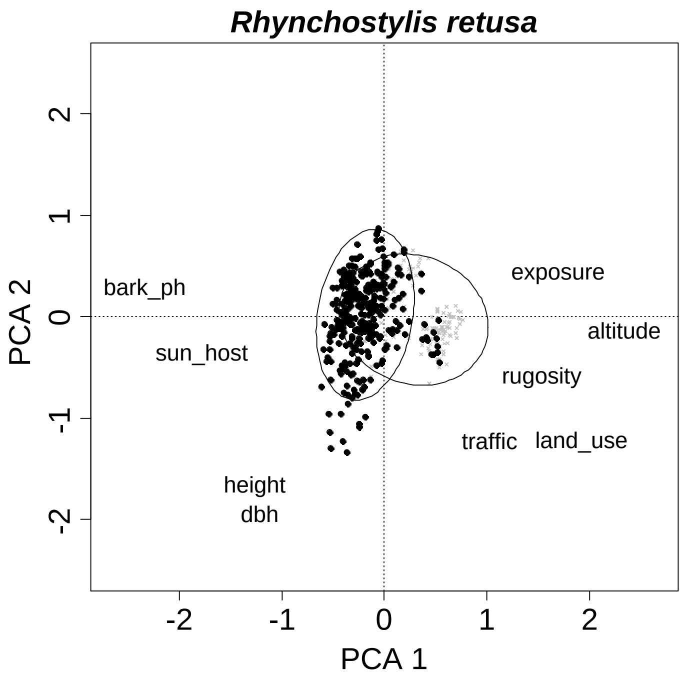

Fig. 3 Principal component analysis of host tree species in the Kathmandu Valley based on host tree characteristics. Tree individuals which host this orchid are displayed as black dots, whereas tree individuals without this orchid as grey dots. Ellipses envelop 90 % of all tree individuals hosting *R. retusa*, respectively not hosting it. The ellipses only overlap a bit; that means the orchid is depending strongly on the indicated site conditions. Site conditions are: Host bark pH, sunlight intensity, exposure to wind, bark rugosity, land use intensities, altitude, host height and dbh, and traffic.

The distribution pattern and microhabitat of *R. retusa*, as characteristics of host species (host bark pH, bark water holding capacity, bark rugosity, and sun light intensity) in different land use types are shown in this publication. *R. Retusa* was found not to be a host-specific orchid species because it was located in a wide range of host tree species. However, *Ficus religiosa* was the most common host species. To a certain degree *R. retusa* preferred rough bark with a pH around 6.5 and bark with a wide range of water holding capacity.

The paper concludes that groups of host tree species function similar to forest habitat. Forest patches and parks are well suitable habitats for several orchid species in urban areas in the Himalayas. Such forest patches and parks are the habitats for certain native tree species (mainly *Alnus nepalensis*, *Ficus religiosa*, and *Schima wallichii*). To improve the population size of *R. retusa* in urban areas existing native host trees (should be conserved and also planted in areas where the orchid species are recently missing.

Candidates own contributions

- Idea, data collection and analysis as well as writing of the manuscript
- Improvement regarding method, analysis and writing with co-author

Micro-site conditions of epiphytic orchids in a human impact gradient in Kathmandu Valley, Nepal

Yagya Prasad ADHIKARI, Anton FISCHER, Hagen Siegfried FISCHER

Geobotany, Department of Ecology and Ecosystem Management,
Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, D- 85354 Freising, Germany

This manuscript was published in

Journal of Mountain Science (2012) **9:** 331–342.
DOI: 10.1007/s11629-009-2262-1

This paper focused on the human impact affecting the distribution of epiphytic orchids in connection with the micro-site conditions. We separated ten types of land-use forms in the study area. These types were transferred into five land-use intensities based on percentage of host tree coverage: from very low (natural forest; national park), low (remnant forest patches in the city), and intermediate (small patches of trees, buildings, infrastructure, and agriculture intermixed) to strong (single tree stand in agriculture land), and very strong (single tree stand in densely settled urban areas). Subsets of points were chosen from these categories. The richness and abundances of epiphytic orchids were different in different human impact categories. Host bark pH (fig. 4; published in Adhikari et al. 2012a), host bark rugosity, host sun light intensity, and host exposure to wind in different human impact categories were analysed.

Significance levels of host dbh in different human impact categories are presented (see table 3; Adhikari et al. 2012a). Species richness and diversity within the very low human impact category were significantly higher than in other land use categories. The remaining forest patches as well as the original forest in the national park were the best suitable habitats for epiphytic orchids.

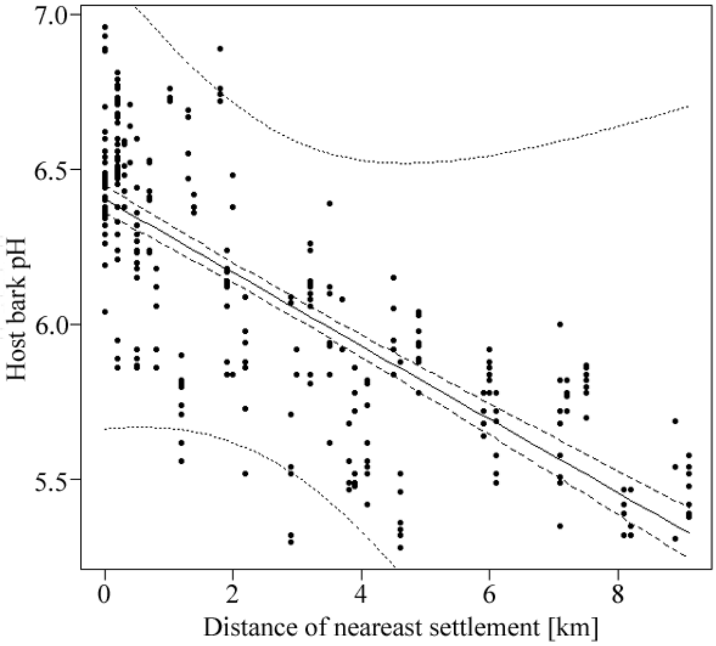

Fig. 4 Mean host bark pH in distance of the nearest settlement in the sample points.

The paper concludes: (i) Remaining natural forest stands in settled areas should be conserved; they offer suitable microsites for epiphytic orchids and can be used as centres for spreading, (ii) Groups of host trees as well as single host trees as small "ecological island" habitats for epiphytic orchids, and as stepping stones between larger forest patches should be protected. (iii) The best suitable native tree species which offer the best micro-site conditions (e.g. *Ficus religiosa*, *Schima wallichii*, *Alnus nepalensis*, and *Rhododendron arboreum*) not only as single trees but in groups, developing some forest habitats for epiphytic orchids as "future host trees" should be planted. (iv) Finally, mixtures of different host tree species should be used to offer a set of different micro-habitats for epiphytic communities.

Therefore, groups of native trees in the parks, temple complexes, and religious sites as well as single isolated native trees are working as small ecological island habitats and as stepping stones between larger forest patches. They represent suitable habitat for several native epiphytic orchid species.

Candidates own contributions

- Idea, data collection as well as writing of the manuscript
- Analysis collaboration with Dr. H.S. Fischer
- Finalized the paper consulting with co-authors

Host tree utilization by epiphytic orchids in different land-use intensities in Kathmandu Valley, Nepal

Yagya Prasad Adhikari • Hagen Siegfried Fischer • Anton Fischer

Geobotany, Department of Ecology and Ecosystem Management,
Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, D- 85354 Freising, Germany

This manuscript was published in

Plant Ecology (2012) **213:** 1393-1412.
DOI 10.1007/s11258-012-0099-0

In this paper we focused on available host trees utilized by epiphytic orchid species in different land-use intensities in Kathmandu Valley and their characteristics. To analyse the orchid diversity and distribution in a gradient of land-use intensities, subsets of points from these land-use intensities were chosen. 16 points of intensities were categorized “VL” (very low) and “I” (intermediate). 21 points were from “S” (strong) and “L” (low) and 22 points were from “VS” (very strong). To analyse the presence of orchid species for host species the expected frequencies of the occurrence were calculated. To compensate the effect of sample size, sample-based rarefaction curves were calculated (fig. 4; published Adhikari et al. 2012b).

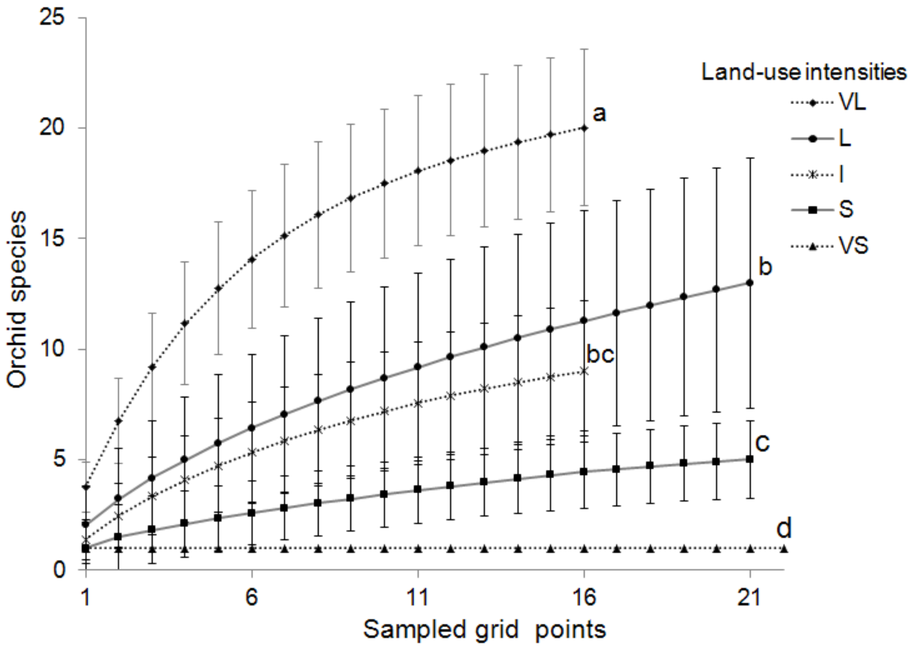

Fig. 4 Orchid species accumulation curves (sample-based rarefaction) within grid points of different land-use intensities; different letters indicate significant differences (p\0.05) between land-use intensities as derived from confidence intervals following Austin and Hux (2002).

Regarding host species, the result showed that some orchid species clearly prefer certain native species: *Schima wallichii, Castanopsis indica,* and *Rhododendron arboreum.* These species harbour more epiphytic orchid species in proportion of host individuals under different land-use intensities, thus being more suitable hosts. The dependence of orchid abundance on land use intensity and host tree characteristics was tested by using a generalized linear model (GLM). The final selected model for epiphytic orchid species richness among the analysed site condition was land-use + host + dbh + rugosity + exposure. Based on this model the result showed that the variables (i) land-use intensities, (ii) host species and (iii) host characteristics (dbh, bark rugosity, and exposure to wind) significantly influenced abundance of epiphytic orchids. For example, the hosts bark pH significantly increased towards higher human impact, showing significant differences between all intensities. However, epiphytic orchid species richness was greatly affected by land use intensity along with host characteristics i.e. group of analysed site conditions along with land use more effective than land use alone.

This paper concludes that the highest epiphytic orchid diversity can be found in close-to-natural forests as expected. Nevertheless, native orchids also occur under strong human impact. The large and /or old host trees are the best suitable orchid hosts. Native host tree species host many of native epiphytic orchids. This paper also suggests that a combination of native trees and species that are highly accepted by people (e.g. *Ficus religiosa*) in cities should be the focus of epiphytic orchid protection in the future. Urban planning in this subtropical region in the future should consider a collection of native species out of the original forest for environmental improvement as well as to protect the natural diversity of epiphytes.

Candidates own contributions

- Idea, data collection as well as writing of the manuscript
- Analysis collaboration with Dr. H.S. Fischer
- Finalized the paper consulting with co-authors

Manuscript

Conservation and sustainable utilization perspectives for epiphytic orchids in the Himalayas

YAGYA PRASAD ADHIKARI[1]*, ANTON FISCHER[1], STEPHAN PAULEIT[2] , TAMARA TICKTIN [3]

[1]Geobotany, Ecology and Ecosystem Management, Technische Universität München
Hans-Carl-von-Carlowitz-Platz 2, D- 85354 Freising, Germany
[2]Strategic Landscape Planning and Management, Ecology and Ecosystem Management, Technische Universität München Emil-Ramann-Str. 6, D-85354 Freising
[3]Botany Department, University of Hawaii at Manoa, 3190 Maile Way, Honolulu, HI 96822, U.S.A.
* E-mail: yadhikari25@gmail.com

This manuscript submitted to
Conservation Biology

In this paper we synthesised the knowledge gained from the previous three publications on human influence on populations of epiphytic orchids. The knowledge of epiphytic orchids micro-habitat requirements supports the development of strategies for their conservation in urbanising areas. A land use gradient from very low (unmanaged forest e.g. national park), low (remnant forest patches), intermediate (mosaic of all land use intensities) to strong (agricultural land) and very strong (highly settled areas i.e. city centre), was taken in Kathmandu valley (Nepal) in the central Himalayas, as an example for subtropical forests. Based on distribution pattern of epiphytic orchids, their micro-site conditions, host trees and their characteristics, and land-use intensities it is suggested that the conservation of epiphytic orchids has to deal with the following three aspects: (i) the elements that should be protected, (ii) the activities that should be carried out to protect valuable elements, and (iii) the socio-economic background of conservation (fig.5). This paper focused on socio-economic aspects in the sustainable conservation approach of epiphytes. Sustainable conservation of epiphytic orchids in the Kathmandu Valley and elsewhere will only be successful if it can be linked to the socio-economic system. In this paper we projected a planning scheme for epiphytes conservation in urban areas in the tropics and subtropics. At the end the different variables of micro-site conditions and land use intensities that help to develop strategies for the conservation of epiphytic species were discussed.

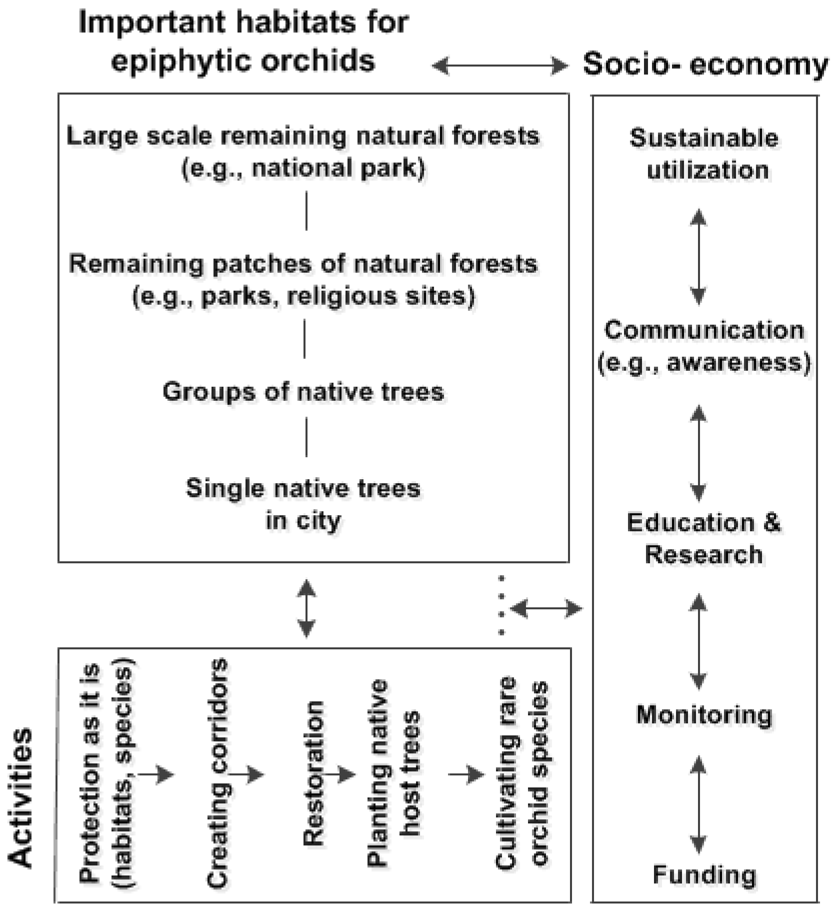

Fig. 5 Key elements for conservation of epiphytes in subtropics

This paper concludes that the remnants of natural habitats are crucial for the conservation of epiphytic orchid's communities; groups of native trees in urban settings can still serve as stepping stones. Proposed key stones of management concept for protection and sustainable utilization are essential for the long-term conservation of the high epiphytic diversity in Himalayas and elsewhere. Finally, habitats with a mixture of mature trees of native species are suitable and essential for conservation of large, viable populations of epiphytic orchids in densely settled areas in tropics and subtropics.

Candidates own contributions

- Idea (Adhikari and Fischer), writing of the manuscript
- Finalized the paper consulting with co-authors

4. Discussion and message of publications

Epiphytic orchids are common in the tropics and subtropics, and both urbanisation and land use intensification are expanding strongly. Epiphytes generally and also epiphytic orchids are decreasing in population numbers and densities. Epiphytes habitats are also becoming more and more destroyed or fragmented. Is this a one way process? Or are there certain possibilities to realise a long-lasting protection of at least a certain portion of epiphytic orchids also in intensively used (intense forestry, conversion of forest land into agricultural land, intensive urbanisation) areas?

We used a systematic and stratified systematic sampling strategy for the selection of sampling points within the study area with 156 grid points in Kathmandu valley across a land-use intensity gradient (national park to urbanised city area). Geographical Information System (GIS) and remote sensing were used for classification of land-use types. Kathmandu Valley was selected to analyse these possibilities because: i) the valley and its surroundings areas are naturally covered with evergreen broad leaved forest, ii) this area is a good habitat for a rich epiphytic orchids flora, iii) it is one of the most settled areas in Nepal, and iv) the urbanisation is spreading continuously. The set of methodologies of previous work on epiphytic communities in different parts of the world is manifold. For example, Laube and Zotz (2006) took three tree species to check host-specify relation in a Panamanian lowland forest. Callaway et al. (2002) selected two epiphytic species (*Tillandsia usneoides* and *Polypodium polypodioides*) and ten host tree species in a coastal plain forest in the south eastern United States to investigate mechanisms for species-specific interactions. Hirata et al. (2008) set up a permanent 4-ha plot (200 m × 200 m) to study host trait preferences and distribution of vascular epiphytes on a north to northwest-facing slope on Mt. Omori in Japan. Similarly, Wolf et al. (2009) proposed a protocol for sampling vascular epiphyte richness and abundance based on plot less basis. - In our study we used the grid net system within the whole landscape with a gradient (from very low human impact to very strong human impact i.e. densely settled area) not one line of landscape but every direction of landscape in a regular grid net (1.5 km × 1.5 km).

Indeed we could show that not all epiphytic orchid species can only life in forest ecosystems. As an example *R. retusa* is able to also live in the city centre (densely settled area), as long as "*suitable*" host trees exist. What does "*suitable*" mean? Host trees must have a certain size which means usually a certain age. Old trees are better hosts for epiphytic orchids than younger ones because the larger the surface area of the host, the larger the area for colonization and higher the possibilities for epiphyte seed to contact a host. Furthermore, the older the host the more time it has been exposed, thus increasing the chances of epiphyte seed contact (Migenis and Ackerman 1993). In the study area for example, old *Ficus religiosa* trees in city centre, parks, and temple complexes are suitable for *R. retusa*. Some orchids have no special requirements on the micro-habitat where they are living, especially regarding tree bark characteristics. Others prefer trees with rough bark because of its better logging seed and water storage capacity. Bark with high water holding capacity may improve the performance of epiphytic plants (Callaway et al. 2002). For our study area it was shown which orchids depended on certain tree species and which required only a certain host tree to live on it.

For future landscape management in respect of protecting epiphyte communities in intensively used and/or urbanized areas this means firstly existing host trees need to be protected, but it also planting new trees that may function as hosts for epiphytic orchids when the old trees have been died ("trees for the future"). If planting trees the species as well as the group size and character can be arranged. Tree species for such plantings should be selected according the preference of certain epiphytic orchids. It is also important that local people accept the trees guaranteeing that they may grow to an old age. Some species have a very positive image, e.g. *Ficus religiosa*, as a holy tree in Hindu and Buddhism religion. Such species should be preferred. Another aspect is that the species should be native. As long as native tree species have nice flowers, produce edible seeds, and have a nice shape, they can easily become mature in the local environment as well as more likely to accept by locals as "their own" trees. If trees are planted there is an option to decide how to plant them. For example, located next to an old tree to replace its host tree function in the future; to plant groups of trees to establish something like forest patch surrogate in the park of cities or to select several instead of only one species again to come closer to a forest situation is essential.

If such aspects are included in modern land-use planning and in urban planning, several epiphytic orchids will have a chance to survive in such areas. Such management cannot stop biodiversity erosion totally, but can help to reduce the degradation process.

The decreasing order of different land use intensities as habitats for epiphytic orchids was: natural habitats (national park), remnant forest patches, mosaic land (mixture of all land use types), agriculture land and isolated tree species in city area. The land-use intensity along with host tree characteristics improved the GLM model than land-use alone. Thus it is clear that the group of analysed site conditions for epiphytic orchids as well as the host characteristics along with land use intensity (land-use + host + dbh + rugosity + exposure) are the important factors influencing epiphytic orchid species richness in the study area. The study was conducted in a certain subtropical environment meaning the results, e.g. which tree species is a good host for many epiphytic orchid species, have only local relevance; the general outcomes, however, are relevant for many agricultural and urban areas in subtropical and tropical region across the world.

Therefore, the existing different habitats of epiphytic orchids in subtropical environment suggests that even small remnants of isolated trees in the city, parks, and temple complexes in tropics and subtropics might help to preserve an important part of epiphytic orchids of these areas.

5. Conclusions

Epiphytes are a suitable model group for studying the anthropogenic disturbances on forest-dwelling life forms. Forest fragments, isolated trees (stepping stones for epiphytic communities), and secondary forests harbour a considerable part of the regional epiphyte flora, which indicates the conservation value of these forest remnants. Nevertheless, epiphyte assemblages on isolated trees gradually become impoverished. Thus their potential for epiphyte conservation is temporally limited. Isolated remnant forest patches in the city, managed and unmanaged forest in and around urban areas are therefore essential for the long-term conservation of the high epiphyte diversity of the Himalayas. Some remnant forest patches and old-growth remnant trees (old trees are not only crucial for those epiphytes but also may serve as a nearby seed source that facilitates the recruitment in the regenerating forest) in settled areas, and suitable micro-climate with available host species are likely to maintain the majority of habitats of epiphytic orchids. The protection of trees, e.g. *Ficus religiosa*, in religious complexes, isolated single native trees, riparian ecosystems especially with native species, mosaic of different land use intensities, remnant isolated forests, and secondary forests around the urban areas may be a realistic opportunity for epiphyte diversity conservation in urbanising tropical and subtropical landscapes, at least for small-sized flagship organisms such as epiphytes.

In order to protect epiphytic orchid diversity, it is necessary to establish corridors by planting native suitable host trees and also synchronizing between primary remnant forests and orchid rich areas in Himalayas. Monitoring of the species population should be part of a management plan for sustainable use e.g. *Cymbidium* and *Dendrobium* species, which are highly endangered in China due to over collecting for the horticultural trade and traditional medicine market (Cameron 2010). Selective collection may conserve and facilitate the restoration of epiphyte numbers and diversity locally. It can however, not safeguard epiphyte diversity on a regional scale. The sustainable use of epiphytes as an alternative non-timber forest product will contribute to community economic development and conservation of both the epiphytes and their hosts. Therefore, there is need for applying conservation practices in the area where epiphytes play ecological roles for canopy of subtropical regions. Considering a threat to orchid populations because of the many anthropogenic activities, it is necessary to carry out scientific research to gain more knowledge about population dynamic of the existing species and needs for their long-term conservation in future.

6. Summary (Zusammenfassung)

This dissertation explored the relationships between distribution of epiphytic orchids in relation to habitat and host tree characteristics on a gradient of different land-use intensities in Kathmandu Valley to support development of conservation management approaches. Firstly, this thesis started with distribution pattern of *Rhynchostylis retusa*, the most common orchid species in urban areas. Secondly, the micro-site conditions of the epiphytic orchids in a human impact gradient in Kathmandu Valley were analysed. Then different host trees and their characteristics under different land-use intensities were analysed. Finally, all results and existing knowledge were used to develop conservation practices for epiphytic communities in tropics and subtropics. This is the first work to include different land-use types as habitats of epiphytes at a single site, compare different micro-site conditions of epiphytic orchids, and develop a management plan for protection of epiphytic community in tropics and subtropics.

Diese Studie untersucht die Beziehung zwischen epiphytischen Orchideen und den von ihnen benötigten Standortbedingungen am Stamm und in der Krone von Trägerbäumen in einem Gradienten zunehmender Landnutzungsintensität vom naturnahen Wald (z.B. geschützt in einem Nationalpark) über den agrarisch genutzten Raum mit einzelnen Baumgruppen bis hin zum dicht besiedelten Stadtzentrum mit nur wenigen verbliebenen Einzelbäumen am Beispiel des Kathmandu-Tales in Nepal. Ziel ist es, auf der Basis der gefundenen Beziehungen generell für die feuchten Tropen und Subtropen gültige Empfehlungen für einen nachhaltigen Schutz epiphytischer Orchideen auch im Kulturland bis hin zu den Zentren städtischen Agglomerationen abzuleiten.

Analysiert werden eingangs die Verbreitungsmuster der epiphytishen Orchidee *Rhynchostylis retusa*, der häufigsten Art in städtischen Bereich des Untersuchungsgebietes, die aber natürlich auch in naturnahmen Bereichen nicht fehlt. Dann werden die kleinstandörtlichen Bedingungen an den Wuchsplätzen epiphytischer Orchideen untersucht sowie ihre Änderung im Gradienten zunehmnder anthropogener Einflussnahme. Im nächsten Schritt wird die Eignung verschiedener Trägerbäume für verschiedene epiphytische Orchideen untersucht. Schließlich werden aus diesen Resultaten Empfehlungen für den Schutz epiphytisfcher Orchideen im genutzten Landschaften gegeben, die nicht nur für das Untersuchungsgebiet gelten sondern auf weite Gebiete der Tropen und Subtropen übertragbar sind.

Diese Studie ist die erste, die bei der Analyse des Lebensraums epiphytischer Orchideen den landwirtschaftlich genutzten und den besiedelten Bereich im Fokusm haben, Landschaftsteile, die heutzutage flächig immer bedeutsamer werden und damit auch neue Anforderungen an den Artenschutz stellen.

References

Acebey, A., T. Kromer, B. L. Maass, and M. Kessler. 2010. Ecoregional distribution of potentially useful species of Araceae and Bromeliaceae as non-timber forest products in Bolivia. Biodiversity and Conservation **19:**2553–2564.

Ackerman, J. D., A. Sabat, and J. K. Zimmerman. 1996. Seedling establishment in an epiphytic orchid: an experimental study of seed limitation. Oecologia **106:**192-198.

Acharaya, K. P., O. R. Vetaas, and H. J. B. Birks. 2011. Orchid species richness along Himalayan elevational gradients. Journal of Biogeography **38:**1821-1833.

Adhikari, Y. P., and A. Fischer. 2011. Distribution pattern of the epiphytic orchid Rhynchostylis retusa under strong human influence in Kathmandu valley, Nepal. Botanica Orientalis – Journal of Plant Science **8:**90–99.

Adhikari, Y. P., H. S. Fischer, and A. Fischer. 2012a. Micro-site conditions of epiphytic orchids in a human impact gradient in Kathmandu valley, Nepal. Journal of Mountain Science **29:**331-342, DOI: 10.1007/s11629-009-2262-1.

Adhikari, Y. P., H. S. Fischer, and A. Fischer. 2012b. Host tree utilization by epiphytic orchids in different land-use intensities in Kathmandu valley, Nepal. Plant Ecology **213:**1393-1412, DOI: 10.1007/s11258-012-0099-0.

Austin, P. C., and J. E. Hux. 2002. A brief note on overlapping confidence intervals. J Vasc Surg **36:**194–195.

Benzing, D. H.1990. Vascular epiphytes general biology and related biota. Cambridge University Press, Cambridge.

Barthlott, W., V. S. Neuerburg, J. Nieder, and S. Engwald. 2001. Diversity and abundance of vascular epiphytes: a comparison of secondary vegetation and primary montane rain forest in the Venezuelan Andes. Plant Ecology **152:**145–156.

Callaway, R. M., K. O. Reinhart, G. W. Moore, D. J. Moore, and S. C. Pennings. 2002. Epiphyte host preferences and host traits: mechanisms for species-specific interactions. Oecologia **132:**221–230.

Cameron, K. M. 2010. On the Value of Taxonomy, Phylogeny, and Systematics to Orchid Conservation: Implications for China’s Yachang Orchid Reserve. Botanical Review. **76:**165–173.

Cardelus, C. L., and M. C. Mack. 2010. The nutrient status of epiphytes and their host trees along an elevational gradient in Costa Rica. Plant ecology **207:**25-37.

Chaudhary, R. P. 1998. Biodiversity in Nepal: status and conservation. S. Devi, Saharanpur, India & Tecpress Books, Bangkok, Thailand.

Chen, J., H. Wang, and S. X. Guo. 2012. Isolation and identification of endophytic and mycorrhizal fungi from seeds and roots of Dendrobium (Orchidaceae). Mycorrhiza **22:**297-307.

Frei, J. K., and C. H. Dodson. 1972. The chemical effect of certain bark substrates on the germination and early growth of epiphytic orchids. Bull Torrey Bot Club **99:**301–307.

Gentry, A. H., and C. H. Dodson. 1987. Diversity and biogeography of neotropical vascular epiphytes. Annals of the Missouri Botanical Garden **74:**205-233.

Hammer, Ø., D. A. T. Harper, and P. D. Ryan. 2001. PAST: paleontological statistics software package for education and data analysis. Palaeontol Electron **4:**9

Laube, S., and G. Zotz. 2006. Neither host-specific nor random: vascular epiphytes on three tree species in a Panamanian lowland forest. Ann Bot **97:**1103–1114.

Neitlich, P. N., and B. McCune. 1997. Hotspots of epiphytic lichen diversity in two young managed forests. Conservation Biology **11:**172-182.

Hirata, A., T. Kamijo, and S. Saito. 2009. Host trait preferences and distribution of vascular epiphytes in a warm-temperate forest. Plant Ecol **201:**247–254.

Koirala, P. N., D. Pyakurel, and K. Gurung. 2010. Orchids in Rolpa district of Western Nepal: Documentation, stock, trade and conservation. Banko Janakari **20:**3-13.

Migenis, L. E., and J. D. Ackerman. 1993. Orchid-phorophyte relationships in a forest watershed in Puerto Rico. Journal of Tropical Ecology **9:**231–240.

Mitchell, A.W., K. Secoy, and T. Jackson. 2002. The global canopy handbook. Techniques of access and study in the forest roof. Global Canopy Programme, Oxford.

Nadkarni, N. M. 1994. Diversity of species and interactions in the upper tree canopy of forest ecosystems. American Zoology **34:**70-78.

Nieder, J. P., and G. Michaloud. 2001. Epiphytes and their contribution to canopy diversity. Plant Ecol **153:**51-63.

Pant, P. R., and D. Dangol. 2009. Kathmandu valley Profile, Briefing Paper: Governance and Infrastructure Development Challenges in the Kathmandu valley. Workshop: 11 – 13 February 2009 Kathmandu Metropolitan City, Nepal pp 15.

R Development Core Team (2010) R: a language and environment for statistical computing. URL: http://www.Rproject. org/. Vienna.

Song, L., W. Y. Liu, W. Z. Ma, and Z. H. Tan. 2011. Bole epiphytic bryophytes on *Lithocarpus xylocarpus* (Kurz) Markgr. in the Ailao Mountains. SW China Ecol Res **26:**351–363.

Weston, P. H., A. J. Perkins, and T. J. Entwisle. 2005. More than symbioses: orchid ecology, with examples from the Sydney region. *Cunninghamia*, **9:**1–1

Wolf, J. H. D. 2005. The response of epiphytes to anthropogenic disturbance of pine-oak forests in the highlands of Chiapas, Mexico. Forest Ecology and Management **212:**376–393.

Wolf, J. H. D., S. R. Gradstein, and N. M. Nadkarni. 2009. A protocol for sampling vascular epiphyte richness and abundance. Journal of Tropical Ecology **25:**107–121.

Zurick, D., J. Pacheco, B. Shrestha, and B. Bajracharya. 2005. Atlas of the Himalaya. International Centre for Integrated Mountain Development (ICIMOD) pp 17–90.

Acknowledgements

First and foremost I want to thank my supervisor Prof. Dr. Anton Fischer, Geobotany, TUM. This dissertation could not have been written without him, who not only served as my supervisor but also encouraged and challenged me throughout my academic career. He never accepted less than my best efforts. It has been an honour to be his Ph.D. student. I appreciate all his contributions of time, ideas, and enthusiasm to make my Ph.D. experience productive and stimulating.

I am also extremely indebted to my second supervisor Prof. Dr. Stephan Pauleit, chief of Strategic Landscape Planning and Management, TUM for his valuable advice, constructive criticism and extensive discussions around my work. I deserve my sincere expression of thanks to Dr. Hagen S. Fischer, Geobotany for helping me in statistical problems. The members of the Geobotany group have contributed greatly to my personal and professional time at TUM, especially, my good friends Markus Zaplata, Matthias Jantsch and Alexey Zharov for their support, and for creating a pleasant atmosphere for me while working there. The group has been a source of friendships as well as good advice and collaboration.

It's my fortune to gratefully acknowledge the support of some special individuals. Words fail to express my appreciation to Dr. Axel Gruppe/TUM for teaching and providing necessary tools for the tree climbing technique. I would like to deserve special thanks to Prof. Dr. Axel Göttlein/TUM for teaching me the right way of bark pH measurement. Similarly, my special thanks to A. Sharma and P. Bhattarai, members of Canopy and Environment Conservation Nepal for their help during field work. It is also a pleasure to mention my brother Dhaka M. Adhikari for his help in remote sensing and GIS mapping and Dr. S. E. Zytynska for her comments and constructive criticism. I am indebted to Technische Universität München Graduate School and Geobotany for research grants.

Especially, I would like to thank my family for all their love and encouragement. Most especially to my parents, who raised me with a love of science and supported me in all my pursuits, my wife Kalpana, my daughters Sonami and Sumani. Words alone cannot express what I owe them for their encouragement, and whose patient love enabled me to complete this dissertation. Special thanks to my wife for her faithful support during research, feeding me and taking me to work hours.

Last but not least, it is a pleasant task to express my thanks to all those who contributed in many ways to the success of this study and made it an unforgettable academic experience for me.

Thank you!

Yagya Prasad Adhikari
TUM, March 2013

Eidesstattliche Erklärung

Ich erkläre an Eides statt, dass ich die bei der
Fakultät Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt der TUM zur Promotionsprüfung vorgelegte Arbeit mit dem Titel:
Distribution pattern, micro-site conditions, host tree characteristics and utilization of epiphytic orchids in the central Himalayas
am Fachgebiet Geobotanik

unter der Anleitung und Betreuung durch Prof. Dr. Anton Fischer ohne sonstige Hilfe erstellt und bei der Abfassung nur die gemäß § 6 Abs. 6 und 7 Satz 2
angegebenen Hilfsmittel benutzt habe.

[X] Ich habe keine Organisation eingeschaltet, die gegen Entgelt Betreuerinnen und Betreuer für die Anfertigung von Dissertationen sucht, oder die mir obliegenden Pflichten hinsichtlich der Prüfungsleistungen für mich ganz oder teilweise erledigt.

[X] Ich habe die Dissertation in dieser oder ähnlicher Form in keinem anderen Prüfungsverfahren als Prüfungsleistung vorgelegt.

[X] Ich habe den angestrebten Doktorgrad noch nicht erworben und bin nicht in einem früheren Promotionsverfahren für den angestrebten Doktorgrad endgültig gescheitert.

Die öffentlich zugängliche Promotionsordnung der TUM ist mir bekannt, insbesondere habe ich die Bedeutung von § 28 (Nichtigkeit der Promotion) und § 29 (Entzug des Doktorgrades) zur Kenntnis genommen. Ich bin mir der Konsequenzen einer falschen Eidesstattlichen Erklärung bewusst.

Mit der Aufnahme meiner personenbezogenen Daten in die Alumni-Datei bei der TUM bin ich

[X] einverstanden, [ ] nicht einverstanden.

Freising, 20.03.2013.............................
(Ort, Datum, Unterschrift)

Attachment of individual publications

Adhikari, Y. P., and A. Fischer. 2011. Distribution pattern of the epiphytic orchid *Rhynchostylis retusa* under strong human influence in Kathmandu valley, Nepal. Botanica Orientalis – Journal of Plant Science **8:**90–99.
DOI: http://dx.doi.org/10.3126/botor.v8i0.5956

Adhikari, Y. P., H. S. Fischer, and A. Fischer. 2012a. Micro-site conditions of epiphytic orchids in a human impact gradient in Kathmandu valley, Nepal. Journal of Mountain Science **29:**331-342.
DOI: 10.1007/s11629-009-2262-1

Adhikari, Y. P., H. S. Fischer, and A. Fischer. 2012b. Host tree utilization by epiphytic orchids in different land-use intensities in Kathmandu valley, Nepal. Plant Ecology **213:**1393-1412.
DOI: 10.1007/s11258-012-0099-0

Adhikari, Y. P., A. Fischer, S. Pauleit and T. Ticktin, Manuscript. Conservation and sustainable utilization perspectives for epiphytic orchids in the Himalayas submitted to Conservation Biology.