Himalayan
JOURNAL OF SCIENCES

PEER REVIEWED JOURNAL OF SCIENCE | Volume 4 • Issue 6 • 2007 | www.himjsci.com | ISSN 1727 5210

- How to create conservation area networks for the Indian region
- Ancient lake in Kathmandu basin
- Retreating glaciers and expanding moraine-dammed lakes in the Himalayas
- E-conference sheds light on negligent management of mountain hazards

INSIDE FRONT COVER

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Thematic Focus Schedule

For the next issue (Vol 5, Issue 8; Sept 2008), “Himalayan Journal of Sciences” will have a double focus:

- Primary: Medical science and technology (including traditional medicine) in the Himalayan region
- Secondary: Agricultural adjustments to climate change

We will have two online e-conferences to discuss these topics in August 2008, and the wrap-up papers will be published. We also invite articles (feature, research, book review) on these themes.

Please note that HJS will also include articles from other fields, but we will give priority to the focal topics.

Subsequent HJS issues will have the following focus priorities:

- Primary: Major mountain infrastructure (dams, roads, bridges, airstrips)
- Secondary: Energy challenges and opportunities

- Primary: Lepidoptera (butterflies and moths)
- Secondary: Juniper and/or rhododendron

- Primary: Computers, Internet and globalization
- Secondary: Gender equity and other issues

The extended schedule (beyond 2008) is provisional. We seek you feedback on these and other focal areas. Please visit our Web site for updates and discussion.

www.himjsci.com

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Cover image: retreating glaciers in the Himalayas; story p 21

HIMALAYAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE HimAAS

Published by
Himalayan Association for the Advancement of Science
Lalitpur, Nepal
GPO Box No. 2838

Editorial Policy

Himalayan Journal of Sciences (ISSN 1727 5210 print issue and 1727 5229 online) is a peer-reviewed annual multi-disciplinary journal. HJS invites authors to share their expertise, discoveries and speculations.

Mission Statement: HJS is dedicated to the promotion of scientific research, informed discourse, and enlightened stewardship of natural and cultural systems in the Himalayan region.

Scope: The problems and opportunities confronting the Himalayan region are so broad and interrelated as to resist treatment within traditional academic disciplines; accordingly, the Himalayan Journal of Sciences publishes articles of scientific merit based on investigations in all fields of enquiry pertinent to the natural and cultural systems of the Himalayan region.

Contribution Categories: HJS publishes works pertinent to the scope of the journal in the following categories: a) Research papers: Report on original research; b) Review papers: Thorough account of current developments and trajectories in a given field; c) Articles: Narrowly-focused account of current development in a given field; d) Editorial: Opinionated essay on an issue of public interest; e) Essay: Similar to editorial but longer and more comprehensive; may include tables and figures; f) Commentary and Correspondence: Persuasive and informed commentary on any topical issues or on articles published in prior issues of the journal; g) Policy and development: Usually a hybrid of opinion and review papers covering a broad topic with rigorous analysis of the issue and bearing on policies relating to science and/or development. The focus may be rather specific, and it may contain primary data or new model of substantial significance; h) Resource review: Evaluation of books, websites, CD-ROMs, and other resources; i) Publication preview: Description of forthcoming books; j) Announcement: Notice of forthcoming conferences, seminars, workshops, and other events.

Guide to Authors

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Acknowledgments

We would like to acknowledge the logistic support (office space, computers, furniture) of International Center for Integrated Mountain Development (ICIMOD). To all our reviewers and authors, for your patience and persistence: Thank you!

Special Acknowledgments

In the business of dissemination of new knowledge relevant to Himalaya, we are assisted in our publication and pre-publication work by certain commercial collaborators. By offering HJS generous discounts (and in some cases waiving all fees), they have significantly reduced our publication costs. We have tried to reciprocate in a small measure by including notices of their services. ScanPro, WordScape and Jagadamba Press: Thank you for standing with us in this venture!

Cover design: Hari Marasini, WordScape Crossmedia Communication, Tripureshwor, Kathmandu, Tel: 4229825
Printed at: Jagadamba Press, Hattiban, Lalitpur, Tel: 5547017, 5547018
Color separation: ScanPro, Pulchowk, Lalitpur, Tel: 5548861, 5551123, 5552335

Notice

- We were unable to publish our journal in 2006. To accommodate editors' time constraints, the publication schedule has been temporarily changed from half-yearly to annual.
- HJS does not bear any responsibility for the views expressed by authors in the journal.

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scientific information for the advancement of society

An open access database for Himalayan environmental management

Environmental management in the Himalayas requires creation of a database with collaborative public sharing of data

Sahotra Sarkar

From arid high terrain in the northwest, through the world's highest peaks in the mid-regions, to tropical wet forests in the southeast, the Himalayan region includes some of the most biologically diverse habitats on Earth as well as homes to a bewildering variety of cultures. During the last half-century it has increasingly become clear that though some parts of the region are ecologically fragile, while others remain relatively intact, all are facing the uncertain effects of climate change. Recent research has established, though not beyond controversy, that the popular model of catastrophic environmental degradation in the Himalayas due to overpopulation and deforestation has little empirical support: understanding the dynamics of environmental change requires attention to socio-political oppression, resource appropriation by outsiders, and other social factors (Ives 2006). Consequently, Himalayan environmental planning must be based on region-wide data on socio-economic structures besides the customary data on physical and biological features, including the geographical distribution of all data. Because ethically appropriate planning must accommodate the cultural diversity of the region, besides its biological and physical diversity, the data sets used must necessarily be both extensive and also have a sufficiently high resolution to support planning at the local level at which most diversity is manifested. A vast amount of data must be collected and analyzed.

Reliable analyses of environmental processes and dynamics on a regional scale require the availability and easy accessibility of relevant data from across the region. To understand the mechanisms behind environmental processes and dynamics so as to make accurate predictions of the future, we need adequate information on the physical, biological and socio-economic features of a region. In the Himalayan region we need to collect, collate, and provide public access to such data on a regional scale...

The purpose of this Editorial is to call for the collaborative creation of an open access database to help meet that challenge. The goal should be to provide free and reliable data sharing between researchers and planners throughout the region (and elsewhere) and to create a database that meets the strictest international standards for functionality. For biodiversity data, several such transnational databases exist (for instance, those maintained by the World Conservation Monitoring [http://www.unep-wcmc.org/] and NatureServe [http://www.natureserve.org/]) though they all provide sporadic coverage and are remarkably poor in Himalayan data.

Creating a dedicated Himalayan database will break new ground. But such a project has to be implemented carefully. Specifically, the database should conform to the following six principles:

- The database must be open access with public sharing of all data. We are living in an age of increased recognition that academic and intellectual exchange is not well served by proprietary attitudes towards data and software—witness the success of projects such as R, OpenBugs, and GenBank, to name just a few of the many successful open access initiatives. Increasingly journals are requiring software to be open access as a condition for publication. Throughout the world, the trend is towards the non-proprietary creation of intellectual products.
- The effort to create the database must be truly collaborative, drawing in researchers from all

the Himalayan regions. There have been many transnational efforts in the Himalayas in recent years (Wikramanayake et al. 2001, CEPF 2005, WWF and ICIMOD 2005) but coverage has not been uniform over the entire region. For instance, there has been less effort directed to Sikkim or Arunachal Pradesh than to many other parts of the Indian Himalayas and to Nepal. As the database gets developed, these biases must be corrected to ensure homogeneous coverage of all regions.

- All data must be geo-referenced and have their provenance recorded. This is the most important requirement that the database must satisfy. Almost all environmental planning today is spatial. Recording locational co-ordinates with GPS units has become technologically trivial and inexpensive and there is no reason not to record such data systematically in every project. Unfortunately there is at present very little high resolution geo-referenced biodiversity data for the Himalayas and this is a major impediment to scientific research. Almost none of the existing records in museums and other databases provide precise longitude-latitude co-ordinates. With respect to socio-economic data, all that often exists are summaries at the level of political units such as sub-divisions, districts, and provinces. This situation must be changed. It is equally important to record the method of collection of the data so that future researchers can independently assess the reliability of data sets and their appropriateness for their specific research needs.
- The database should be made available at several different mirror sites both within the Himalayan region and outside, wherever there is significant research and policy interest in the region. Several universities, research institutes and academies within the region, especially in China, India, and Nepal, as well as the International Centre for Integrated Mountain Development (ICIMOD) are natural host sites and should be brought into the discussion as the database is planned.
- The process of creating the database will require significant commitment to the information technology infrastructure of the host sites within the Himalayan region. Developing this infrastructure should be accompanied by relevant technology transfer and capacity building, especially the transfer of knowhow to young researchers from the Himalayan region. Collaborators from Northern institutions must make an explicit commitment to the training of local personnel, and this commitment must be monitored.
- Finally, care must be taken to ensure the proper design of the database so that eventual growth in size does not destroy functionality. The software must be stable. Database queries should receive fast answers. There must be variable ways of searching, for instance, based on taxonomic or geographical specifications. Data should be downloadable in a variety of formats. Contributors should be able to upload data and edit their own information easily following a straightforward protocol. There are many other such criteria and these should be discussed and correctly implemented from the outset.

...Analyses based on such data will both advance our understanding of regional environmental challenges and also let us assess the geopolitically convenient explanations of environmental problems that the countries and institutions in the region have long advocated. It is high time we create a collaborative open-access database that can receive public input and access to data while meeting international standard of functionality.

An example of a collaborative open access database is the Latin American Biodiversity Database (http://www.consnet.org/biodiversity/) which does not include socio-economic data. However, it is a helpful pointer to where to take efforts to initiate a database project for the Himalayas.

The expertise and technological and financial resources required to create such a database are not particularly daunting. However, for success, co-operation will be necessary from regional and international museums, herbaria, and other repositories of information from the region such as the Kew Gardens (http://www.kew.org/) and the California Academy of Sciences (http://www.calacademy.org/). Much of the traditional data stored in these repositories may be useless for most planning purposes because they are not georeferenced. However, they may still be valuable for historical analyses. Most importantly, the bulk of the data must come from individual researchers who must be brought into collaboration in all aspects of the project—including its design and management—so that everyone remains committed to the goals of data sharing and open access. There should be no doubt that such a project would be valuable and that it can be implemented—if there is the will.

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Road to ruin

Tough laws won't save poor nations' ecosystems until the impacts of developments are taken seriously

William Laurance

Dozens of Indonesians killed by landslides this spring have paid the price of unchecked development. Many other innocents in developing nations die each year as rampant illegal logging and deforestation denude steep hillsides, loosening soil and allowing heavy rains to create deadly deluges.

Such environmental perils are increasingly common across much of the world as native forests are fragmented, waterways polluted, and oceans over-harvested. The onslaught is especially alarming in the tropics, where an area of forest the size of 40 football fields is destroyed every minute. Thousands - perhaps millions - of species are at risk.

Yet remarkably, many developing nations have good laws to regulate development and protect their natural ecosystems. Indonesia, Brazil, Bolivia and the Democratic Republic of the Congo, for example, all have strong forestry codes and environmental laws. So why aren't they working?

A key problem is that environmental impact assessments (EIAs), required by law for most development projects, are often utterly inadequate. Nowhere is this clearer than in Brazilian Amazonia, which is yielding to the biggest expansion in paved highways in its history. By greatly increasing access to the heart of the Amazon, these highways are opening a Pandora's box of threats such as illegal logging, hunting, mining and land colonisation. But the EIAs for these new highways only evaluated the direct effects on the narrow strip of land being cleared for each road. None of the alarming indirect impacts that commonly follow highway construction were covered.

A similarly narrow evaluation is under way for the planned expansion of the Panama Canal, which will allow supertankers to travel the waterway. As less than 700 hectares of rainforest will be destroyed, everyone expects the project will get the green light. Yet this $5.2 billion scheme will have a profound impact on a nation as small as Panama. Increased land speculation, overheated development and growing demand for construction timber will put pressure on forests across the country. Even cursory consideration of the project's indirect effects reveals these issues.

In addition, many EIAs are laughably superficial. For example, a biological survey for a planned housing complex in Panama's suburban forests identified only 12 common bird species. A 2-hour census of the same area by experienced birdwatchers tallied 121, including several rare and threatened species. The project was approved despite scientists' warnings to the authorities of flaws in the study.

Why are EIAs often so poor? Firstly, they are usually paid for by the project backer, who pushes to ensure approval with minimum costs. In such a system, environmental firms that get projects accepted with few mitigation measures are in high demand, while those with a rigorous reputation are avoided.

Environmental impact assessments are often laughably superficial.

Secondly, government agencies that evaluate EIAs often fail to apply their own environmental rules. The process is also vulnerable to corruption, since government employees are often poorly paid while project backers have deep pockets and a large financial stake to protect. Even EIAs with glaring faults are sometimes approved.

Finally, it is rare for a project to be halted on environmental grounds because the burden of proof falls on those who oppose it, not those who favour it. A planned highway might sever a critical forest corridor, or open up a pristine valley to exploitation, but unless it can be shown that it would irreparably harm an endangered species or rare ecosystem, the road may be approved regardless. Fighting development projects takes considerable time, money and expertise, and this stacks the deck heavily against citizens and public-interest groups who often oppose risky developments.

What can be done to improve the situation? Increasing public awareness should help focus attention on the EIA process and its many weaknesses - including a dire need to evaluate both the direct and indirect impacts of major projects. Equally important is greater involvement by society and by environmental groups. Government agencies that approve or halt projects are often responsive to external pressure, and they rely on lobbying by conservationists to help balance development forces. If you want to help the global environment, supporting an active environmental group in a developing nation may be a key strategy.

Of course, serious flaws in EIAs are not confined to developing countries. The drafter of the US Environmental Protection Act, Lynton Caldwell, has often bemoaned the failure of EIAs to balance the needs of nature against human activities. But in developing nations, conservation interests are often less established, and pressures for exploitation are stronger and more immediate. Better environmental decision-making is crucial if we are to limit these growing threats to the natural world.

Reprinted with permission from *New Scientist*, issue 2607, 06 June 2007, page 25

William Laurance is a biologist at the Smithsonian Tropical Research Institute in Panama. His latest book is "Emerging Threats to Tropical Forests" (with Carlos Peres, University of Chicago Press, 2006).

Special announcement

Call for nominations: Sir Edmund Hillary Mountain Legacy Medal

For current Hillary Medal information, see www.HillaryMedal.org

The Sir Edmund Hillary Medal is sponsored by the Environment and Planning Program of The Royal Melbourne Institute of Technology University (www.rmit.edu.au)

Description of medal

The Sir Edmund Hillary Mountain Legacy Medal was initiated in 2003 both in order to recognize Sir Edmund's life-long commitment to the welfare of mountain people and their environment and also to encourage the continuing emulation of his example. Sir Edmund's contributions and the work of the foundations he founded or inspired in New Zealand, Canada, United States and Germany have resulted in the construction of some thirty schools, two airstrips, two hospitals and eleven village clinics as well as a reforestation program in Sagarmatha National Park. Authorized by Sir Edmund Hillary himself, the Sir Edmund Hillary Mountain Legacy Medal was initiated in 2003 by Mountain Legacy, a Nepalese NGO (www.mountainlegacy.org).

Nomination return date

Nominations and supporting material, whether submitted in hardcopy or electronic form, are due by midnight (Australian Eastern Daylight Time) on Friday, February 22, 2008.

Qualification criteria

The Sir Edmund Hillary Mountain Legacy Medal is awarded "for remarkable service in the conservation of culture and nature in remote mountainous regions."

- Nominees working in remote mountainous regions anywhere in the world are eligible.
- As the award is for both cultural and environmental conservation,nominees should be working in inhabited remote mountain regions.
- One purpose of this award is to draw attention to efforts that are in need of broader support; therefore nominees should be currently engaged in such a project.
- Nominations of third parties as well as self-nominations will be accepted.
- Hillary Medal recipients cannot be re-nominated; however, unsuccessful candidates may be re-nominated without prejudice.
- Two or more individuals may share a joint nomination if equal credit is due for the same project(s); however, in such a case only one medal will be awarded.
- The identities of nominators and of unsuccessful nominees shall remain confidential.

Former Sir Edmund Medal winners

2003: Husband and wife team of Michael Schmitz and Helen Cawley who for the previous decade had been working on keystone cultural and ecological projects in the Solu-Khumbu area of Nepal. Their work entailed assessing the requirements of the recently reconstructed Tengboche Monastery and implementing improvements including drinking water supply, sanitary facilities, porter lodge, accommodations for the monks, information center, clinic staffed by trained amchi (traditional Tibetan medicine specialist), reforestation, and conservation of endangered species.

Schmitz and Cawley also carried out the Thubten Chholing Monastery Development Project at the request of His Holiness Trulshik Rinpoche, one of the teachers of the Dalai Lama. This monastery houses more than 300 monks who sought refuge there after fleeing Chinese oppression in Tibet. The project entailed construction of a new large prayer hall, kitchen, dining hall, classrooms, printing press, library, water system, toilets and hydro-power station.

2006: Dr Alton C Byers, Director of Research and Education at the Mountain Institute based in Elkins, West Virginia. From 1993 to 1994 Byers worked with the local residents and the government of Nepal to establish the Makalu-Barun National Park and Conservation Area. From 1994 to 1996 he founded and directed programs in the Huascaran National Park, Peru. Between 1998 and 2000, Dr Byers directed the Appalachian Program and the 400-acre Spruce Knob Mountain Centre in West Virginia.

Byers' work has been instrumental in bringing awareness to the critical environmental damage that was occurring in the alpine meadow and sub alpine ecosystems with his project "Community-Based Conservation and Restoration of the Everest Alpine Zone Project". With support from the American Alpine Club and National Geographic Society this project has now become a Sherpa-directed program aimed at protecting and restoring the fragile ecosystems of the Khumbu that have been damaged by decades of under-regulated adventure tourism.

More information and nomination form

Contact: Dr Beau B Beza
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Acts of God are not the problem

Human negligence turns hazards into disasters

Seth Sicroff

Mountain tourism both increases the risks posed by mountain hazards and also provides the economic opportunity to effectively cope with those hazards. Salient points and recommendations from participants in "Mountain Hazards, Mountain Tourism" e-conference include:

- **Although climate change is increasing the likelihood of glacial lake outburst floods (GLOFs), we now have the scientific tools to monitor and quantify such hazards.**
- **Unfortunately, those tools are not being used on a regular basis. This increases the hazard of media sensationalism, which in turn increases the risk of serious economic damage as well as lost scientific credibility.**
- **Contrary to published reports, the hazard mitigation project at Tsho Rolpa in Rolwaling was left in an incomplete state and without provision for scientific monitoring; the lake still poses a great risk.**
- **More attention must be paid to the human component of mountain hazards. Ethnic cleansing programs such as the current disaster in Bhutan cause suffering and economic damage on a scale that beggars most natural events.**
- **A useful step toward the rational confrontation with all sorts of disasters (not just those that impact mountains) would be the conversion of King Gyanendra's palace into a Disaster Management University.**

This paper is a synthesis of an e-conference held on the Mountain Legacy listserv from Nov 7 to Dec 7, 2006. The discussion was originally intended as a precursor to a "face-to-face" event, The Rolwaling Conference: Mountain Hazards, Mountain Tourism, which was canceled due to lack of sufficient funding. The wrap-up is by no means comprehensive; we urge you to read the details in the archived discussion at www.econf.org.

The Rolwaling Conference was to have three interlocking agendas: a general theme (mountain hazards as they relate to mountain tourism), a specific geographic focus on Rolwaling Valley, and a logistical and conceptual roundtable on a proposed interdisciplinary research station to be established in Rolwaling Valley. The latter theme was omitted from the e-conference agenda.

Active participation in the e-conference was limited primarily to important presentations from three experts, plus ancillary discussion and commentary by a few other participants. A keynote presentation, "Fools rush in: A mountain dilemma", was contributed by Prof Jack D Ives, Carleton University, Ottawa, Canada. A second feature presentation was "Glacial hazard assessment and risk management: Lessons from Tsho Rolpa and new perspectives," by Professor John M Reynolds, Managing Director, Reynolds Geo-Sciences, Ltd (RGSL). Dr Janice Sacherer, an anthropologist with the University of Maryland University College Asia (Okinawa) contributed "Tsho Rolpa, GLOFs, and the Sherpas of Rolwaling Valley: A brief anthropological perspective."

Mountain tourism

Tourism has the potential to alleviate many problems in impoverished mountain areas. First, it offers economic opportunities that are greater and also less destructive than extractive industries (such as logging or hunting) and out-migration. Second, tourism generally entails the expansion of services deemed necessary for recreational comfort. Electricity, medical services, imported foods, warmer clothing, and other perquisites are eventually extended to host communities. In the same way, concern for the safety of tourists (as well as downstream infrastructure) can result in huge expenditures for the mitigation of hazards which would not likely be undertaken merely for the sake of those who live with them on a year-round basis.

The downside of tourism is dependency on a market that can collapse instantaneously and for reasons beyond the control of those involved in the tourism trade. Global and regional political instability, terrorism, and economic recession can all effectively quench people's taste for recreational travel. Real or perceived hazards at the remote destination site can result in a redirection of traffic that may last longer than the threat itself, whether or not the disaster materializes.

Mountain hazards

What exactly do we mean by "mountain hazards"? Normally we think of threats to human life and property that are posed by natural processes – generally by extreme events, often aggravated (or even caused) by human activity. Floods and mass wasting are the most familiar agents. But if we are thinking in terms of mitigation strategies, we should probably look at the entire range of "bad things" that happen in the mountains. In this context, Ives brings up the ongoing

Bhutanese "crimes against humanity," which have caused more suffering than nearly any other mountain disaster on record, and also pose a substantial threat of regional armed conflict. Of course, there are more commonplace disasters. For instance, the unavailability of modern medical services is arguably the cause of nearly every single death in remote areas. How do we assign priorities for hazard mitigation when the aggregate cost of ordinary flash floods during the monsoon probably exceeds anything we might attribute to a certifiable disaster such as a glacial lake outburst flood (GLOF)?

On the other hand, there is a danger of paralysis in the headlights of equity. "To do nothing unless the whole picture is addressed," Reynolds observes, "is unrealistic."

Mountain hazard #1: The media

Both Ives and Reynolds have addressed the issue of an ill-informed and irresponsible press. In some cases, there is simply a distortion of expert views. Reynolds alludes to misrepresentations even in supposedly reliable publications such as *New Scientist*. However, as Ives has made clear in *Himalayan Dilemma* and more recently in *Himalayan Perceptions*, sensationalism is nurtured by bad science and corrupt politics. The risks include distorted priorities (and therefore unfair and ineffective use of limited resources), loss of scientific credibility, defamation of population sectors wrongly accused of causing or exacerbating the hazard, and failure to recognize and/or act on hazards that are politically less glamorous.

Reynolds cites the example of the 2003 fiasco surrounding Palcacocha, Peru. The crisis began when NASA published a press release based on ASTER satellite imagery that was incorrectly interpreted as showing cracks in a glacier, portending imminent collapse and glacial flood. Losses in the tourism sector have been estimated at $20 million. Both NASA and *New Scientist*, which gave the story extensive play, declined to issue retractions or even to remove the false reports from their Web sites.

In Nepal, the 1997 panic over the Tsho Rolpa threat led to a costly disruption of economic activity in Rolwaling Valley, and concomitant mass-wasting of scientific credibility. Nonetheless, another media feeding-frenzy accompanied the publication of the UNEP/ICIMOD *Inventory of glaciers* for Nepal and Bhutan (Mool et al. 2000). Because the inventory omitted any specific assessment of actual hazards posed by the lakes catalogued, and because it included some lakes that are not hazardous (while excluding some that are), it gives a misleading impression about the extent of the hazards.

Reynolds agrees that media inaccuracy is a problem, but notes that the distortions cut both ways:

> Undoubtedly there have been exaggerations for effect in some quarters, for a variety of reasons, and such excesses are to be deplored, but so too are the protestations of the vociferous few who downplay the seriousness of the adverse effects of climate change, however it is caused.

Mountain hazard #2: Armed conflict

Ives points out that the greatest devastation to mountain peoples is caused by conflict. The modalities range from conventional warfare (as in Afghanistan and Kashmir) to guerrilla insurrections (as in Nepal) to the "expropriation of land for major infrastructure or for the establishment of national parks; and pervasive discrimination against the poor, the under-privileged, and the politically marginalized." One under-reported and on-going disaster is the oppression of the Lhotsampa by the government of Bhutan, resulting in the displacement of some 100,000 refugees.

Again, Ives accuses the press and the politicians of distorting the truth. Development agencies and donor organizations have collaborated to whitewash Bhutan's royal government, to accept without guffaws the king's pap about "Gross National Happiness" even while he perpetrates one of the more conspicuous programs of ethnic cleansing. Mountain Forum, which has the responsibility to facilitate exchange of information of practical importance to researchers and planners, has a policy of suppressing politically sensitive postings, thereby increasing the likelihood of a cultural "meltdown" with regional consequences outweighing those of natural hazards.

Mountain hazard #3: Global warming

Global climate change has been linked to a cascade of potential or actual disasters at the regional or watershed scale. These include increased incidence of avalanche, proliferation of GLOFs, and disappearance of glaciers, resulting in loss of tourist attractions as well as disruption of the water supply on which local and downstream ecosystems depend.

These days very few scientists deny that unusually rapid climate change is occurring and that human activity is a significant factor. Jack Ives does however take issue with the tenor of discourse on this significant issue. Ives equates the Cassandraism that pervades discussion of global warming with the previous exaggerations of the danger of deforestation. He cites predictions by the World Bank and the Asian Development Bank that "no accessible forest would remain in Nepal by the year 2000" and compares these with such reports as the 2002 article by Fred Pearce in the *New Scientist* in which John Reynolds is quoted as warning that "the 21st century could see hundreds of millions dead and tens of billions of dollars in damage [from GLOFs]." Reynolds has characterized this quote as "journalistic licence" and "an exaggeration" of his actual statement, although the potential impact of GLOFs and their secondary effects would affect significant numbers of people and have serious consequences for many vulnerable infrastructural installations and communities downstream. Regarding the prediction that the Himalayan glaciers will disappear and the Ganges shrink to a mere trickle, Ives wonders at the logic: even if the snow and ice gave way to rain, surely the rivers would still keep running!

The problem Ives alludes to goes beyond hysterical conclusions on the part of untrained reporters. He refers to misleading use of supposedly "replicate photographs" that purportedly illustrate glacial shrinkage. Reynolds argues that the shrinkage is real and probably under-reported, due to the fact that substantial thinning of a glacier can occur without much measurable decrease in surface area.


Pepper Etters

Band-Aid solution for a major GLOF threat: in 2000, an engineering project lowered the level of Tsho Rolpa (Rolwaling, Nepal) by 3.5 meters – less than one-third of the minimum recommended by experts.

As in *Himalayan Dilemma*, Ives is concerned with not only scientific credibility, the loss of which endangers us all, but also hazard inflation. When "supercrises" (with only long-term and speculative solutions) jostle for public attention, how can we make any headway on the more modest crises that can be addressed and remedied in the short term? He cites Alton Byers' work on the destruction of alpine vegetation as one of many unspectacular problems – and a somewhat unusual one in that Byers seems poised to address it effectively, thanks to a remarkable collaboration with the American Alpine Club.

On the specific issue of GLOF hazards, Ives notes that, contrary to prevailing wisdom, climate warming can be an attenuating factor. He explains that water accumulations next to and underneath glaciers normally become smaller and drains more frequently as the glacier shrinks. As for water accumulations behind moraines, they generally result in only one GLOF, since the breached moraine is no longer capable of impounding large quantities of water.

On this point, Reynolds concurs that "a warming trend will reduce the hazard pertaining to ice-dammed lakes while increasing that resulting from moraine-dammed lakes." However, Reynolds cautions that repeat GLOF events are possible, and gives the examples of Dig Tsho in Nepal's Khumbu (still a threat), and Artesanraju at Laguna Paròn (Peru), which in 1951 experienced two GLOF events a few months apart.

Mountain Hazard #4: GLOFs

Remote mountain tourism destinations are inherently at risk due to their relative inaccessibility, dynamic geology, and dramatic meteorology. The declivity and human settlement patterns (as well as recreational activities) particularly aggravate the risks of avalanche, landslide, and flooding. GLOFs have drawn attention in recent decades due to three factors:

- Like an inland tsunami, a GLOF can inflict a huge amount of damage over a great distance, and poses a devastating threat to vital infrastructure including hydroelectric plants, bridges, and roads and trails, as well as to entire communities.
- Like the legendary sword of Damocles, GLOF threats are relatively easy to identify; on the other hand, the timing of a given event is difficult to predict. And this sword cuts both ways: inaccurate prognostications may lead to panic and economic disaster.
- GLOFs are linked to climate change. They are likely to occur with greater frequency as glaciers retreat. It has been argued that they are also likely to become increasingly common currency in political discourse, not to mention posturing and hand-wringing.

GLOFs and Politics

In his keynote presentation, “Fools rush in,” Jack Ives notes that a United Nations University study of hazards in Kakani and Khumbu (Nepal) concluded that GLOFs represent the most serious mountain hazard in those areas, a conclusion underscored soon afterward by the outbreak of Dig Tsho, near Thame.

Political contingencies have hampered GLOF research and mitigation efforts. Essential aerial photography was classified as secret. Ives’ recommendation that ICIMOD take a lead in studying and mapping the hazards was ignored by ICIMOD under Dr Rosser. Although Dr Vic Galay and individual staff members of the Water and Energy Commission provided assistance for Ives’ research, His Majesty’s Government (HMG) ignored their recommendations. Only after global warming had become a sexy topic in the mid-1990s did ICIMOD (with UNEP support) produce an inventory of potentially hazardous glacial lakes in Nepal and Bhutan.

Arun III Hydro-Electric Power Project

Jack Ives gives a semi-insider’s account of the politicization of GLOF hazards as pertains to the aborted Arun III hydropower project. According to Ives it was due to the generalized GLOF fears that the World Bank and HMG undertook a narrowly focused review of the project in 1995. Only GLOF threats in the Arun Valley itself were to be discussed, and all other factors were excluded from the review. While there was no evidence of a GLOF hazard to the hydropower site itself, Teiji Watanabe passed on to Ives his findings about the serious GLOF threat posed by Imja Lake in the neighboring valley.

Volunteer expedition brings modern health care to Rolwaling

In the fall of 2000, I spent a month in Rolwaling as a member of Bridges-PRTD (”Projects in Rational Tourism Development”), a private volunteer/study abroad company that had was trying to help promote backpacker tourism as a resource for economic development. (See www.bridges-prtd.com.) We were quartered at the main village of Beding (3700m), some thirty drab houses clustered around a small monastery about six days’ trek up from the road head at Dolakha. At the time, there was no electricity, no health clinic, no functioning school. The monastery was dilapidated and the *stupa* had been washed away by a GLOF. Every able-bodied man and most of the women had left to work elsewhere as porters and guides, leaving only a few dozen women, children, and lamas to tend the fields.

Although our resources were limited, we did set up a handful of teahouses – merely by providing signs and English menus; we bought some paint and lumber and gave the *gompa* a face-lift; we identified and marked a suitable waste disposal site; we gave a few lectures on first aid, and donated a trunk-load of medical supplies. A Kathmandu engineering firm was hired to produce a feasibility study and design for a micro-hydro plant.

Since 2003, Bridges-PRTD had suspended operations due to the political instability in Nepal. As often happens with small development efforts, we had raised hopes but failed to follow through with the kind of assistance that might make a long-term difference.

Last October I was finally able to pull together an expedition of health care professionals with the objective of decisively upgrading healthcare facilities in Beding and sharing with this remote community the advantages of modern science. The team included my wife Jody Swoboda Etters, Medical Director Laurie Strasburger PA-C, Ken Zawaki MD, Ami Zawaki MD, Kristi LaRock PA-C, Clairane Vost RN, Tom Willard EMT, Vannessa Willard, Eddie Sandoval and Perry LaRock. Our support network included anthropologist Janice Sacherer, climber Nick Arding, Everest veterans Jon Gangdal and Dawa Chirri Sherpa of the Rolwaling Foundation, and Scott MacLennan and his staff at the Mountain Fund. Unlike the situation that prevailed back in 2000, when virtually no one outside Nepal had heard of Rolwaling, there is now an international web of individuals and groups interested in both the valley and its people.

On the trail north along the Tamba, not much had changed since 2000. The road had been extended to Singate, which meant we didn’t have to deal with the 2000m descent (and ascent, coming back) just northeast of Dolakha. There were no signs of the sort of prosperity you see along the Everest trail – the fact that Rolwaling had been closed to independent trekkers for thirty years meant that most visitors passed through in self-contained caravans, contributing precious little to the economy. The Maoist insurgency effectively removed the official restrictions on travel, but few tourists wanted to face being shaken down for a “contribution.”

At our first stop, we happened on a man carrying his eleven-year-old daughter in a *dhoko,* a conical wicker basket supported by a tumpline over his head. They were coming from Simigaon, racing toward the hospital in Dolakha, although they had no money and were not optimistic about getting help. It turned out that the girl had a serious kidney infection which had lead to sepsis. For two days we treated her with intravenous fluids and antibiotics. It was touch-and-go the first night, but when we parted ways she was walking and on her way to recovery. We were soon besieged by requests for medical assistance.

In Beding, there were signs of activity. A new *stupa* had been constructed, a new school built and staffed, and a diversion project had been along the river – not

Ives was able to argue that if Imja gave way, the catastrophe would cause such consternation that it would likely derail the nearby Arun III project. According to Ives, this argument proved trenchant; in the end, it was fear of bad publicity, rather than concern for human safety and ecological sustainability, that led the German and Japanese to withdraw their support, and killed the project.

John Reynolds provides a somewhat more nuanced but not necessarily contradictory account of the demise of Arun III. According to Reynolds, the main consultants to the project had given the go-ahead on the basis of outdated maps which showed no glacial lakes in the area. Alert members of the Water and Energy Commission Secretariat (WECS) staff showed Reynolds much more recent photographs that revealed there were indeed glacial lakes in the Arun catchment. At the request of the World Bank, Reynolds produced a "notional scheme" to assess the actual hazard and was granted $500,000 to carry it out, but the entire scheme was suddenly aborted; to date, no glacial hazard assessment has ever been carried out in the Arun Valley. Reynolds reports that the Germans withdrew because they

Pepper Etters

to mitigate a potential lake outburst, but to control the normal monsoon floods. The Rolwaling Foundation is moving ahead with plans for a small hydropower plant to supply households with electricity as well as to develop local lodges so that independent backpacker tourism can finally take off.

After settling into the host families' homes, the team was welcomed to the village with a tea ceremony in which all the community members offered *katas* (ceremonial scarves) and blessings to the volunteers. Following the ceremony, we set to work. There was a side room attached to the school, and we converted that into a clinic, installing furniture and medical supplies. Solar panels provide light and charging capacity for small equipment, including a microscope donated by Colorado Mountain Medical, a clinic in Vail, Colorado. At the same time, we undertook public health improvements in areas such as sanitation, drinking water, waste management, nutrition and first aid training.

Meanwhile we were training Jangmu, the Nepali nurse hired to run the clinic on a long-term basis. Together we treated villagers for a variety of complaints. There were relatively few acute infections and injuries, while chronic and persistent disorders were much more prevalent. Respiratory diseases, cataracts, arthritis, tooth decay, gingivitis, and arthritis are all too common. While we were able to deal with most problems, several could not be addressed without more advanced diagnostics. A few members of the community may have cancer and other life threatening illnesses, but without making the trek to Katmandu, we couldn't be sure, much less provide effective treatment.

During the ten days we spent in the Rolwaling Valley, we also encountered a substantial demand for medical services on the part of tourists. Despite the fact that most packaged tours had medical supplies and trained staff, we were called on to provide assistance for quite a few cases of altitude sickness. As tourist traffic increases, we expect this need to increase.

We have begun to look for resources to address these issues and hope to bring volunteer specialists including dentists and oral surgeons, eye surgeons and orthopedists as well as additional general practitioners who will continue to train and support Jangmu and her eventual successors so that they can continue to care for the community with whom they have been entrusted.

On a personal note, I would like to add that I am saddened by the recent death of Sir Edmund Hillary. Both as a member of Bridges-PRTD and as the organizer of this medical expedition, I have been keenly aware that we are following in the huge footsteps of the man who gave the world an enduring model of volunteer development. Sir Edmund undertook only those projects specifically requested. He made it clear that he was undertaking this work out of gratitude for Sherpa collaboration on a project that had brought him immense personal satisfaction (as well as world fame). He didn't proselytize or set conditions; he came and personally participated in the projects; and he returned, again and again and again. I hope that the death of Sir Edmund will remind people of his work, and the work that remains to be done. The need is great, and the experience is life-transforming.

Pepper Etters
Pepper Etters directs Rolwaling Health Care Project, and owns Adventurous Spirit Photography (http://www.adventurousspiritphoto.com/splash.php).

considered the project "flawed," but not because of the Imja Lake GLOF hazard. Based on research subsequently carried out by his team, Reynolds does not consider Imja Lake a "major hazard," although he says it should be monitored.

Rolwaling

According to John Reynolds' account, concern about the GLOF risk at Tsho Rolpa can be dated to the 1991 outbreak flood from Chubung, a much smaller lake; the damage from this relatively minor event led the community to start worrying what would happen if the much larger Tsho Rolpa were to give way.

Even after the partial fix, the known threat from Tsho Rolpa is much greater than that from any other Himalayan glacial lake. According to the Web site of the Department of Hydrology and Meteorology,

> If the dam breaches, about 30–35 million m^3 of water could be released and the resulting GLOF could cause serious damage for 100 km or more downstream, threatening lives, villages, farmland, bridges, trials, roads, 60 MW Khimti Hydro power and other infrastructure.

The story of the Tsho Rolpa mitigation project is in many ways just as alarming as the hazard threat itself. Even Reynolds' brief account is far too detailed to bear summarizing here, but I will highlight some of the points that I consider most telling.

1. Pleas for assistance from the Sherpas themselves were ignored both by the Nepalese government and by the many embassies they addressed. It was only the fortuitous visit and subsequent persistence of a Dutch national that resulted in international assistance. This unforeseeable good fortune was frittered away in a diplomatic freeze-out between the Netherlands and Nepal that developed out of an incident involving an unauthorized Dutch movie filmed in Nepal. Although Reynolds himself does not explicitly make the point, I think it is rather clear that without his largely *pro bono* work, and his unusual prior experience in Peru, the Tsho Rolpa project would not have had much chance of success. In other words, there simply was no viable procedure in place capable of dealing routinely with such hazards; that situation persists today largely unchanged.
2. Efforts to mitigate the Tsho Rolpa threat were stymied by political insouciance and bureaucratic malice. In 1996, after several years of research and experimentation with siphons, the project was moved from the Water and Energy Commission Secretariat (WECS) to the Department of Hydrology and Meteorology (DHM). The WECS GLOF unit was cut loose. The Japanese workers went home. Some Nepalis went to ICIMOD. Reynolds observes, "This has been the source of the friction between ICIMOD and DHM ever since and was to play a part in the public fracas associated with the 1997 work."
3. Plans developed by scientists in consideration of extremely important circumstances were unwisely disregarded by bureaucrats both in Nepal and elsewhere. The Dutch eliminated Reynolds' proposal for "integrated hazard management," resulting in a situation where the locals do not have resources or expertise to manage the project after installation.
4. The 1997 panic over an impending outbreak flood at Tsho Rolpa was due to irresponsible and inaccurate reporting by the media, aggravated by what Reynolds characterizes as "sniping from the sidelines by former WECS staff who were opposed to DHM's handling of the matter and were holding press conferences that had the effect of undermining DHM's position."
5. While the Tsho Rolpa GLOF Risk Reduction Program successfully reduced the lake level by 3.5 meters in 2000, research conducted between 1997 and 2000 led scientists to conclude that internationally recognized safety standards could be achieved only through further reduction by 11.5 meters, and preferably by 16.5 meters. This recommendation, along with recommendations that the moraine be monitored on a continuing basis, has not been implemented. In fact, moraine stability has not been assessed since 2000. Given Reynolds' findings that thermokarstic degeneration within the moraine can occur more rapidly than previously suspected, further remediation efforts are urgently needed.

Tsho Rolpa: the human impact

According to oral histories collected by Janice Sacherer, the only notable event reported up to the time of her doctoral research in 1974 was the temporary blocking of the Rolwaling River by a snow avalanche; this occurred sometime between 1900 and 1950 and there were no fatalities.

A warming trend is responsible for more recent developments. The thawed moraine on the north side of Tsho Rolpa has turned the trail over Tashi Labtsa pass (19,000 ft above sea level) into a monstrous Plinko game, with rocks of all sizes careening down on travelers. In the late 1990s, traffic shifted to a new longer trail on the south side of the glacier.

There have also been two GLOFs in recent decades. In 1979, a comparatively small event issued from a south-facing glacier on Menlung Pass directly north of Beding, and resulted in the death of a woman who was grinding grain at a water-powered mill at the confluence of the Menlung stream and the Rolwaling River.

Regarding the second GLOF, I quote Sacherer's account:

> In 1991, a much larger GLOF occurred when a lake under the ice of the Ripimo Shar glacier, a south facing glacier on the east side of a small high altitude north-south valley above the village of Na, burst through the ice. This happened in the late afternoon of a summer religious festival ... in the village of Beding when almost all of the Rolwaling people were gathered at the temple in Beding. The villagers first noticed that the Rolwaling River had turned brown and then that it began rising rapidly. Dressed in their holiday finery, they ran uphill, as Beding is located in a narrower part of the valley. The flooding went on until dark, washing away the village chörten and some houses and potato fields. Thus the people of Rolwaling spent the entire night out in the open in the rain, as high on the hill as they could climb.

> Today, they are still dealing with the erosion caused by the river and the loss of some of their best potato fields.

Sacherer disputes the accuracy of certain press reports on the reaction of the Rolwalingpa to the Tsho Rolpa threat. Contrary to assertions that the Sherpas were not disturbed by the threat because they consider Tsho Rolpa the sacred precinct of a goddess, she points out that while nearby Oma'i Tsho (fed by Ripimo Shar glacier) is sacred to the local goddess Tseringma, Tsho Rolpa is said to be the home of only a few *lü* (*naga*), lower-status snake divinities. If there was a perception that the Rolwaling people were not afraid, Sacherer suggests that it was probably due to "Sherpa fatalism and courage in the face of adversity" rather than lack of concern.

According to Sacherer, fear of an outburst of Tsho Rolpa was a major factor leading to outmigration of most of the Rolwaling community. About 85% of the population now spend nine or more months outside the valley. She admits that Kathmandu offers advantages other than safety, including comfort, as well as better employment opportunities and schooling for the children; moreover, for newly wealthy mountain guides and tour operators, building a house in Kathmandu is a better investment than building one in Rolwaling given that both government policies and the Maoist insurgency had effectively impeded tourism.

The result, according to Sacherer, is that the permanent residents of Rolwaling are "predominantly the old, the poor, the alcoholic, the incapacitated, and those with no close relatives in Kathmandu – the very people who could least afford to lose everything." Furthermore, since the likelihood is that a GLOF would strike during the monsoon, when most of the economically productive members of the community are in the valley, the disaster would have long-term repercussions. Since the valley has little usable space, most of which would be rendered useless by debris, the valley would probably be abandoned, which Sacherer speculates would have a "national impact, as an abandoned valley lying just south of the Tibeto-Chinese border would not be seen as politically desirable from the Nepalese government's point of view."

Based on interviews conducted during three Bridges-PRTD expeditions to Rolwaling, I doubt that the GLOF threat is the immediate cause of current out-migration from Rolwaling. As Sacherer points out, most of the community returns to the valley precisely when it is most vulnerable – and when comfort and employment opportunities in Kathmandu are at low ebb. Furthermore, many Rolwaling informants seem dubious of the imminence of the threat. This may be due to the fact that the widely publicized predictions of 1997 did not come true, and also because people have been reassured by the 3-meter reduction in the lake level. (A recent communication from Sacherer notes that "As for Tsho Rolpa, [the Rolwalingpas] unanimously trust in western technology and believe that there is no further danger because of the amelioration work already done.")

Whether or not the GLOF risk is still a factor in outmigration, Sacherer is clearly correct that the hazard has hampered attempts to raise funds for development in Rolwaling. Without electrification (and light, heat, telephones, and internet), the Kathmandu-educated generation will probably not return to settle in Rolwaling. Certainly, there has been a delay in the development of tea-house tourism, and concomitant economic opportunity, due to the lack of amenities.

Urgent recommendations from "Mountain Hazards, Mountain Tourism" symposium include:

- **rigorous application of available assessment and mitigation technology,**
- **international attention to simmering Bhutanese problem, and**
- **conversion of King Gyanendra's palace into a Disaster Management University.**

Perceived development needs in Rolwaling

Based on interviews in Kathmandu and correspondence with recent visitors to Rolwaling, Sacherer reports on the status of development. These are the areas of need most commonly cited:

River containment Sacherer reports that the most pressing need is for control of the Rolwaling River, especially as it passes Beding. In the 1990s, the river destroyed the largest area of arable land in the area, in addition to the village chörten and three houses. The greatest damage was caused by the 1991 Chubung GLOF. However, the containment walls that were undertaken in 1999 were intended primarily to manage the high waters from annual monsoons. Based on my observations and reports from village members, the initial lowering of Tsho Rolpa was well managed and caused no damage.

According to recent information from Dr Sacherer, a more ambitious river control project has been already begun with the aid of Dr Ruedi Baumgartner and Swiss Development Cooperation. Again, it seems unlikely that this project could be intended to control an outbreak flood from Tsho Rolpa.

Gompa restoration Now that the ruined gompa at Na (an hour above Beding) has been rebuilt, the monastery at Beding is an important priority. The Beding gompa is the spiritual center of Rolwaling, a *beyul* or "sacred valley" according to Tibetan Buddhist tradition. It is also the center of community social life, hosting a year-round series of village festivals. In 2002, Bridges-PRTD volunteers donated materials and labor to complete the precinct gateways and repaint the outer walls and metal ornaments. However, the outer frescoes are damaged, and those inside are in danger. Sacherer reports that she has donated money and mobilized resources to undertake a more substantial rehabilitation of the Beding gompa.

Health clinic There is a strong consensus on the need for a health clinic, or, if that proves impossible, a mobile team, training for a village health worker and further supplies of the type Bridges-PRTD donated several years before, which informants agree was well administered by Ngawang Chokling. Currently, Pepper Etters, a former Bridges-PRTD associate, is organizing a medical expedition which will bring supplies and training in the fall of 2007 (see box on p 14).

School The school at Beding was originally built by Sir Edmund Hillary. However, it was unused in recent years, both because of delapidation and because the schoolteachers prove unreliable. Several years ago John Reynolds gave a considerable sum to be used for educational upgrades, but the entire amount was reportedly embezzled and spent on *chang* (local beer). More recent efforts have resulted in a larger and better heated structure, but staffing remains a problem.

Electricity In 2001, Bridges-PRTD commissioned a Kathmandu-based engineering firm to do a feasibility study for a 3.5 kw Peltric set that would have provided electric lighting in all permanent households as well as the school and gompa. Half the cost would have been underwritten by a Nepal government program, leaving only about $5,000 to raise. However, given the activities of the Maoist insurgents, it was impossible to proceed with this effort. More recently there have been renewed explorations of electrification schemes.

For the most part, the people of Rolwaling maintain a cohesive community near Bouddha, just east of Kathmandu proper. They would like to see enough modernization and economic prosperity to interest their children in returning, or at least to make it place for comfortable summer and retirement. They are willing to invest their own resources, and, like the Khumbu Sherpas, they have international friends with deep pockets. If the GLOF threat is lifted and if the new democratic government of Nepal does not reinstate the restrictive measures that prevented development of tea-house trekking, Rolwaling has a good chance of reinventing itself before an irreversible diaspora sets in. But there isn't much time.

Moving ahead

An essential element of any disaster management program must be the perception of scientific objectivity. Whatever the reality behind the debacles discussed in our e-conference, we know for sure from the sordid tale of Hurricane Katrina that political cronyism, incompetence, profiteering, racism, and indifference can and do compete with heroism, altruism and sound judgment. What can be done to mitigate the likelihood of bad disaster management?

Again, the media have an important role to play in disseminating information; we should not and they cannot be expected to be reliable unless there is an authoritative entity to serve as an information clearinghouse. Who will take on that role?

Finally, we need to establish a firewall between engineering consultants who assess risk and those who design infrastructure, in order to eliminate the potential for and perception of conflict of interest. With the limited available expertise pertaining to complicated hazards and development projects, is it reasonable to hope for enough redundancy to keep these roles separate?

Disaster U

Perhaps the time is right to found a new type of academic institution: one based on a real-world problem rather than a preconceived "discipline." Why not establish a Disaster Management University? Here are some of the considerations:

1. Many types of disasters are unlikely or rare enough that it doesn't make sense to design an academic career specifically for them. These would include asteroid collision, nuclear terrorism, bird flu, mid-plate volcanism and earthquake, and others. Even though they may seem to pertain to disparate fields, they have important strategic points in common, particularly rescue and evacuation.
2. The existence of a recognized degree would make it less likely that incompetents would get into positions where they can make the disaster more catastrophic (such as the directorship of FEMA).
3. The establishment of a single Disaster U, presumably at the graduate level, would probably inspire universities around the world to offer disaster management as an undergraduate degree. This would assure enough redundancy of expertise to allow for informed debate, peer review, and separation of interests.

Kathmandu would be a logical location for an international university of this sort because of the concatenation of man-made and natural hazards. Specifically, the royal palace would present a perfect campus. (Presumably the King would be offered a less pretentious and portentous domicile somewhere outside the capital, as befits a modern constitutional monarch.) Apart from the substantive contributions to local as well as regional safety, an international university would be a significant foreign-exchange magnet for Kathmandu.

A protocol for glacial hazard assessment

Subsequent to the Arun-III debacle, the World Bank modified its policy, requiring that proper glacial hazard assessments be undertaken prior to approval of hydropower projects. The UN followed suit. Yet there was no definition of what that assessment should entail. Furthermore, the terminology varied; one Peruvian project required a *glacial hazard analysis*, without further specification. Interpretation was left up to contractors bidding on the project, and in the end the successful bidder came up with a minimalist version.

On the other hand, there is the danger that perceived – rather than demonstrable – hazards will be taken as sufficient to block a hydropower project. Given the economic importance of these projects, such a perspective could have a devastating effect on Nepal and other countries where hydropower is the principal natural resource.

The alternative to emotive and subjective characterizations is a scientific protocol with clearly defined criteria for the assessment of risk at any given site. Reynolds summarizes the tools currently available:

> ...It is now possible to identify and map glacial lakes using remote sensing techniques and to produce Digital Elevation Models from stereo satellite images; to derive an inventory of glaciers and map all glacial lakes using

> both manual and semi-automatic land classification procedures; to monitor flow rates as small as 2 cm/day for debris-covered glaciers using Synthetic Aperture Radar imagery; and to map where proto-supra-glacial lakes are most likely to develop in the next two to three decades. Working with colleagues originally at the University of Zurich it is possible to calculate and map the probability of inundation from debris flows and glacial lake outburst floods. Since 1996 we have also developed and tested different geophysical techniques on moraines to determine if they are ice-cored or not at a wide variety of Himalayan glacial lakes (e.g., Delisle et al. 2003, Hanisch et al. 1998, Pant and Reynolds 2000, Reynolds 2006).

In 2000, the [British] Department for International Development awarded Reynolds Geo-Sciences Ltd (RGSL) a 3-year contract "to develop glacial hazard and risk minimisation protocols in rural environments." The result is a set of weighted criteria that can be measured by non-experts and plugged into formulas that yield an objective glacial hazard rating. Details are available online either through RGSL's web-site (www.geologyuk.com) or through the British Geological Survey's web-site (www.bgs.ac.uk; DFID Knowledge and Research portal, then Search for *Glacial hazards*). The system has since been adopted by the Union Commission for the Cryospheric Sciences Working Group on Glacial and Permafrost Hazards.

Now that there are standards for risk measurement, it would make sense to have an international entity in charge of a well-publicized program. Such a Mountain Hazard and Disaster Watch could direct graduate students and other researchers to areas in need of study. It could serve as a clearinghouse to review, assemble, and track research, and as an authoritative source of prognostications and advisories.

Localized efforts

The Sherpas of Nepal have been very successful at developing ongoing "sponsorship" relationships with trekking and mountaineering clients. While comparable enterprise is not often found in other remote travel destinations, the likelihood is that it would be easy to develop. All that is required is that an organization gather email addresses of visitors to each locale, perhaps in exchange for news and photo updates. The email list could then be used to solicit donations in the event of catastrophe, as well as for development, and also to stimulate interest in return visits.

One local target should be to establish depots of rescue tools, blankets, and communication devices. Placement of the depots would necessarily entail some thought to emergency access and evacuation.

Rolwaling

Quite a few important opportunities have already been missed. As noted above, Reynolds' integrated disaster management/social development plan was not implemented. A great engineering effort was mounted that resulted in a very small draw-down of the lake level. The full draw-down plan was abandoned, meaning the lake is still dangerous, and unmonitored. We have heard reports of possible continuation of the project, but nothing firm yet. Reynolds concludes:

> There is a clear consensus that the future viability of Rolwaling communities is tied up with the reduction in hazard at Tsho Rolpa, and infrastructure development within the valley. This must be done sensitively with respect to both the physical and social environments, and should include the provision of electricity and other social benefits, as other contributors to the e-conference have also suggested.
>
> ... As Dr Sacherer states in her article, unless Tsho Rolpa is remediated, the further development of Rolwaling will not happen and this is likely to lead to the demise of the communities within the valley.

In Rolwaling we have been afforded the luxury of a long-drawn-out training period. Tsho Rolpa will not be the last GLOF hazard. Whatever we learn there will certainly have applications elsewhere. Let's hope the lessons are best-practices, and not missed chances.

Ecological Society (ECOS)

A need to form a regional network and interactive professional society was realized by ecologists of South Asia while observing SAARC Environmental Year in 1992. The society was initially named as "Ecological Society for SAARC countries". For technical reasons, it was renamed as the "Ecological Society" (ECOS), with the distinguished ecologists its advisor.

Objectives

ECOS is a non-governmental, non-profitable organization of ecologists founded in 1992 with the following objectives:

- To identify the interrelated problems and their solutions in the SAARC countries.
- To communicate and cooperate with various ecological organizations
- To exchange and promote ecotechnology.
- To conduct/coordinate research on environmental issues in the region.
- To publish bulletin, journal and seminar proceedings.
- To organize national, regional/international conferences on ecology/environment.

Membership and fee

Membership is open to persons who are interested in the advancement of ecology or its application and to those who are engaged in any aspect of the study of organisms in relation to environment. The individual membership fee (Nepal NRs 400, India IRs 400, other countries US$30) should be payable to the Ecological Society (ECOS), saving account number 46521, Nepal Bank Ltd., Kirtipur, Kathmandu, Nepal.

Activities

ECOS periodically publishes a bulletin – ECOVIEWS (since 1993) – and a biannual peer reviewed journal – ECOPRINT: An International Journal of Ecology (since 1994). The journal includes review articles, research papers, news, notes, book reviews, conference reports, etc.

ECOS organized a Regional Conference on Environment and Biodiversity in 1994 and International Conference on Environment and Agriculture in 1998 (INCEA '98) at Kathmandu. The regional conference was attended by over 300 participants from 15 countries. Proceedings of the conference – *Environment and Biodiversity: In the context of South Asia* – carried 58 peer reviewed articles. INCEA '98, inaugurated by the late King Birendra of Nepal, was attended by over 500 participants from 27 countries. ECOS published the proceedings in two volumes: *Environment and Agriculture: At the cross road of The New Millennium*, and *Environment and Agriculture: Biodiversity, Agriculture and Pollution in South Asia*, which carried 61 and 85 peer reviewed papers, respectively.

ECOS actively supported National Seminar on Recent Advances in Plant Sciences in 2002 at Birgunj, Nepal and published the proceedings entitled *Environment and Plants: Glimpses of Research in South Asia*, containing 28 peer reviewed papers. ECOS also jointly organized a "National Seminar on Natural Resource Management" at Biratnagar in 2004 and published the proceedings entitled *Natural Resource Management*, which contains 73 peer reviewed papers. The third national seminar was organized by ECOS jointly with Institute of Forestry and PN Campus, Pokhara on April 22-23, 2007. The seminar was attended by over 200 participants . Two volumes of the proceedings (*Medicinal Plants in Nepal* and *Sustainable Use of Biological Resources*) are in the process of publication. The fourth National Seminar will be held at Institute of Agriculture and Animal Sciences, Rampur in 2009.

Publications

- Sustainable Use of Biological Resources in Nepal (Mar 2008)
  Editors: PK Jha, SB Karmacharya, MK Chettri, M Balla, CB Thapa and BB Shrestha
- Medicinal Plants in Nepal (Dec 2007)
  Editors: PK Jha, SB Karmacharya, MK Chettri, CB Thapa and BB Shrestha
- Environment and Plants: Glimpses of Research in South Asia (2006, 307 pp)
  Editors: PK Jha, RP Chaudhary, SB Karmacharya and V Prasad
- Natural Resource Management: Proceedings of the National Seminar on Natural Resource Management (2006, 474 pp)
  Editors: SB Karmacharya, MR Dhakal, SN Jha, TN Mandal, MK Chettri, BR Subba, U Koirala, B Niroula and KP Limbu
- Environment and Agriculture: At the Crossroad of the New Millennium (Vol. 1, 2000, 578 pp)
  Editors: PK Jha, SB Karmacharya, SR Baral and P Lacoul
- Environment and Agriculture: Biodiversity, Agriculture and Pollution in South Asia (Vol. 2, 2001)
  Editors: PK Jha, SR Baral, SB Karmacharya, HD Lekhak, P Lacoul and CB Baniya
- Reclaiming Rato Mato (1999)
  Editors: SR Baral, MB Malla and J Howell
- Environment and Biodiversity: In the Context of South Asia (1996, 413 pp)
  Editors: PK Jha, GPS Ghimire, SB Karmacharya, SR Baral and P Lacoul

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An assessment of contemporary glacier fluctuations in Nepal's Khumbu Himal using repeat photography

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A preliminary study of glacial fluctuations in Sagarmatha (Mt Everest) National Park, Nepal was undertaken in Oct–Nov 2007 using repeat photography. Photographs from scientific and cartographic expeditions to the upper Imja Khola region ca. 1950 were replicated in order to derive a better, empirically-based understanding of what changes had occurred in the region's glaciers during the past half century. Over 40 distinct panoramas were replicated which demonstrated the (a) complete loss of certain small (< 0.5 km^2), clean glaciers (C-Type) between approximately 5400–5500 masl, (b) the retreat of larger (>0.5 km^2) clean glaciers by as much as 50 percent of the ca. 1955 volumes at elevations ranging from approximately 5500–5600 masl, (c) the formation of new and potentially dangerous glacial lakes that had been debris covered glaciers (D-Type) in the 1950s, and (d) the ablation of most of the D-Type glaciers re-photographed. The findings support and complement those of recent investigations based almost entirely on remote sensing and computer modelling. However, detailed, on-the-ground field studies of potential climate change impacts on the people and environments of the Mt. Everest region are disturbingly absent. I suggest that only by systematically combining field and laboratory-based investigations will we acquire the tools to enable us to identify the real threats, non-threats, and ways in which local people can adapt and reduce vulnerabilities to climate change.

EDITOR'S NOTE This preliminary report on a study of Himalayan glaciers has been released without peer review in order to share important findings. A detailed report will be forthcoming.

Between 1955 and 1963, the Austrian climber and cartographer Erwin Schneider completed a terrestrial photogrammetric survey of the mountain valleys to the south and west of Mt Everest (Schneider 1963, Byers 2005) which resulted in the beautiful 1:50,000 map of Khumbu Himal, first published in 1965 (Arbeitsgemeinschaft für Vergleichende Hochgebirgsforschung 1999). In 1956, an eight-month study of the region's glaciers was conducted by the Swiss glaciologist Fritz Müller (Müller 1958) following his participation as scientific leader to the successful 1956 Swiss Everest expedition. Both efforts resulted in the production of thousands of oblique black and white photographs of the Khumbu's cultural, physical, and high altitude landscapes. Half a century later, these photographs are now of immense value to our understanding of contemporary impacts of climate change on the world's highest mountain landscapes, especially when combined with other analytical tools such as remote sensing, computer modeling, GIS, and field-based biophysical and social science studies.

Over the years, I have replicated many of Schneider's 1955–1963 landscape photographs of the lower Khumbu valleys (3,200–4,200 meters above sea level, masl) in an effort to better understand contemporary landscape change processes and their prospective causes (Byers 1987a, 1987b, 1987c, 1996, 1997, 2003, 2005). However, it was not until 2002 that, thanks to Jack D Ives, I came into possession of hundreds of historic photographs of glaciers and high altitude landscapes from the Müller archives (see postscript). In October–November 2007, I spent 30 days in the upper Imja Khola watershed of the Sagarmatha (Mt Everest) National Park relocating the photopoints from which Müller and Schneider took their photographs, and then re-photographing the landscapes, in order to derive a better, empirically-based understanding of what changes had occurred in the region's glaciers during the past half century.

I conducted my field work in the upper Imja Khola region between 12 October and 12 November, 2007. I used a Nikon D-80 with Bogen tripod and Manfrotto 3039 head. I recorded locations and altitudes using a Garmin Summit GPS, and also noted other attributes such as date, time, and aspect. I shot the photographs using aperture priority at 15º and 30º intervals, and subsequently stitched individual frames into complete panoramas using Adobe Photoshop. I was able to replicate more than forty panoramas and hundreds of individual photographs. In this paper, I present four pairs of original and replicate images together with a discussion of preliminary results and recommendations.

Preliminary results

Four photo-pairs are presented as Plates 1 through 4, taken in the upper Imja Khola watershed at approximately 86º 50' E and 27º 53' N. The earlier of each pair was taken by Fritz Müller in 1956; the Schneider panoramas and photographs will be

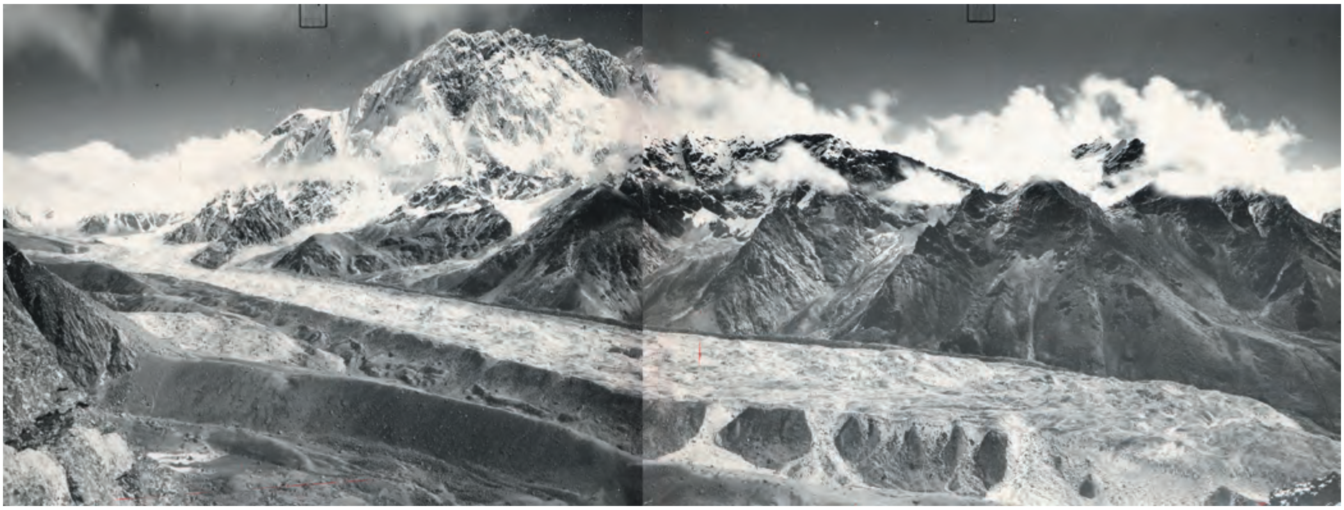

Plate 1. The lower Khumbu Glacier in 1956 (top, Plate 1a; photograph taken by Fritz Müller), and in 2007 (bottom, Plate 1b), revealing very slight change in the lower tongue

presented in future publications. **Plates 1a** and **1b** illustrate that, superficially at least, and despite recent dramatic claims to the contrary, the lower tongue of the Khumbu Glacier has changed very slightly over the last 50 years. In contrast, the small Pokhalde Glacier (**Plate 2**) has entirely disappeared over the same period. **Plates 3** and **4** illustrate the pronounced retreat and collapse of the lower tongue of the Imja Glacier. This development introduces an associated phenomenon, i.e., the creation of moraine-dammed lakes (Imja Lake) in the frontal zones of retreating glaciers. In turn, this raises the prospect of glacial lake outburst floods (GLOFs, also known as *jökulhlaups*, the Icelandic term, Iceland being the country where systematic study of glacier outburst floods began almost 100 years ago).

Plate 1a shows the lower Khumbu Glacier as it appeared to Fritz Müller in 1956, taken from Awi Peak (5245 m) north of Dugla (4620 m), and **Plate 1b** is the 2007 replicate. When Muller took his first photograph, he, and most other glaciologists, would have been thinking about the likelihood of a recurrence of the 'Little Ice Age' rather than prospects for a widespread glacier melt-down. The lower glacier appears to have changed very little. Close examination, however, will reveal several recently-formed melt-water ponds among the boulders which constitute a nearly complete surface moraine. Two points must be borne in mind. First, a very thick cover of surface debris (as occurs on a "D-type" glacier) will insulate a glacier surface and so protect it from higher air temperatures. On the contrary, a thin debris cover will accelerate surface melting as heat due to solar insolation of the relatively dark debris is transferred to the ice below. Second, the lower Khumbu Glacier receives its supply of ice from one of the world's highest accumulation areas, i.e., the Western Cwm. At this extreme altitude, an increase of a few degrees in mean temperature has little impact on the rate of snow-melt. Furthermore, the ice supply to the lower tongue cascades down the precipitous and rapidly moving Khumbu icefall as it discharges from the Western Cwm on Mt Everest.

On the other hand, the Pokhalde Glacier (**Plates 2a** and **2b**), as it appears from just below the Kongma La pass (5535 m), has entirely disappeared since it was photographed by Müller in 1956. It is virtually the opposite extreme of the Khumbu Glacier – small total area and relatively low altitude accumulation zone. Furthermore, it had no conspicuous cover of surface debris and so could be classified as a 'clean' ("C-type") glacier. The same inferred explanation (disappearance on account of the current global warming) is used to explain the disappearance of many small glaciers in Glacier National Park, USA. This pattern is also characteristic of the European Alps and many other mountain regions. As mentioned, altitude has also played a role in the

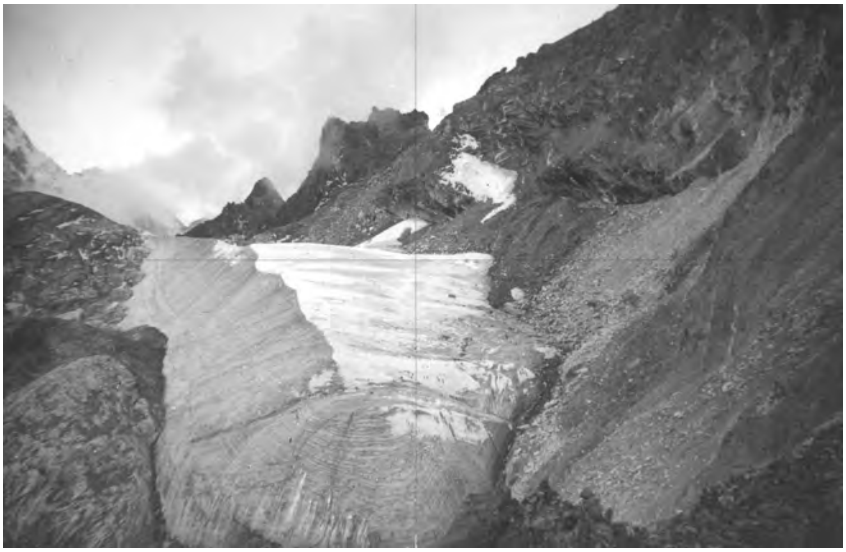

Plate 2. Pokhalde Glacier in 1956 (top, Plate 2a; photograph taken by Fritz Müller), and in 2007 (bottom, Plate 2b) when it completely disappeared

disappearance and/or retreat of small C-type glaciers in the Khumbu, with the zone between approximately 5400 and 5600 masl being the most heavily affected because of its warmer overall conditions. Within this range, I observed the entire disappearance of one C-type glacier (i.e., Pokhalde), the retreat by half of three C-type glaciers on the Jobo Lhaptsan (6440 masl) ridge toward Cho La, and upward retreat of dozens of ice sheets on most glaciated slopes re-photographed.

In one sense, Imja Glacier (**Plates 3** and **4**), as seen from a point above Amphu lake (Plates 3a and 3b) and again from the upper slopes of Island Peak (**Plates 4a** and **4b**), falls between the two extremes. It is a large glacier fed by two vigorous upper tributaries. A detailed study of Imja Lake and Glacier was initiated by the United Nations University (UNU) mountain hazards mapping program in 1983. The lake is totally absent in Müller's 1956 photograph, although a few small melt-ponds can be detected, comparable to those showing on the lower Khumbu Glacier today. Imja Lake only became of significance to UNU research when the late Dr Brad Washburn made available to the research team air photographs that he obtained in the course of producing the National Geographic Society's superlative 1:50,000 map of the Everest region.

The UNU identification of Imja Lake – we can't say "discovery," as its presence was previously known to the local Sherpas – coincided with the initial study of the glacial lake outburst from Dig Tsho, also in the Khumbu, in 1985. This occurred towards the end of UNU's mapping of mountain hazards in the area and facilitated one of the earliest on-the-ground post-facto analyses of such an event in Nepal, and discussion of its implications (Ives 1986, Vuichard and Zimmermann 1986). Thereafter a systematic collection of 'old' photographs was initiated and a series of expeditions to study Imja Lake was launched (Watanabe et al. 1994, 1995).

Interest in the Imja Lake continues to accelerate as a result of its rapid growth (WWF 2005, Bajracharya et al. 2007), relative ease of access, proximity to the popular trekking peak objective Island Peak, and the fact that it is located at the foot of Mt Everest, one of the world's most powerful media draws. Based on temporal series of satellite images from 1962 to 2006 combined with some field verification data, Bajracharya et al. report that the lake increased in area from 0.82 km^2 in 2001 to 0.94 km^2 in 2006, with the glacier currently receding at the rate of 74 m/yr. The lake increased in length from 1,647 m to 2,017 m during the same period, exhibiting an average depth of 41.6 m in 2002 that contains 35.8 million m^3 of water. They report that during the past six years, 34 major lakes appear to be growing in the Khumbu, and 24 new lakes have appeared, 12 of which are classified as "dangerous." They advocate early warning systems as the most cost-effective means of dealing with the risk of glacial lake outburst, and in fact a Japanese team installed a video cam to monitor lake levels in November of 2007. In May of 2008, Asian Trekking and the International Centre for Integrated Mountain Development (ICIMOD) are planning an "EcoEverest Expedition" designed in part to raise awareness of the potential problems associated with proliferation and expansion of glacial lakes as a result of climate change.

Discussion

Over 40 distinct panoramas were replicated which demonstrated, among other phenomena to be described in forthcoming papers, the (a) complete loss of certain small (<0.5 km^2), clean glaciers (C-Type) between approximately 5400–5500 masl, (b) the retreat of larger (>0.5 km^2) clean glaciers by as much as 50 percent of the ca. 1955 volumes at elevations ranging from approximately 5500–5600 masl, (c) the formation of new and potentially dangerous glacial lakes that had been debris covered glaciers (D-Type) in the 1950s, and (d) the ablation of most of the D-Type glaciers re-photographed. The findings support and complement those of Bajracharya et al. (2007), and illustrate the advantage of combining remote sensing and computer modeling with thorough and systematic field verification. However, detailed, on-the-ground field studies of potential climate change impacts on the people and environments of the mountain world – on water, agriculture, safety, glacial lakes, tourism – are disturbingly absent, and all too frequently substituted with well meaning, but frequently erroneous and sensationalistic reports based entirely on anecdotal evidence alone. For example, I found the terminus of the Khumbu glacier to be exactly where it was 50 years ago, despite stories heard in Kathmandu to the effect that it had receded by 5 km; and the “glacial lake outburst” in Kunde village reported on the Internet last summer was in fact a centuries-old torrent that floods at least once every several decades; there are no glacial lakes on Khumbui Yul La, the peak that rises above Kunde. My informal interviews with Sherpa informants suggest that a wide range of opinions exists regarding the impacts, or lack of impact, of climate change, and I can find no systematic studies that have attempted to determine what *local people* think. More than ever, we now need to emulate the thorough work of Müller and Schneider half a century ago, with on-the-ground field studies by mountain geographers, anthropologists, glaciologists, and social scientists with those of the laboratory. Only by combining both field and laboratory results, especially in collaboration with local people, will we have the tools that enable us to identify the real threats, non-threats, and ways in which local people can adapt and reduce vulnerabilities to climate change.

I also suggest that much more field-based analysis of glacial lakes in general is needed in the Khumbu and elsewhere in the Himalaya. For example, some have argued that controlled breaching of dangerous lakes is too expensive, and that early warning systems are the only practical solution. Yet, Peruvian engineers, for example, have over 45 years of experience in the successful control of glacial lakes in the Cordillera Blanca region of Peru (Byers 2000). This experience needs to be reviewed for possible adaptation to conditions in Nepal. Cost is clearly *not* prohibitive if dozens of lakes have been controlled in another developing country such as Peru. Regardless, the savings of lives, land, and infrastructure that could result from an outburst would appear to dwarf the expense of its prevention. Early warning systems, although potentially a viable component of GLOF management, provide only a brief opportunity to get out of the path of destruction for those lucky enough to hear them, and do little for the hundreds of farmers, porters, and trekkers who may be on the trail between villages when the

Plates 3. Imja Glacier, as seen from a point above Amphu lake in 1956 (top, Plate 3a, photograph by Fritz Müller) and in 2007 (bottom, Plate 3b) show pronounced retreat and collapse of the lower tongue of the glacier and formation of new melt-ponds

Plates 4. Imja Glacier, as seen from the upper slopes of Island Peak in 1956 (top, Plate 4a, photograph by Fritz Müller) and in 2007 (bottom, Plate 4b) show pronounced retreat and collapse of the lower tongue of the glacier and formation of new melt-ponds

outburst occurs. Likewise, classifying a lake as "dangerous" based on remotely-sensed size and volume alone does not take into account the more frequent causes of lake outbursts, such as catastrophic ice fall (e.g., as with the Langmoche flood), earthquake, or natural failure of the terminal moraine dam. Much uncertainty in these regards could be removed through the development and implementation of more thorough ground verification methods, followed by the implementation of controlled breaching and early warning systems where indicated.

Conclusion

The photographs compared here, and the dozens of other replicate panoramas that I took in order to highlight change over a 50-year period, represent only a tiny fraction of those remaining in the Müller/Schneider archives. More work is planned for the future in partnership with ICIMOD's Decision Support System (DSS) project, The Mountain Institute, and the American Alpine Club. This should provide a database to facilitate more objective assessment of changes that are occurring in the Khumbu, as well as development of a model applicable to other mountain regions of the world. In this way a more reliable basis can be built for the formulation of policies promoting adaptation to change as well as mitigation of disasters. The paper is also intended to encourage the incorporation of more field-based studies of the biophysical and human aspects of climate change in the mountains in order to realistically understand its impacts on peoples' lives, livelihoods, and safety.

Postscript (by Jack D Ives)

The preservation of Fritz Müller's 1956 photographs is a saga in its own right. Fritz formed the scientific 'team' on the successful Swiss Everest-Lhotse expedition of 1956. He stayed behind to continue his glaciological and permafrost studies after the climbers had departed for home. He remained for nine months at altitudes in excess of 5,000 metres – a non-indigenous record for the time [see note]. Afterwards he divided his energies as professor of geography between McGill University (Montreal), and ETH (Zurich). During this time he initiated and led a series of expeditions to Axel Heiberg Island in Canada's High Arctic (the island's largest ice cap is named in his honor). He also campaigned against what he perceived as reckless development of hydroelectric facilities in the Swiss Alps. It was while haranguing news reporters on the Rhonegletscher that he suffered a fatal heart attack in 1980, at the age of 54. In the confusion that followed his tragic death most of his photographic collection was lost. A single box of photographs was salvaged by one of his doctoral students, Dr Konrad Stefan, and brought to Boulder, Colorado. Koni presented the box to me, knowing that I had begun to focus my UNU activities on the Khumbu Himal. Inspection revealed that there were no negatives (apparently they had been inadvertently destroyed) and that most of the prints were 35mm contacts. Remarkably, the Imja Glacier photographs were amongst the very few that had been enlarged (to about 12 by 20 cm). Recently, Alton Byers was able to utilize the rapidly developing digital technology to enlarge and enhance many of the other contact prints. He is currently planning major photo exhibits featuring the comparative panoramas at the American Alpine Club's Brad Washburn Mountaineering Museum, Golden, Colorado; and in celebration of the 25th anniversary of ICIMOD in Kathmandu.

I present the story of the Müller photographs here in the hopes that it will encourage similar efforts to retrieve, restore, and utilize historic photographs. It is also meant to be a tribute to one of the most effective and imaginative Swiss-Canadian glaciologists I have ever known, Professor Fritz Müller.

Acknowledgements
I would like to gratefully acknowledge the financial support for this project provided by The Mountain Institute, Washington, DC, the American Alpine Club, Golden, Colorado, and the International Centre for Integrated Mountain Development, Kathmandu, Nepal. I would also like to thank Jack D Ives for so generously entrusting me with the Müller archives, and hope that their use will stimulate continued advances to our understanding of the high mountain world.

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Note (from postscript)
One of my prized pieces of personal memorabilia is a postcard sent to me by Fritz from the South Col. It includes the official Swiss expedition diagram of the Everest group with Fritz's annotations to the following effect: he apologizes for not having had time before his departure for Nepal to assist me with my doctoral dissertation saying that, at least, I can claim it all as my own work; he goes on to say that, after struggling with his permafrost studies and after drilling holes in the Khumbu icefall for movement stakes, he needed a rest break; this he obtained by joining a party of Sherpas to carry a load to the South Col. I last saw Fritz on the Rhonegetscher just two years before his death in the same place.

Conservation area networks for the Indian region: Systematic methods and future prospects

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We present a framework for systematic conservation planning for biodiversity with an emphasis on the Indian context. We illustrate the use of this framework by analyzing two data sets consisting of environmental and physical features that serve as surrogates for biodiversity. The aim was to select networks of potential conservation areas (such as reserves and national parks) which include representative fractions of these environmental features or surrogates. The first data set includes the entire subcontinent while the second is limited to the Eastern Himalayas. The environmental surrogates used for the two analyses result in the selection of conservation area networks with different properties. Tentative results indicate that these surrogates are successful in selecting most areas known from fieldwork to have high biodiversity content such as the broadleaf and subalpine conifer forests of the Eastern Himalayas. However, the place-prioritization algorithm also selected areas not known to be high in biodiversity content such as the coast of the Arabian Sea. Areas selected to satisfy a 10% target of representation for the complete surrogate set provide representation for 46.03% of the ecoregions in the entire study area. The algorithm selected a disproportionately small number of cells in the Western Ghats, a hotspot of vascular plant endemism. At the same target level, restricted surrogate sets represent 33.33% of the ecoregions in the entire study area and 46.67% of the ecoregions in the Eastern Himalayas. Finally, any more sophisticated use of such systematic methods will require the assembly of Geographical Information Systems (GIS)-based biogeographical data sets on a regional scale.

Key words: Indian biodiversity, Eastern Himalayas, complementarity, area prioritization, reserve selection, surrogacy

The Indian subcontinent is a region of moderate to very high biodiversity including two of the global hotspots of vascular plant endemism: the Western Ghats and the Eastern Himalayas (Myers et al. 2000). It has also had a long cultural history of biological conservation, going back almost 2,500 years in recorded history. Since independence in 1947, and particularly since 1970, India has been one of the international leaders in setting aside land for biodiversity conservation. In spite of strong local interest, a highly developed scientific infrastructure, and considerable political will for conservation, systematic conservation planning methods from contemporary conservation biology have rarely been used in any Indian context (see, however, Pawar et al. 2007). Our purpose here is to provide a brief introduction to these neglected methods with particular attention to the Indian context, and then apply them to two Indian data sets. However, the data sets we use were generated from publicly available coarse-grained data from the World Wide Web. The only geographical data that are thus available for India are for environmental, that is, climatic and topographical, features. No geographical distributional data for biota were available. Consequently, we could only test the adequacy of using environmental features by assessing what fraction of each ecoregion was selected when we prioritized places for conservation using these features. However, the surrogates that we used effectively represent components of biodiversity in other regions (Sarkar et al. 2005, Margules and Sarkar 2007). Because of these limitations, our results indicate what conservation planning might achieve if the ongoing Indian and transnational ecoinformatics projects compile adequate data in appropriate form. They should not guide policy formulation. In the future, we hope to repeat this analysis with more adequate data sets, and to provide

Himalayan Journal of Sciences 4(6): 27–40, 2007
Available online at www.himjsci.com

Box 1. Glossary of technical terms

Conservation area: Any geographical unit at which a conservation plan for biodiversity is being implemented. There is no restriction on what such a plan may be.

Conservation area network: A network of *conservation areas* which are jointly intended to satisfy *representation targets* for biodiversity and other *goals*. The main goal of systematic conservation planning is to identify such networks.

Estimator surrogate: See *surrogate*.

Goal: A desired spatial configuration of conservation areas in a conservation area network, for instance, with specified sizes or shapes of individual areas, their dispersion across the study region, or the connectivity between them. Also refers to desired social, political, and economic consequences of a conservation area network.

Representation level: A quantitative measure of the extent to which a biodiversity surrogate is present in a *conservation area network*, for instance, the fraction of the habitat of some species.

Surrogate: Biological or environmental (climatic or topographic) features that are used to measure biodiversity in conservation planning. Biological features may be sets of species or other taxa as well as community types. *True* surrogates are those such features used to capture biodiversity generally. *Estimator* surrogates are used to represent true surrogates when the geographical distributions of true surrogates cannot be accurately measured.

True surrogate: See *surrogate*.

Target: A required *level* of *representation* for each *surrogate* in an adequate *conservation area network*.

policy recommendations. Nonetheless, for one case in peninsular India our results do suggest the need for a new program of investigative research. (For an explanation of the terminology used in this paper, see **Box 1**.)

The following section of this paper describes a systematic conservation planning and management framework previously used by conservation planners in many countries, including Australia, Canada, Papua New Guinea, and South Africa. (For details, see Margules and Sarkar 2007; for a historical review, see Justus and Sarkar 2002.) We tailored the discussion to the Indian context. In the "Materials and methods" section, we describe the data sets, algorithms, and software tools we use. In the "Results" section, we provide our initial findings and analyze their implications in "Discussion" section.

Systematic biodiversity conservation planning and management

The aim of biodiversity conservation planning is to select conservation area networks (CANs) and to devise methods for their adequate management. We define a conservation area as an area in which some conservation action is implemented. Such actions include the designation of traditional reserves with human exclusion, but they also include sustainable human use and management. (This is why we prefer the term "conservation area" to the more traditional "reserve.") **Box 2** details the framework for systematic conservation planning and management as an eleven-stage process which is described in detail by Margules and Sarkar (2007; see also Margules and Pressey 2000). The first stage is the identification of stakeholders for a given region and discussion of process and general goals. The next stage is data collection. It is critical that the data be georeferenced and recorded in a Geographical Information System (GIS) model. As part of this stage, planners must identify the biological entities that are of the most interest for conservation. These obviously include species that are at risk and also those that are endemic or rare. Planners must also assess the quality of the data. Even though no techniques exist as yet to quantify uncertainties in the data, and how these propagate through the analysis, the best possible assessment of the quality of the data must nevertheless guide the interpretation of results. The last point will be illustrated as we discuss our own results.

The third stage of conservation planning is the selection of surrogates to represent general biodiversity. In this context, there is an operationally useful distinction between "true" and "estimator" surrogates for biodiversity (Sarkar and Margules 2002, Margules and Sarkar 2007). The former must represent biodiversity in general. However, since general biodiversity has so far proved impossible to define, we must use some convention. Though there are many plausible alternatives, the most common convention has been to regard the set of all species as a true surrogate set (Sarkar 2002). Unfortunately, complete distributions of such comprehensive true surrogate sets are almost always impossible to obtain in practice: consequently, conservation planners have to use estimator surrogates. Whereas true surrogates have general biodiversity as their target of representation, estimator surrogates have true surrogates as their target. Estimator surrogates must be landscape features that are easily and accurately quantified and assessed. These surrogates may be sets of species or higher taxa, as well as environmental parameters such as climatic variables and land classes. Whether an estimator surrogate set adequately represents an explicitly specified true surrogate set is a question that conservation planners must evaluate empirically in the field. Planners can evaluate the extent to which an estimator surrogate set represents a true surrogate set in two ways: (i) planners can use the estimator surrogate distributions to predict the true surrogate distributions, for instance, through niche modeling; or (ii) planners can compare results of planning using estimator surrogates to those obtained using the true surrogates. So far planners have never successfully implemented method (i) for large complements of biota at the landscape scale. However, planners have used method (ii) with some success (Ferrier and Watson 1997, Garson et al. 2002a, Sarkar et al. 2006). Typically, planners must survey a small, suitably randomized set of sites for both the true and potential estimator surrogates. Planners must then prioritize

Box 2. Systematic conservation action

1. **Identify stakeholders for the planning region:**
   - Stakeholders include: (a) those who have decision-making powers; (b) those who will be affected by conservation plans for region; (c) those with expertise about the region and (d) those who may commit resources for conservation plans;
   - Include both local and global stakeholders;
   - Ensure transparency in the involvement of all stakeholders from the beginning.

2. **Compile, assess, and refine biodiversity and socio-economic data for the region:**
   - Compile available geographical distribution data on as many biotic and environmental parameters as possible at every level of organization;
   - Compile available socio-economic data, including values for alternate uses, resource ownership and infrastructure;
   - Collect relevant new data to the extent feasible within available time; remote sensing data should be easily accessible; systematic surveys at the level of species (or lower levels) will usually be impossible;
   - Assess conservation status for biotic entities, for instance, their rarity, endemism, and endangerment;
   - Assess the reliability of the data, formally and informally; in particular, critically analyze the process of data selection;
   - When data do not reflect representative samples of the landscape, correct for bias and model distributions.

3. **Select biodiversity surrogates for the region:**
   - Choose true surrogate sets for biodiversity (representing general "biodiversity") for part of the region; be explicit about criteria used for this choice;
   - Choose alternate estimator surrogate sets (for representing true surrogate sets in the planning process);
   - Prioritize sites using true surrogate sets; prioritize sites using as many combinations of estimator surrogate sets as feasible, and compare them;
   - Potentially also use other methods of surrogacy analysis to assess estimator-surrogate sets, including measures of spatial congruence between plans formulated using the true and estimator surrogate sets;
   - Assess which estimator surrogate set is best on the basis of (i) economy and (ii) representation.

4. **Establish conservation targets and goals:**
   - Set quantitative targets for surrogate coverage;
   - Set quantitative targets for total network area;
   - Set quantitative targets for minimum size for population, unit area, etc.;
   - Set design criteria such as shape, size, dispersion, connectivity, alignment, and replication;
   - Set precise goals for criteria other than biodiversity, including socio-political criteria.

5. **Review the existing conservation area network (CAN):**
   - Estimate the extent to which the existing set of conser-vation areas meets the conservation targets and goals;
   - Determine the prognosis for the existing CAN;
   - Refine the first estimate.

6. **Prioritize new areas for potential conservation action:**
   - Using principles such as complementarity, rarity, and endemism, prioritize areas for their biodiversity content to create a set of potential conservation area networks;
   - Starting with the existing CAN, repeat the process of prioritization to compare results;
   - Incorporate socio-political criteria, such as various costs, if desired, using a trade-off analysis;
   - Incorporate design criteria such as shape, size, dispersion, connectivity, alignment, and replication, if desired, using a trade-off analysis.
   - Alternatively, carry out last three steps using optimal algorithms.

7. **Assess prognosis for biodiversity within each newly selected area:**
   - Assess the likelihood of persistence of all biodiversity surrogates in all selected areas. This may include population viability analysis for as many species using as many models as feasible;
   - Perform the best feasible habitat-based viability analysis to obtain a general assessment of the prognosis for all species in a potential conservation area;
   - Assess vulnerability of a potential conservation area from external threats, using techniques such as risk analysis.

8. **Refine networks of areas selected for conservation action:**
   - Delete the presence of surrogates from potential conservation areas if the viability of that surrogate is not sufficiently high;
   - Run the prioritization protocol again to prioritize potential conservation areas by biodiversity value;
   - Incorporate design criteria such as shape, size, dispersion, connectivity, alignment, and replication.

9. **Examine feasibility using multi-criteria analysis:**
   - Order each set of potential conservation areas by each of the criteria other than those used in Stage 6;
   - Find all best solutions; discard all other solutions;
   - Select one of the best solutions.

10. **Implement a conservation plan:**
    - Decide on most appropriate legal mode of protection for each targeted place;
    - Decide on most appropriate mode of management for persistence of each targeted surrogate;
    - If implementation is impossible return to Stage 5;
    - Decide on a time frame for implementation, depending on available resources.

11. **Periodically reassess the network:**
    - Set management goals in an appropriate time-frame for each protected area;
    - Decide on indicators that will show whether goals are met;
    - Periodically measure these indicators;
    - Return to Stage 1.

areas using both true and estimator surrogate sets (see the discussion of the sixth stage below) and compare the results. The subset of potential estimator surrogates that achieves the closest level of representation of the true surrogate set is the best to use for the entire region for which the full distributions of true surrogates are not known.

At the fourth stage, conservation planners must establish explicit targets and goals for the conservation area network. Here, targets refer to the quantitative level of representation of surrogates in conservation area networks (see below). Goals refer to both the spatial configuration of networks (the size, shape, dispersion, connectivity, etc. of the areas in the network) as well as social and economic aspects. Without explicit targets and goals, it is impossible to assess the success of a conservation plan. However, setting such targets and goals provides ample scope for controversy. Typically, planners use two types of targets: (i) a level of representation for each surrogate within a conservation area network (CAN); or (ii) the area of land that can be put under a conservation plan. A common target of type (i) is to set the level of representation at 100% for species at risk and 10% for all other surrogates. A common target of type (ii) is 10% of the total area of a region, as originally proposed by the World Wide Fund for Nature (WWF) and the International Union for the Conservation of Nature and Natural Resources (IUCN) (Dudley et al. 1996). However, the actual numbers used are not entirely determined by biological criteria. Rather, they represent conventions arrived at by educated intuition. Similarly, while planners generally accept on ecological grounds that larger conservation areas are better than smaller

Table 1. Representation of ecoregions among selected cells for the Indian region

Ecoregion	All Surrogates 5%	All Surrogates 10%	Restricted Surrogates 5%	Restricted Surrogates 10%
Andaman Islands rain forests	0.00	42.88	0.00	0.00
Baluchistan xeric woodlands	4.26	14.11	0.04	7.76
Brahmaputra Valley semi-evergreen forests	0.39	0.78	0.00	0.20
Central Afghan Mountains xeric woodlands	6.04	15.71	0.03	10.11
Central Deccan Plateau dry deciduous forests	4.70	7.45	0.05	6.06
Central Tibetan Plateau alpine steppe	1.42	3.37	0.02	2.84
Chhota-Nagpur dry deciduous forests	9.10	11.21	0.07	8.83
Chin Hills-Arakan Yoma montane forests	12.20	28.65	0.13	23.68
Deccan thorn scrub forests	4.62	6.36	0.02	11.54
East Afghan montane conifer forests	0.00	0.00	0.00	7.47
East Deccan dry-evergreen forests	0.00	0.00	0.00	0.00
Eastern highlands moist deciduous forests	4.71	12.13	0.04	10.38
Eastern Himalayan alpine shrub and meadows	6.68	9.79	0.07	10.26
Eastern Himalayan broadleaf forests	14.77	26.69	0.10	28.66
Eastern Himalayan subalpine conifer forests	24.64	28.34	0.30	37.78
Goadavari-Krishna mangroves	0.00	1.92	0.02	1.92
Himalayan subtropical broadleaf forests	6.12	26.78	0.01	3.20
Himalayan subtropical pine forests	7.37	15.28	0.05	10.20
Hindu Kush alpine meadow	0.00	7.74	0.02	14.04
Indus River Delta-Arabian Sea mangroves	13.76	19.88	0.00	25.85
Indus Valley desert	0.00	0.00	0.00	0.00
Karakoram-West Tibetan Plateau alpine steppe	4.00	14.19	0.05	6.60
Khathiar-Gir dry deciduous forests	2.57	5.59	0.03	10.55
Kuh Rud and Eastern Iran montane woodlands	0.42	10.02	0.00	0.42
Lower Gangetic Plains moist deciduous forests	3.50	5.98	0.04	6.27
Malabar Coast moist forests	1.32	2.33	0.00	0.98
Meghalaya subtropical forests	7.18	17.02	0.05	11.42
Mizoram-Manipur-Kachin rain forests	4.41	11.72	0.01	2.08
Myanamar Coast mangroves	0.00	0.00	0.00	0.00

ones, ecology does not specify how large is good enough. The question of connectivity also remains controversial: while connectivity might help species migrate to find suitable habitat, it may also enable the spread of infectious disease.

At the fifth stage, planners must assess the performance of existing conservation areas in meeting the targets and goals of the fourth. This will determine what conservation action (if any) they should take. Because conservation practitioners have never implemented systematic conservation planning in India, it is unknown whether, and to what extent, the existing network of protected areas adequately represents India's biodiversity. It is only in the southern region (Kerala, southern Karnataka, and Tamil Nadu) that close to 10% of the land is under some form of protection. However, we do not know whether the existing areas are spatially economical, that is, selected so as to represent biodiversity maximally in the area of land that has been put under protection.

The sixth stage consists of prioritizing places for conservation action to satisfy the stated targets and goals of the fourth stage. The result is a potential CAN. This problem corresponds to the traditional problem of reserve network selection. We purposely chose the term "place prioritization" rather than the more traditional "reserve selection" in order to emphasize that systematic conservation planning envisions a variety of conservation actions, including, but not limited to, the designation of reserves. A wide variety of algorithms and other methods are available for place prioritization (Cabeza and Moilanen 2001). The algorithm used here will be discussed in "Materials and methods" section. It is designed to construct a CAN as economically

Myanmar coastal rain forests	5.07	22.79	0.04	8.76
Narmada Valley dry deciduous forests	3.39	8.15	0.04	8.38
Nicobar Islands rain forests	10.01	0.00	0.00	0.00
North Tibetan Plateau-Kunlun Mountains alpine desert	3.69	7.40	0.03	7.39
North Western Ghats moist deciduous forests	5.86	15.09	0.03	7.83
North Western Ghats montane rain forests	14.09	22.59	0.06	16.78
Northeast India-Myanmar pine forests	1.15	3.47	0.00	2.31
Northeastern Himalayan subalpine conifer forests	2.34	5.83	0.02	6.05
Northern dry deciduous forests	0.20	2.76	0.00	0.60
Northern Triangle temperate forests	0.00	0.00	0.03	4.04
Northwestern Himalayan alpine shrub and meadows	9.15	18.19	0.07	17.55
Northwestern thorn scrub forests	3.70	5.83	0.01	5.76
Orissa semi-evergreen forests	3.17	16.89	0.00	4.22
Pamir alpine desert and tundra	3.34	4.86	0.03	4.52
Rann of Kutch seasonal salt marsh	4.51	16.45	0.07	7.39
Registan-North Pakistan sandy desert	4.93	11.13	0.06	10.67
Rock and ice	11.69	23.74	0.12	23.42
South Deccan Plateau dry deciduous forests	0.00	5.44	0.00	5.87
South Iran Nubo-Sindian desert and semi-desert	21.16	32.18	0.24	35.02
South Western Ghats moist deciduous forests	3.08	7.19	0.07	1.03
South Western Ghats montane rain forests	11.04	24.19	0.09	4.22
Sri Lanka dry-zone dry evergreen forests	0.00	3.30	0.00	0.00
Sri Lanka lowland rain forests	0.00	9.81	0.03	0.00
Sri Lanka montane rain forests	4.17	12.50	0.21	12.50
Sulaiman Range alpine meadows	0.00	2.58	0.00	1.74
Sundarbans freshwater swamp forests	0.00	0.00	0.00	0.00
Sundarbans mangroves	0.00	0.00	0.00	4.22
Terai-Duar savanna and grasslands	0.00	5.77	0.03	6.14
Thar desert	4.25	6.85	0.03	5.50
Upper Gangetic Plains moist deciduous forests	1.57	1.86	0.00	0.67
Western Himalayan alpine shrub and meadows	11.93	22.04	0.08	22.34
Western Himalayan broadleaf forests	14.85	21.54	0.16	25.00
Western Himalayan subalpine conifer forests	12.56	18.22	0.13	23.03

Table 2. Representation of ecoregions among selected cells for the Eastern Himalayas

Ecoregion	Restricted surrogates 5%	Restricted surrogates 10%
Brahmaputra Valley semi-evergreen forests	1.49	10.82
Chin Hills-Arakan Yoma montane forests	4.20	4.59
Eastern Himalayan alpine shrub and meadows	5.00	11.02
Eastern Himalayan broadleaf forests	6.59	15.55
Eastern Himalayan subalpine conifer forests	4.70	6.67
Himalayan subtropical broadleaf forests	8.45	48.99
Himalayan subtropical pine forests	4.50	4.69
Lower Gangetic Plains moist deciduous forests	0.90	70.25
Meghalaya subtropical forests	5.53	10.19
Mizoram-Manipur-Kachin rain forests	3.81	5.40
Northeast India-Myanmar pine forests	5.74	6.74
Northeastern Himalayan subalpine conifer forests	4.84	7.51
Northern Triangle temperate forests	3.41	8.65
Rock and ice	2.50	3.66
Terai-Duar savanna and grasslands	6.42	13.30

as possible, that is with the least number of areas put under management for biodiversity conservation.

However, the current representation of biodiversity in a CAN does not solely ensure its persistence: conservation planners must also take into account the level of threat from ecological and anthropogenic factors. The seventh stage of systematic conservation planning consists of assessing such risks (Gaston et al. 2002). This is often a difficult task, and planners have paid relatively little attention to it. Techniques for coping with risk include population and habitat-based viability analysis, as well as threat estimation (Boyce 1992, Boyce et al. 1994). Planners have not carried out any of these for any Indian region.

In the eighth stage, conservation planners drop areas with a poor prognosis for relevant biodiversity features and repeat the place prioritization excluding these areas. Biodiversity conservation is not the only possible use of land. Competing uses such as agriculture, recreation, or industrial development, place strong socio-economic constraints on environmental policy. The ninth stage consists of attempting to synchronize all these criteria. Many interesting conceptual and practical problems arise at this stage, the main one being whether we can compound all these criteria in one utility function to be maximized (Janssen 1992, Faith 1995, Sarkar and Garson 2003, Moffett and Sarkar 2006). Systematic conservation planning in India has never reached this stage.

The end of the ninth stage produces a plan for implementation. An attempt at implementation constitutes the tenth stage of the conservation process. If implementation is impossible, as it sometimes is because of the constraints encountered, new plans must be formulated. This requires a return to the sixth stage. Finally, conservation action is not a one-time process. The status of biological entities changes over time. Consequently, the last stage consists of repeating the entire process after a period of time. Conservation planners may set this period of time in absolute terms (a specified number of years, once again chosen by convention) or planners may determine the period by keeping track of explicitly specified indicators of the health of a conservation area network. The conservation planning literature sometimes refers to this iterative process as adaptive management.

Materials and methods

Data sets Our starting point is the map of terrestrial ecoregions of the world produced by the WWF (http://www.worldwildlife.org/ecoregions/, Olson et al. 2001). In **Figure 1**, we overlaid all of the ecoregions that partly or fully overlap the political map of India to produce the region of analysis. The first part of our analysis encompasses the entirety of this region which we will refer to as the "Indian region." We divided this region into cells at a resolution of 0.1° × 0.1° of longitude and latitude, resulting in 63,954 cells which varied in size from 94.6 to 123.6 sq. km. (The variation in area is due to the fact that the distance between lines of longitude decreases away from the equator.) The region of analysis has a total area of 6,987,279.29 sq. km and represents 63 ecoregions.

As estimator surrogates we used climatic parameters (annual mean temperature, the minimum temperature during the coldest period, the maximum temperature during the hottest period, and precipitation), slope, elevation, aspect, and soil classes. Since we had no access to biogeographical distributional data, we judged the adequacy of our surrogate set on the basis of its ability to select representative fractions of the ecoregions. (Olson et al. [2001] defined the ecoregions based in part on coarse-grained biological features.) However, we have previously shown this estimator surrogate set to be adequate in representing biota for two widely different data sets from Queensland and Québec (Sarkar et al. 2005).

We obtained elevation data from the GTOPO30 DEM which is a 30 arc-second DEM available from the United States Geological Survey (USGS) (USGS 1998, http://edcdaac.usgs.gov/gtopo30/gtopo30.html). We created slope and aspect layers using the Spatial Analyst extension in ArcGIS 8.1 (ESRI 2002) from the DEM as specified in the Hydro 1K elevation derivative database methodology

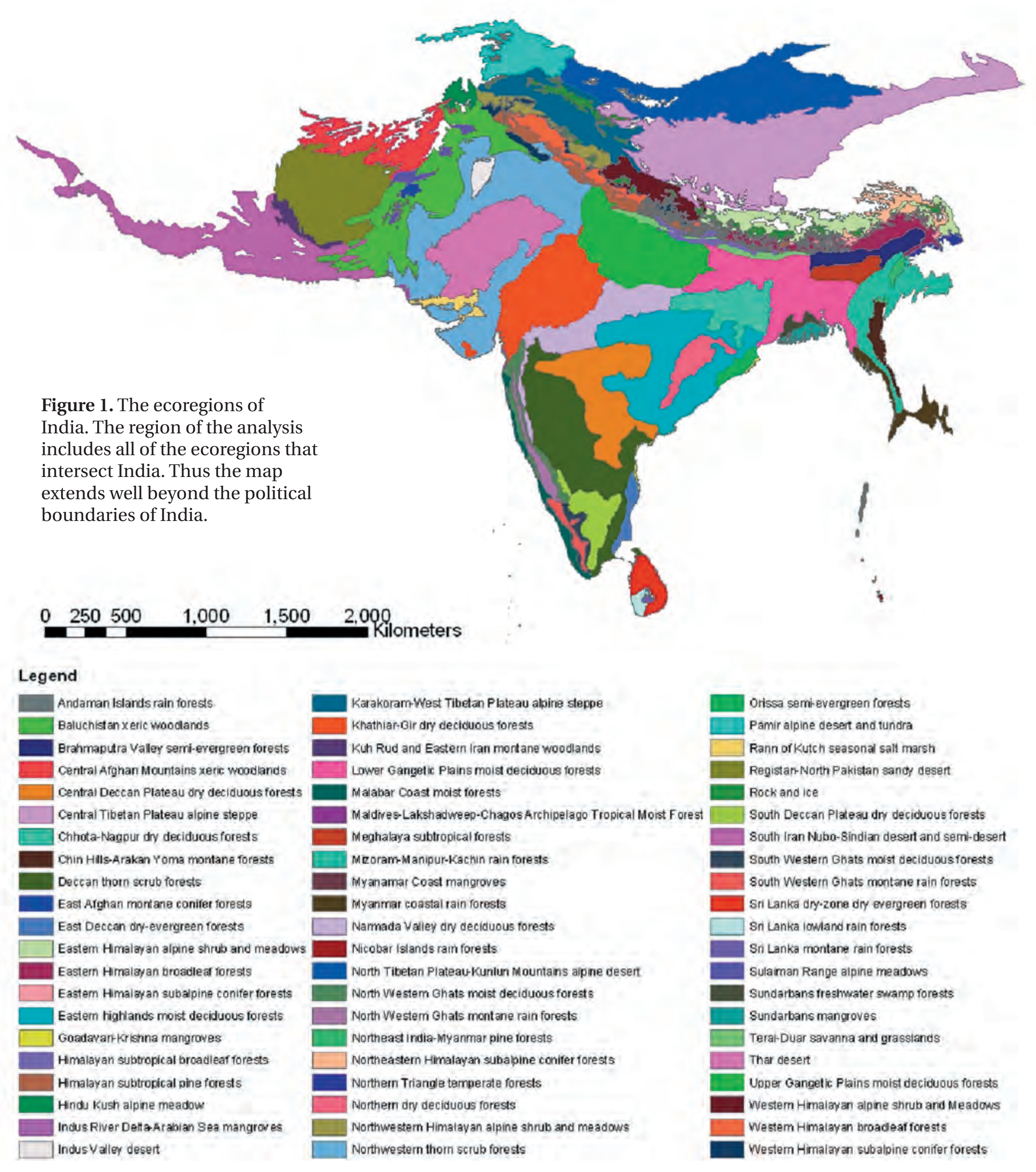


Figure 1. The ecoregions of India. The region of the analysis includes all of the ecoregions that intersect India. Thus the map extends well beyond the political boundaries of India.

(http://edcdaac.usgs.gov/gtopo30/hydro/index.html) also available from USGS.

We created the annual precipitation, mean temperature, minimum temperature of the coldest period, and maximum temperature of the coldest period layers from the GTOPO30 DEM and the FAOCLIM worldwide agroclimatic database (FAO 2000, http://www.fao.org/sd/2001/EN1102_en.htm) using the ANUSPLIN 4.1 (Hutchinson 2000, http://cres.anu.edu.au/outputs/anusplin.html) and ANUCLIM 5.1 (Houlder et al. 2000, http://cres.anu.edu.au/outputs/anuclim.html) software packages available from the Centre for Resource and Environmental Studies at the Australian National University. We used procedures for running ANUSPLIN and ANUCLIM identical to those used in the

Australian BioRap analysis (Hutchinson 1991, Hutchinson et al. 1996). In ANUSPLIN, we used the same default values as in BioRap analysis for the SELNOT and SplineB programs.

We obtained soil classifications for India from the world soil resources map (http://www.fao.org/sd/eidirect/gis/chap7.htm) created by the Food and Agriculture Organization of the United Nations (FAO 1993). There were only 13 associations of soil types, making this the most coarse-grained (and least satisfactory) of our estimator surrogate sets.

We divided the annual mean temperature data (range: –19° to 29° C) and annual precipitation data (range: 15 to 7,873 mm) into 10 equal interval classes. We divided the minimum temperature of the coldest period of the year (range: –40° to 24°C) and the maximum temperature of the warmest period of the year (range: 0° to 45°C) into four equal interval classes. We did not attach any significance to the exact number of classes: these choices reflect the intuition that mean temperature matters more for biodiversity than the annual high and low temperatures. However, there is an important reason why we used equal intervals: this attempts to ensure that a conservation plan adequately represents biotic features found in rare temperature regimes (for instance, species found in hot desert and cold tundra environments).

We divided slope into five classes based on standard deviations (range: 0° to 52° below the horizon). The use of standard deviations reflects an assumption that mid-range slopes are more important for biodiversity than extremes. We based this assumption on the fact that the two biodiversity hotspot regions in the Indian region (the Western Ghats and the Eastern Himalayas) are in mountains that have most of their biota in the mid-range of slope. However, this assumption may introduce an unjustified bias against the plains, which are also important for Indian biodiversity. To guard against this bias, we divided elevation (1 to 8752 m) into 25 classes based on quantiles. The use of quantiles gives preference to flatter regions. We divided the soil data into 13 classes based on the 13 soil association types that occur within the region (FAO 1993). We divided aspect into eight classes based on the cardinal directions (N, NE, E, SE, S, SW, W, NW).

Thus, there were a total of 79 estimator surrogates. We also repeated our analysis without using slope, aspect, and elevation since these were used to calculate the climatic parameters. There were then a total of 41 estimator surrogates in the repeated analysis.

For our second data set, we partitioned the Eastern Himalayas at the finer scale of 0.01° × 0.01° of longitude and latitude to obtain some preliminary indicative results because we plan to do further work on this region. We overlaid the 15 ecoregions that intersected with the Eastern Himalayas and then eliminated non-mountainous terrain using an elevation threshold of 400 m. There were 365,347 cells which varied in area between 1.06 and 1.18 sq. km. The total area of the region was 401,834.03 sq. km.

In the Eastern Himalayas, there are 15 ecoregions. We only used the truncated estimator surrogate set in order to keep the computations tractable. We divided the annual mean temperature data (range: –19° to 25°C) and annual precipitation data (395 to 7873 mm) into 10 equal interval classes. We divided the minimum temperature of the coldest period of the year (–40° to 14°C) and the maximum temperature of the warmest period of the year (0° to 36°C) into four equal interval classes. Soil data were divided into four classes, corresponding to the four soil association types that occur in the region. We did not include elevation, aspect, and slope data in this analysis. Thus, there were a total of 32 estimator surrogates.

Algorithms and software We performed all computations using the ResNet Ver. 1.2 software package initialized with rarity (Garson et al. 2002b). This software package implements a CAN selection algorithm fully described by Sarkar et al. (2002). We used targets of 5% and 10% of the total distribution of the surrogates. To initiate the construction of a CAN, we selected the first cell by the presence of the rarest surrogate in the data set. We then iteratively augmented the CAN by adding cells using rarity again and, if there were ties, by breaking them by complementarity. (The complementarity value of a cell is the number of surrogates in it that have not yet achieved their targets.) We broke remaining ties by a random selection of a cell. Finally, we removed redundant cells. It is well-established that such rarity-complementarity algorithms lead to very economical CANs, that is, those that achieve all the prescribed targets with as few cells as possible (Csuti et al. 1997, Pressey et al. 1997). Such economy is important because the addition of a unit to a CAN imposes costs, including the cost of acquisition and the cost of forgone opportunities (Sarkar et al. 2006).

Results

Figure 2a shows the selected cells for the entire Indian region when we used all 79 surrogates with a target of representation of 5%; **Figure 2b** is the result when we set the target at 10%. ResNet selected 3,223 cells with an area of 353,991.82 sq. km. or 5.07% of the total area in **Figure 2a**; 6,472 cells with an area of 688,047.22 sq. km. or 10.32% of the total area in **Figure 2b**. **Table 1** shows the percentage of the area selected for each of the 63 ecoregions. These results permit some assessment of the adequacy of our estimator surrogates. When we used a target of 5% representation of surrogates, only 20 out of 63 ecoregions have at least 5% of their area selected; at a 10% surrogate representation, 29 ecoregions achieve a 10% area representation. With very few exceptions, the areas selected at the 10% representation augment those selected at the 5% representation.

In **Figures 3a**, **b**, the result of using only 41 surrogates is superimposed on those of using all 79 surrogates for 5% and 10% targets for the Indian region. The observation that a very high percentage of cells was selected in the Himalayan region motivated this exercise. It is possible that the selection of these cells is an artifact of the fact that these mountain ranges have extremes of slope and elevation. Moreover, we used slope, aspect, and elevation in our calculation of the climatic layers. Thus these three parameters and the climatic parameters are not independent of each other and it is at least intuitively plausible—though it has never been

Figure 2. Selected areas in the Indian region: (a) target of representation of 5%; (b) target of representation of 10%. The selected cells are shown in dark blue.

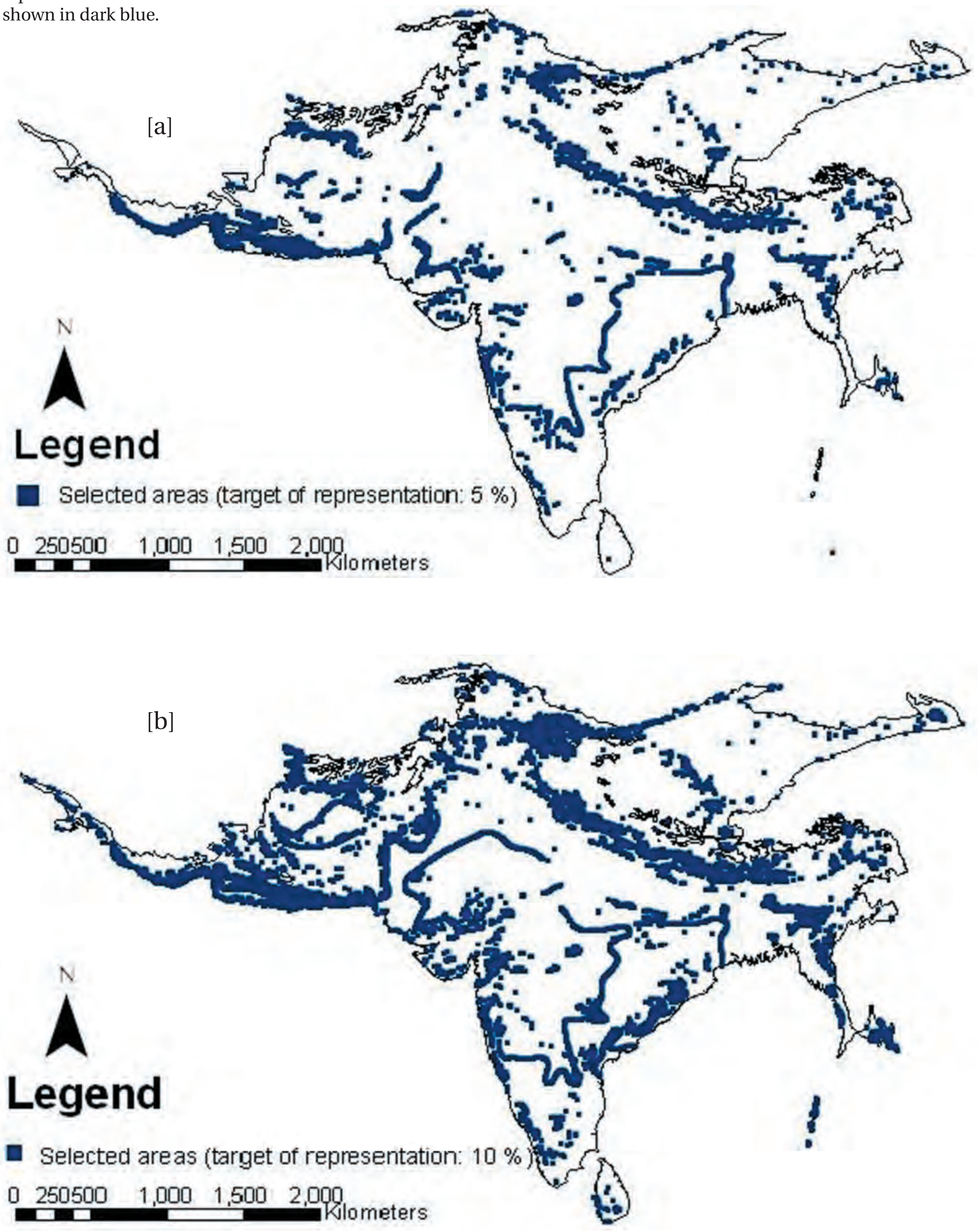
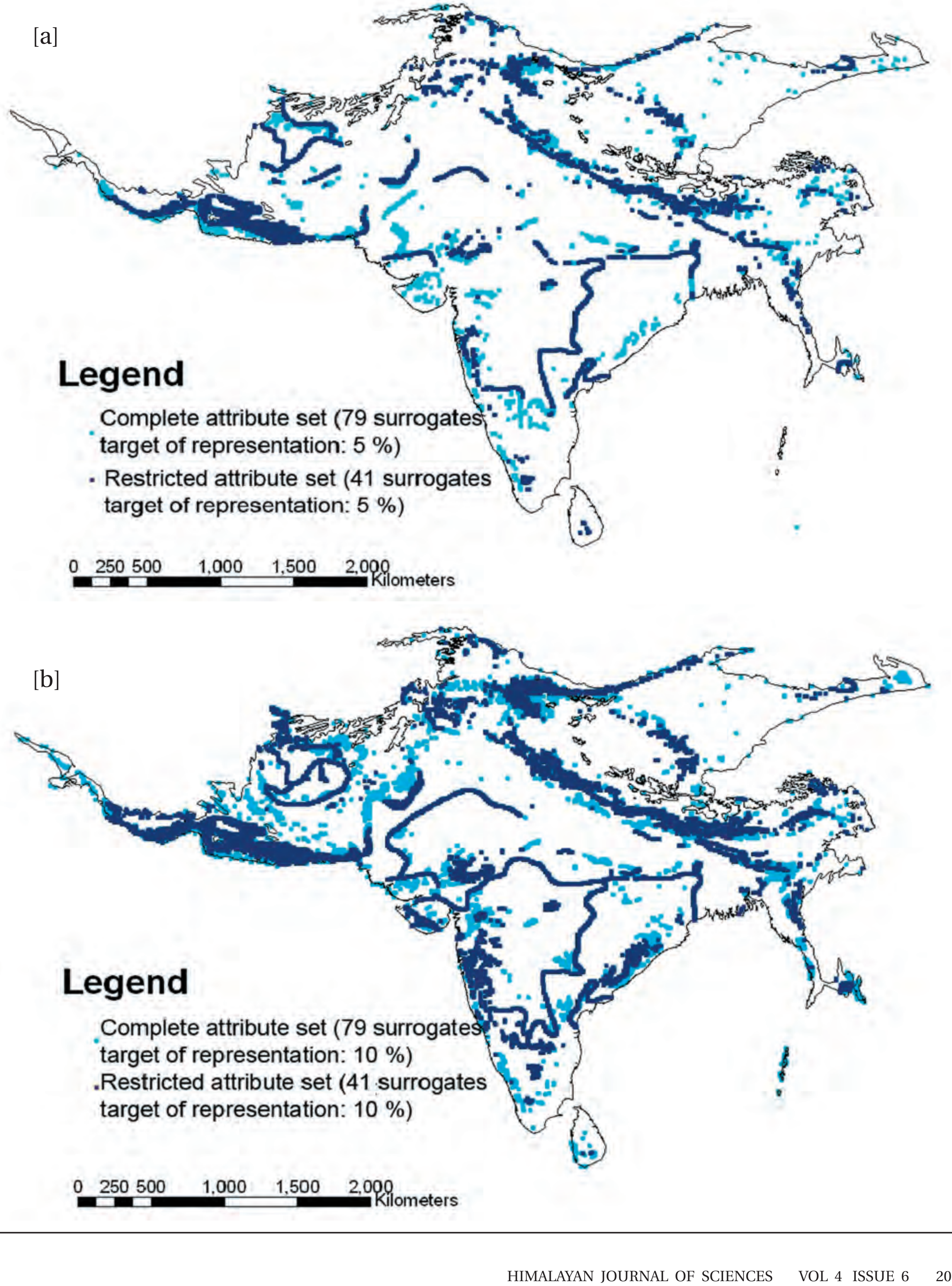


Figure 3. Effect of surrogate set composition on selected areas: (a) target of representation of 5%; (b) target of representation of 10%. When we used all 79 surrogates, the areas selected are shown in light blue. When we used only 41 surrogates (excluding slope, aspect, and elevation), the selected cells are super-imposed in dark blue. (The additional cells selected when there are 79 surrogates appear visible in light blue.)



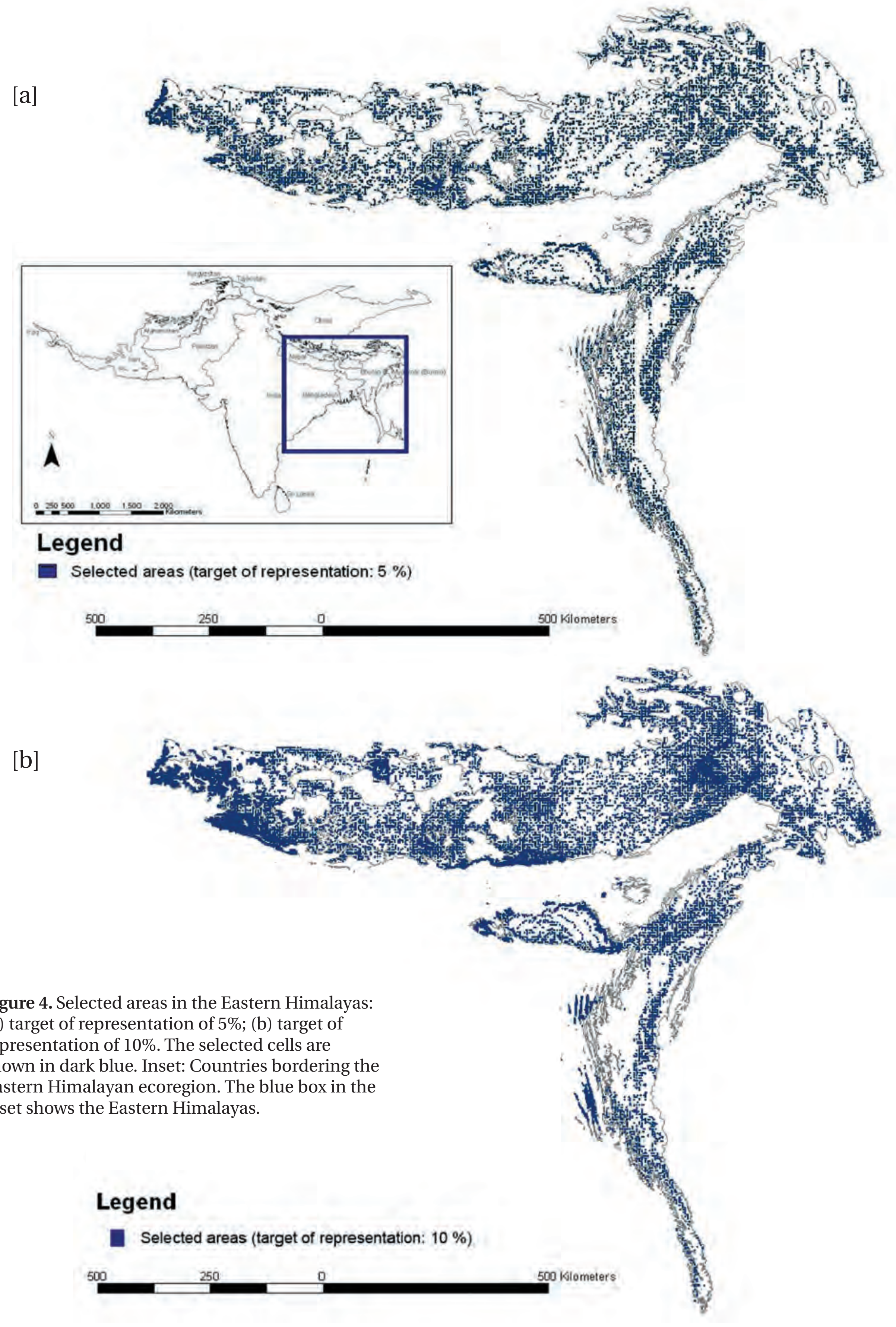


Figure 4. Selected areas in the Eastern Himalayas: (a) target of representation of 5%; (b) target of representation of 10%. The selected cells are shown in dark blue. Inset: Countries bordering the Eastern Himalayan ecoregion. The blue box in the inset shows the Eastern Himalayas.

proved—that the best estimator surrogate sets are those that include only independent parameters. In this case, no ecoregion achieves 5% area representation with 5% surrogate representation. However, 21 ecoregions achieve a 10% area representation with a target of 10% surrogate representation. Thus, at least at the 5% level, we do not recommend using results obtained with the truncated surrogate set for policy development. However, the results shown in **Figures 3a**, **b** are not qualitatively different from those in **Figures 2a**, **b** though, as expected, with fewer surrogates, ResNet selected less cells. In **Figure 3a**, ResNet selected 2 816 cells with an area of 308,219.26 sq. km. or 4.41% of the total area; in **Figure 3b**, 5,637 cells with an area of 618,275.36 sq. km. or 8.85% of the total area.

Figures 4a shows the selected cells for the entire Eastern Himalayas at a 0.01° × 0.01° longitude × latitude scale when we used 32 surrogates, ignoring slope, aspect, and elevation, with a target of representation of 5%; **Figure 4b** is the result when we set the target at 10%. As noted before, we used the truncated set for computational efficiency. Below we will show that it does not perform as poorly for the Eastern Himalayas as it does for the entire Indian region. The fact that conservation planning in the Indian region takes place at the regional rather than the subcontinental level motivated this exercise. We investigated whether there is a significant loss of economy if targets of (local) representation must be met within the confines of each region. In **Figure 4a**, ResNet selected 17,985 cells with an area of 19,745.31 sq. km. or 4.91% of the total area; in **Figure 4b**, 35,945 cells with an area of 39,386.67 sq. km. or 9.8% of the total area. **Table 2** shows the shows the percentage of the area selected for each of the 15 ecoregions.

At both the 5% and the 10% surrogate representation level, seven out of the 15 ecoregions achieved the corresponding level of area representation (5% or 10%). That the truncated surrogate set performs relatively well for the Eastern Himalayas is probably a result of their being fewer ecoregions present compared to the entire Indian region (15 versus 63). (It is unlikely that this difference in percentage is due to the change in the spatial scale of analysis. In general, surrogates perform better at larger spatial scales Garson et al. (2002a), and this effect is likely to be enhanced when there are fewer surrogates present.)

Discussion

With the increasing population and *per capita* resource use in India, the near future will see an increase in anthropogenic demands on habitats. Consequently, systematic conservation planning and management is a necessity, not a luxury. However, going beyond the preliminary and incomplete results of this analysis will require the availability of GIS-based biogeographic data on as many taxa and habitat types as possible at regional or larger scales. Planners should regard the creation of such databases as one of the highest priorities for biodiversity conservation in India. This will require large-scale collaborative efforts between governmental and non-governmental institutions including those involved in education and environmental advocacy. These efforts must begin with an assessment of what data are available in computerized and non-computerized forms, and also of the data quality. This was the first stage of the framework presented in the section "Systematic biodiversity conservation planning and management". Collaborative biodiversity conservation programs would be beneficial in South Asia because participant countries could work together to solve funding, infrastructure, and training problems (Gupta et al. 2002). International collaborations of this sort have proven fruitful for mangrove conservation in South Asia (Clüsener-Godt 2002, WWF and ICIMOD 2001), bioprospecting for marine natural products (Berlinck et al. 2004), and research in medicinal botany supported by the International Cooperative Biodiversity Group (Lewis 2003). In addition, a larger proportion of the biodiversity content of the Indian region could be surveyed if several countries participate in the conservation planning process (WWF and ICIMOD 2001, CEPF 2005). Collaborative conservation programs will require the establishment of common standards for the representation of data, a problem that is yet to be fully solved anywhere. Until the creation of databases conservation planning in India can only be *ad hoc*, a procedure that is known to be uneconomical (Pressey 1994, Pressey and Cowling 2001). Such *ad hoc* CAN selection often leads to the inclusion of biologically irrelevant areas in CANs, and thus the illegitimate exclusion of human economic and other interests. For obvious political reasons, this is a situation that is best avoided.

With respect to the entire Indian region, the Himalayas are over-represented in our nominal CANs (**Table 1**, **Figures 2a**, **b**). This should come as no surprise because we used elevation, slope, and aspect along with climatic parameters derived using them. This region is known to have high biodiversity content. However the selection of a large number of cells in the coastal region along the Arabian Sea west of India may be entirely an artifact of the data set used. The variation in environmental parameters selected by our analysis does not correspond to known variation in biodiversity content. It is also surprising that ResNet selected relatively few cells in the Western Ghats. We conjecture that while environmental estimator surrogates may adequately capture biological diversity, they do not perform well at capturing endemism which is much more dependent on the biogeographic history of a place. Similarly, the representation of the Sunderbans and Nicobar Island rain forests is not adequate. In peninsular India, ResNet also selected cells along fronts simultaneously separating soil association types and climatic regimes. Planners have generally ignored these in conservation decisions in this region. Our results suggest that conservation practitioners should systematically investigate these areas for their biodiversity content: this is the only case where our results are more than merely illustrative and may have practical use.

For the Eastern Himalayas, the most interesting result is that the selected cells are fairly evenly distributed across most of the Eastern Himalayas. If this result continues to hold when a conservation plan uses demonstrably adequate surrogate sets, and across spatial scales, it will have an important implication for conservation planning for the Eastern Himalayas: conservation planning must pay attention to the entire region, and not only to a small set of large conservation areas. Our results are partially discordant with those obtained by Pawar et al. (2007) who found priority areas to be somewhat more concentrated towards the higher elevation regions of the landscape (rather than the low elevation Brahmaputra valley). However, that study used modeled amphibian and reptile distributions as surrogates and explicitly noted that planners should not interpret the results to identify priority areas for all biota.

Finally, we emphasize again that we intend the analysis presented here to be illustrative and not to guide policy. We have shown how decision-makers can draw many conclusions with implications for conservation planning even from limited data so long as those data are represented as a GIS model. However, for such an analysis to have even partial relevance for policy formulation, at the very least, the conservation plan must include accurate vegetation maps. If, as a first step, such maps were made available, then future studies could test the adequacy of the surrogates used here. Classification of remotely sensed data (that is, satellite imagery) can often provide such vegetation maps. However, our results do suggest that planners should systematically investigate the fronts separating soil association types and climatic regimes in peninsular India for their biodiversity features. We end with the suggestion that conservation practitioners make it an immediate priority to create GIS-based vegetation maps for India's two recognized hotspots of vascular plant endemism, the Western Ghats and the Eastern Himalayas.

Software availability

Users can download the ResNet Ver. 1.2 software package for free from http://uts.cc.utexas.edu/~consbio/Cons/Labframeset.html.

Acknowledgements

This work was supported by NSF Grant No. SES-0645884.

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Expansion of an ancient lake in the Kathmandu basin of Nepal during the Late Pleistocene evidenced by lacustrine sediment underlying piedmont slope

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We investigated the geomorphology and surface geology of the piedmont slope on the margins of the Kathmandu basin in the Nepal Himalaya in order to establish Late Pleistocene geography and especially the extent of the ancient lake in the basin. The piedmont slope consists of detrital deposits of colluvial or fluvial origin, underlain and interfingered by organic muddy sediments with radiocarbon ages of about 30,000 yr BP. Detritus from the surrounding hillslopes and lacustrine sediments were alternately deposited as the lake level rose at about that time. The ancient lake in the Kathmandu basin thus reached a level of between 1400 and 1440 m at around 30,000 yr BP, when it covered almost the entire basin. Because the cols on the surrounding divide are higher than this estimated lake level, and because reddish soils and weathered bedrock are observed on these cols, we conclude that overflow from an outlet other than the Bagmati River probably did not occur. Drainage of the ancient lake by the Bagmati River began just after 30,000 yr BP.

Key words: Nepal, Kathmandu basin, piedmont slope, lacustrine, lake level change, Late Pleistocene

According to local legend, Kathmandu basin once held a large lake; the god Manjushree cut the gorge at Chobhar with his mighty Sword of Wisdom to release the lake and open the highly fertile Kathmandu basin to human settlement. The geological record tells a similar story. In this paper we present our findings about the maximal extent of Kathmandu Lake in the Late Pleistocene.

The Kathmandu basin, an intradeep (intramontane basin) on the southern slope of the Nepal Himalaya, is filled with a thick sequence of lacustrine sediments deposited during the Pliocene and Pleistocene. Several terrace surfaces formed as the level of the ancient lake fell. Many studies of these basin-fill deposits and geomorphic surfaces have clarified the paleoclimate and sedimentary environment as well as crustal movement in and around the basin (Yoshida and Igarashi 1984, Gautam et al. 2001, Kuwahara et al. 2001, Sakai 2001, H Sakai et al. 2002, Fujii and Sakai 2002, Dill et al. 2003, Paudayal and Ferguson 2004).

Yoshida and Igarashi (1984) identified six terraces in the basin: from highest to lowest, the Pyanggaon, Chapagaon, Boregaon, Gokarna, Thimi, and Patan geomorphic surfaces. The higher surfaces of middle Pleistocene age (Pyanggaon, Chapagaon, and Boregaon) are distributed only in the southern part of the basin, whereas the Gokarna, Thimi, and Patan surfaces, which formed during the last glacial period, occupy the more northerly part of the basin. Yoshida and Igarashi attributed this distribution to a northward shift of the lake caused by uplift of the southern part of the basin. In contrast, T Sakai et al. (2002) explained the distribution of geomorphic surfaces in terms of a difference in the sedimentary environments of the northern and southern parts of the basin at the time of maximum lake level. They suggested that the higher geomorphic surfaces in the southern basin had been caused, not by crustal movement, but by the disparities in the catchment area and geomorphic conditions. These divergent explanations for geomorphic developments in the Kathmandu basin require further investigation.

In order to elucidate the paleogeography of the Kathmandu basin, particularly the date at which the ancient lake reached a maximal extent and when it began to drain, we have undertaken a geomorphological investigation of the margins of the basin, where evidence for the lake's extent is most likely to be found. We focus on the characteristics, distribution, and interrelationship of the piedmont slope and the lacustrine sediments.

Study area and characteristics of the piedmont slope

The floor of the Kathmandu basin, currently between 1250 and 1400 m, is surrounded by ridges of approximately

Himalayan Journal of Sciences 4(6): 41–48, 2007
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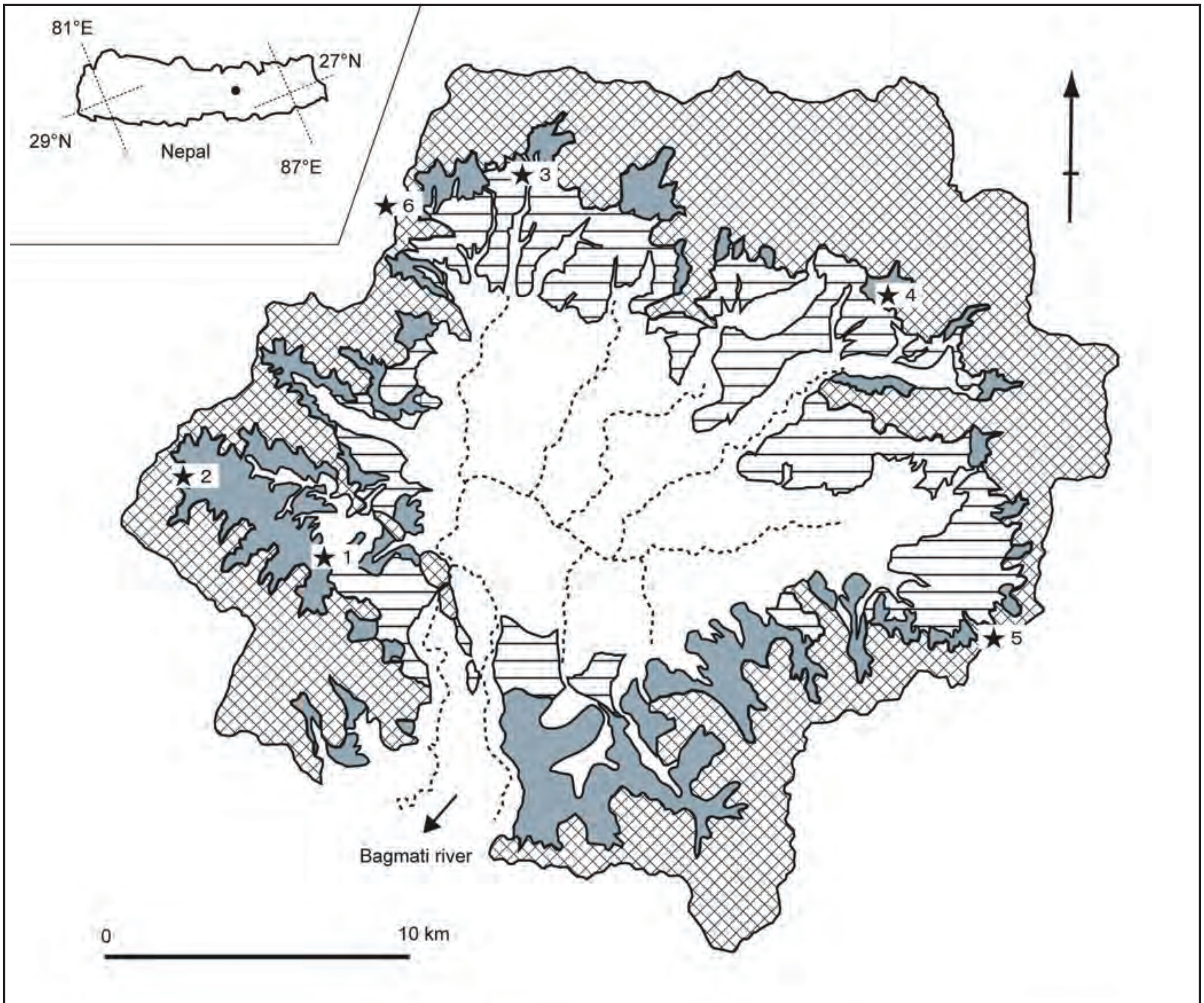

Figure 1. Distribution of the piedmont slope and Gokarna geomorphic surface in the Kathmandu basin (modified from Yoshida and Igarashi, 1984). Numbered stars show study sites. Geomorphic surfaces lower than Gokarna surface are omitted.

2000 m in elevation. At present, the basin is drained by the Bagmati River.

The piedmont slope is well developed where the basin floor meets the surrounding hillslope (**Figures 1** and **2**). This slope, mostly extending to elevations greater than 1400 m, has a smooth surface with a slightly concave or almost linear longitudinal profile that dips 7° to 15° basinward. In many places, it transitions basinward into the Gokarna surface and fades into narrow valleys in the back slopes. This slope corresponds to the alluvial and talus cones of Yoshida and Igarashi (1984), the colluvial slope of Saijo (1991), and the alluvial cones of Sakai et al. (2001). Based on aerial photo interpretation and analysis of the consistent geomorphological and altitudinal characteristics, we regard the three higher terraces in the southern part of the basin as part of the piedmont slope. Saijo (1991) showed that the "colluvial slope" (which we refer to as the "piedmont slope" in this paper) is the result of frequent landslides and debris flows as the climate warmed and became more humid after ca. 25,000 yr BP.

Stratigraphy of the piedmont slope

We observed the materials composing the piedmont slope at several locations. If the sediments contained organic matter, they were dated by conventional radiometric methods at Beta Analytic Radiocarbon Dating Laboratory, Miami, Florida, USA. The characteristics of the sediments are as follows:

Loc. 1 (1430 m)

Location 1 is in a gully that dissects the piedmont slope in the southwestern part of the basin. A poorly sorted gravel layer, alternating beds of organic mud and sand, and a gravelly layer, in descending order, are exposed in the sidewall of the gully (**Figures 3** and **4**). On the basis of its sedimentary facies, we conclude that the uppermost layer, composed mainly of cobble- to boulder-sized subangular and subrounded gravel with a silty matrix, is a debris flow deposit. The underlying unit consists of three conspicuous organic mud layers that interfinger sand layers containing abundant pebble- to cobble-sized gravel, sometimes in lenticular beds, and a little inorganic clay. These sedimentary features indicate that the depositional environment repeatedly changed between swamp and river channel, with occasional small debris flows. Radiocarbon ages obtained from the three organic mud layers are 29,190 ± 500 yr BP (Beta-135432), >36,940 yr BP (Beta-135433), and 37,130 ± 340 yr BP (Beta-135434), in descending order (**Figure 4**). The lowest layer is an unsorted and unbedded gravelly deposit. Most of the gravel is pebble- to cobble-sized and deeply weathered. We interpret this layer, like the uppermost, to be a debris flow deposit.

Loc. 2 (1460 m)

Location 2 is in another gully dissecting the piedmont slope in the southwestern part of the basin. We found, from top to bottom, a poorly sorted gravelly deposit containing silty layers in several horizons, a clayey layer accompanied by gravel and sand, and a silty layer (**Figure 4**). The upper gravelly deposit is composed of cobble- to boulder-sized subangular gravel in a silty matrix. These characteristics suggest that this deposit is of debris flow origin. Although the clayey layer beneath the gravelly deposit is composed mostly of grayish white or brownish gray clay, an organic mud ca. 10 cm thick and dating to 32,160 ± 200 yr BP (Beta-140257) is intercalated in the middle part of the layer. This organic mud is interpreted to have been deposited under swampy conditions. The base of the overlying gravelly deposit is clearly defined, and undulating in places, suggesting an unconformable relationship between these two units.

Loc. 3 (1420 m)

Location 3 is on the piedmont slope in the northernmost part of the basin. Two organic mud layers, which also contain abundant inorganic matter, alternate with sandy or clayey layers and are overlain by a sandy bed (**Figures 4** and **5**). The surficial sandy bed is partly stratified and composed of grayish white coarse sand and scattered angular granule- to pebble-sized gravel. On the basis of their sedimentary facies, we conclude that the two organic mud layers alternating with sandy or clayey layers were deposited in a swamp into which a small river channel occasionally flowed and the surficial sandy bed is a fluvial deposit. The top horizons of the two organic mud layers yielded radiocarbon ages of 37,100 ± 1150 yr BP (Beta-140259) and >40,300 yr BP (Beta-140260).

Figure 2. A view of the piedmont slope near Loc. 1. The smooth slope gently dipping northward (left side) and partly cultivated is a piedmont slope

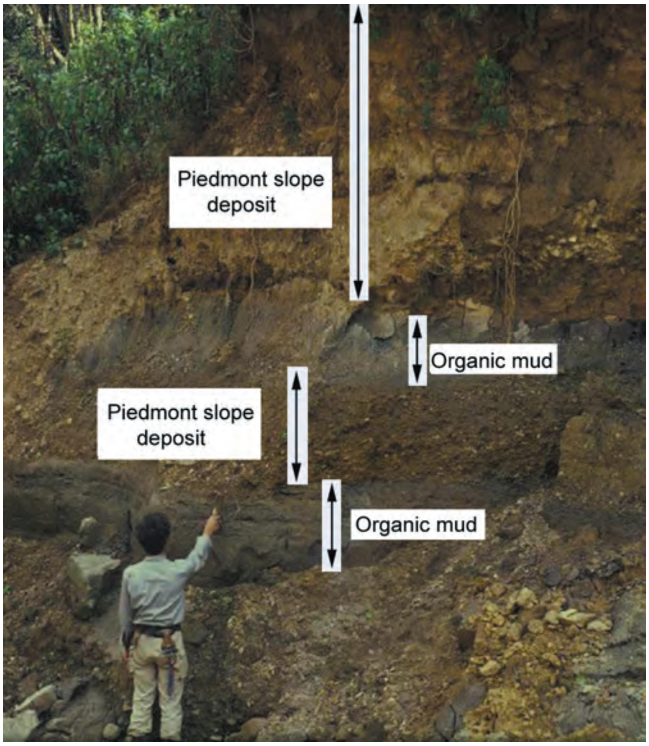

Figure 3. Piedmont slope deposits and organic mud near Loc. 1

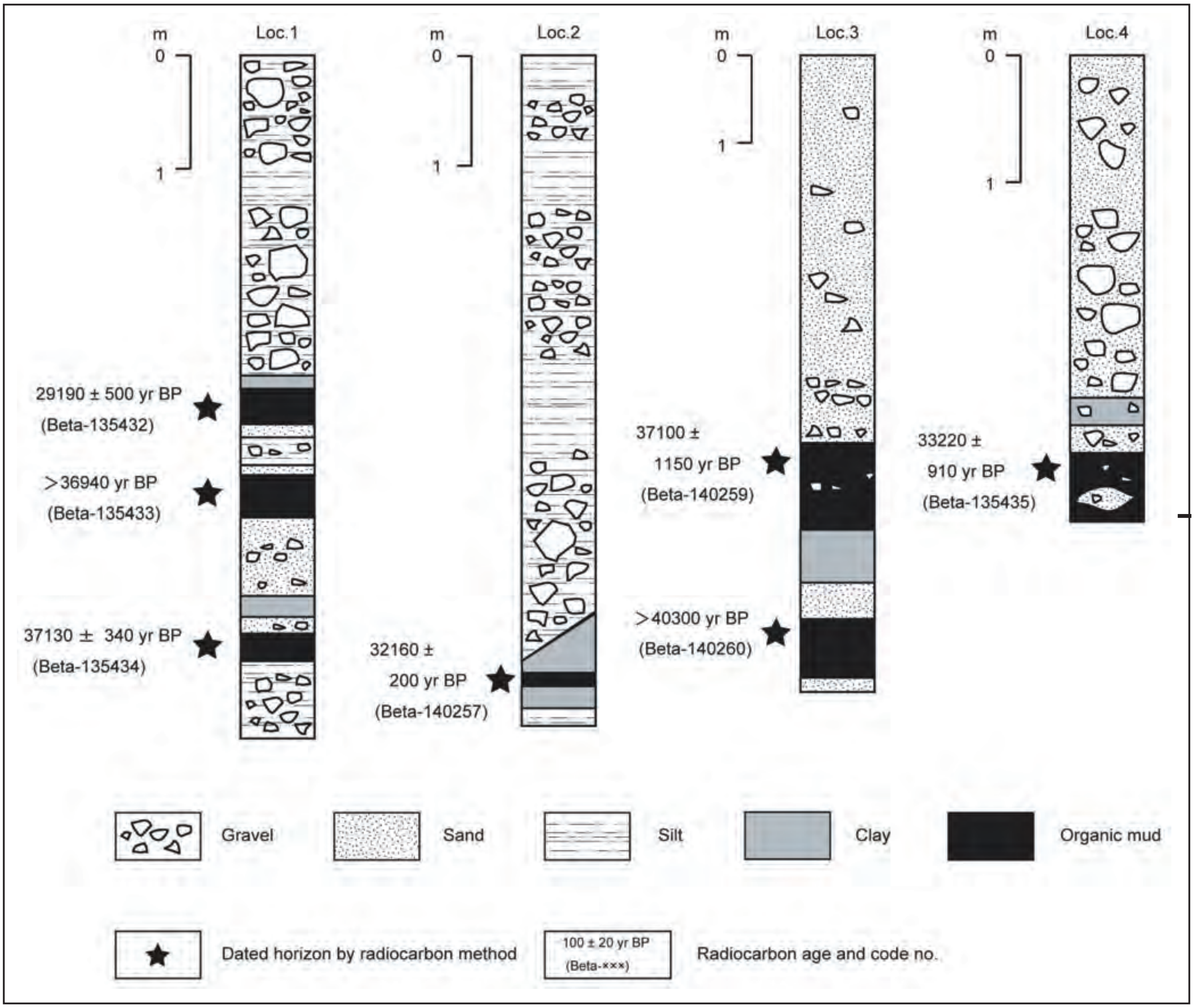

Figure 4. Stratigraphic sections of Locs. 1–4

Loc. 4 (1435 m)

Location 4 is on the piedmont slope in the northeastern part of the basin. A gravelly deposit, clay and sand beds with pebble-sized gravel, and an organic mud layer, in descending order, are exposed (**Figure 4**). The upper gravelly deposit is composed of subangular and subrounded gravel within a sandy matrix. The organic mud layer contains abundant sand and granule- to pebble-sized gravel, sometimes in lenticular beds. The sedimentary facies shows that this organic mud layer is a swampy sediment and the overlying clastic sediments are of debris flow origin. The uppermost part of the organic mud was dated at 33,220 ± 910 yr BP (Beta-135435).

At all these sites (Locs. 1–4), the uppermost parts of the piedmont slope are composed of poorly sorted gravel or sandy layers with gravel. Both their facies and their geomorphological settings indicate that these sediments (hereafter, piedmont slope deposits) are colluvial or fluvial deposits derived from the hillslope. The sediments underlying the piedmont slope deposits are organic muds including, or alternating with, clastics. These characteristics suggest that the sediments were deposited in a swampy environment where inflow of colluvial or fluvial sediments occurred frequently.

Elevations and topsoils of low cols on the surrounding divide

All of the contemporary rivers in the Kathmandu basin belong to the Bagmati River system. The surrounding ridges, which divide the Bagmati River catchment from the Kosi River catchment to the east and the Trisuri River catchment to the west, have some relatively low cols. Because, as discussed below, we found that the level of the ancient lake in the basin was above 1400 m at around 30,000 yr BP and that the lake water covered almost the entire basin, we believe it is likely that the ancient lake was drained at that time not by the Bagmati River but by another river. To investigate this possibility, we surveyed the elevations of two of the low cols and examined their topsoils.

Loc. 5 (1520 m)

The lowest col between the Bagmati River catchment and the Kosi River catchment, elevation ca. 1520 m, is near the village of Saga (Loc. 5). Red soil and weathered bedrock are found on the western (Kathmandu basin side) slope of this col down to 1440 m, whereas organic muddy sediments, which we regard as lacustrine sediments deposited in the ancient lake in the Kathmandu basin, are distributed below 1430 m (**Figure 6**). We interpret the red soil and weathered bedrock as the product of long-term weathering under warm and humid climatic conditions, and their presence at a given site suggests that the site was not submerged (at least not during the Late Pleistocene). Thus, the Saga col and its western slope above 1440 m have not been submerged throughout the Late Pleistocene.

Loc. 6 (1465 m)

The lowest col between the Bagmati and the Trisuli River catchments, which is also the lowest col anywhere on the divide, is the Tinpiple col (Loc. 6), at an elevation of ca. 1465 m. Organic muddy sediments, which we regard as lacustrine sediments deposited in the ancient lake, can be recognized up to 1400 m on the Kathmandu basin side of this col, and red soil and weathered bedrock are exposed at Loc. 6 (**Figure 7**), suggesting that this site has not been submerged since the Late Pleistocene.

Discussion

Because organic muddy sediments underlie or interfinger with the piedmont slope deposits, it is evident that swampy conditions existed at both the northern and southern margins of the Kathmandu basin around 30,000 yr BP. There are two ways in which a swamp environment might have formed. One is that swamps were formed at the hillfoot independent of the ancient lake in the Kathmandu basin. In that case, the water level of the swamps would have had no relation to the level of the lake. Alternatively, the swamps may have been part of the shoreline of the lake in the basin, which means that the shoreline had expanded to approach the base of the surrounding mountains.

We consider that the formation of local swamps independently of the lake in the Kathmandu basin is improbable for the following reasons. First, it is not easy to explain the appearance of local swamps, which would require a small depression at all four sites identified as Loc. 1, Loc. 2, Loc.3, and Loc. 4. At Loc. 1 and 2, small depressions might have formed in relation to activity of the Chandragiri fault (Saijo et al. 1995) or the Thankot fault (Asahi 2003), which pass near these locations with NW–SE strike. However, no geomorphological settings likely to produce small depressions, such as active faults or landslides, are recognized near Loc. 3 and 4. Further, the depositional ages of the organic muddy sediments of Loc.1 to 4 are almost identical. If each of them had been deposited in a different swamp, then their similarity in age would be difficult to explain. The hypothesis that the organic

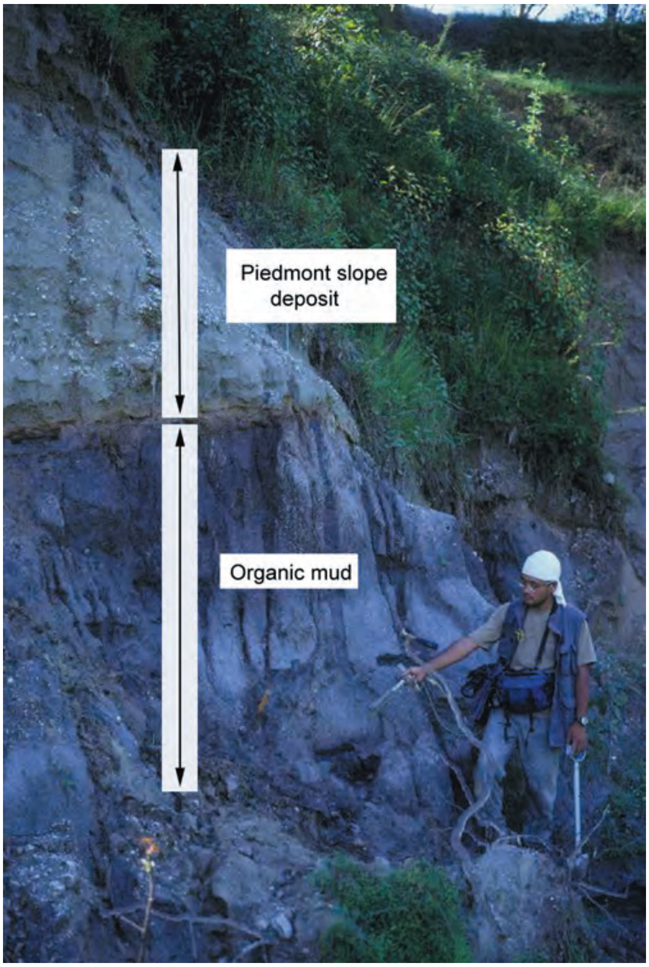

Figure 5. Piedmont slope deposits and organic mud at Loc. 3

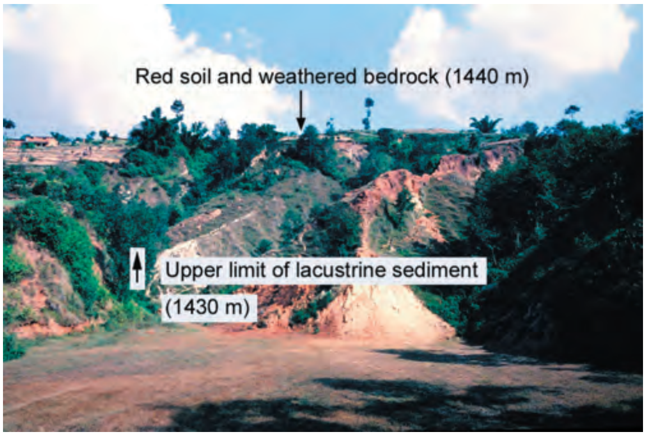

Figure 6. Distribution of lacustrine sediments and red soil and weathered bedrock near Loc. 5

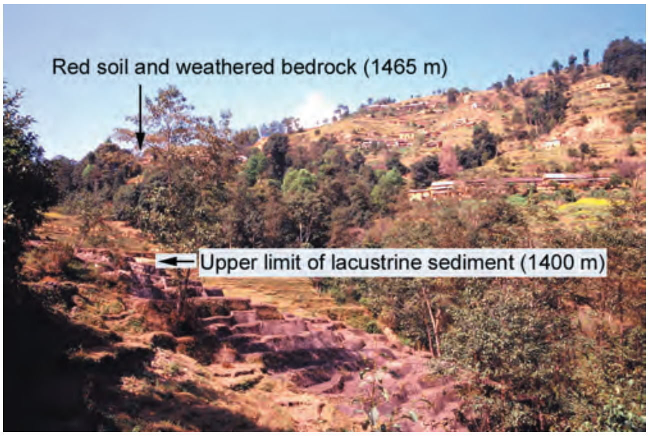

Figure 7. Distribution of lacustrine sediments and red soil and weathered bedrock near Loc. 6

muddy sediments were deposited on the margin of the lake in the basin does not raise the same questions, and is thus plausible. Therefore, we regard the organic mud underlying the piedmont slope deposits as sediments laid down near the shoreline of the ancient lake in the Kathmandu basin. **Figure 8** shows our interpretation of a sedimentary environment in which deposition alternated between organic sediments and detritus as the lake level rose in the foothills. Radiocarbon dates obtained from the uppermost organic sediments indicate that they were deposited at around 30,000 yr BP, suggesting that the shoreline of the ancient lake at that time approached the base of the surrounding mountains, and that lake water occupied almost the entire basin (**Figure 9**).

We know from the elevations of the described locations that the water level of the ancient lake was certainly above 1400 m at around 30,000 yr BP. At Loc. 5, however, the lake level apparently did not exceed 1440 m, whereas the elevation of Loc. 2 is obviously higher than 1440 m. This discrepancy can be explained by the fact that Loc. 2 is on the hanging wall of the active Chandragiri fault. The rate of vertical displacement of this fault is estimated to be 1.0 mm/yr (Saijo et al. 1995). Therefore, the ground surface near Loc. 2 may have been uplifted 30 m or so during the past 30,000 years, suggesting that the original elevation of Loc. 2 might have been ca. 1430 m. Although the lake level about 30,000 yr BP cannot be determined precisely, we presume that it was at 1420 m or higher.

If tectonic movement is discounted, the elevations of the low cols were higher than the estimated lake level. In addition, the red soil and weathered bedrock observed on the cols indicate that they have not been covered by lake water and, therefore, that the lake water did not overflow the cols. Even though the ancient lake persisted until 10,000 yr BP (Sakai 2001), drainage of the lake by the Bagmati River began just after 30,000 yr BP. The Gokarna surface emerged as the lake drained. Debris continued to be supplied from the surrounding mountains even after recession of the lake, resulting in the formation of the piedmont slope.

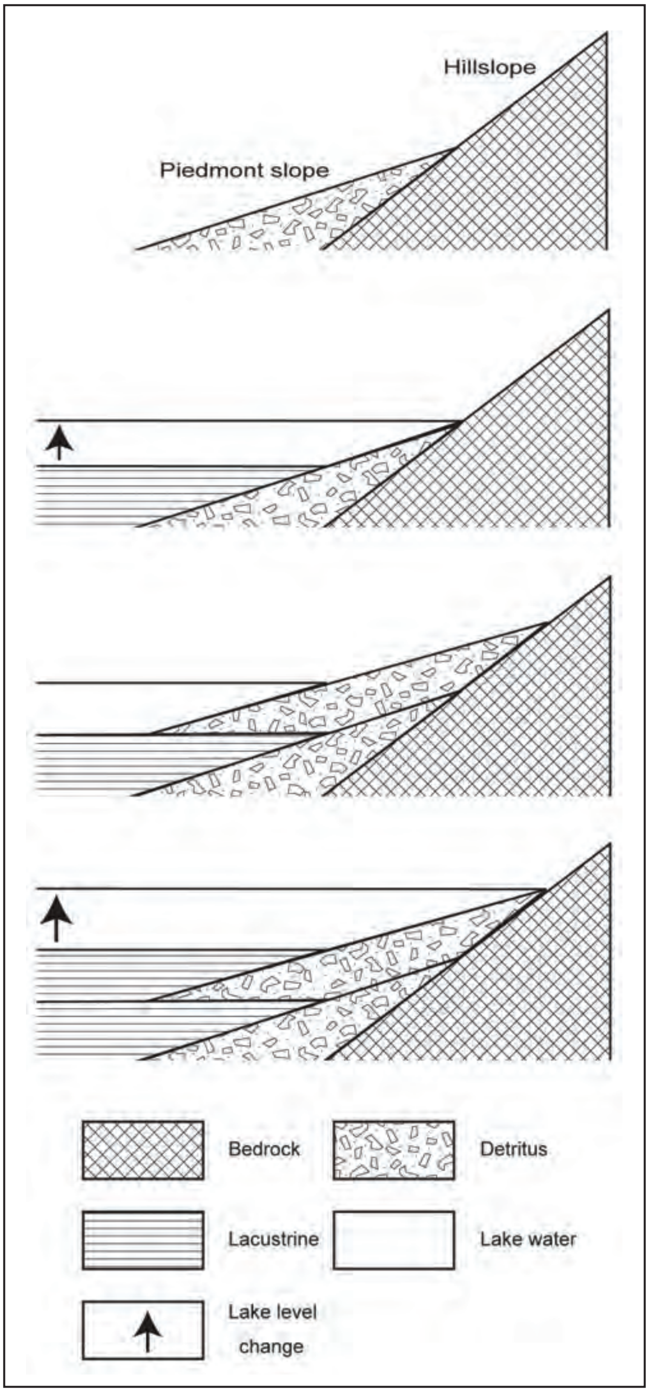

Figure 8. Schematic diagram showing development of interfinger of piedmont slope deposits and lacustrine sediments as lake level rose (chronologically, from top to bottom)

Conclusions

We undertook a geomorphic survey of the marginal area of the Kathmandu basin to investigate its paleogeography and landform development in relation to lake level change during the Late Pleistocene. The major results are as follows:

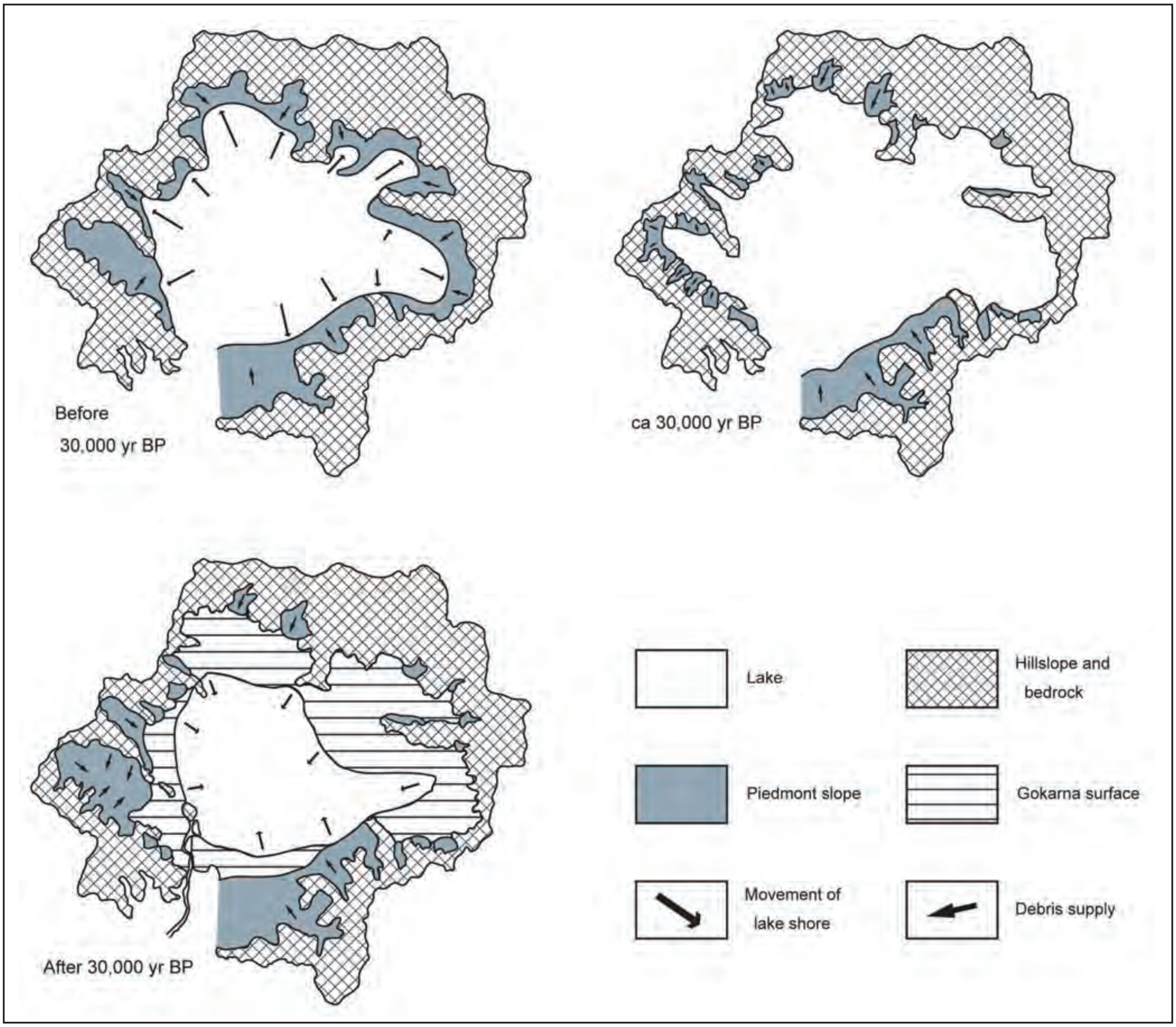

Figure 9. Paleogeography of the Kathmandu basin around 30,000 yr BP

1. The piedmont slope is well developed at the foot of the mountains surrounding the Kathmandu basin. This slope, which dips basinward at about 10°, has a smooth surface and a slightly concave to almost linear longitudinal profile. It transitions basinward into the Gokarna surface and fades into narrow valleys in the back slopes.

2. The surficial deposits (mostly several meters thick) of the piedmont slope are composed of detritus of colluvial or fluvial origin, and organic muddy sediments underlie or interfinger with the detrital deposits. The detrital deposits from hillslope (piedmont slope deposits) are inferred to have been deposited near the shoreline of the ancient lake in the Kathmandu basin, alternating with lacustrine sediments as the lake level rose.

3. The organic muddy sediments under the piedmont slope deposits yield radiocarbon ages mostly around 30,000 yr BP. This fact, along with the sedimentary environment, suggests that the ancient lake covered almost all of the Kathmandu basin at that time. We estimate that the water level of this huge lake was then between 1400 and 1440 m.

4. Elevations of the cols on the surrounding divide are higher than the estimated highest level of the expanded ancient lake. In addition, we observed reddish soils and weathered bedrock on these cols, suggesting that they were never covered by lake water and, therefore, that the lake did not drain through an outlet other than the Bagmati River.

5. Drainage of the ancient lake by the Bagmati River began

just after 30,000 yr BP. The Gokarna surface emerged as the lake drained. Debris continued to be supplied from the hillslopes even as the lake receded, resulting in the formation of the piedmont slope.

Acknowledgments

We thank Kazunori Arita and the Japan Society for the Promotion of Science for financial support of this work by Grant-in-Aid for Scientific Research (A) No. 11691112.

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Phenology and water relations of eight woody species in the Coronation Garden of Kirtipur, central Nepal

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Phenological activities of eight woody species planted in Kirtipur (central Nepal) were examined, each for one dry season between September 2001 and June 2003. From Pressure Volume (P-V) analysis, we determined relative water content at zero turgor (RWC_z), osmotic potential at zero turgor (ψ_{sz}) and full turgor (ψ_{sf}), and bulk modulus of elasticity (ε) once a month through the course of dry season. Both evergreen species (*Cotoneaster bacillaris* Wall., *Quercus lanata* Sm., *Ligustrum confusum* Decne., *Woodfordia fruticosa* (L.) Kurz.) and deciduous species (*Celtis australis* Linn., *Alnus nepalensis* D.Don., *Bauhinia variegata* Linn. and *Lagerstroemia indica* Linn.) put out their new leaves during the dry summer when day length and temperature were increasing. Generally, bud break coincided with concentrated leaf fall during the dry summer and the leaf fall reduced total leaf area to its lowest value. The deciduous species were leafless for one to three months, followed by a prolonged period of leaf production and shoot elongation. Evergreen and deciduous species manifested distinct adaptive strategies to water deficit. Evergreens can reduce osmotic potential (ψ_s) to its low value and maintain proper water potential (ψ) gradient from soil to plant, which facilitates absorption of water during dry season. Elastic tissue in deciduous species is coupled with leaf shedding during the dry season; both factors may help maintain proper ψ_s for new growth during dry period. One evergreen species (*Woodfordia fruticosa*) and three deciduous species (*Celtis australis, Bauhinia variegata* and *Lagerstroemia indica*) have inherently high dehydration tolerance due to their elastic tissue. During drought there has been osmotic adjustment in *Quercus lanata*, and elastic adjustment in *Ligustrum confusum, Celtis australis* and *Lagerstroemia indica*.

Key words: Himalayas, Pressure Volume (P-V) curve, relative water content (RWC), osmotic adjustment, elastic adjustment

Phenology, the distribution of plant activities in time, is highly correlated with seasonal changes in water status of trees (Borchert 1994a, b). Leaf phenology in both seasonal and non-seasonal environments is a central element in plant strategies for carbon gain (Kikuzawa 1995). The timing of leaf fall and bud break in tropical and subtropical trees is generally determined by plant water status, which in turn is a function of the interaction between the environmental water status and the structural and functional state of the tree (Reich 1994). Seasonal variation in water status not only determines phenology but also the distribution of trees and forest composition (Borchert 1994a, Zobel et al. 2001). Engelbrecht et al. (2007) has shown that differential drought sensitivity shapes plant distribution in tropical forests at both regional and local scales. The role of drought in controlling species distribution and performance is still poorly understood for Himalayan trees, although indirect evidence and existing measurements suggest that tree distribution is strongly related to drought (Zobel and Singh 1995, Tewari 1998, Poudyal et al. 2004, Shrestha et al. 2006a).

In the context of global warming, mountain ecosystems are being affected more than lowlands, and the extent of drought in mountains is likely to increase in the future (Iyngararasan et al. 2002). Alteration in seasonal coordination of photoperiod and thermal regime affects plant performance (Hanninen 1991), competitive relationships among forest trees, and species distribution and abundance (Lechowicz and Koike 1995). Because the water relations of Himalayan tress cannot be accurately understood only by inference from forest studies elsewhere (Zobel et al. 2001) there is a need for detailed study on water relations and their relationships to phenology and adaptation to seasonal drought. Due to the monsoon, Himalayan trees are exposed to drought for several months each year (Zobel and Singh 1997). Despite their unequal leaf life spans, most trees of this region

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Table 1. Studied species with their distribution in Nepal

Name of Species	Family	Distribution (masl)*
Evergreen species		
Cotoneaster bacillaris Wall.	Rosaceae	1800–2300
Quercus lanata Sm.	Fagaceae	450–2600
Ligustrum confusum Decne.	Oleaceae	800–2900
Woodfordia fruticosa (L.) Kurz.	Lythraceae	200–1800
Deciduous species		
Celtis australis Linn.	Ulmaceae	1300–2200
Alnus nepalensis D.Don.	Betulaceae	500–2600
Bauhinia variegata Linn.	Leguminosae	150–1900
Lagerstroemia indica Linn.	Lythraceae	1000–1500

* Following Press et al (2000)

produce new leaves and flower during the dry summer season just before the June – September wet season (Ralhan et al. 1985, Shrestha et al. 2006b). Although the environment is dry, trees must maintain the proper turgidity required for growth (Hsaio 1973). Tree species may postpone (Shrestha et al. 2006b, Borchert 1994b) or tolerate dehydration by elastic and osmotic adjustment (Grammatikopoulos 1999, Fan et al. 1994, Mainali et al. 2006). In this paper, we have analyzed pressure volume (P-V) curves of eight woody species, and we consider the connections between water relations parameters (relative water content, osmotic potential, osmotic and elastic adjustment) and phenology, in order to understand species' natural distribution and adaptation to seasonal drought.

Materials and methods

We selected for study eight woody species (four evergreen and four deciduous, Table 1), all native to Nepal and planted at the Coronation Garden (27°40'–27°41' N, 85°16'–85°18' E, elevation 1280–1400 masl), Tribhuvan University (Kirtipur, Kathmandu, Nepal). Nomenclature and altitudinal range of distribution follows Press et al. (2000). *Ligustrum confusum* and *Woodfordia fruticosa* are shrubs and the others are trees. Five species (*Cotoneaster bacillaris*, *Quercus lanata*, *Ligustrum confusum*, *Woodfordia fruticosa*, and *Alnus nepalensis*) were sampled from September 2001 to June 2002 (Year 1) and the remaining three (*Celtis australis*, *Bauhinia variegata* and *Lagerstroemia indica*) from August 2002 to June 2003 (Year 2). Although the natural habitats of these species range from the tropics to the temperate zone, they have been planted in a subtropical environment at the Coronation Garden. The climate has three distinct seasons: hot and dry summer (February to May), hot and moist rainy season (June to September) and cold and dry winter (October to January). Annual rainfall during the study period was 1872 mm in 2002 and 1648 mm in 2003, with about 80% falling during the rainy season (**Figure 1**). Temperature and rainfall of Year 1 were not significantly different from those of Year 2 (ANOVA, $p = 0.9$ and 0.8, respectively). On this basis, we assumed that the year-to-year variation in water relations attributes was statistically insignificant for the study period.

Phenological activities were recorded every month, and

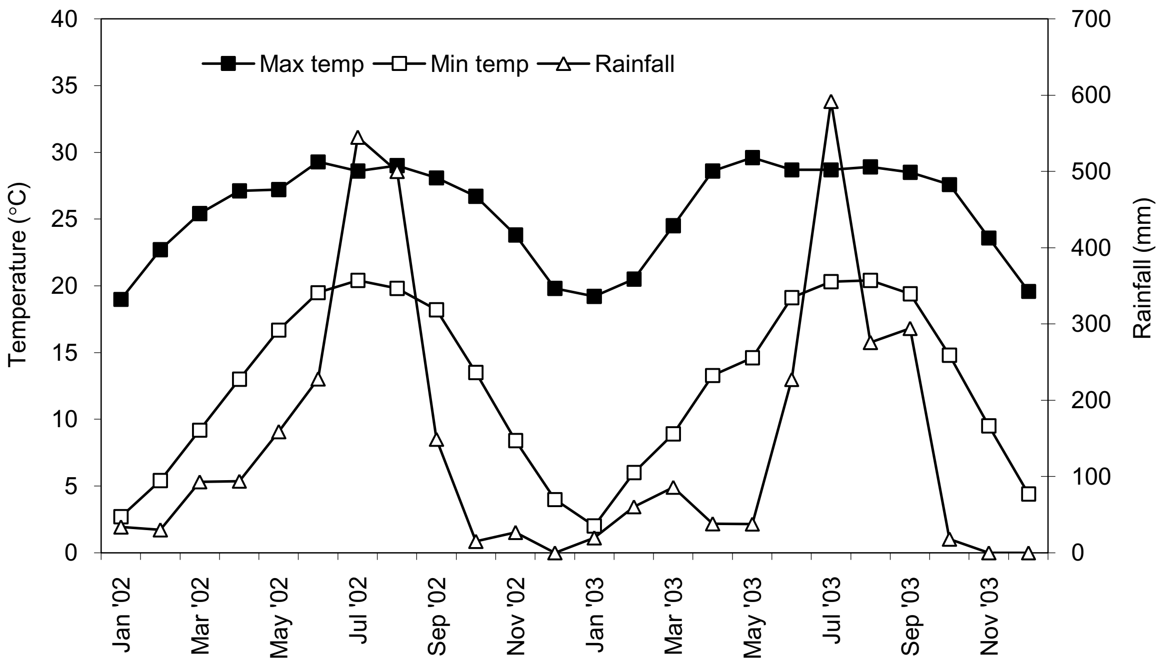

Figure 1. Climate data of Kathmandu valley during the study years (2002 and 2003). (Source: Dept. of Hydrology and Meteorology, Kathmandu, Nepal). The data were recorded at Tribhuvan International Airport (27˚ 42' N, 85˚ 22' E, alt. 1336 masl), which is about 5 km east of the study site.

Table 2. Major phenological events of various species. The marked individual of *Celtis australis* was a sapling; thus it did not produce flowers and fruit. *Ligustrum confusum*, *Woodfordia fruticosa* and *Bauhinia variegata* did not retain fruit, probably due to premature abscission of flowers. Seasons: summer (Feb to May), rainy (Jun to Sep) and winter (Oct to Jan)

Species name	Bud break	Leaf production	Flowering	Fruiting	Leaf fall	Leafless month(s)
Cotoneaster bacillaris	March	Mar–May	Apr–May	May	Mar–Apr	None
Quercus lanata	April	May–Jun	Apr–June	Jul	Jan–May	None
Ligustrum confusum	April	Apr–Jun	Jun	na	Nov–Apr	None
Woodfordia fruticosa	March	Mar–Jun	Apr	na	Nov–Jun	None
Celtis australis	March	Mar–Nov	na	na	Nov–Feb	Feb–mid Mar
Alnus nepalensis	March	Mar–Sep	Jun	Oct	Jan–Mar	mid Feb–mid Mar
Bauhinia variegata	April	Apr–Aug	Mar–May	na	Sep–Feb	Mar-Apr
Lagerstroemia indica	March	Mar–Apr	Jun–Aug	Sep	Oct–Dec	Jan-Mar

Table 3. Mean values of water relations parameters of evergreen vs. deciduous species and canopy vs. under-canopy species. Also shown is the significance level (*p* values) of ANOVA between groups of species (N: number of species, and n: total number of samples). Symbols, RWC_z: Relative water content at zero turgor, ψ_{sz}: osmotic potential at zero turgor, ψ_{sf}: osmotic potential at full turgor, ε: bulk modulus of elasticity

Parameters	Evergreen (N= 4, n= 29)	Deciduous (N= 4, n= 35)	*p* value	Canopy species (N= 4, n= 33)	Under canopy sp (N= 4, n= 31)	*p* value
RWC_z (%)	82 ± 6	75 ± 7	0.000	78 ± 9	79 ± 5	0.57
ψ_{sz} (MPa)	−2.72 ± 0.78	−1.86 ± 0.38	0.000	−2.43 ± 0.84	−2.05 ± 0.53	<0.05
ψ_{sf} (MPa)	−2.10 ± 0.39	−1.47 ± 0.31	0.000	−1.87 ± 0.46	−1.6 ± 0.42	<0.05
ε (MPa)	12 ± 5	6 ± 2	0.000	10 ± 6	7 ± 2	<0.05

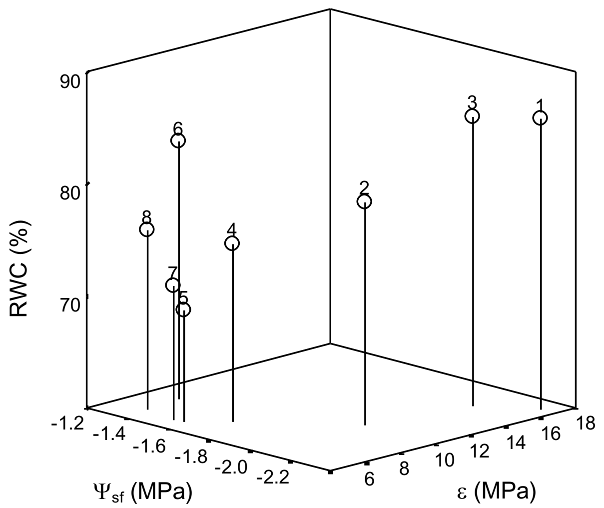

Figure 2. Species level variation of relative water content at zero turgor (RWC_z, %), osmotic potential at full turgor (ψ_{sf}, MPa) and bulk modulus of elasticity (ε, MPa). Evergreen sp: 1. *C. bacillaris, 2. Q. lanata, 3. L. confusum, 4. W. fruticosa;* Deciduous sp: *5. C. australis, 6. A. nepalensis, 7. B. variegata, 8. L. indica*

every two weeks during the period of active growth in three marked individuals of each species. Timing of bud break, leaf production (shoot elongation), flowering, fruiting and leaf fall were recorded. Leaf fall was estimated visually based on fresh leaf litter on the ground and presence of leaves on ultimate branches of the marked individuals. The pressure-volume (P-V) curve was developed by the bench drying method (Pallardy et al. 1991) at Central Department of Botany, Tribhuvan University, Kathmandu. A single sample from the fully exposed side was randomly collected from one of the marked trees of each species and used for the construction of P-V curve on each sampling date, with rehydration period 24 h. During peak rainy months (July-August in Year 1 and August in Year 2), and also when twigs of deciduous species at sampling height were leafless, the plants were not sampled for P-V analysis. Relative water content (RWC) and twig water potential (ψ, negative of balance pressure, BP) were determined simultaneously and repeatedly. BP was measured by pressure chamber (Model 1000, PMS Instrument Co., Corvallis, OR USA). From the P-V curve, we estimated RWC at zero turgor (RWC_z), osmotic potential at full turgor (ψ_{sf}) and zero turgor (ψ_{sz}) and bulk modulus of elasticity (ε).

Statistical analysis We compared mean RWC_z, ψ_{sz}, ψ_{sf}, and ε using Post Hoc Multiple Comparison of one-way ANOVA. ANOVA was also used to compare these parameters for evergreen and deciduous species, shrubs and trees, and canopy and under-canopy species. We determined the Pearson correlation (r) among the parameters for each species. We established the relationship between the parameters using linear regression analysis. We used the annual mean RWC_z, ψ_{sf} and ε of individual species to develop a 3-D diagram. SPSS (2001) version 11 for Windows was used for all statistical analysis.

Results

Phenology We found the leaf lifespan of evergreen species

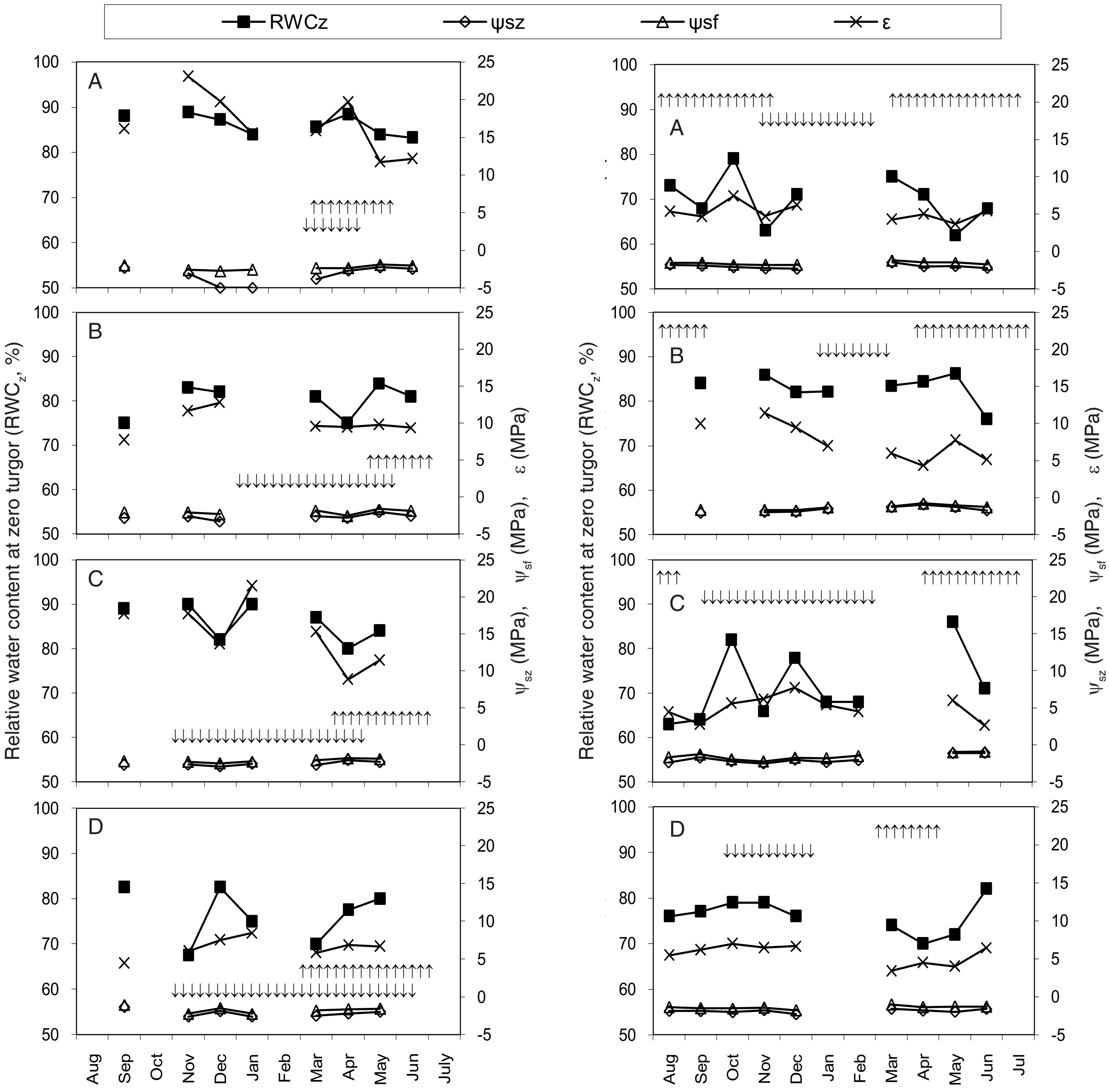

Figure 3. Relative water content at zero turgor (RWC_z, %), bulk modulus of elasticity (ε, MPa), osmotic potential at full turgor (ψ_{sf}, MPa) and zero turgor (ψ_{sz}, MPa) for evergreen species (A. *Cotoneaster bacillaris* B. *Quercus lanata* C. *Ligustrum confusum* D. *Woodfordia fruticosa*). The values were obtained from the pressure volume (P-V) analysis of a single sample in each sampling date. (↑↑↑ indicates leaf production and ↓↓↓ leaf fall)

Figure 4. Relative water content at zero turgor (RWC_z, %), bulk modulus of elasticity (ε, MPa), osmotic potential at full turgor (ψ_{sf}, MPa) and zero turgor (ψ_{sz}, MPa) for deciduous species (A. *Celtis australis* B. *Alnus nepalensis* C. *Bauhinia variegata* D. *Lagerstroemia indica*). The values were obtained from the Pressure Volume (P-V) curve analysis of single sample in each sampling date. (↑↑↑ indicates leaf production and ↓↓↓ leaf fall)

Table 4. Annual mean of relative water content at zero turgor (RWC_z, %), summer mean RWC_z, osmotic potential at zero turgor (ψ_{sz}, MPa), osmotic potential at full turgor (ψ_{sf}, MPa), difference between maximum and minimum ψ_{sf} ($\Delta\psi_{sf}$, MPa), bulk modulus of elasticity (ε, MPa) and difference between maximum and minimum ε ($\Delta\varepsilon$, MPa). The significant difference between species is shown by different letters (p = 0.05). Sampling years – 1: 2002, 2: 2003

Species	Habit*	Sampling year	Mean RWC_z		ψ_{sz}	ψ_{sf}	$\Delta\psi_{sf}$	ε	$\Delta\varepsilon$
			Annual	Summer					
Cotoneaster bacillaris (n=8)	UCT	1	86^{e}	86^{d}	-3.35^{a}	-2.34^{a}	0.85	16.72^{c}	11.34
Quercus lanata (n=7)	CT	1	80^{cd}	$81b^{cd}$	-2.7^{b}	-2.05^{a}	0.95	10.05^{b}	5.04
Ligustrum confusum (n=7)	S	1	86^{e}	84^{cd}	-2.56^{bc}	-2.14^{a}	0.69	15.14^{c}	12.63
Woodfordia fruticosa ((n=7)	S	1	76^{bc}	76^{abc}	-2.17^{bcd}	-1.7^{b}	1.19	6.55^{a}	4.03
Celtis australis (n=9)	CT	2	70^{a}	69^{a}	-2.01^{cd}	-1.58^{bc}	0.6	5.18^{a}	3.73
Alnus nepalensis (n=8)	CT	1	83^{de}	85^{cd}	-1.62^{d}	-1.35^{c}	0.91	7.58^{a}	7.1
Bauhinia variegata (n=9)	CT	2	72^{ab}	76^{abc}	-1.93^{d}	-1.54^{bc}	0.3	5.04^{a}	5.08
Lagerstroemia indica (n=9)	UCT	2	76^{bc}	72^{ab}	-1.85^{d}	-1.37^{bc}	0.74	5.56^{a}	3.57

* CT: canopy tree, UCT: under canopy tree, S: shrub. Under canopy trees and shrubs are under canopy species.

Table 5. Pearson correlations (r) among various attributes of plant water relations for each species

Parameters		*Cotoneaster bacillaris*	*Quercus lanata*	*Ligustrum confusum*	*Woodfordia fruticossa*	*Celtis australis*	*Alnus nepalensis*	*Bauhinia Variegata*	*Lagerstremia indica*
RWC x	ψ_{sz}	0.06ns	0.38ns	−0.40ns	0.84*	0.31ns	0.20ns	0.43ns	0.17ns
	ψ_{sf}	−0.39ns	0.60ns	−0.34ns	0.79*	0.13ns	0.05ns	0.21ns	−0.18ns
	ε	0.86**	0.62ns	0.91**	0.002ns	0.67*	0.44ns	0.50ns	0.77*
ψ_{sz} x	ψ_{sf}	0.82*	0.78*	0.91**	0.96**	0.95**	0.96**	0.93**	0.85**
	ε	−0.29ns	−0.38ns	−0.54ns	−0.51ns	−0.46ns	−0.77*	−0.38ns	−0.36ns
ψ_{sf} x	ε	−0.75*	−0.23ns	−0.57ns	−0.57ns	−0.62ns	−0.85**	−0.55ns	−0.73*

*Significant at p = 0.05, ** Significant at p = 0.01, ns: non significant

to be slightly more than one year. The deciduous species remained leafless for one to three months (**Table 2**). In all species buds broke in March and/or April. Among evergreen species, leaf production and shoot elongation were completed in June; thus they retained fully mature leaves during the rainy season. Deciduous species continued to produce new leaves until late rainy season. The marked individuals of *Celtis australis* were saplings (dbh < 10 cm, height > 137 cm) in which leaf production continued until November. In *Lagerstroemia indica* leaves produced in the first flushing matured in two months; but this species has multiple leafings and produced 2-3 crops of leaves. In all evergreen species, leaf production was completed in two (*Quercus lanata*) to four (*Woodfordia fruticosa*) months (**Table 2**). Leaf fall was most concentrated in *Cotoneaster bacillaris,* which completed the process in two months.

Water relations parameters

Evergreen vs. deciduous

In this study, evergreen and deciduous species differed significantly (ANOVA, p = 0.000) when parameters were considered separately (**Table 3**) but the difference was not clear when mean values of RWC_z, ψ_{sf} and ε were considered together (**Figure 2**). *Woodfordia fruticosa* is an evergreen shrub but resembles deciduous species in most parameters (**Table 4, Figure 2**). Evergreens had higher RWC_z and ε than deciduous species, but ψ_{sf} and ψ_{sz} were lower in evergreens. RWC_z was highest in two evergreen species (*Cotoneaster bacillaris* and *Ligustrum confusum*) and lowest in a deciduous species (*Celtis australis*) (**Table 4**). Mean $\Delta\psi_{sf}$ for evergreens was 0.92 MPa, compared with 0.64 MPa for deciduous. ψ_{sz} and ε did not vary significantly among the deciduous species but the variation of these parameters was significant among the evergreen species. $\Delta\varepsilon$ was 8.26 MPa and 4.87 MPa for evergreen and deciduous species, respectively.

Species level variation

All evergreen species studied except *Woodfordia fruticosa* exhibited reduced osmotic potential (ψ_s) before their leaves flushed out (**Figure 3**). *Cotoneaster bacillaris* had the highest mean RWC_z and the lowest mean ψ_{sz} and ψ_{sf} of all species (**Table 4**). In this species ψ_{sf} increased (Figure 3A) during bud break (**Table 2**). *Quercus lanata* had low RWC_z and ψ_{sf} in April (Figure 3B) when the trees were producing new leaves (bud break, Table 2). In April the ψ_{sf} value for *Q. lanata* fell by 0.71 MPa from the value recorded for March. During the summer months ε apparently did not change. *Ligustrum confusum*, with the highest RWC_z among all species, reduced

RWC_z and ε to their lowest values in the month of bud break (Figure 3C). In *Woodfordia fruticosa* RWC_z was low in March and increased, along with ψ_{sf}, until late summer (Figure 3D). During March ε decreased by 2.65 MPa from the maximum value (8.48 MPa) recorded in January.

Celtis australis had the lowest RWC_z among the eight species (**Table 4**). During April and May, when RWC_z was decreasing, ε was low (Figure 4A). In May RWC_z and ε both were at their lowest. In *Alnus nepalensis*, RWC_z and ψ_{sf} were high in April but ε was lowest in the same month (Figure 4B). For the dry period (October to May) RWC_z was lowest in December, when ψ_{sf} decreased to the lowest value. During bud break (March, Table 2, Figure 4B) RWC_z and ψ_s both were increasing whereas ε was decreasing. *Bauhinia variegata* also had very low RWC_z, in the same range as *Celtis australis* (Table 4). ψ_{sf} was lowest in November; after November, it increased until June, apart from a slight decrease in January (Figure 4C). In *B. variegata,* mean ε and it's June value for ε were the lowest of the eight species' (Table 4). *Lagerstroemia indica* had RWC_z <80% except in June (Figure 4D). After November RWC_z decreased until reaching its lowest value in April. From March through May, when RWC_z was low, ψ_{sf} was high and ε low.

The shrubs and trees (Table 4) in this study did not differ significantly (p> 0.05) in the measured water relations parameters. Similarly, canopy and under-canopy species differed significantly (p<0.05) in ψ_{sf}, ψ_{sz} and ε but not in RWC_z (Table 3). Canopy species had lower ψ_{sz} and ψ_{sf} but higher ε than the under-canopy species. Species with a primary distribution range in the temperate region (2000–3000 masl) had high RWC_z, while the other species (except *Celtis australis*) with their primary distribution range in the subtropical region (1000–2000 masl) had low RWC_z. In contrast to other temperate species, *C. australis* had the lowest RWC_z (Table 4) but distributed up to temperate region.

Relations among the parameters

The correlation between RWC_z and ψ_{sf} was significant only in *Woodfordia fruticosa* (**Table 5**). The correlation between RWC_z and ε was significant in *Cotoneaster bacillaris, Ligustrum confusum, Celtis australis* and *Lagerstroemia indica.* ψ_{sf} increased when ε declined but the correlation was significant only for *C. bacillaris, Alnus nepalensis* and *L. indica.*

Linear regression analysis showed that low ψ_s in our species was associated with high RWC_z, although the relation was only marginal ($R^2 = 0.05$, p = 0.08 for ψ_{sz} vs RWC_z; and $R^2 = 0.08$, p<0.05 for ψ_{sf} vs RWC_z). ε appears to be an important parameter which could explain >50% of the variation in RWC_z and ψ_{sf} (Figure 5). Species with less elastic tissue (higher ε) had higher RWC_z. Both RWC_z and ε were higher for evergreen species than for deciduous. Species with more elastic tissue (lower ε) had higher values of ψ_{sz} (**Figure 5**).

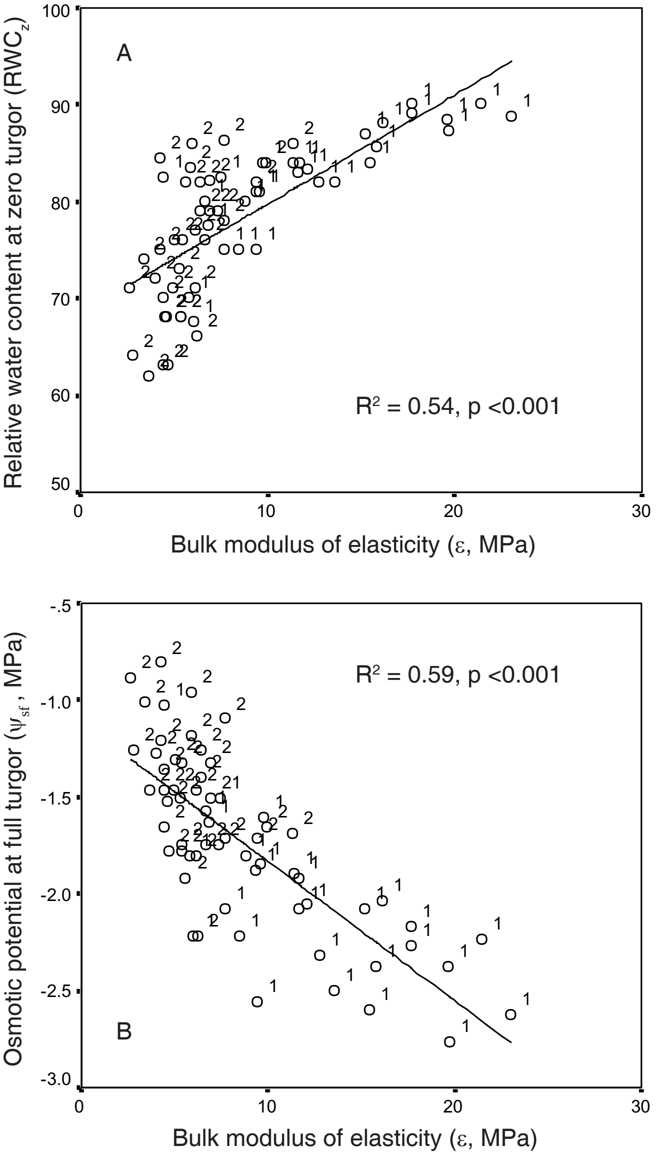

Figure 5. Linear regression of bulk modulus of elasticity against relative water content at zero turgor (A) and osmotic potential full turgor (B); 1: evergreen species, 2: deciduous species

Discussion

The studied evergreen and deciduous species all put out their new leaves during the dry months of March and April (Table 2), when day length is increasing and temperatures are rising (Figure 1), bearing the cost of leaf production every year. A one-year leaf lifespan has been observed in most of the broadleaved evergreen species of the central Himalayas (Ralhan et al. 1985, Poudyal et al. 2004). However, the duration of leaf production is longer in most of the deciduous species than in evergreens (Table 2, Figures 3, 4). Species with a shorter period of leaf production appear to have more concentrated leaf fall. This difference in leaf production may lead to differences between evergreen and deciduous species as concerned many structural and functional traits (Volkenburgh 1999). Due to the prolonged period of shoot elongation and leaf production in the deciduous species, the leaves are widely spaced and fresh new leaves are present throughout the rainy season. This can maximize the photosynthetic rate (Kikuzawa 1995) and may compensate for the short leaf longevity of deciduous species.

Such a pattern of leaf production is common among most of the early successional species in the central Himalayas (Singh and Singh 1992). The maximum photosynthesis during rainy season may be low in these evergreens, as the rate of photosynthesis declines with the aging of leaves (Kikuzawa 1995). Deciduous species like *Celtis australis, Alnus nepalensis* and *Bauhinia variegata* retained >50% of leaves during the dry winter season. They may represent a transitional stage between the winter deciduous species of temperate latitudes and the evergreen species of the Himalayas, with leaf lifespan of nearly one year (Singh and Singh 1992).

Deciduous species, which could reduce RWC to lower value before turgor loss, have more elastic tissue and higher ψ_{sz} and ψ_{sf} than evergreens (Table 3, Figure 5). This supports the suggestion that elastic cell walls are important for drought resistance in trees (Fan et al. 1994, Lambers et al. 1998) but appears to contrast Davis (2005) who showed that a less elastic cell wall was also important in drought resistant trees. It appears that elastic walls allow tissue to maintain turgor longer as water is lost, while the stiff (less elastic) walls cause ψ to drop quickly as water is lost, increasing the gradient of ψ from soil to leaf and increasing water uptake (DB Zobel, Oregon State Univ., per. comm.). The question seems to be which of these two possibilities is most important in different situations. In general, our evergreen species have stiff cell walls and lose turgor at high tissue water content (RWC, Figure 5A), but they have lower ψ_s than do deciduous species (Figure 5B). Low ψ_s maintains the necessary ψ gradient from soil to plant and promotes water absorption during the dry season. Deciduous species have different strategies; they avoid excessive dehydration by shedding leaves, and also maintain turgidity despite low tissue water content thanks to their elastic tissues.

In *Cotoneaster bacillaris*, although correlation between RWC_z and ε was significant ($p = 0.01$, Table 5), no osmotic or elastic adjustment was apparent during the dry period. However, low ψ_s (Table 4) obviously facilitates absorption of water from soil during seasonal drought. *Quercus lanata* reduced ψ_{sf} in April just before leaf flushing, which helped to maintain turgidity for new growth. When ψ_{sf} is low, plants can maintain turgidity at low RWC_z. Osmotic adjustment of this kind has also been reported in other oaks (e.g., *Quercus petraea*) where soil drying induced the accumulation of fructose and glucose (Epron and Dreyer 1996). *Myrica esculenta*, an evergreen understory tree of subtropical to temperate region in the Himalayas, also showed a large osmotic adjustment (1.07 MP) in response to seasonal drought (Shrestha et al. 2007). Osmotic adjustment could enable the plant to maintain turgor at lower water potential (ψ) and continue to absorb water from relatively dry soil (Lambers et al. 1998). In *Ligustrum confusum* increasing tissue elasticity (or decreasing ε, i.e. elastic adjustment) helped to maintain required turgidity during new growth. Although *Quercus lanata* and *Ligustrum confusum* showed osmotic and elastic adjustment, respectively, their high RWC_z (Table 4) may not allow successful establishment at dry sites (Lambers et al. 1998). Having most elastic tissue of the studied plants (lowest ε) and lowest RWC_z (Table 4), *Woodfordia fruticosa* has an inherently high tolerance for dehydration. This inherent capacity of dehydration tolerance is more important than adjustment (Fan et al. 1994). This capacity has enabled *Woodfordia fruticosa* to grow on dry rocky slopes of river valleys in central Nepal (BBS, per. observation).

Except for *Alnus nepalensis*, all deciduous species (Table 2) appear to have an inherent capacity to tolerate dehydration, due to their elastic tissue (low ε) and low RWC_z (Table 4); thus they can grow successfully at dry sites (Lambers et al 1998). In deciduous species, water conserved in the tree trunk after leaf fall is an important resource for new growth during the dry period (Borchert 1994a, Shrestha et al. 2006b). *Celtis australis* and *Lagerstroemia indica*, both producing new leaves in March, reduced their RWC_z during dry months by increasing tissue elasticity (Figure 4A, D). *Bauhinia variegata* generally had low ε and RWC_z (Table 4, Figure 4C), indicating an inherent capacity to tolerate dehydration. The change in ψ_{sf} and ε in response to moisture stress was not apparent in *B. variegata* (Figure 4C). Assuming that species in which osmotic adjustment is important reduce ψ_s during drought (Lambers et al. 1998), the deciduous species of this study did not show any osmotic adjustment. This result contrasts with findings of Auge et al. (1998) who reported that in twelve deciduous species high dehydration tolerance was associated with increasing capacity for osmotic adjustment. Due to their inherent capacity to tolerate dehydration (*Bauhinia variegata*) or to elastic adjustment (*Celtis australis* and *Lagerstroemia indica*), the deciduous species (except *Alnus nepalensis*) were able to thrive at dry sites (Kramer and Boyer 1995). Without this capacity, *A. nepalensis* is commonly confined to north facing moist slopes (Jackson 1994). Water conserved in tree trunk after leaf fall contributed to a high ψ_s (Borchert 1994b), which might be adequate to begin new growth during the dry summer.

In conclusion, evergreen and deciduous species both sprout new leaves during the dry summer, when day length is increasing and temperatures are rising. Evergreens can reduce ψ_s and maintain a viable ψ gradient from soil to plant, which facilitates absorption of water during the dry season. Elastic tissue in deciduous species is associated with leaf shedding during the dry season; both strategies may help maintain proper plant ψ for new growth during the dry period. One evergreen species (*Woodfordia fruticosa*) and three deciduous species (*Celtis australis*, *Bauhinia variegata* and *Lagerstroemia indica*) had inherently high dehydration tolerance due to the presence of more elastic tissue. Weak osmotic adjustment was recorded in *Quercus lanata*, and elastic adjustment was observed in *Ligustrum confusum*, *Celtis australis* and *Lagerstroemia. indica* during drought.

Acknowledgements

We are thankful to DB Zobel (Oregon State University, Oregon, USA) for his critical comments and suggestions on the first draft of the manuscript.

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Plant species richness and composition in a trans-Himalayan inner valley of Manang district, central Nepal

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Species richness normally decreases with increasing elevation. However, a hump and a plateau have been documented in species richness curves in the Nepal Himalaya. We sampled species richness and composition in 80 plots located in the north and south aspects of the dry valley of Manang, a trans-Himalayan inner valley of Nepal, between 3000 and 4000 masl. We used regression and ordination to relate species richness and composition to the physical environment. *Pinus wallichiana*, *Juniperus indica*, *Abies spectabilis*, *Betula utilis* and *Salix* species are the dominant tree species. *B. utilis* is found only in the moist north aspect and *Juniperus* species are more common in the dry south aspect. Moisture is the most important determinant of species richness and composition. At the local level, our results show a plateau in species richness at the elevation range of 3000–4000 masl. There were significantly more species on the north aspect than on the south.

Key words: aspect, altitude, beta-diversity, ordination, species richness, soil moisture

Species richness is currently the most widely used measure of diversity (Stirling and Wilsey 2001). It is a simple and easily interpretable indicator of biological diversity (Peet 1974, Whittaker 1977). A complex of various factors determines species richness (Schuster and Diekmann 2005). Numerous studies have examined the relationships between plant species richness, climate and spatial variables. In broader scale, plant diversity correlates with size of area (Rosenzweig 1995), latitude (Currie and Paquin 1987), elevation (Stevens 1992, Merganic et al. 2004), precipitation (Whittaker and Niering 1965) and evapotranspiration (Currie 1991, Rohde 1992). Variation of species richness with elevation has been known for a long time. Many studies reported a decline in the number of species with increasing elevation (Brown 1988, Stevens 1992, Begon et al. 1996, Lomolino 2001). However, Rahbek (1995) showed a mid-altitude peak in species richness. Other studies, that found humped relationship between species richness and altitude, include Whittaker and Niering (1975), Liberman et al. (1996), Grytnes and Vetaas (2002) and Carpenter (2005).

Grytnes and Vetaas (2002) analyzed plant species richness along the Himalayan altitudinal gradient in Nepal. They concluded that interpolated species richness in the Himalaya showed a hump-shaped structure. The maximum richness of flowering plants of Nepal has been found between 1500 and 2500 masl. A study of total species richness from ca. 300 to 6000 masl in Nepal indicated a very little variation between 3000 and 4000 masl (Grytnes and Vetaas 2002) generating a high-elevation plateau. Observing this pattern of species richness on large scale, the aim of present work was to test this hypothesis on local level by sampling in a dry inner valley of Nepal Himalaya. The altitudinal range considered for the present work falls under the range of this plateau. The null hypothesis for the study was that there is no change in species richness between 3000 and 4000 masl.

Although the interpolated species richness gives one value for each elevation band, it is well known that richness may vary at different aspect in mountainous environment (Ferrer-Castan and Vetaas 2003). Aspect significantly influences richness and composition of plants. Literatures show that the primary impacts of aspect are expressed through regulating energy budgets and site moisture relationships. However, there is less generality in the effects of these impacts on the expression of vegetation (Bale et al. 1998). Mostly the north facing aspects get more moisture than the south facing aspects in the Himalayas (Vetaas 2000). In our knowledge, no studies have been done so far on the influence of aspect on species richness in the dry inner valley of Nepal Himalaya. The main aims of the present study are: (1) to describe plant species composition and relate it to environmental factors using ordination; (2) to test null hypothesis deduced from the interpolation, of no change in richness in between 3000 and 4000 masl; and (3) to evaluate the effect of aspect on species richness and composition.

Himalayan Journal of Sciences 4(6): 57–64, 2007
Available online at www.himjsci.com

Materials and methods

Study area The study area, a part of Annapurna Conservation Area, lies in Manang district of Nepal in the northwest Central Himalayas (**Figure 1**). The U-shaped inner valley extends east to west and is situated between 28°37'56" and 28°39'55" N latitude and 83°59'83" and 84°07'97" E longitude. The valley is surrounded by the Annapurna range on the south; Manasalu on the east; Peri, Himlung and Choya on the north; and Damodar and Muktinath on the west. The elevation ranges from 3000 to 3500 masl and the climate is dry, characteristic of the trans-Himalayan region. Due to the rain shadow of the Annapurna massif, the mean annual precipitation is ca. 400 mm (ICIMOD 1995). Average maximum and minimum temperatures, recorded at Jomsom (the nearest meteorological station approximately 12 km west of the study area with similar climatic conditions) were 7.9°C and –1.75°C in winter and 22.6°C and 14.15°C in summer, respectively (DHM 1999). Snow covers the valley during winter. Soil moisture decreases from east to west in the valley, and the south facing slopes are significantly drier than those facing north (Bhattarai et al. 2004). The Marsyangdi River drains the valley.

Vegetation is dominated by *Pinus wallichiana*. On the north aspect *P. wallichiana* is abundant from the lower belt up to 3500 masl, above which *Abies spectabilis* and *Betula utilis* are common. *Juniperus indica* and *Rosa sericea* with other shrubs are dominant on the dry south facing slopes (Miehe 1982). The ground layer consists of scattered patches of thorny cushion plant species such as *Caragana*, *Astragalus* with species of *Primula*, *Saxifraga* and *Androsace*. The riverbanks are occupied by *Salix*, *Populus* and *Hippophae*

Table 1. DCA summary

Axes	1	2	3	4
Eigenvalues	0.451	0.298	0.218	0.144
Lengths of gradient	3.045	2.844	2.182	2.156
Species-environment correlation	0.855	0.865	0.595	0.444
Cumulative % variance of species data	9.7	16.1	20.8	23.9

Table 2. Inter-set correlation of main underlying environmental gradients with CA – axes

Axes	1	2	3
Altitude	0.51	0.70	–0.027
Aspect	0.62	–0.41	0.32
Slope	0.15	–0.08	–0.05
Canopy	0.20	–0.69	0.22
pH	–0.17	0.26	–0.63
Moisture	0.77	0.056	0.32

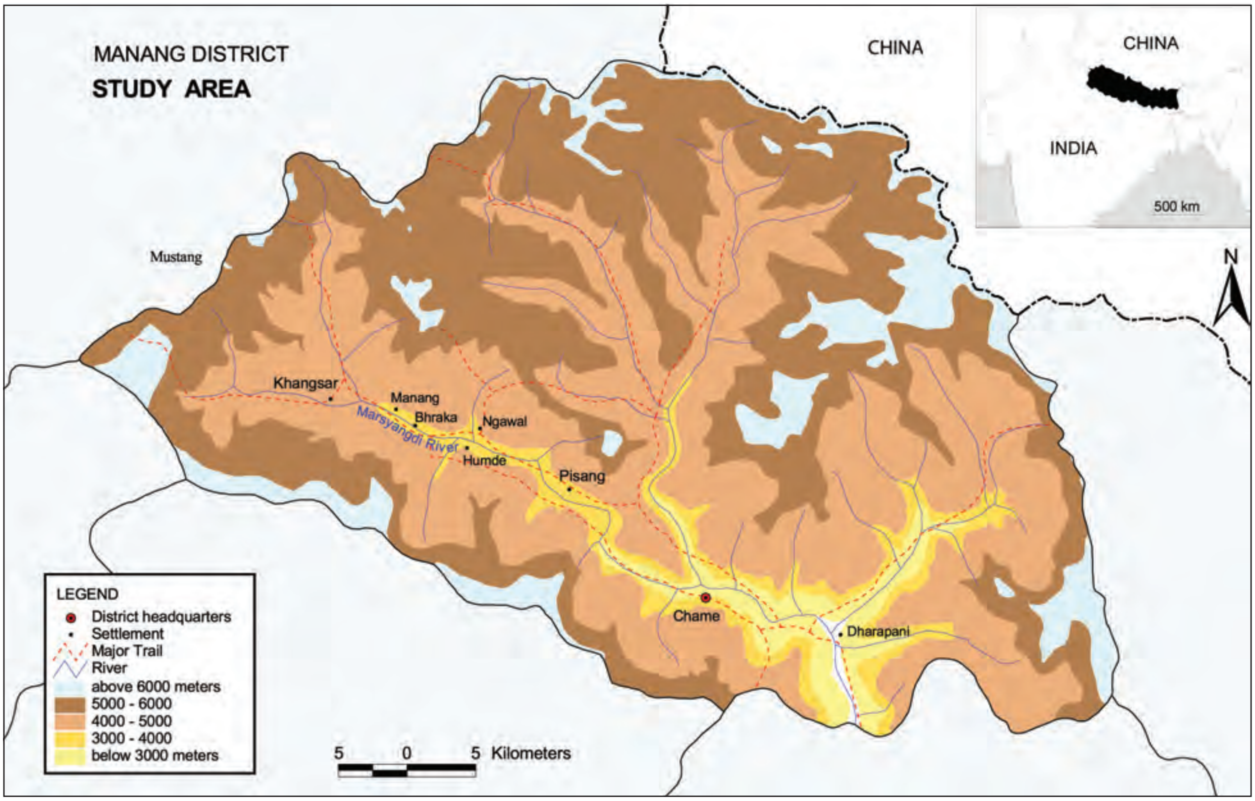

Figure 1. Location of the study area: Upper Manang, a trans-Himalayan dry inner valley in Manang, Central Nepal. (Source: Pawan Ghimire, Department of Geography, University of Bergen)

Table 3. Total species richness

Altitudinal range (masl)	Total species	Total species in N aspect	Total species in S aspect	Species common in both	Species only in N aspect	Species only in S aspect
3200 – 3300	31	22	17	8	14	9
3300 – 3400	36	21	28	13	8	15
3400 – 3500	33	25	18	10	15	8
3500 – 3600	31	24	13	6	18	7
3600 – 3700	29	21	14	6	15	8
3700 – 3800	29	21	12	4	17	8
3800 – 3900	34	26	15	7	19	8
3900 – 4000	39	29	20	10	19	10
Total	68	58	46	36	22	10

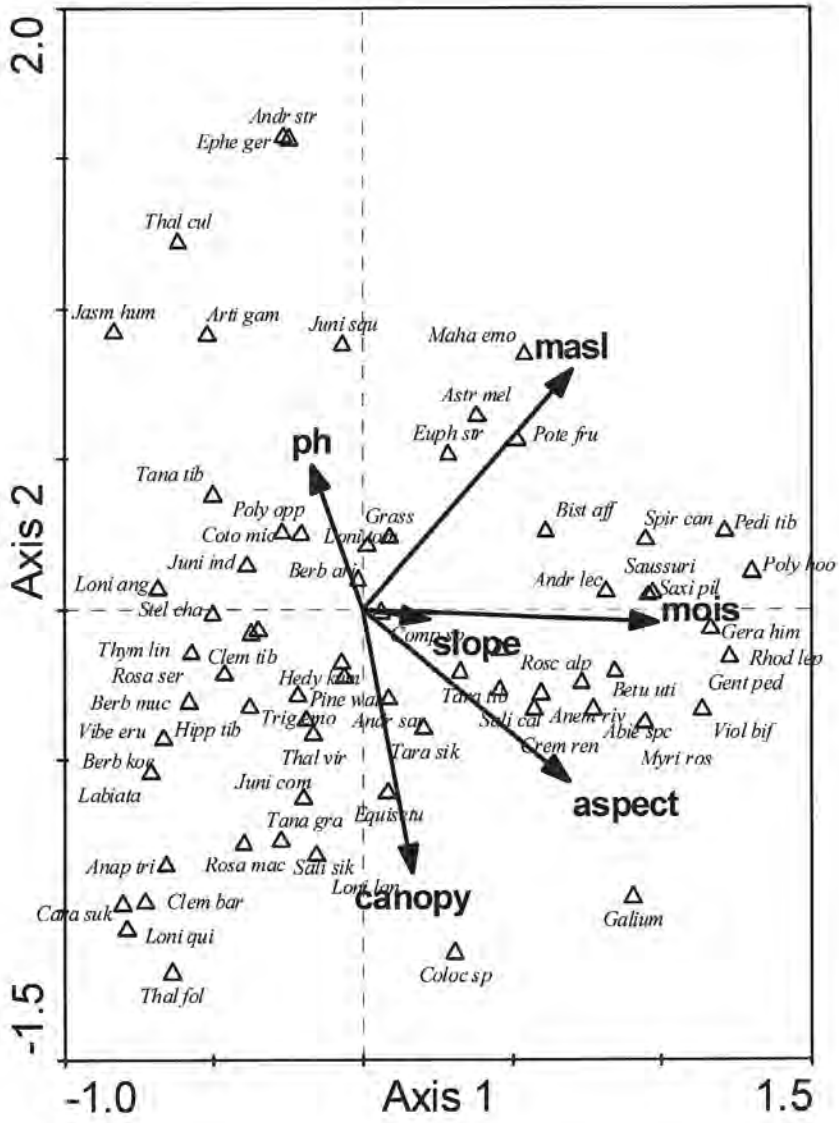

Figure 2. Ordination biplot diagram for species and environmental variables. Plots are displayed by triangles and species are labeled by the first four letters of the generic name and three letters of the species name. Complete plant names are given in Appendix 1. Right side of the axis 1 represents north aspect and left side represents south aspect of the study area.

species. *Picea smithiana* and *Tsuga dumosa* grow on at few locations on the north aspect of the valley.

Field sampling Data on species composition and richness of vascular plants were collected from 80 plots during May and June 2004. Plots (10 m x 10 m) were located using a stratified random sampling design. The sampling was done at 100 m intervals from 3200–4000 masl on the north and south aspects of the valley. Individuals of all species rooted in the plots were counted. The following environmental variables were assessed for each plot: percentage of canopy cover of each tree species (visual estimation), pH and moisture of soil (using a DM 15 gauge, Takemura Electric Works Ltd., Japan), elevation (using an altimeter), and slope (with a clinometer). The nomenclature follows Hara et al. (1978, 1982), Hara and Williams (1979), and Press et al. (2000). All the voucher specimens have been deposited at the Tribhuvan University Central Herbarium (TUCH), Kathmandu, Nepal.

Numerical methods We used ordination to analyze species composition and beta diversity. Detrended correspondence analysis (DCA) is a widely used indirect ordination method (e.g. Økland and Eilertsen 1996, Exner et al. 2002, Lepš and Šmilauer 2003) and provides an effective approximation of the underlying environmental gradients (ter Braak 1995). DCA (Hill and Gauch 1980) was used to describe the total species composition and differences between the two aspects and to estimate the compositional gradient length in SD-units (i.e. beta diversity) (Hill 1973, Lepš and Šmilauer 2003). A preliminary analysis showed SD-unit greater than two and no arch-effect; we used correspondence analysis (CA) to relate species composition to the environmental factors. This was done on the total data (80 plots) and on the two aspects separately (n = 40).

We also performed regression on the total data set in order to analyze species richness. We used species richness as the response variable and the principal environmental factors (moisture, aspect, pH, canopy) as explanatory variables. We checked distribution on normal Gaussian and Poisson models and selected the former as more suitable. We also performed separate analyses for each aspect in relation to canopy cover, elevation and moisture. The difference in mean species richness between the two aspects was tested by student t-test. We analyzed the data using S-PLUS (Anonymous 2002), as well as CANOCO version 4.5 (ter Braak 2002) and its graphical programme CANODRAW (Smilauer 2002).

Results

Species composition DCA results (**Table 1**) show that the compositional gradient lengths of the first and second axes are 3.0 and 2.8 (eigenvalues 0.451 and 0.298), respectively. The DCA summary reveals that the first gradient is by far the longest, explaining 9.7% of the total species variability, whereas the second and higher axes explain much less. *Pinus wallichiana* was the only dominant tree species found on both north and south aspects. It is located near the central position of the species plot of ordination diagram (**Figure 2**). *Juniperus* species were located towards the negative side of first axis, i.e. on the dry side, while *Betula utilis* and *Abies spectabilis* appeared towards positive side of first axis, which is moister. *B. utilis* was reported only from the north aspect. Other woody species as *Rosa sericea* and *Lonicera* species were found at low elevations of both aspects, while *Rhododendron lepidotum* was noticed at high elevation of the north aspect. At least one or two species of *Berberis* were reported throughout the altitudinal gradient. Among herbs, *Polygonatum oppositifolium*, *Stellera chamaejasme*, *Androsace* spp., *Potentilla fruticosa*, and *Primula* spp. were common.

Correspondence analysis (CA) revealed that moisture, soil pH and canopy cover are the main underlying environmental gradients for species composition. The first and second axes are well correlated with the environmental factors ($r = 0.855$ and 0.865, respectively) and the correlation for the other axes is considerably lower (not shown). Moisture has the strongest correlation with the first axis (**Table 2**, **Figure 2**). The second axis correlates with canopy cover and the third axis with pH. The south aspect is relatively dry with high pH (6.8). The two spatially independent factors – elevation and aspect – were correlated with both first and second axes.

Species richness Sixty eight plant species belonging to 50 genera and 31 families (**Appendix 1**) were recorded. The number of species increased from 3200 to 3400 masl, followed by a gradual decrease up to 3800 masl. Above 3800 masl, the number of species again increases towards high elevation (3900–4000 masl, **Table 3**). In general, however, variation in species richness as function of elevation between 3000 and 4000 masl is not significant, and a high-elevation plateau in richness is found. Species richness is correlated with moisture ($r = 0.232$, **Figure 3**). Normally, south aspect is dry and north aspect is moist. Mean species numbers on the south and north aspects are 10.0 and 11.8, respectively. Species richness is significantly higher on the north aspect than on the south ($t = -2.86$, $p = 0.005$ for 78 df). The total number of species reported from the north aspect is 58, with beta diversity 3.10 and eigenvalue 2.7. The total number of species from the south aspect is 46 with beta diversity 2.97

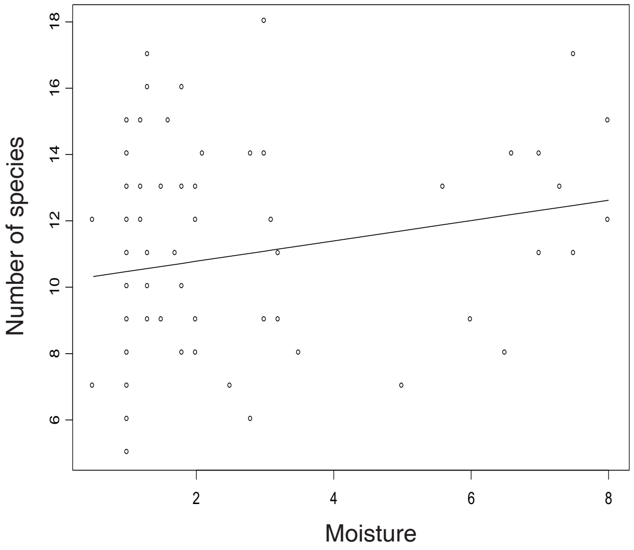

Figure 3. Correlation of total species richness with moisture (arbitrary unit), r = 0.232

and eigenvalue 2.1. In total 36 species are common to the both aspects (**Table 3**).

Discussion

A monotonic decline in the number of species with increasing elevation has often been considered a general pattern (Brown 1988, Stevens 1992). However, our results indicate that species richness does not follow this pattern in our study sites. A plateau in species number is observed between 3000 and 4000 masl. This is consistent with patterns for overall interpolated species richness in the Nepal Himalaya found by Grytnes and Vetaas (2002) and Vetaas and Grytnes (2002). Studies that have employed the interpolative method on elevation gradients are becoming more common, as for example Fleishman et al. (1998) for butterflies and Grytnes and Vetaas (2002) for plants. Our empirical results confirm that there is a little change in species richness between 3000 and 4000 masl. The small variation in species number may be due to seasonal movement of animals. Livestock (yak, horse, mule, sheep and goats) are brought to alpine pasture to graze during the summer months of April to September (Bhattarai et al. 2004) and stay in the valley bottom during the winter. Seed dispersal via animal dung, hooves and coats (Sykora et al. 1990, Poschlod et al. 1998, Moe 2001) may be important in reducing disparities in species number along the elevation gradient.

The striking high-elevation plateau of species richness might seem anomalous, but similar patterns have been found previously, particularly in ornithological surveys. The species richness of birds in Manu National Park of Peru (Patterson et al. 1998) and also in Bolivia (Herzog et al. 2005) show similar plateau with identical richness values. However, this phenomenon is still not well understood (Herzog et al. 2005). Gill et al. (1999), describing the changes of plant diversity after fire, mention a period of plateau formation in species richness. Fire is not used as a management tool at our study site. Although there were occasional forest fires, their influence on species richness is uncertain.

Moisture is the main environmental factor impacting plant species richness and composition. There is a significant (r=0.232) relationship between moisture and species richness. Moisture is positively correlated with canopy and negatively correlated with pH (**Figure 2**). Soil pH is also related to the availability of soil nutrients, but has no apparent relation to species richness. Increase in species richness from acidic to neutral soil is common in temperate forests (Palmer 1990, Pausas 1994) and a pattern of richness increasing with higher pH has been reported in the Arctic tundra (Gough et al. 2000). Grime (1973) found that the maximum number of species in unmanaged grassland occurs at a pH of 6.1– 6.5, with species richness declining in both acidic and alkaline soils. Canopy is also a significant factor, probably through its influence on the light intensity reaching the ground, as suggested by several authors (e.g., Spurr and Barnes 1973, Tilman 1985).

Aspect regulates the quantity and duration of soil moisture, partly through temperature (Parker 1991). The northern aspect is moister with more canopy cover than the southern aspect; these two factors both have a positive influence on species richness. An understanding of aspect is important in forest management and planning (Bale and Charley 1994), because of its influence on tree diameter growth (Verbyla and Fisher 1989) and forest productivity (Hutchins et al. 1976). The natural forest in the inner valley extends from 3000 to 4200 masl in the north aspect, while its upper limit is below 4000 masl in the south aspect. Aspect also relates with species richness. Since the influence of aspect on species richness in the inner valleys of the Himalayas has not been studied adequately, we could not make further comparisons.

As elevation increases, temperature decreases with the reduction of evapotranspiration on the slopes (Eklund et al. 2000). The elevation contributes to a difference in mean temperature of up to 3.0°C (lapse rate 0.51°C/100 m, Vetaas 2000). In an empirical analysis involving North American plants and animals, Currie (1991) concludes that potential evapotranspiration is the best predictor of animal species richness. For tree species, actual evapotranspiration was shown to be the best predictor of richness, with a monotonically increasing relationship (Currie and Paquin 1987, Francis and Currie 1998).

The beta diversity of the north aspect (3.10) exceeds that of the south aspect (2.1), suggesting greater species turnover on the north side. The turnover in species is mainly attributable to high moisture, along with other supporting environmental factors. Besides the common species found on both the north and south aspects, a total of 22 species reported from the north aspect were not found in the south aspect. In dry habitats, species number increases towards the relatively wetter areas, as observed by Kassas and Zahran (1971) in Egypt, and by Vetaas (1993) in Sudan. In New Zealand total tree species richness was found to increase with soil and atmospheric moisture (Leathwick et al.1998). In dry and semi arid areas moisture is often the limiting factor, and thus has a strong influence on species richness (Olsvig-Whittaker et al. 1983, Belsky et al. 1989). The difference in microclimate between the north and south aspects is associated with differences in the composition and richness of species, which can be compared with the findings of Pook and Moore (1966) on the influence of aspect on the composition and structure of forest on Black mountain, Canberra.

In short, total species richness shows a plateau between 3000 and 4000 masl at the local level. Species richness is significantly higher on the north facing slope than on the south facing slope. It also can be concluded that moisture and factors influencing evaporation (i.e. canopy and aspect), are the main environmental factors influencing species composition and richness in the dry inner valley of the trans-Himalaya.

Acknowledgements

We would like to acknowledge the cooperation of the people of Manang Valley. We thank BK Ghimire for his energetic help during the field work and Pawan Ghimire for providing a map of Manang. Our research was sponsored by the Norwegian Council for Higher Educations Programme for Development Research and Education (NUFU Project ID: PRO 04/2002), and OR Vetaas was funded by Norwegian Research Council (project no.148910/730). MP also thanks the Central Department of Botany, TU, for laboratory facilities, and Tribhuvan University, Nepal for granting a study leave.

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APPENDIX: 1. Plants recorded from sampled plots

Abbreviation	Plant name	Family
Abie spe	*Abies spectabilis* (D. Don) Mirb.	Pinaceae
Anap tri	*Anaphilis triplinervis* (Sims.) C. B. Clarke	Compositae
Andr leh	*Androsace lehmannii* Wall. ex Duby	Primulaceae
Andr sar	*Androsace sarmentosa* Wall.	Primulaceae
Andr str	*Androsace strigillosa* Franch.	Primulaceae
Anem riv	*Anemone rivularis* Buch.-Ham. ex DC.	Ranunculaceae
Arti gam	*Artemisia gemelinii* Web. Ex Stechm	Compositae
Astr mel	*Astragalus melanostachys* Benth. ex Bunge.	Leguminosae
Berb ari	*Berberis aristata* DC.	Berberidaceae
Berb koe	*Berberis koehneana* C.K. Schneid.	Berberidaceae
Berb muc	*Berberis mucrifolia* Ahrendt	Berberidaceae
Betu uti	*Betula utilis* D. Don	Betulaceae
Bist aff	*Bistorta affinis* (D.Don) Greene	Polygonaceae
Cara jub	*Caragana jubata* (Pall.) Poir.	Leguminosae
Cara suk	*Caragana sukiensis* C.K.Schneid.	Leguminosae
Clem bar	*Clematis barbellata* Edgew.	Ranunculaceae
Clem tib	*Clematis tibetana* Kuntze	Ranunculaceae
Colo sps	*Colocacea* species	Araceae
Comp sps	Composite species	Compositae
Coto mic	*Cotoneaster microphyllus* Wall. ex Lindl.	Rosaceae
Crem ren	*Cremanthodium reniforme* (DC.) Benth.	Compositae
Ephe ger	*Ephedra gerardiana* Wall.ex Stapf	Ephedraceae
Equi sps	*Equisetum* species	Equisetaceae
Euph str	*Euphorbia stracheyi* Boiss.	Euphorbiaceae
Gali sps	*Galium* species	Rubiaceae
Gent ped	*Gentiana pedicellata* (D.Don) Griseb.	Gentianaceae
Gera him	*Geranium himalayense* Klotzsch	Geraniaceae
Gras one	Grass species	Gramineae
Gras two	Grass species	Gramineae
Hedy kum	*Hedysarum kumaonense* Benth. ex Baker	Leguminosae
Hipp tib	*Hippophae tibetana* Schltdl.	Elaeagnaceae
Jasm hum	*Jasminum humile* L.	Oleaceae
Juni com	*Juniperus communis* Pall.	Cupressaceae
Juni ind	*Juniperus indica* Bertol.	Cupressaceae
Juni squ	*Juniperus squamata* Buch.-Ham. ex D.Don	Cupressaceae
Labiatae	*Labiatae* species	Labiatae
Loni ang	*Lonicera angustifolia* Wall. ex DC.	Caprifoliaceae
Loni lan	*Lonicera lanceolata* Wall.	Caprifoliaceae
Loni qui	*Lonicera quinquelocularis* Hardw.	Caprifoliaceae
Loni tom	*Lonicera tomentella* Hook. f. & Thomson	Caprifoliaceae
Maha emo	*Maharanga emodi* (Wall.) A. DC.	Boraginaceae
Myri ros	*Myricaria rosea* W.W.Sm.	Tamaricaceae
Pedi tib	*Pedinogyne tibetica* (C.B.Clarke)Brand	Boraginaceae
Pinu wal	*Pinus wallichiana* A.B.Jacks	Pinaceae
Poly hoo	*Polygonatum hookeri* Baker	Liliaceae
Poly opp	*Polygonatum oppositifolium* (Wall.) Royle	Liliaceae
Pote fru	*Potentilla fruticosa* var. *rigida* (Wall. ex Lehm.) Wolf.	Rosaceae
Prim den	*Primula denticulata* Sm.	Primulaceae
Rhod lep	*Rhododendron lepidotum* Wall. ex D. Don.	Ericaceae

Rosa mac	*Rosa macrophylla* Lindl.	Rosaceae
Rosa ser	*Rosa sericea* Lindl.	Rosaceae
Rosc alp	*Roscoea alpina* Royle	Zingiberaceae
Sali cal	*Salix calyculata* Hook. f. ex Andersson	Salicaceae
Sali sik	*Salix sikkimensis* Andersson	Salicaceae
Saus del	*Saussurea deltoidea* (DC.) Sch. Bip.	Compositae
Saxi pil	*Saxifraga pilifera* Hook. f. & Thomson	Saxifragaceae
Spir can	*Spiraea canescens* D. Don	Rosaceae
Stel cha	*Stellera chamaejasme* L.	Thymeleaceae
Tana gra	*Tanacetum gracile* Hook. f. & Thomson	Compositae
Tara sik	*Taraxcum sikkimense* Hand.- Mazz.	Compositae
Tara tib	*Taraxacum tibetanum* Hand.- Mazz.	Compositae
Thal cul	*Thalictrum cultratum* Wall.	Ranunculaceae
Thal fol	*Thalictrum foliolosum* DC.	Ranunculaceae
Thal vir	*Thalictrum virgatum* Hook. f. & Thomson	Ranunculaceae
Thym lin	*Thymus linearis* Benth.	Labiatae
Trig emo	*Trigonella emodi* Benth.	Leguminosae
Vibu eru	*Viburnum erubescens* Wall. ex DC.	Sambucaceae
Viol bif	*Viola biflora* L.	Violaceae

Production of haploid wheat plants from wheat (*Triticum aestivum* L.) x maize (*Zea mays* L.) cross system

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The present study was carried out taking single F_1 wheat and four maize varieties, viz. Arun-1, Arun-2, Khumal Yellow and Rampur Composite, to determine the efficiency and influence of maize genotypes on various parameters of haploid formation. Wheat spikelets were hand pollinated with freshly collected maize pollen, and 1 ml of 100 ppm 2,4-D was immediately injected on the uppermost internode. Twenty-four hours after 2,4-D injection, the cups of the florets were filled with the same solution of 2,4-D for two more consecutive days. Seventeen days after pollination, the embryos were excised and cultured in half-strength MS basal medium supplemented with 30 g/l sucrose, and 7 g/l agar. The cultured embryos were maintained at 25°C with 16/8 hours light/darkness after treating in the dark for seven days at 4°C and incubation in the dark for seven days at 25°C. Application of 2,4-D after pollination was found to be essential to the recovery of culturable size of embryos. The significant effect of maize genotypes on frequency of ovary development, embryo formation and haploid plant per pollinated floret was observed. The mean percentages of embryo formation and haploid plants per pollinated floret varied from 5.17 to 21.45 and 0.96 to 10.15, respectively, depending upon the maize varieties used. The highest frequency of embryo recovery and plant per floret was found when wheat F_1 was pollinated with Arun-2 followed by Arun-1 and Khumal Yellow. It is suggested that the production of dihaploids (DHs) in wheat can be enhanced by using more responsive maize genotypes as pollinators.

Key words: 2,4-D, caryopsis, floret, haploid embryo, wheat x maize cross

Wheat is one of the most important life-supporting cereals in Nepal and ranks third in terms of area and production. The aim of the Nepalese wheat breeding program is to produce high-yielding wheat varieties with enhanced adaptability and shorter growth period to fit into the rice-wheat cropping system. In Nepal, however, the development of a homozygous wheat cultivar can take up to 14 years. In other countries the time needed to reach homozygosity has been markedly reduced through the adoption of haplodiplodization (HD) technique (Baenziger et al. 2001). Since the discovery of haploid plants from *Datura inoxia* (Guha and Maheshwari 1964), HD based on gamete selection is considered the fastest means of cultivar development. This technique not only substantially reduces the time required to attain absolute homozygosity, but also increases many fold the selection efficiency of crop breeding (Choo et al. 1985). In conventional plant breeding, the chances of obtaining truly homozygous lines are rare and most selections contain some heterozygous loci (Baenziger et al. 2001), markedly reducing the precision of selection. For successful and cost-effective use in a breeding program, a HD system should fulfill three criteria (Snape et al. 1986): i) easy and consistent production of large numbers of dihaploids (doubled haploid from polyploid species) from all genotypes, ii) Dihaploids (DHs) should be genetically normal and stable, and iii) DHs should contain a random sample of the parental gametes.

In wheat, haploid/dihaploid plants can be produced either through anther/microspore culture (Patel et al. 2004, Liang et al. 1987) or intergeneric crossing of wheat with barley (Barclay 1975), maize (Laurie and Bennet 1988) and various other grasses belonging to the Gramineae (Pratap et al. 2005). Intergeneric crosses between wheat and maize followed by elimination of the genome of maize has been considered an efficient method for the induction of haploid zygotic embryos and subsequent haploid and dihaploid plants (Suenaga and Nakajima 1989, Inagaki 1997). The maize-mediated haploid production system for wheat has shown to be less genotype dependent and more efficient and simple than wheat x *Hordeum bulbosum* crosses (Suenaga 1994) or anther culture (Sadasivaiah et al. 1999, Bitsch et al. 1998, Kisana et al. 1993). The *Hordeum bulbosum* technique in wheat is constrained by the presence of incompatible genes (Kr_1 and Kr_2) situated on the 5A and 5B wheat chromosomes that markedly reduce the crossability between wheat and *H. bulbosum* (Falk and Kasha 1981). Nonetheless, maize pollen appears to be insensitive to

Himalayan Journal of Sciences 4(6): 65–69, 2007
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Table 1. Effect of four maize genotypes on ovary development, embryo formation and subsequent haploid plant regeneration

Maize genotypes	F_1 Wheat (Acc #7103/WK 1204)				
	No. of florets pollinated	No. of developed ovaries	No. of embryos formed	No. of embryos culture	Haploid plants/ florets pollinated
Khumal Yellow	116	52 (44.37) [a]	22 (18.91) [a]	15	7 (6.04) [a]
Rampur Composite	91	28 (30.65) [b]	5 (5.17) [b]	4	1 (0.96) [b]
Arun-1	102	36 (35.18) [a]	19 (18.51) [a]	16	7 (6.81) [a]
Arun-2	111	49 (44.32) [a]	24 (21.45) [a]	18	11 (10.15)[a]
Total	420	165 (38.631)	70 (16.01)	53	26 (6.00)
Coefficient of variation (%)	-	8.82	15.31	-	25.22

Figures in parentheses indicate the original mean percentage of well-developed ovaries (ovaries/pollinated floret), embryo formation (embryos/pollinated floret) and haploid plant formation (seedlings/pollinated florets). Original means within parentheses followed by the same letter are not significantly different at α =0.05

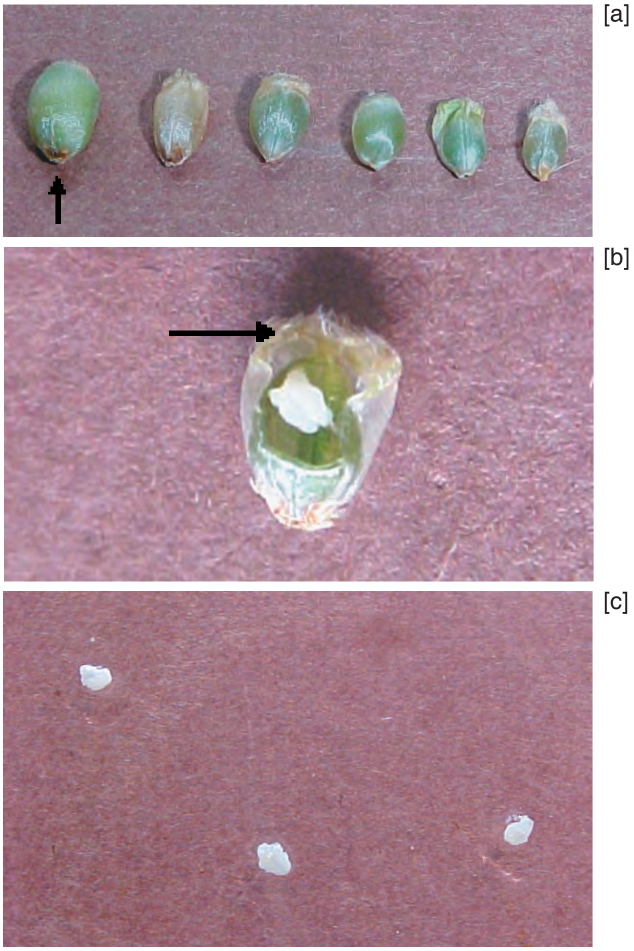

Plate 1. a) wheat caryopses obtained following selfing (arrow) and wheat x maize intergeneric crosses, b) seventeen-day old haploid floating embryo in watery embryo sac (arrow), c) variations in size and shape of embryos

these crossability limiting factors, and pollen can be taken from a wide range of maize germplasm (Suenaga 1994). Moreover, the sexual route of dihaploid production systems in wheat is free from tissue culture associated variations and the problem of albinism in regenerants. Haploid embryo induction and subsequent plant regeneration from wheat x maize crosses have been greatly improved by manipulating factors affecting the overall efficiency of this system (Gracia-llamas et al. 2004, Campbell et al. 1998, Suenaga et al. 1997). Some researchers have reported that this method is also significantly affected by both wheat and maize genotypes used in crossing programme (Berzonsky et al. 2003, Chaudhary et al. 2002, Verma et al. 1999). As a result some of the combinations yielded better than others.

Although this technique may be useful in more rapidly breeding elite wheat cultivars, Nepal has not yet tested its efficacy as compared to other methods. Therefore, as a part of the breeding efforts, this study was carried out to standardize the technique of wheat × maize method suitable for the Nepalese environment, and to study the effect of maize genotypes on haploid embryo formation and plantlet regeneration.

Materials and methods

F_1 wheat seeds derived from the cross between a landrace, Acc. No. 7103 (early but low yielder), and WK-1204 (yellow rust resistant, high yielder, but late) were planted in five earthen pots; three seeds per pot at a time, and repeatedly planted four times at six day intervals and grown in natural condition during the 2004–05 wheat growing season at Khumaltar, Nepal. Four staggered plantings of each maize cultivar (viz. Arun-1, Arun-2, Khumal Yellow and Rampur Composite) were made 10 days after the first wheat sowing at seven day intervals in order to insure an adequate source of pollen and to synchronize the flowering time of maize with wheat. Each maize genotype was planted in six plastic buckets (35 x 25 cm^2) at a time and grown in a glasshouse. During winter, the glasshouse was illuminated in the morning and evening for four hours to enhance the length of photoperiod. The wheat plants were thinned to a single plant per pot at the two-three leaf stage. Once the wheat heads were ready for emasculation, four healthy pots containing single plants were selected and five of the spikes from each plant were hand-emasculated one or two days prior to anthesis. The emasculated spikes were covered with 5 x 12 cm plastic bags until pollination.

The experiment was carried out in completely randomized design with four replications; each spike was considered a replication. One to two days after emasculation the spikes of wheat were hand-pollinated with freshly collected maize pollen from each cultivar; the plastic bags were then replaced with glassine bags. One ml of 100 ppm 2,4-D was immediately injected on the uppermost internode of wheat with a one-ml capacity hypodermic insulin syringe following the procedure of Suenaga and Nakajima (1989). The pore was sealed with vaseline to prevent leakage. Twenty-four hours after 2,4-D injection, the cups of the pollinated florets were filled with the same concentration of 2,4-D; this was repeated twice on two consecutive days. Once the application of 2,4-D completed, the whole pollinated spikes were covered with glassine bag until the embryo harvest. The extra spike from each pot was treated only with distilled water as a control. Seventeen days after pollination, the spikes were harvested and the number of intact, non-selfed florets from each replication was counted and recorded as the number of florets pollinated. Well-developed caryopses were removed from the florets, sterilized in 70% ethanol for 30 seconds, briefly rinsed in sterile distilled water, and then sterilized for 15 minutes in 1% sodium hypochlorite. Finally, the caryopses were again rinsed three times with sterile distilled water. The embryos were aseptically extracted under a stereomicroscope. Small and poorly developed embryos were counted to determine the total embryos formed, but they were not cultured: only well developed embryos longer than 0.5 mm were cultured aseptically on to 70 mm petri plates containing a half-strength MS (Murashige and Skoog 1962) basal medium supplemented with 0.5 mg/l nicotinic acid, 0.1mg/l thiamine HCl, 0.5 mg/l pyridoxine HCl, 2 mg/l glycine, 30g/l sucrose, and 7 g/l agar as gelling agent. The cultured embryos were kept at 4°C for seven days in the dark and then transferred to an incubation room for the next seven days at 25±1°C in dark. After incubation, the cultured embryos were kept in a temperature-controlled chamber for regeneration at 25±1°C with alternating periods of 16 hours light and 8 hours dark. When the plantlets reached the two three-leaf stage, they were hardened and transferred into soil and then maintained in a temperature-controlled chamber as in the off-season nursery. The traits for analysis included: percentage of swollen caryopses containing florets, percentage of embryos formed (number of embryos divided by number of florets pollinated), and frequency of haploid plants per floret (number of regenerated seedling compared to total number of pollinated florets).

Depending on the nature of data in respective parameters, the percentage values were transformed into arcsine $\sqrt{x}$ and square root function $(x + ½)^{0.5}$ in order to normalize the distribution before analysis of variance (Gomez and Gomez 1984). The control data was excluded from statistical analysis. Duncan's Multiple Range Test (DMRT) was used for comparing the mean effect of maize genotypes on three parameters using MSTATC (version 1.3, 1989). The ploidy level of regenerated plantlets was determined by counting the chromosomes in root tip cells, using the standard acetocarmine squashing technique.

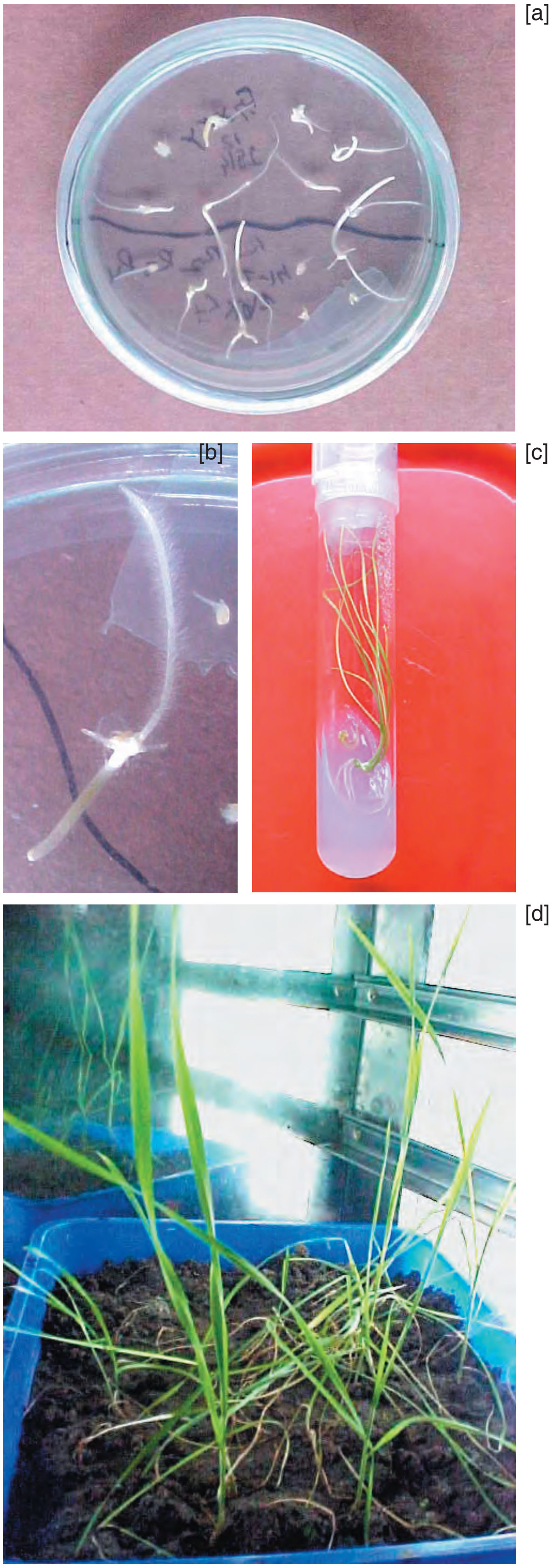

Plate 2. a–b) germinating embryos ten days after incubation, c) plantlet regeneration after 4 weeks, wheat x Arun-2, d) established haploid plants obtained from wheat x Arun-2 crosses

Results and discussion

In the present study the protocol for maize pollen mediated haploid production in wheat was standardized to existing laboratory environments. Pollination of wheat florets by maize pollen following 100 ppm 2,4-D treatment proved effective in producing haploid embryos. Application of 2,4-D after pollination was found to be essential to the recovery of embryos of culturable size via the wheat x maize system (**Plate 1c**). Each cross combination produced many haploid embryos (**Table 1**). The embryos obtained through this system were observed floating in watery embryo sacs (**Plate 1b**), from which they were rescued and placed on the culture medium (**Plate 2, a–c**). Lack of endosperm in the developed caryopsis after harvest served as the initial criterion for identifying haploid embryos. Altogether twenty-six haploid plants were successfully produced by pollinating 420 wheat florets with four maize genotypes (**Table 1, Plate 2d**). We were able to demonstrate the highly significant effect of maize genotypes on ovary development, embryo formation and florets per plant. Among pollen sources, the highest mean percentage of well developed ovaries (44.37%) was recorded for Khumal Yellow (**Plate 1a**), whereas Rampur Composite showed the lowest (30.65%). Similarly, the mean percentage of embryo formation varied from 5.17 – 21.45, depending on the maize variety (**Table 1**). The highest percentage of embryo recovery was found when wheat genotype was pollinated with Arun-2. Among the four maize varieties tested, Rampur Composite showed the lowest overall results in the tested parameters. The ratio of haploid plants to florets pollinated ranged from 0.96–10.15% with an average of 6.0%. The plantlets, when transplanted into soil, grew into green haploid plants. The haploid status (n = 3x = 21) of these plants was confirmed by their somatic chromosome counts.

A failure of normal caryopsis and endosperm development was also reported in wheat when pollinated with several genera of grasses (Pratap et al. 2005, Chaudhary et al. 2005). With the post-pollination application of 2,4-D, however, ovary tissues enlarge as in normal caryopsis development, appear turgid, but are filled with liquid; within such caryopses embryos may or may not be found (Suenaga and Nakajima 1989). In our study also, when 2,4-D was not applied after pollination, the caryopses failed to grow due to the lack of endosperm and most of them were shrunken and collapsed within 9 to 14 days after pollination (data not shown). The present results are consistent with other studies that have shown significant influence of maize genotypes on percent of embryo formation and on ratio of haploid plants per pollinated floret (Zhang et al. 1996, Suenaga 1994, Verma et al. 1999, Karanja et al. 2002). Karanja et al. (2002) obtained 8.53–19.34% embryos per floret when wheat was pollinated with six maize genotypes using similar method except that wheat was grown in green house. Likewise Suenaga (1994) also obtained a varying rate of embryo formation efficiency (1.6–36%) when a single wheat genotype, Fukoho-komugi, was pollinated with 52 diverse maize genotypes. Based on analysis of variance, this study also showed highly significant effect of maize genotypes on frequency of embryo and subsequent plant formation. Among three better maize genotypes, the response of Arun-2 was the best for haploid plant regeneration and plants per floret pollinated. Using this combination, 11 plants were successfully produced from 111 pollinated florets (**Table 1**). This figure was found consistent with the results of Sadasivaiah et al. (1999) who reported an average of 6.29 plant per 100 florets pollinated. The present study also clearly indicated that a high incidence of swollen ovaries does not always lead to a high yield of culturable embryos; this was the case with Rampur Composite (**Table 1**), where only five embryos were obtained out of 28 developed caryopses. This might have been due to the use of 2,4-D without maize pollen fertilization.

The larger number of embryos of culturable size is one of the crucial factors that determine the germination and post-germination efficiency of wheat x maize system. The number of embryos of culturable size can be increased through the judicious application of an auxin source such as Dicamba, alone or in combination with 2,4-D (Gracia-llamas et al. 2004). The number of embryos can also be improved by fine-tuning environmental factors such as temperature regime (Knox et al. 2000, Campbell et al. 1998) and relative humidity (Ballesteros et al. 2003), and by using the middle portion of the spikelet (Martins-Lopes et al. 2001) during pollination. Moreover the efficiency of this system is also influenced by other factors such as timing and technique of hormone manipulation, age of embryo to be cultured and *in vitro* conditions (Kaushik et al. 2004). The slight discrepancy between the results reported in this study and those of previous studies might be attributable to differences in wheat and maize genotypes and their interactions that influenced the rate of embryo recovery and subsequent plantlet formation (Chaudhary et al. 2002, Verma et al. 1999). Therefore, selection of better responsive maize genotypes such as Arun-2, Arun-1, and Khumal Yellow would seem to offer a likelihood of higher rates of haploid wheat induction. In summary, wheat x maize system was found to be simple and efficient and can be used as alternative to other systems of haploid induction in wheat.

Acknowledgements

The authors are grateful to K Suenaga, Japan International Research Center for Agricultural Sciences, 1–2 Ohashi, Tsukuba, Ibaraki 305, Japan for his assistance in providing some of the valuable research papers.

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Research paper

Distribution pattern and habitat preference of barking deer (*Muntiacus muntjac* Zimmermann) in Nagarjun forest, Kathmandu

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The distribution pattern and habitat preference of barking deer (*Muntiacus muntjac* Zimmermann) were analyzed during spring and rainy seasons of 2005 in Nagarjun Forest, Kathmandu. A total of 14 observations (seven males and seven females), 247 pellets and 118 footprints of barking deer were recorded in the spring and 14 observations (nine males and five females), 151 pellets and 140 footprints were recorded during the rainy season. The result showed uneven or clumped distribution patterns for deer in both spring ($S^2\sqrt{X}$ = 331.03 > 1; χ^2 = 331.02, p = 0.01) and rainy season ($S^2\sqrt{X}$ = 233.48 > 1; χ^2 = 233.48, p = 0.01). Among four types of habitats (*Schima wallichii* forest, mixed broadleaved forest, pine forest and dry oak forest), the mixed broadleaved forest was much preferred in spring (RPI = 0.81) and pine forest during the rainy season (RPI = 0.15).

Key words: Barking deer, *Muntiacus muntjac*, distribution, habitat preference, Nagarjun forest, Nepal

The barking deer (*Muntiacus muntjac* Zimmermann, Cervidae, Artiodactyla), also called muntjac, is a small, solitary ruminant, living in dense tropical and subtropical forests of Asia (Oli and Jacobson 1995, Shrestha 1997). *Muntiacus* spp. have a broad geographic range and are found in Indo-Malayan countries, China, Taiwan, Japan, Sri Lanka, north India and Nepal (Prater 1980). In Nepal, distribution, habitat use and preferences of the barking deer have been analyzed by many researchers (e.g. Tamang 1982, Heggdal 1999, Kuikel 2003, Thapa 2003, Pokharel 2005). Tamang (1982) reported that barking deer prefer Sal (*Shorea robusta*) and riverine forests, and are often seen on meadows in Chitwan. In Bardia, the barking deer prefer riverine forest followed by Sal forest with *Mallotus* as major associate (Heggdal 1999). Kuikel (2003) also observed the animals in the mixed forest, Sal forest and riverine forest. The distribution patterns of the species in various habitats have been documented by Thapa (2003) in Barandabhar Forest (Chitwan) and Pokhrel (2005) in Royal Suklaphanta Wildlife Reserve. They found that barking deer have a clumped distribution and show no significant difference in preference among the forested habitats.

Most studies on barking deer have focused on the lowlands of Nepal. Thus the information on barking deer distribution and habitat preference is inadequate for the mid-hills, which have experienced a higher rate of habitat loss and degradation. The present study has assessed the distribution, habitat use and diets of the barking deer in Nagarjun Forest. It is hoped that our findings will be useful for the management of barking deer in Nagarjun Forest as well as other parts of Nepal's middle hills.

Materials and methods

Study area Nagarjun forest (27°43'37.13" to 27°46'22.84" N; 85°13'52.97" to 85°18'14.38" E; 1220 to 2188 masl) lies on the northernmost border of Kathmandu Valley (**Figure 1**) and occupies an area of 16.45 km^2. The study area is underlain largely by quartzite but also consists of limestone, siliceous limestone and calcisilicate rocks to some extent (Hagen 1959). Soil composition varies with forest type, ranging from dry hard, light brown to black soil with low to high humus content (Kanai et al. 1970). Mean monthly temperature in the study year ranged from 3.05 to 30.53°C, relative humidity 54.7 to 94.2%, rainfall 5.15 to 548.73 mm. July, August and September are the most humid months, with highest precipitation in July and August. Forests in Nagarjun can be categorized into four types: *Schima wallichii* forest, pine forest, mixed broadleaved forest (*Phoebe lanceolata, Machilus duthiei, Michelia kisopa* as major species) and dry oak forest (Kanai and Shakya 1970). There are few small patches of grassy meadow (Nagarkoti 2006). The fauna includes bats, *Presbytis entellus* (common langur), *Melursus ursinus* (sloth bear), *Martes flavigula* (Himalayan yellow throated marten), *Hieraaetus fasciatus* (bonelli's eagle), *Urocissa flavirostris* (yellow-billed blue magpie), *Urocissa erythrorhyncha* (red-billed blue magpie) etc. (Malla 2000; Shrestha 2001).

Methods For ease of study, the entire forest was divided into four blocks, each 4.11 km^2 (**Figure 1**). Habitat types were classified and mapped using a geographic information system (GIS). Line transects of 0.5–1.5 km length were laid out at 100 m intervals corresponding to the topographic contour lines

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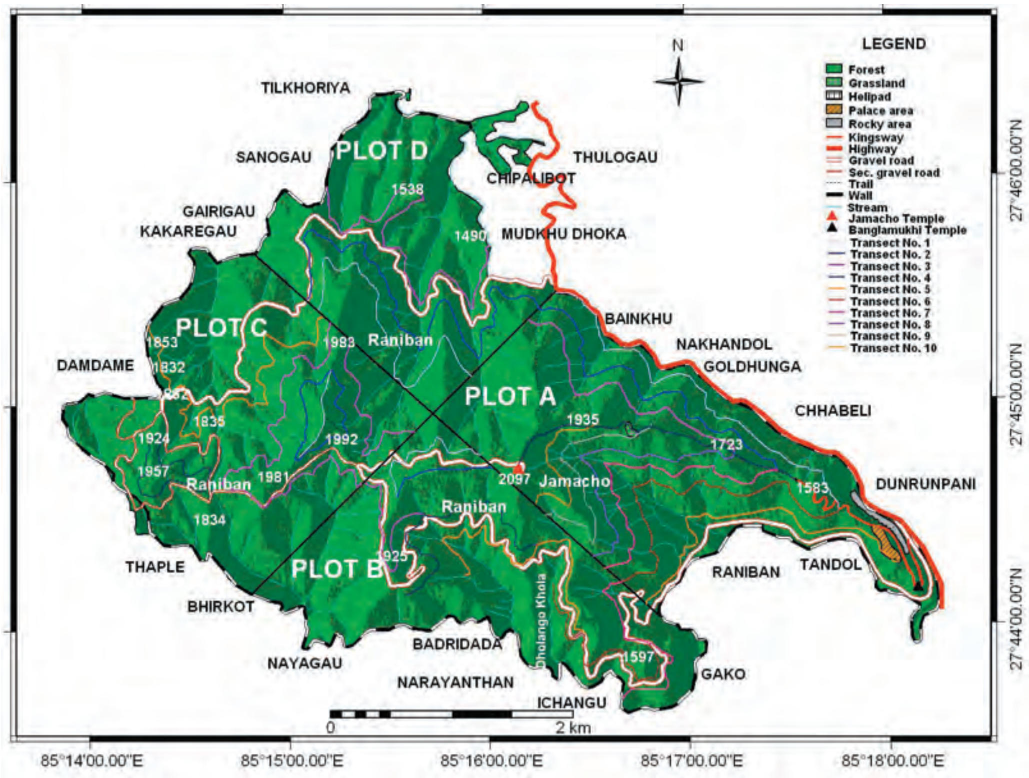

Figure 1. Study area with sampling plots and transects

of maps. Plots A, B, C and D contained 10, 7, 5 and 3 transects respectively, as constrained by the topography. Data collection entailed a total of 144 hours of work over a period of sixteen days in each season (April-May and July-August). We recorded sightings of animals and other evidence such as footprints and pellets within five meters of the transect lines. At each sighting, we recorded the GPS coordinates, altitude and habitat type. We used observational data such as number of individuals, footprints and pellets recorded in each habitat type to determine the distribution pattern and habitat preference following the methods described by Jayson (1999).

We used a χ^2 test to arrive at the distribution pattern and a relative preference index (RPI), one-way analysis of variance (ANOVA) to test differences in habitat use, and a t-test to quantify the difference between habitat use in the spring and rainy season. The deer's distribution pattern was calculated by variance-to-mean ratio (Odum 1971). A chi-square goodness-of-fit test was carried out to determine whether barking deer were distributed according to the availability of habitat types. According to Stinnett and Klebenow (1986),

We used area estimates of vegetation types obtained from topographic maps in order to calculate percentage availability of habitats.

Results

Forest cover Among the four types of forests recognized in Nagarjun hill, the *Schima wallichii*, forest constituted nearly 2/3rd of the total forest cover. In present study, we updated information on the boundaries of the various forest types; GIS analysis showed that coverage of *Schima wallichii* forest, mixed broadleaved forest, pine forest and dry oak forest in Nagarjun hill was 61.29%, 27.91%, 9.08% and 1.72%, respectively.

Distribution During the spring we recorded 14 individuals (7 bucks and 7 does), 247 pellet groups and 118 footprints of barking deer; during the rainy season we observed 14 individuals (9 males and 5 females), 151 pellet groups and 140 footprints. In the spring of 2005, we found evidence of deer presence most frequently in mixed broadleaved forest (three males, two females, 121 pellets and 65 footprints); no such evidence was recorded in the dry oak forest. On the other hand, during the 2005 rainy season, the highest incidence of evidence was observed in *Schima wallichii* forest (nine males, five females, 151 pellets and 140 footprints) whereas only one footprint was recorded in dry oak forest. In the Nagarjun forest, barking deer were encountered in almost all areas. However, we found a clumped distribution pattern both during spring ($S^2\sqrt{X} = 331.03 > 1$) ($\chi^2 = 331.03$, $p = 0.01$) (**Figure 2**) and rainy seasons ($S^2\sqrt{X} = 233.48 > 1$; and $\chi^2 = 233.48$, $p = 0.01$) (**Figure 3**).

Habitat use and preference The mixed broad leaved forest was much preferred (RPI = 0.81) in spring season while *Schima wallichii* forest (RPI = –0.25) and pine forest (RPI = –0.62) were not preferred during this season. Dry oak forest was completely avoided (RPI = –1) during spring season. During rainy season the deer preferred pine forest (RPI = 0.15) and mixed broad leaved forest (RPI = 0.14) while *Schima wallichii* forest (RPI = –0.06) and dry Oak forest (RPI = –0.81) were not preferred (**Figure 4**). However, no significant difference was

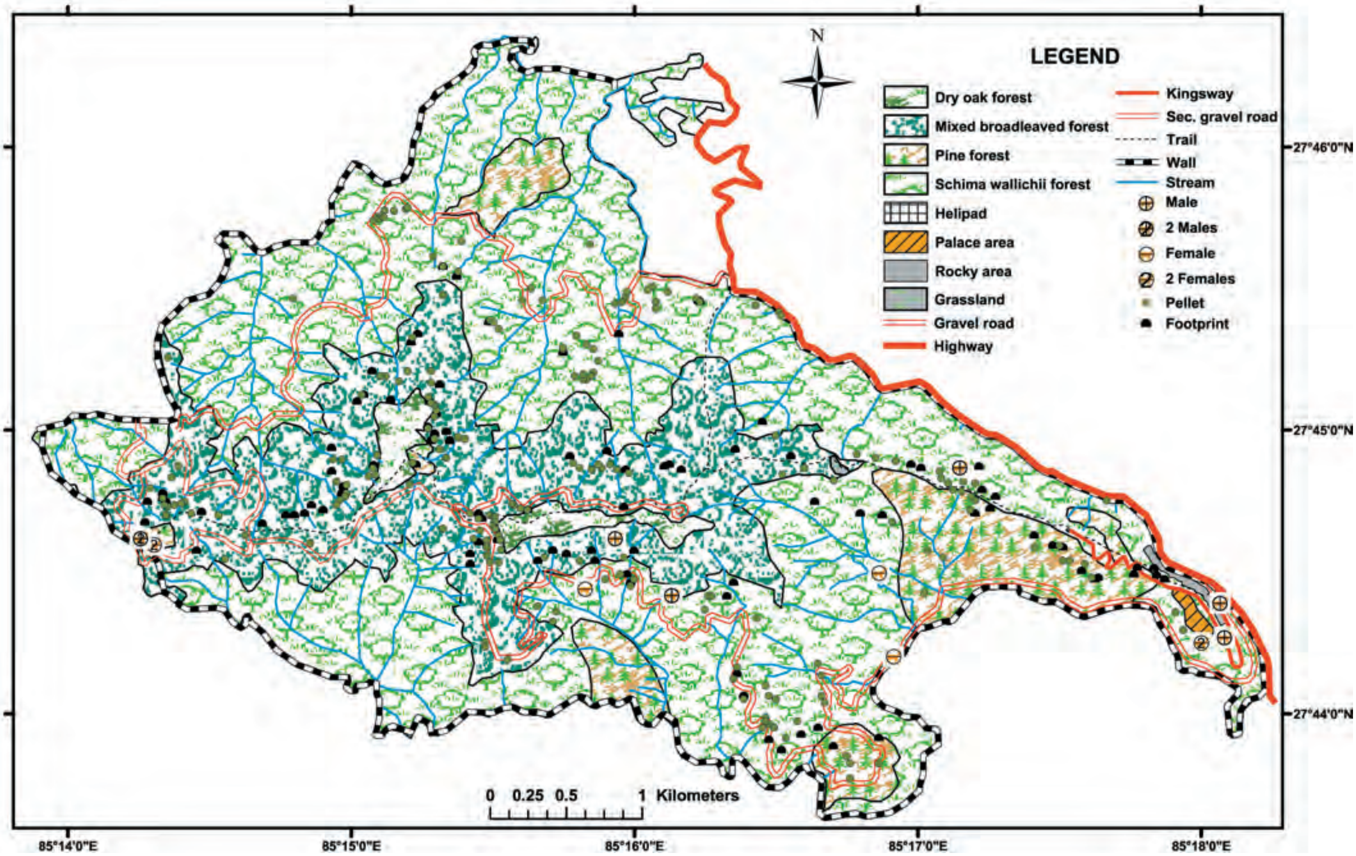

Figure 2. Distribution of barking deer in Nagarjun forest for spring season (2005)

found in using different habitat types by the deer ($p>0.05$). Similarly, the t-test also showed no significant difference in habitat use between spring and rainy seasons ($p>0.05$).

Discussion

The distribution of barking deer in the Nagarjun forest showed a clumped pattern which is presumably explained by the fact that in natural habitats such resources as food, water, and cover are not distributed uniformly. Barking deer exhibit seasonal differences in habitat preferences. The feeding habits of barking deer correspond to those of small African forest ruminants that Hofmann and Stewart (1972) characterize as 'selectors of juicy concentrated herbage'. Such food is relatively abundant in shrub habitats (Song and Li 1994). Dense canopy cover is another important factor in barking deer habitat selection (Teng et al. 2004). Preference for a high percent of canopy cover could be an anti-predatory strategy: in a forest or woodland, dense cover can minimize visual detection (Geist 1974). In the Royal Bardia National Park, Heggdal (1999) found that barking deer favored riverine forest for foraging and night-time habitat.

In the Nagarjun forest, coverage of shrub and surface layers was relatively dense in mixed broadleaved forest, as compared to that of other forest types (Kanai and Shakya 1970), causing concentration of deer in this habitat. Because barking deer usually drink water at least once a day, most often in the morning or midday, they like to remain close to a water source (Rafinesque 1968, Yonzon 1978). In the Nagarjun forest water sources are mainly available in the mixed broadleaved forest. Thus, the preference of barking deer for mixed-broad leaved forest in spring season is most

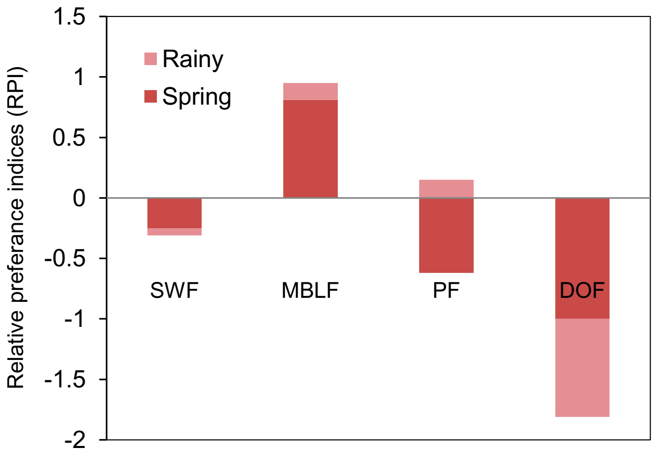

Figure 4. Relative preference indices (RPI) for habitat types during spring and rainy season, 2005. (SWF= Schima wallichii forest, MBLF=mixed broadleaved forest, PF=Pine forest, and DOF=dry oak forest)

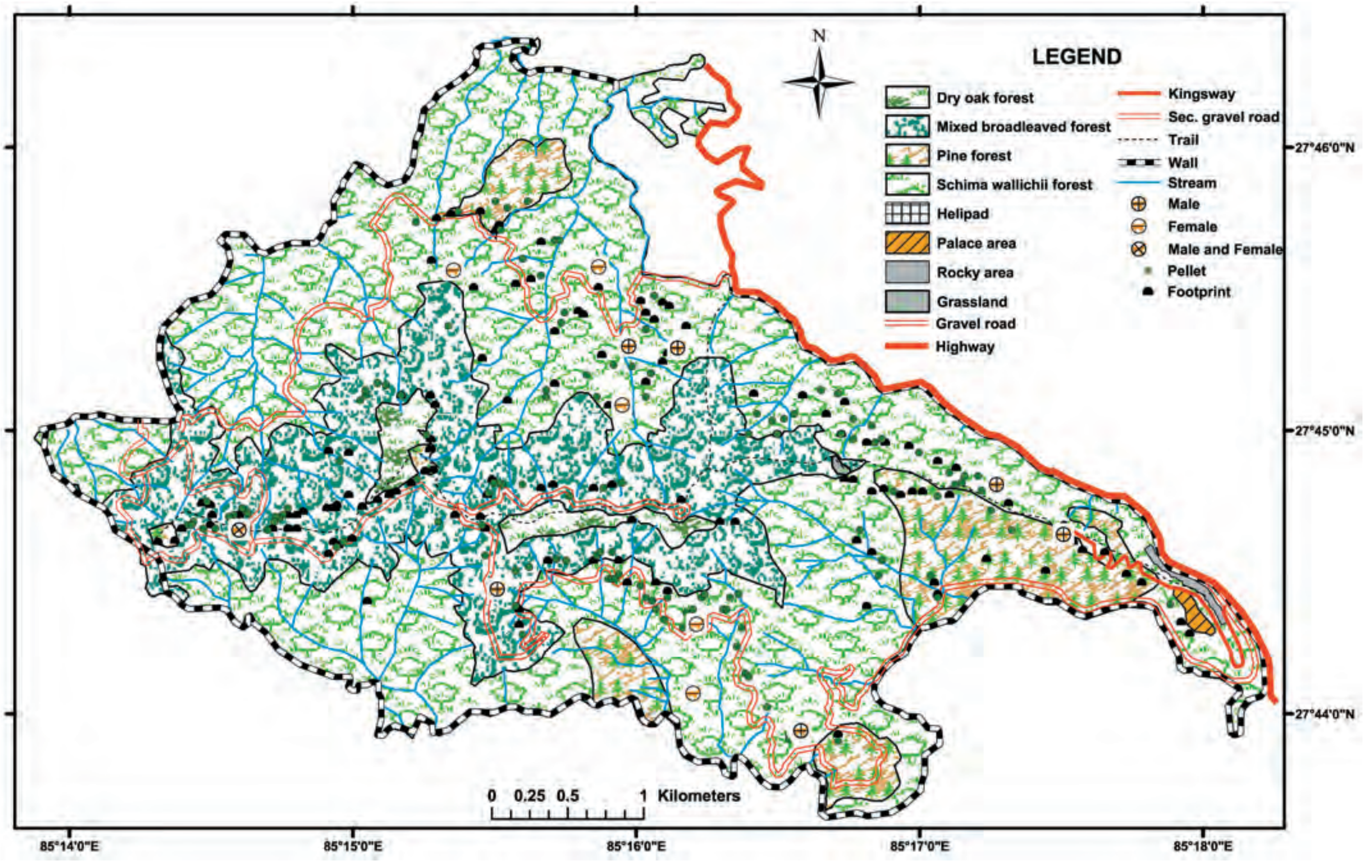

Figure 3. Distribution of barking deer in Nagarjun forest for rainy season (2005)

likely due to the availability of food, shelter and water sources. The slightly higher preference for pine forest as opposed to mixed-broadleaved forest (RPI = 0.14) during the spring may be explained by an inclination to avoid wet and muddy areas during the rainy season as mixed-broad leaved forest is wet and muddy at that time of the year. Wet and muddy areas are uncomfortable, dangerous and difficult to negotiate, and suboptimal sites for foraging and resting. The pine forest is relatively preferable and also drier in the rainy season than other habitat types in study area. In Royal Chitwan National Park the movement of barking deer in dry places increased during the monsoon season but remained less frequent than that of Chitals (Yonzon 1978). The presence of a substantial shrub layer (mostly fruit yielding *Berberis asiatica*) and surface layer (containing most preferred food *Imperata cylindrica* and *Pogonatherum paniceum*) significantly contribute to the habitat value of pine forest.

In conclusion, barking deer are unevenly distributed in Nagarjun forest. A clumped distribution pattern is found in both spring and rainy seasons. Although the deer is a generalist in habitat use, most individuals apparently prefer mixed broadleaved forest (in the spring) and pine forest (during the rain season) over other forest types.

Acknowledgements

We thank KK Shrestha and V Adhikari (Central Department of Botany, Tribhuvan University) for helping in plant identification.

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