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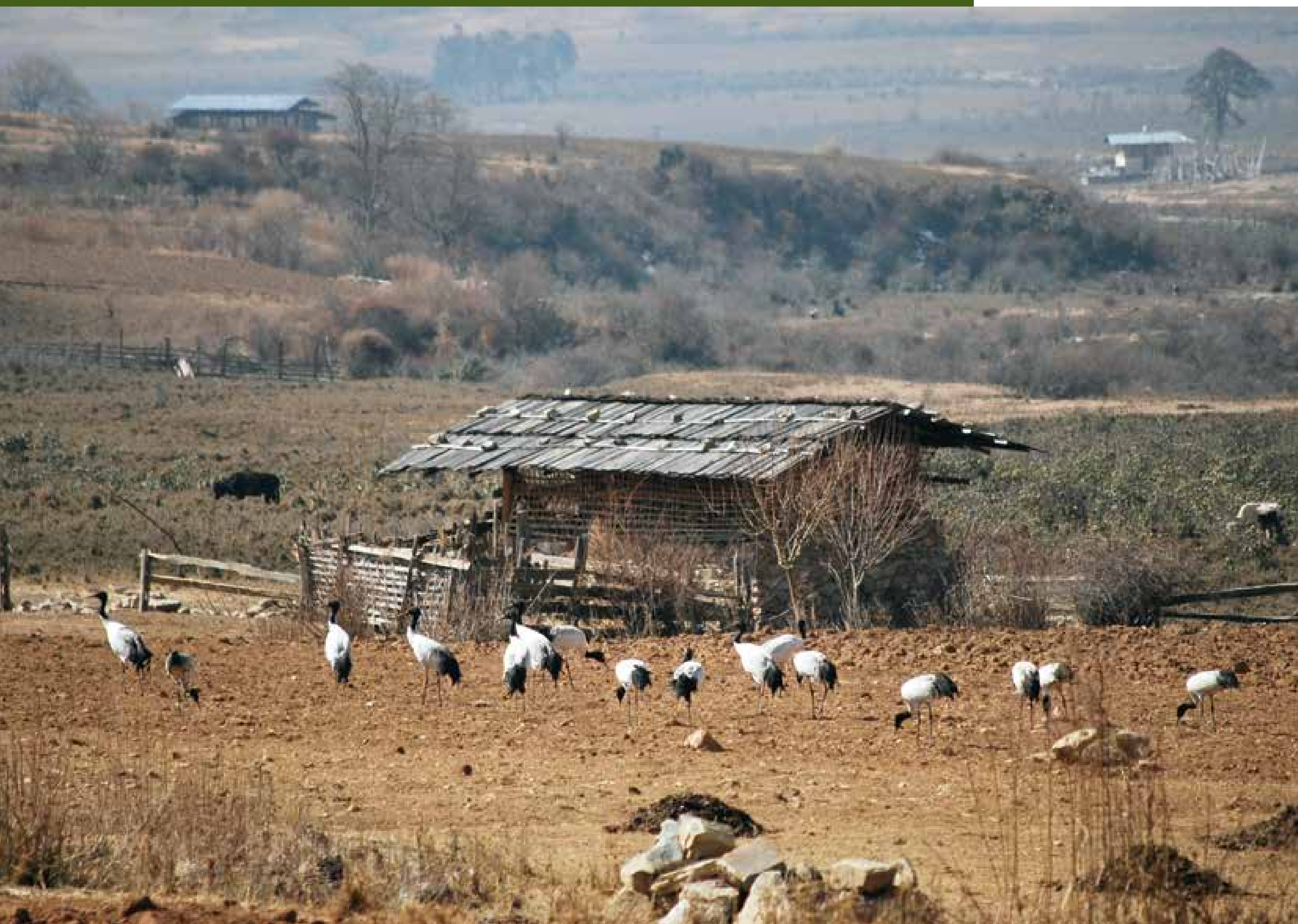
An Integrated Assessment of the Effects of Natural and Human Disturbances on a Wetland Ecosystem

A Retrospective from Phobjikha Conservation Area, Bhutan

ROYAL SOCIETY FOR PROTECTION OF NATURE

2011-2020 United Nations Decade on Biodiversity



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An Integrated Assessment of Effects of Natural and Human Disturbance on a Wetland Ecosystem:

A Retrospective from Phobjikha Conservation Area, Bhutan

International Centre for Integrated Mountain Development (ICIMOD),
Kathmandu, Nepal

and

Royal Society for Protection of Nature (RSPN)
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International Centre for Integrated Mountain Development, Nepal, April 2014

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Foreword

Himalayan wetlands function as habitats for several endangered species, migratory birds, and hydrophilic vegetation; as water reservoirs and carbon sinks; and as important sources of livelihoods for poor and marginalized communities. Sustaining and restoring wetlands and their resources as a basis for improving peoples' livelihoods, while maintating the integrity of wetland biodiversity, are important agendas of global conventions. With climate change emerging as a serious driver of change in the Himalayas, it is crucial to understand the vulnerability of wetlands, and their adaptive potential. This is especially vital considering the links wetlands have to climate, air, and water regulation and to people's livelihoods.

This study on Phobjikha Valley in Bhutan is a collaborative research between the International Centre for Integrated Mountain Development (ICIMOD) and the Royal Society for the Protection of Nature (RSPN). It is an effort to understand the changes taking place within the broader Phobjikha Landscape Conservation Area, along with the impacts on wetland biodiversity and surrounding land uses, and subsequently on livelihoods of people living around the valley. Equally importantly, the research contributes to conservation of the habitat of the globally vulnerable and migratory Black-necked crane.

The study adopts an integrated research framework that elaborates on the importance of harnessing information from both natural and social sciences to interpret changes on the ground, understand the vulnerabilities of ecosystems and communities, and identify effective climate change responses.

We are extremely proud that RSPN and ICIMOD could work together in this applied research, blending their respective missions of, "inspiring personal responsibility and active involvement of the people of Bhutan in the conservation of the Kingdom's environment through education, research and sustainable livelihood opportunities," and, "enabling sustainable and resilient mountain development for improved and equitable livelihood through knowledge and regional cooperation."

We believe this submission will provide much needed evidence-based information for developing an effective management action plan for the entire Phobjikha Landscape Conservation Area. We hope this will inspire cumulative action from a wide range of stakeholders to conserve this unique high-altitude wetland in Bhutan and support the continued flow of ecosystem services.

On behalf of ICIMOD and RSPN, we would like to thank all the partners, teams, and individuals who contributed to this publication, including the MacArthur Foundation who made this collaborative research possible.

David Molden, Ph.D
Director General, ICIMOD

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Executive Summary

Wetlands are among the most productive ecosystems in the world. Due to their ability to store and slowly release water, they are a lifeline for several other habitats and biodiversity in general. In the context of climate change, sustaining and restoring wetlands is considered a cost-effective strategy for climate adaptation that also brings co-benefits related to poverty reduction and biodiversity conservation.

Phobjikha Valley, a wetland situated on the western slopes of Jigme Singye Wangchuck National Park, is an important wintering habitat for the vulnerable Black-necked crane (*Grus nigricollis*). One of the largest high-altitude wetlands in Bhutan, the valley is surrounded by an important watershed proposed as Phobjikha Landscape Conservation Area (PLCA). This study is limited to the main watershed considering the Black-necked crane habitat, Phobjikha Conservation Area (PCA). There is already great pressure on the Phobjikha wetland from changes in population dynamics, gradual land-use and cover change, waste and garbage management, drainage for commercial agriculture, and pressure to convert the wetland for economic purposes. The most significant concern is over changes in the wetland habitat and vegetation change in the core area, which is crucial for the survival of the Black-necked crane.

It is now pressing to deepen understanding of the Phobjikha wetland, its vulnerability to change, and the implications of these changes for surrounding land uses, ecosystem services, biodiversity, surrounding communities, and the Black-necked crane. In this regard, the International Centre for Integrated Mountain Development (ICIMOD) and the Royal Society for Protection of Nature (RSPN) jointly developed a multidisciplinary research framework under the auspices of a MacArthur funded project on biodiversity and climate change adaptation in the eastern Himalayas. The project included downscaling of climate change scenarios, assessment of biodiversity and ecosystem services, economic valuation of selective services, and analysis of livelihoods vulnerability of local people and their perceptions of environmental changes.

Discussion of the findings revolves around:

Biodiversity and ecosystems goods and services:

The most dominant vegetation type, dwarf bamboo (*Yushania microphylla*), covers 60% of the core area. The lower slope adjacent to the core wetlands in the northern valley is dominated by coniferous forest and some temperate broadleaf species. The most significant fauna is the endangered Black-necked crane, which migrates from the Tibetan Plateau to roost in Phobjikha Conservation Area (PCA) each winter. In terms of ecosystem services, while cultural services are gaining prominence (Phobjikha is becoming a major tourist attraction for Bhutan), provisional services still received the highest value indicating the dependence of communities on the resources of PCA as a whole. Considering 2012 production and economic values, an average household in the valley derived USD 2,610 worth of annual economic benefit from provisioning services, with 84% of the total value coming from potato farming. The total economic value contribution from provisioning services, carbon sequestration, and tourism was about 36%, 24%, and 39% respectively. The surrounding forest ecosystem was also prominent in providing significant economic benefits to local people.

Socioeconomic profile

Local livelihoods in PCA rely mainly on agriculture and animal husbandry. The local economy is singularly dependent on commercial potato farming. Good institutional support was available for the communities in times of stress with assistance primarily from family, friends, and local financial institutions including national and district-based institutions.

Drivers of change, community perception, and impacts

Climate change scenarios (2020s, 2050s, 2080s), developed through general circulation models for maximum and minimum temperatures based on 1961-1990 baseline showed an increasing trend in both minimum and maximum

temperatures. The projection for 2080 maximum temperature against different scenarios ranged from 0.77 °C to 2.07 °C. The model indicated inconsistent trends for precipitation.

With regard to land cover change from 1978 to 2010, there was an increase in agriculture and settlements, and a decrease in marshes. Phobjikha has experienced rapid changes in the last few years as a result of increasing development activities, social transformation, and modernization. Aware of the changes, communities are most concerned about erratic and unpredictable weather conditions that are damaging their crops. The flowering of *Yushania* and its natural death causes concern in terms of ecological implications. The gregarious flowering (simultaneous flowering of all plants of a particular type) and longer duration of natural regeneration for dwarf bamboo may change the ecological function played by this species and increase the risk of forest fire due to drying bamboo stumps. Livestock grazing is also stressed by changing weather patterns and land-use changes. Gradually changing settlements and agricultural expansion within PCA affects crane migration; the resultant loss of cultural linkages associated with this migration was deeply felt among the communities. Vulnerability indicators for the Phobjikha valley recorded higher sensitivity to health and sanitation issues and food and water security than to exposure to risks such as climate variability, and natural and economic shock; livelihood vulnerability was also high given the sole dependence on potato monoculture.

Despite these changes, there is ample opportunity for conservation and development in Phobjikha. A management zonation scheme was proposed with four zones – critical wetland zone, critical forest and watershed zone, forest utility zone, and farms and settlement zones – to differentiate ecosystem services from each zone and design specific strategies for their maintenance. To increase both ecological and socioeconomic resilience, the study recommends the following responsive strategies:

- Take stock of climate uncertainty and monitor changes continuously;
- Improve social protection services;
- Diversify livelihood options to reduce poverty and social inequality;
- Strengthen adaptive strategies building on coping strategies;
- Manage natural ecosystems for sustained ecosystem goods and services;
- Promote and strengthen integrated conservation and development approaches through conducive policies and institutions; and
- Raise awareness of ecosystem services.

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We are grateful to Dr David Molden, Director General of ICIMOD, for his inspiration and for providing the required facilities. We are also thankful to the former Minister Dr Pema Gyamtsho and Secretary Sherub Gyaltshen, Ministry of Ariculture and Forest, Royal Government of Bhutan for their support. This publication was possible as a result of the untiring efforts of the team of professionals from ICIMOD and RSPN, as indicated in the Contributors section. We also thank the Department of Meteorology for their substantial contribution of the observed data from Phobjikha and Mr Karma Tsering for technical support. Financial support from the MacArthur Foundation and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) for conducting this analysis is greatly appreciated.

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Acronyms and Abbreviations

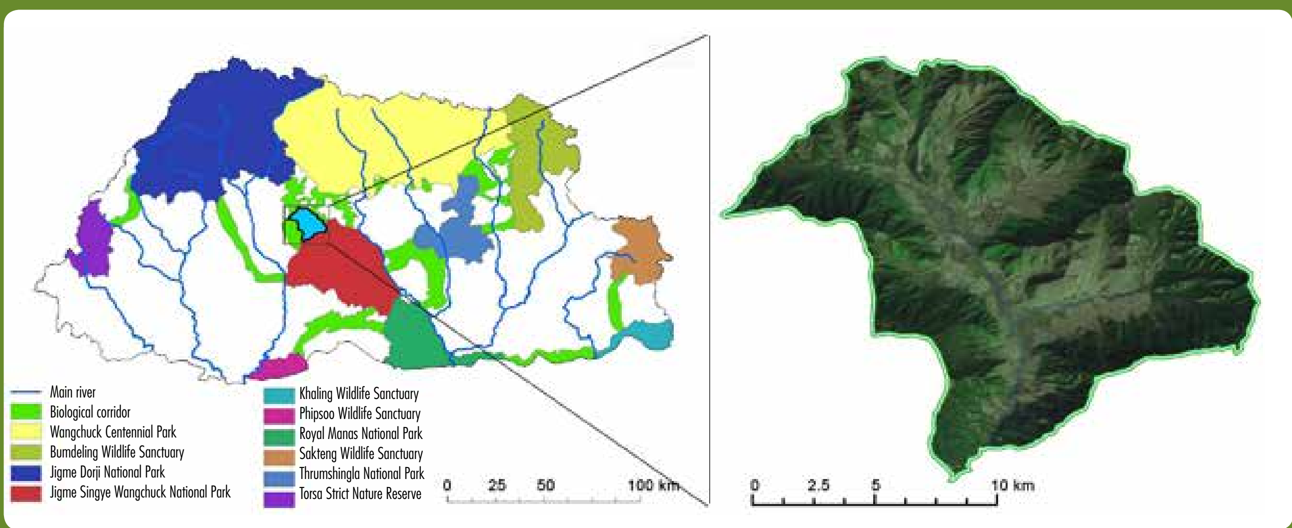
BNPP	Bhutan National Potato Program
CSI	Carbon Sequestration Index
ETM	Enhanced Thematic Mapper
GCM	General Circulation Models
ICIMOD	The International Centre for Integrated Mountain Development
LAT	Livelihoods Assessment Tool
LVI	Livelihoods Vulnerability Index
MEA	Millennium Ecosystem Assessment
MLVI	Mountain Livelihoods Vulnerability Index
MSS	Multispectral Scanner
NCEP	National Centre for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NTFP	Non-timber forest product
PCA	Phobjikha Conservation Area
RGoB	Royal Government of Bhutan
RSPN	Royal Society for Protection of Nature
SDSM	Statistical Downscaling Model
SRES	Special Report of Emission Scenario

Introduction

Among the most fragile environments in the world, wetlands are a repository of rich biodiversity, water, and other ecosystem services, and they supply surrounding lowlands with these goods and services (Barbier et al. 1997; Mitsch and Gosselink 2000; TEEB 2010). As an ecosystem, they are home to one of the highest number of species (Mitsch and Gosselink 2000). Wetlands are likely to experience wide-ranging effects in both environmental and socioeconomic spheres from climate change, such as changes in the hydrological cycle. These changes may significantly change the distribution, seasonality, and amount of precipitation leading to changes in river runoff and ultimately affecting not just the wetlands, but lowland regions as well (Beniston 2003). Though the prevailing climate change scenario in the Himalayas is somewhat incomplete and scattered, anecdotal evidence indicates alarm for the fate of Himalayan biodiversity and its services (Shrestha et al. 1999; Liu and Chen 2000; Shrestha et al. 2000; Chaulagain 2006; Shrestha et al. 2012; Kulkarni et al. 2013). Though global communities are trying to understand the nexus between biodiversity, livelihoods, and climate change, there are still large information and research gaps in the Hindu Kush Himalayas. Recent efforts to understand this nexus (Chettri et al. 2010, Tshering et al. 2010) revealed that generalized models with low resolution climate models and limited data on biodiversity and human development achieve dubious results. Here, we present a systematic retrospective analysis based on local-level primary data on livelihoods, biodiversity, ecosystems services, and climate change to understand the nexus from one of Bhutan's most important wetland ecosystems.

The Phobjikha Valley, situated on the western slopes of the Black Mountains, is one of the largest high-altitude wetlands of Bhutan. An important wintering habitat for the endangered Black-necked crane, the valley may have been formed through glaciations (Caspari et al. 2009). The wetland is surrounded by an important watershed, which has been proposed as the Phobjikha Landscape Conservation Area (PLCA) (CBD-Bhutan 2010) (Figure 1). This study is limited to the main watershed considering the habitat of the Black-necked crane, the Phobjikha Conservation Area (PCA). PCA, with mean elevation of 3,500 masl, covers 162 km^2 of an area within the coordinates 89°57′54″–90°17′30″N latitude and 27°13′50″–27°31′27″ E longitude and is spread along the two gewogs (administrative unit made up of a group of villages) of Gangtey and Phobji. Lapchekha (4,200 masl) is the highest point, while the valley floor is about 2,000 masl. (RSPN 2007). The wider stretches of PCA also include part of the biological corridor between Jigme Dorji National Park and Jigme Singye Wangchuck National Park. The Nake Chu River bisects the valley and runs in a north-southeast direction. Two significant streams, the Lolephage Chu and the Gau Chu, enter the valley from the east.

Figure 1: **Location of Phobjikha Conservation Area and protected areas of Bhutan**



Source: WCD and ICIMOD

The ecologically unique PCA contains several interesting biodiversity features, such as the dwarf bamboo (*Yushania microphylla*) that dominates the core wetland area of the valley floor and serves as a roosting habitat for the endangered Black-necked crane. A relatively wide valley, the core wetland area is encircled by moderate to steep slopes of agricultural land and forests with pure stands of blue pine (*Pinus wallichiana*) and juniper (*Juniperus recurva* and *Juniperus pseudo sabina*) forests; endemic rhododendrons (such as *Rhododendron bhutanense*); varieties of bird species [(including the Himalayan griffon (*Gyps himalayensis*), Himalayan monal (*Lophophorus impejanus*), kalij pheasant (*Lophura leucomelana*), blood pheasant (*Ithaginis cruentus*); and several species of mammals (including the samber (*Rusa unicolor*), muntjac (*Muntiacus muntjak*), wild pig (*Sus scrofa*), and leopard (*Panthera pardus*)]. The landscape's scenic beauty is enhanced by the revered 16th century Gangtey Monastery, which makes Phobjikha Valley a popular destination for both domestic and international tourists. In 2009 alone, around 6,975 international tourists visited the valley (RSPN 2010). The most significant dimension of PCA is the harmonious co-existence between the communities, their culture and traditions, and the Black-necked cranes that come from the Qinghai-Tibet Plateau to winter in Phobjikha Valley.

The communities in PCA, mostly dominated by the Ngalop ethnic group are agrarian and dependent mostly on farming and livestock rearing. Historically, the majority of the population practised 'Jow pang' (ploughing fallow open grasslands each year, burning the vegetation, and cultivating mainly buckwheat) and transhumance (migrating annually between their villages in colder areas (such as Moll, Tokha, Santana, and Gangtey) to warmer lower farmlands in Chitokha, Sha, Ngawang, and Ada) (Phuntsho, 2010a, RSPN 2008). While some households in Gangtey and Phobji still perform this traditional nomadic ritual in winter, some farmers have now permanently resettled in the valley (RSPN 2010). Sedentarization of the communities seems to follow the introduction of potato cultivation beginning around the 1980s, which also invited settlements from the adjoining Dzongkhags and surrounding Athang, Bjena, Nyesho, and Sephu Gewogs (Pradhan et al. 2004; RSPN 2007).

The clustered settlements are mainly made up of old traditional houses, though several new ones are emerging. A dirt road that diverts 3.5 km from Pelela Pass is the only way to access to the valley. The road continues along the western side of the valley and diverges at Tabiting; one carries on further south and ends at Gangphey and the other passes the primary school an crosses to the other side of the valley ending at Taphu. Some rough logging tractor trails also pass through some of the villages. Government facilities in the area include two primary schools, one middle secondary school, one health unit with one doctor, two Gewog Administration Offices, a range offices of the Jigme Singye Wangchuck National Park, and one renewable natural resources extension centre that includes forestry, livestock, and agriculture components.

Like other global wetlands, Phobjikha faces challenges from the intensification of farming practices, changes in land use, the use of fertilizers and pesticides, growing family size and land fragmentation, farm mechanization, new and unplanned infrastructure and businesses, and the impacts of climate variability and climate change (Dorji et al. 2004; RSPN 2007; Chettri et al. 2010). There is increasing pressure to convert the Phobjikha wetland for economic development, particularly for roads, hotels, and other tourism infrastructure. Such development together with the change in population dynamics and gradual land use and land cover change are stressing the wetland's ecological infrastructure, evident by waste and garbage management issues, wetland drainage, and the rise of commercial agriculture. Enhancing economic development without compromising the wetland is a significant challenge (Dorji and Tobgay 2003). Shoring up the wetland habitat and ecosystem's resilience to various drivers of change – including climate change – and ensuring the survival of the endangered Black-necked crane are major concerns. Wetland conservation objectives, Black-necked crane research and long-term monitoring, and socioeconomic development must be integrated to promote holistic landscape-level understanding and management interventions. The proposal to designate the entire landscape as PCA emerged from this urgent need (RSPN 2010).

Bhutan's only conservation NGO, the Royal Society for Protection of Nature (RSPN), has strongly supported the Royal Government of Bhutan in managing the PCA, particularly in maintaining the sanctity of the ecosystems in the Phobjikha landscape and protecting endemic and endangered flora and fauna. In its 25 years of establishment, RSPN has collaborated with several international and regional organizations such as International Crane Foundation, International Centre for Integrated Mountain Development (ICIMOD), and Resources Himalayas, among others, to develop a comprehensive knowledge base on PCA.

With its regional mandate and experience facilitating regional landscape initiatives in the Hindu Kush Himalayas, the International Centre for Integrated Mountain Development (ICIMOD) joined hands with RSPN in 2011 to develop a comprehensive understanding of landscape dynamics in the PCA and to strengthen the basis for implementing conservation and development programmes. With support from the MacArthur Foundation, under the aegis of the 'Support Organization's Efforts to Better Understand the Impact of Climate Change on Biodiversity and Related Ecosystem Services in the Eastern Himalayas and Advance Collaboration on Regional Adaptation Strategies' project, ICIMOD and RSPN collaborated on action research and review work to:

- Investigate the state of biodiversity in the PCA, including ecosystem goods and services and people's dependency on these resources;
- Identify drivers of change and their impacts on people, biodiversity, and ecosystem goods and services, and understand the vulnerability of core livelihood options from wetland ecosystems;
- Investigate people's perceptions towards change, and response (or coping) strategies practised by local communities in the context of environmental stresses; and
- Identify biodiversity conservation and management interventions and capacity building and policy needs to sustain ecosystem services from different land cover types in the Phobjikha Valley.

This report is a synthesis of the findings of multidisciplinary assessments carried out by RSPN and ICIMOD as a part of a MacArthur funded project, as well as from the review of secondary information available to date. The report highlights the state of the ecosystems and biodiversity, socioeconomic development, and the effects of climate variability and other drivers of change on weather-dependent biodiversity resources, such as wetland ecosystems, agriculture, and migratory species. Particular attention is paid to the impact of climate change on ecosystem goods and services and their consequences for communities' livelihoods. The report discusses in detail the factors influencing people's adaptive capacity, along with the identification of coping strategies communities have adopted in response to perceived changes. It discusses the prospect of management zonation for enhancing ecosystem services, addressing aspects of community vulnerabilities, and socioeconomic development. The report concludes with suggestions for increasing the ecological and socioeconomic resilience in PCA.

Research Framework and Methodologies

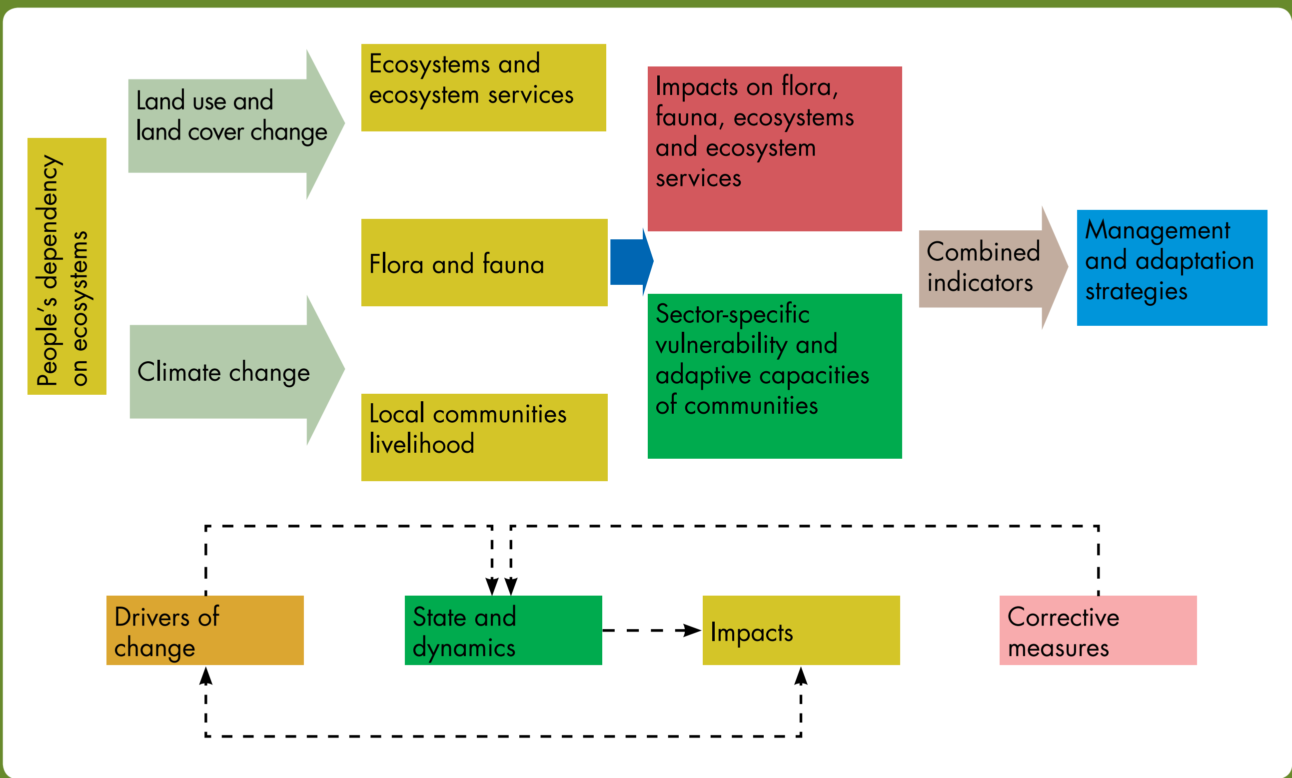
A conceptual research framework (Figure 2) was prepared to guide understanding of the interlinkages between major drivers of environmental change and their impacts on the state of ecosystem dynamics, ecosystem goods and services, and community livelihoods. This understanding was then used to identify management and adaptation strategies to decrease communities' vulnerability to change – particularly to climate change in the long run – and to increase the resilience of wetland ecosystems to climatic and non-climatic stressors. It should be noted that we used 'drivers of change' as a generic term considering anthropogenic pressure, climatic change, and land use and land cover change as drivers or factors also influenced by other drivers. For example, land use and land cover change is highly influenced by disasters, land management policies, and overexploitation, but land use and land cover change could also affect biodiversity.

The research methodology involved both primary action research and a literature review of secondary information. Participatory action research focused on assessments of the state of biodiversity, ecosystem services, and livelihood vulnerability. Geospatial analysis included land use and land cover change in relation to the spatial and temporal changes in ecosystem services. The overall purpose was to understand the impact of various drivers of change – in particular land use and land cover change and climate variability – on the wetland's biodiversity and ecosystem goods and services and on people's livelihoods, and to make inferences on ecosystem management and climate change adaptation strategies. Details of methodologies for each action research are described below:

Downscaling of climate change scenarios

Climate data from 1985 to 2003 were collected from the weather station established in Phobjikha by the Meteorology Department of the Royal Government of Bhutan. Downscaling of the general circulation model (GCM) outputs was carried out based on the observed data. The outputs of two GCMs: CGCM3 and HadCM3 were used

Figure 2: **Conceptual research framework showing the need for intersectoral information for determining effective adaptation strategies**



Source: ICIMOD

for the study. Emission scenarios A1B and A2 were used for CGCM3. A2 and B2 for HadCM3 were considered (IPCC 2001). Based on the observed predictor variables from the National Centre for Environmental Prediction (NCEP), the Statistical Downscaling Model (SDSM), was used following Wibly and Dawson (2007) and GCMs predictor sets under Special Report of Emission Scenario (SRES) emission scenarios were applied for temperature and precipitation changes.

Land use and land cover change analysis

For the image analysis, medium spatial resolution satellite images from the Landsat satellite taken in 1978, 1990, 2002, and 2010 were used to generate a land cover map. A predefined classification scheme with seven classes used by RSPN in previous documents was followed (RSPN 2007). Land cover information was derived that consisted of pre-processing and classification using object-based algorithms. Imagery from three sensors – Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) – were rectified into Universal Transverse Mercator (UTM) Zone 45. Because the different sensors have different resolutions, all of the images were resampled into 15 m resolution following the cubic convolution method. Image resampling is a process by which new pixel values are interpolated from existing pixel values whenever the raster's structure is modified, such as during projection, datum transformation, or cell resizing operations. Various resampling methods can be employed to resize an image; when an image is enlarged or reduced, changes are necessarily made to the value assigned to each pixel (Prakash and Beyer 1981; Vogelmann et al. 2001; Wade and Sommer 2006). Object-based image analysis (OBIA) provides a methodological framework for machine-based interpretation of complex classes (defined by spectral, spatial, contextual, as well as hierarchical properties) and yields better classification results with a higher degree of accuracy than pixel-based methods, as it uses both spectral and spatial information (Lang et al. 2011). A hierarchical classification scheme was used with six major land classes based on a land cover classification system following Di Gregorio (2005). This was necessary to harmonize the land use and land cover legends with global standards (Bajracharya et al. 2010). Major land cover classes used were forest, agriculture, grassland, marshes and swamps, rivers and streams, and sand and gravel. A multi-resolution segmentation algorithm was used to classify these categories. This method consecutively merges pixels or existing image objects by identifying single image objects of one pixel in size and merging them with their neighbours based on relative homogeneity criteria (Blaschke and Hay 2001). Multi-resolution segmentations are groups of similar pixel values that merge the homogeneous areas into larger objects and heterogeneous areas in smaller ones (Baatz et al. 2006).

During class modelling used information on spectral values, vegetation indices like the Normalized Difference Vegetation Index (NDVI), and a land-water mask created through band ratio and texture information. NDVI is a standardized index allowing for the generation of an image displaying greenness (relative biomass). Index values can range from -1.0 to 1.0. An area containing a dense vegetation canopy will tend to show positive values (around 0.3 to 0.8), while clouds and snow fields will be characterized by negative values. In a preprocessing stage, the NDVI image was created using customized features applying the formula: NDVI = (RED - IR)/(RED + IR), where RED is the red band value of a cell and IR is the infrared value of a cell. The land-water mask was created using the formula IR/Green*100, where IR is the infrared value of a cell and Green is the green band value of a cell.

Land-water mask index values can range from 0 to 255, but water values typically range between 0 and 50. The next step was to label those image objects according to their attributes, such as NDVI, land-water mask, layer value and colour, and relative position to other objects using user-defined rules. Objects with an area smaller than the defined minimum mapping unit were merged with other objects. The classified land cover map of PCA was exported to a raster file format for further analysis.

In the ArcGIS environment, the analysed land cover was interconnected to two sets of data, namely a) species data matrix based on their habitat use and significance, and b) a score based on the sum of scores for provisioning, regulating, supporting, and cultural services. Values were obtained from each of the land use and land cover types as discussed in the following sections.

Biodiversity assessment

Detailed floristic studies were completed at two sites. The first studied the influence of aspect on the floristic composition along south and north facing slopes and vegetation composition of the *Yushania* dominated wetland area. Five plots measuring 10 m x 10 m were established at 100 m intervals, from 2,900 masl at the valley bottom to 3,500 masl at the top of the mountain along the altitudinal gradient of the Nganglang series. The second site at Zomma was at an altitude of 3,200 masl, covering vegetation along two aspects – north and south.

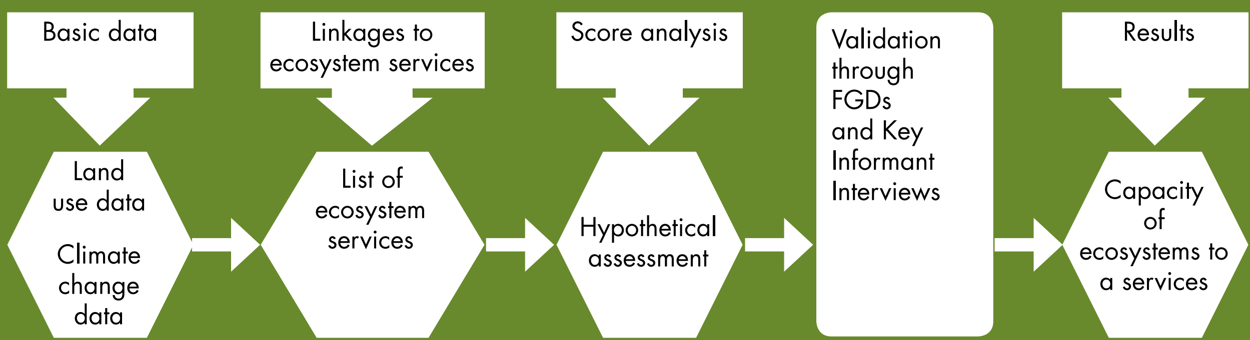
All woody plants were recorded within the plots, along with their height and diameter at breast height (1.37 m from the base). For all species of herbaceous vegetation, the average height of plants and percent coverage (%) were recorded from 2 m x 2 m sub-plots within the larger plots. All seedlings and saplings of tree species were enumerated within the sub-plots, including their estimated height, to assess the status of regeneration. Soil moisture content (%) was measured using a hydro-sensor with a 12 cm probe. Five random measurements were recorded in each plot. Similarly, soil hardness (trampling or compaction) was measured using a soil hardness tester (*Yamanakas*). Instantaneous air temperature and relative humidity was also recorded through five measurements in each plot. Species basal area (cm^2) was calculated from the diameter at breast height data of tree individuals, and relative basal area of tree species was calculated in per cent (%). The relative basal area of each species was used as a measure of species dominance in a community.

The report also considered findings of a series of field investigations on vegetation ecology carried out between 2010 and 2011, using 32 plots with 10 m x 10 m sizes. The plots were used to measure various ecological parameters, but also to determine optimal size for sample plots for different habitat types. Some of the plots were established as permanent plots where changes and tree and shrub composition were observed at both temporal and spatial scales (Pradhan 2011).

Ecosystem services assessment

An assessment framework proposed by Burkhard et al. (2009) was adopted to assess the capacity of ecosystems to provide ecosystem services (Figure 3). Land cover types were regarded as individual ecosystems and sources of goods and services; four broad ecosystem services – provisional, relulatory, supporting and aesthetic – were adopted from the Millennium Ecosystem Assessment (MEA 2005). To supplement the framework, a brief questionnaire was prepared in collaboration with RSPN to assess the qualitative and quantitative use of ecosystem services. RSPN conducted the questionnaire survey with the same households included in the Livelihoods Assessment (see the section on Assessment of Livelihoods Vulnerability). The ecosystem services questionnaire covered identification of the land cover or ecosystem types perceived by local people to be most important in PCA, enumeration of ecosystem services provided by different land covers, and changes in some of the services over the years due to different drivers of change.

Figure 3: **Framework for assessing a landscape's capacity to provide ecosystem services**



Adapted from Burkhard et al. 2009

Economic valuation of ecosystem services

This study uses a combination of market price and value transfer methods to estimate the economic value of the most important wetland goods and services. The main ecosystem services considered include ten provisioning services, one regulating service (carbon sequestration), and one cultural service (tourism); the other indirectly used services and non-use values were ignored due to information and methodological constraints. The method used to estimate the economic value of identified ecosystem services is discussed below.

Provisioning services: Income from potato and other provisioning services provided by wetland resources have been estimated on the basis of average quantities harvested and their prices, irrespective of what proportion was sold – in other words, valuing subsistence consumption at market prices. While the cost involved in realizing the benefits from potato is included, it was not possible to estimate the direct cost of collecting other wetland products in the absence of information on the imputing opportunity cost (shadow wage) of labour time involved in the collection process. This means the shadow price of labour involved in collecting resources is assumed to be zero, considering the high unemployment rate among local people in the absence of alternative livelihood opportunities. The total values of the wetland provisioning services for all dependent households residing in the Phobjikha Valley is calculated as the average annual value of resources harvested, or benefit per sample household multiplied by the estimated total number of dependent households using the following equation:

$$TVP_i = \sum_{i=1}^{n} (\%hh_i \, x \, HH \, x \, NV_i) \qquad (1)$$

where i represents the different wetland provisioning services; $\%hh_i$ is the percentage of total households dependent on each of the ith provisioning service (dependency weight); HH represents the total number of households residing in the buffer zone; and NV_i is the average annual net benefit per user household from the wetland provisioning service estimated from equation 1 above. This information provides the basis for estimating the weighted average of resources harvested per household and per hectare.

Domestic water supply benefit: In the absence of scientific biophysical/hydrological information on groundwater recharge of the wetland as a source of domestic water supply to the surrounding buffer zone populace, an attempt was made to find a suitable unit value transfer through extensive review of contemporary literature in the region. Emerton and Kekulandala (2003) estimated avertive expenditures of Sri Lankan rupees (LKR) 3.78 million per year (LKR 1,232 ha/LKR 2,363 HH) as a domestic water supply benefit from the Muthurajawela Marsh wetland, which covers an area of 3,068 ha in Colombo, Sri Lanka. This gives the inflation adjusted unit transfer value of USD 37.7 per household in 2010 prices, as estimated by CSUWN (2011) for use in the Koshi Tappu Wildlife Reserve, Nepal. Considering that the Koshi Tappu Wildlife Reserve, a freshwater wetland, is the only source of maintaining the groundwater level for domestic water supply (on which over 97% of of households rely as their source of drinking water), this transfer value has been used to estimate the value of domestic water supply benefits after converting it to 2012 prices using the consumer price index.

Carbon sequestration: Wetlands generally function as a carbon sink due to vegetation biomass. At the same time, wetlands are also a source of carbon through methane formation. Little is known about how the complex interplay of carbon and methane (a more potent greenhouse gas than carbon) influences the source-sink carbon dynamics of wetlands (Cao et al. 1998; Xu and Tian 2012). With no comparable carbon sequestration estimate available for wetlands, this study had to rely on a default value based on the carbon sequestration index (CSI) provided by Pagiola et al. (2007). This index assesses different land-use types according to their capacity to sequester stable carbon in soil and hardwood. The main land-use types assumed to sequester carbon in the Phobjikha Valley are conifer forest, broad-leaved forest, mixed forest, shrub, and grassland. These land-use types were matched and adjusted using their corresponding CSI value and unit price to arrive at the total carbon sequestration value. Details are discussed in a later section on 'Value of regulating services'.

Ecotourism: The travel cost method is the best approach to estimate the economic value of recreational tourism. In the absence of such studies, the net economic value of ecotourism has been estimated using the expenditure method, which considers the revenue generated from entry fees for tourists as well as the total amount spent by tourists during their average length of stay. A flat rate of 35% of the gross unit value is assumed to be the annual cost of management to arrive at the net tourism benefit.

Assessment of livelihood vulnerability

Despite diverse interpretations of vulnerability, the key concepts of exposure, sensitivity, and adaptive capacity are common elements of many dominant approaches (Miller et al. 2010). The vulnerability of a system to environmental change is interlinked with the wider political economy of resource use. Vulnerability research usually focuses on the response to hazards and shocks, rather than on long-term or medium-term adjustments and change (Miller et al. 2010). The consequences of short-term actions on longer-term social-ecological resilience have also often been neglected in vulnerability studies (Venton and la Trobe 2008).

According to the IPCC's Third Assessment Report (IPCC 2007), vulnerability is defined as the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. So, vulnerability is defined as a function of exposure, sensitivity, and adaptive capacity. Considering that the improvements in adaptive capacity actually reduce vulnerability (Brooks 2003), while the dimensions of exposure and sensitivity contribute to it, vulnerability can be expressed as follows:

$$\textit{Vulnerability} = f\ (\textit{exposure} + \textit{sensitivity} - \textit{adaptive capacity})$$

Exposure refers to the magnitude and duration of the climate-related exposure, such as drought or a change in precipitation. Sensitivity is defined as the degree to which a system is affected, either adversely or beneficially, by climate variability or climate change. Adaptive capacity is defined as the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007). Each of these dimensions has further sub-dimensions and indicators (Annex 1), which were assessed to determine the livelihoods vulnerability of PCA. This formula was used to construct the overall Mountain Livelihoods Vulnerability Index.

The Livelihoods Assessment Tool (LAT) is a household questionnaire based on the Mountain Livelihoods Vulnerability Index (MLVI) framework developed by Gerlitz et al. (2014), which is based on the Livelihoods Vulnerability Index (LVI) provided by Hanh et al. (2009). The LVI framework was adjusted for a mountain context considering 'mountain specificities,' as defined by Jodha (1992). These include inaccessibility, fragility, marginality, biological niches, and human adaptation mechanisms. The tool covered thematic areas like socio-demographic profile, access to basic facilities, health and healthcare, accessibility, housing, education, assets, use of ecosystem services, household consumption, food security, water security, and exposure and adaptive capacity to shocks and medium-term climatic and environmental changes. Data on various indicators of livelihood vulnerability were collected with the LAT.

Before implementation, the LAT was field tested by local partner institutions in Nepal and Bhutan. The resultant feedback was used to further adjust the tool for local contexts and the practical aspects of a survey. A total of 218 households were randomly surveyed across PCA between April and July 2011. The LAT was implemented following the steps described below:

- **Orientation and training session:** Discussions with the field team on the objectives of the study, research design, sampling method, survey technique, ethics, confidentiality protocol, and questionnaires.
- **Pre-survey preparation:** Debriefing sessions to collect feedback from enumerators and provide clarification and preparation for household survey.
- **Household survey:** Individual household interviews were conducted in the primary local language of the region and required an hour and a half to administer. Completed questionnaires were collected, and checks were carried out by the local coordinator in close consultation with enumerators.
- **Post-survey re-visit:** In cases of discrepancies, enumerators re-visited particular households to seek clarification.
- **Data entry and compilation:** LAT information was entered into a data entry mask designed with the SPSS Statistics software package. After entering the data, plausibility checks were performed to control for entry errors and inconsistencies and to guarantee data quality.

People's perceptions of environmental change

A community-level study was conducted to discover climatic and non-climatic pressures on the wetland ecosystems, as well as the impacts of such pressures, and changes in community livelihoods and wellbeing in PCA. Targeted participatory tools were applied to focus on perceptions of local communities on changes to weather, and the

resultant impact on livelihoods and the wetland ecosystem. Maachi's Vulnerability and Capacity Assessment (2011) was slightly modified; the focus on the impacts of climate change and other stressors on livelihoods was widened to encompass aspects of ecosystem services provision. Primary data was collected at the community level from PCA. Participatory rural appraisal exercises were conducted in all the selected locations, followed by focus group discussions. These results were then analysed for local trends.

Results and Discussion

Overview of biodiversity

Vegetation and floral diversity

Seven different vegetation types are defined by the Phobjikha Landscape Conservation Area management plan (RSPN 2007): broadleaf forest, mixed broadleaf forest, juniper forest, blue pine forest, mixed conifer forest, marsh, and open fields. The central valley, mostly inhabited by the Black-necked crane, features dwarf bamboo, which extends to the nearby hills and forest in numerous patches and covers about 60% of the valley floor, or the core area. Other common herbs in the Yushania dominated marshland include species of *Caltha, Aster, Euphorbia, Pedicularis, Primula, Swertia, Arisaema, Carex,* and *Juncus* (Pradhan 2011). The lower slope adjacent to the wetlands in the northern valley is dominated by coniferous forest consisting mainly of blue pine (*Pinus wallichiana*), birch (*Betula utilis*), and several species of rhododendron, wild rose, and maple in the understorey (Dorji and Tobgay 2003). The farmlands lie along the periphery of the wetland. Forest vegetation is of the cool temperate type, comprised of mostly conifers and some temperate broadleaf species. *Pinus wallichiana* forms pure stands in and around the valley with undergrowth of *Berberis, Daphne, Cotoneaster, Rosa,* and *Gaultheria* species (Pradhan 2011). Common tree species in the broadleaf forest are *Quercus semecarpifolia, Rhododendron grandi, R. arboreum,* and species of *Ilex, Acer, Betula,* and *Symplocos*. Common undershrubs included *Smilax myrtillus, Sarcococca, Strobilanthes, Hypericum* and *Berberis*. Moss cover was about 80%. Other common herbaceous species include ferns; species of *Arisaema, Carex, Cyperus*; and ground orchids. The forest composition changes to spruce-fir towards the upper ridges, with suppressed hemlock (*Tsuga dumosa*) and rhododendron in the midstory.

Blue pine, dwarf bamboo, fern (*Pteridium* sp.), and shrubby elements such as species of *Berberis, Lonicera, Vaccinium, Osmanthus, Primula*, and *Rubus* form the understory (Pradhan 2001, 2011). Pure stands of *Juniperus recurva* and *J. indica*, all laden with hanging lichen (*Usnea longissima*), form the upper limit of forests, giving way to alpine meadows at higher altitudes. The different age groups of juniper patches were evident along the meadows of Thangkha. *Daphne bholua* was the most common shrub occurring in the juniper forest, while groundcover was dominated by a variety of mosses (Pradhan 2011). Moist alpine meadows between 3,900 masl and 4,200 masl included several medicinal plants and shrubs such as *Rhododendron bhutanense* (endemic to Bhutan), *R. aeruginosum, R. setosum, R.wallichii, Berberis cooperi*, and *Ribes laciniatum* (Pradhan 2011).

The recent rapid biodiversity assessment indicated *Pinus wallichiana* was the dominant life-form along the Nganglang series (Table 1). Other conifers included *Juniperus recurva, Larix griffithiana* and *Tsuga dumosa. P. wallichiana* dominates 100% at an altitude of 3,057 masl where soil moisture is only 12.8%. The P2 transect along the high humidity area had the second highest dominance of *J. recurva*.

The composition of ground flora (including dwarf shrubs, undershrubs, and herbs) along the Nganglang series is shown below (Table 2). The wetlands are dominated by *Yushania microphylla*, a dwarf bamboo with a profuse spreading habit.

On the north-facing aspect towards Zomma forest, the top canopy is represented by *Larix griffithiana*. However, a more prominent species was *P. wallichiana*, which indicates dryness. *Tsuga* and *Juniperus* were also present on the ridge. Evergreen species such as *Rhododendron campylocarpum* and *R. barbatum* were found more on slopes while *R. arboreum* had a wider distribution range from the valley bottom to the ridge. Evergreen species were mostly found in high-moisture areas. Deciduous species such as *Acer pectinatum, Lindera heterophylla, Enkianthus deflexus*, and *Prunus rufa* were mostly found on the slope. *Hydrangea heteromalla, Prunus rufa*, and *Salix longiflora* were growing in the valley bottom, while *Lyonia ovalifolia* and *Vibernum nervosum* were found at the ridge top (Table 3).

Along the south-facing aspect, the top canopy *Pinus wallichiana* was dominant in the south facing transect, followed by *Juniperus recurva*. Three evergreen species, *Euonymus tingens*,

Table 1: **Tree species along Nganglang transects (numbers indicate relative density of species)**

Nganglang (Altitudinal series)	P1	P2	P3	P4	P5
Altitude (masl)	**3,550**	**3,461**	**3,392**	**3,282**	**3,057**
Conifers					
Pinus walliciana	74.9	82	95.6	77.2	100
Juniperus recurva	1.2	13	4.3	–	–
Larix giffithiana	–	5	–	–	–
Tsuga dumosa	–	–	–	22.8	–
Sub-total	**76.1**	**100**	**99.9**	**77.2**	**100**
Deciduous					
Sorbus cuspidata	13.1	–	–	–	–
Enkianthus deflexus	4.3	–	–	–	–
Lyonia ovalifolia	1.6	–	–	–	–
Sorbus microphylla	1.1	–	–	–	–
Rosa sericea	–	–	0.1	–	–
Sub-total	**20.0**	**0.0**	**0.1**	**0.0**	**0.0**
Evergreen					
Rhododendron cinnabarinum	3.7	–	–	–	–
Rhododendron campylocarpum	0.2	–	–	–	–
Sub-total	**3.8**	**0**	**0**	**0**	**0**
Total	**100**	**100**	**100**	**100**	**100**

Table 2: **Herb species along the Nganglang series (numbers indicate relative density of species)**

Nganglang (Altitudinal series)	P1	P2	P3	P4	P5
Yushania microphylla	100	96.8	94.3	92.8	–
Pteridium aquilinum	–	3.2	–	5.2	18.5
Brachypodium sylvaticum	–	–	3.8	–	–
Viola betonicifolia	–	–	0.9	2.1	1.9
Vaccinium nummularia	–	–	0.9	–	–
Fragaria nubicola	–	–	–	–	37
Cyperus cyperoides	–	–	–	–	18.5
Berberis praecipua	–	–	–	–	7.4
Daphne bholua	–	–	–	–	7.4
Elsholtzia eriostachya	–	–	–	–	3.7
Cotoneaster microphyllus	–	–	–	–	1.9
Anaphalis triplinervis	–	–	–	–	1.9
Potentilla peduncularis	–	–	–	–	1.9
Total	**100**	**100**	**100**	**100**	**100**

Table 3: **Floristic composition at the ridgetop of Zomma Forest (numbers indicate relative density of species)**

North-facing series				Valley			Slope		
Species	NA	NB	NC	ND	NE	NF	NG	NH	NI
Conifers									
Larix griffithiana	–	–	–	–	–	–	–	45.3	–
Pinus wallichiana	–	–	–	–	–	–	–	–	70.6
Tsuga dumosa	–	–	–	–	–	–	–	–	20.6
Juniperus recurva	–	–	–	–	–	–	–	–	1
Evergreen									
Rhododendron arboreum	3.6	0.8	–	–	–	0.7	–	2.3	6.2
Rhododendron keysii	2.2	–	–	–	–	–	–	–	–
Rhododendron triflorum	–	–	0.2	–	–	–	–	1.1	–
Rhododendron campylocarpum	–	–	–	15	1.8	6.6	5.4	1	–
Rhododendron barbatum	–	–	–	–	4.8	3.7	3.2	14.9	–
Rhododendron cinnabarinum	–	–	–	–	–	–	9.2	9.0	0.4
Deciduous									
Hydrangea heteromalla	35.5	10	2.5	–	–	10.8	–	–	–
Prunus rufa	28.0	–	8.9	30.3	–	6.8	–	–	–
Salix longiflora	21.5	–	–	–	–	–	–	–	–
Philadelphus tomentosa	7.9	–	–	–	–	–	–	–	–
Schisandra grandiflora	1.3	–	–	–	–	–	–	–	–
Acer pectinatum	–	77.8	25	–	55.1	26.8	–	–	–
Lindera heterophylla	–	11.4	–	50.1	19.8	26.6	2	8.8	–
Euonymus tingens	–	0	–	0.6	–	2.6	–	1	–
Sorbus wallichi	–	–	48.8	–	16.2	–	–	–	–
Acer sikkimensis	–	–	11.2	–	–	–	–	–	–
Enkianthus deflexus	–	–	3.4	3.9	2.2	11.4	28.1	–	–
Lyonia ovalifolia	–	–	–	–	–	4.1	38.6	13.7	1.2
Vibernum nervosum	–	–	–	–		–	11.3	2.9	–
Schefflera impressa	–	–	–	–	–	–	1.2	–	–
Sorbus microphylla	–	–	–	–	–	–	0.9	–	–
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Rhododendron arboretum, and *Rhododendron campylocarpum*, were distributed from slope to ridge; only one deciduous species, *Sorbus cuspidata*, was found on the slope (Table 4).

A total of 55 tree, 73 shrub, and 254 herb species have been recorded within PCA (Annex II). *P. wallichiana* was the main canopy tree in all transects. Common associates of blue pine include *Yushania microphylla, Rhododendron arboreum, R. barbatum*, and *R. campylocarpum*. However, there was considerable variability in the herbaceous layer, dependent on altitude, aspect, and ground moisture. In some cases all the pioneer species of conifer forest – *Pinus wallichiana, Larix griffithiana*, and *Juniperus recurva* – grew together. The rhododendron species seem to be of the same age as the conifer species, even though their height and girth were small. In patches, where *Yushania microphylla* are flowering, several herbaceous species were recorded (Table 5), *Trifolium repens* being the most dominant.

Faunal diversity

The valley is particularly well-known for the endangered Black-necked crane, which is protected under the Forest and Nature Conservation Rules of Bhutan (RGoB 1995). The crane migrates from the Tibetan Plateau through four different migratory routes (Lhendhup and Webb 2009) to roost and feed in the wetlands of PCA each winter (Figure 4).

Table 4: **Floristic composition (tree layer) along the south-facing series of Zomma Forest (numbers indicate relative density of species)**

South facing series	Valley		Slope		Ridge
Species	SA	SB	SC	SD	SE
Pinus wallichiana	74.2	94.3	93.9	89.3	85.3
Juniperus recurva	25.8	–	5.8	9.6	14.5
Euonymus tingens	–	5.7	–	–	–
Sorbus cuspidata	–	–	0.3	–	–
Rhododendron arboreum	–	–	–	1.1	–
Rhododendron campylocarpum	–	–	–	–	0.2
Total	**100**	**100**	**100**	**100**	**100**

Table 5: **Floristic composition in the wetland core area (numbers indicate relative density of species)**

Species	Fenced	Unfenced
Yushania microphylla	55.3	49.3
Trifolium repens	28.6	32.9
Fragaria nubicola	4.3	1.9
Brachypodium sylvaticum	1.7	4.1
Juncus wallichianus	1.6	–
Frimbristylis complanata	1.1	–
Cyperus cyperoides	1	–
Prunella vulgaris	0.9	1.9
Pedicularis siphonantha	0.9	–
Anaphalis nepalensis	0.7	–
Viola betonicifolia	0.6	–
Primula denticulata	0.5	1.9
Aster himalaicus	0.5	–
Poa annua	0.4	–
Potentilla anserina	0.4	–
Viola biflora	0.4	0.3
Luzula multiflora	0.3	0.1
Swertia bimaculata	0.3	1.7
Galium aparine	0.3	0.1
Thalictrum virgatum	0.1	–
Potentilla eriocarpa	0.1	–
Ophiopogon bodinieri	–	3.1
Plantago erosa	–	0.5
Ranunculus chinensis	–	0.5
Cirsium falconeri	–	0.4
Caltha palutris	–	0.4
Geranium nepalense	–	0.4
Anemone rivularis	–	0.1
Remusatia vivipara.	–	0.1
Astragalus sikkimensis	–	0.1
Myriactis nepalensis	–	0.1
Aletris pauciflora	–	0.1
Gentiana capitata	–	0
Total	**100**	**100**

The cranes also visit other parts of Bhutan, such as Bomdeling in Tashi Yangtse, Tangmachu in Lhuntse, and Gyetsa and Thangbi in Bumthang, and the Khotokha Valley under Wangdi Dzongkhag; however, Phobjikha hosts the largest group of the migratory bird (Dorji and Tobgay 2003). The valley is a conservation hotspot for the crane and is one of the major wintering (non-breeding) areas outside China (RSPN 2007). PCA withnessed a significant increase in the number of cranes from 100 in 1990 to more than 350 in 2010 (Figure 5). Bird Life International has recognized the PCA as an Important Bird Area for its special conservation value; the Royal Government of Bhutan has designated it as a conservation area (RGOB 2002).

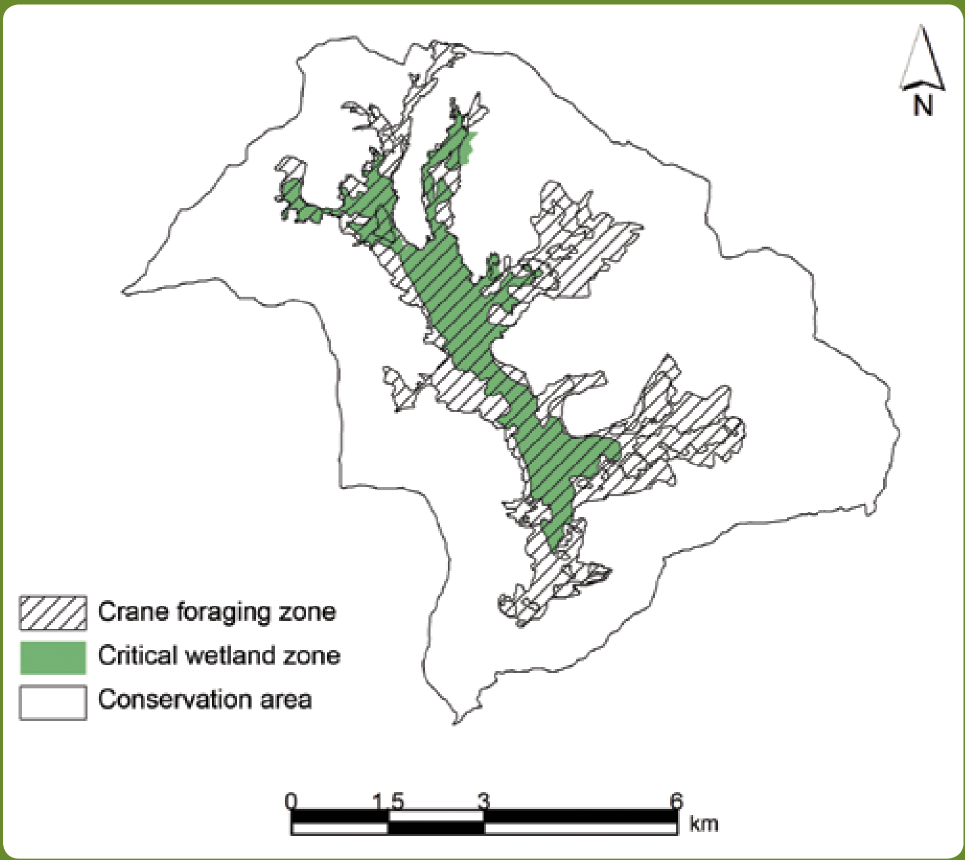
With regard to bird diversity, the Black-Necked Crane Centre recorded some 90 species of birds within PCA (RSPN 2007), the majority of which are resident (Figure 6). Some common bird species include Himalayan griffons, Himalayan monals, kalij pheasants, blood pheasants, tits, flycatchers, leaf warblers, sunbirds, nutcrackers, and gross beaks. A preliminary list of bird species in PCA is given in Annex III.

About 25 species of mammals have been recorded in PCA (Annex IV). Among wild species (Figure 7), sambar (*Rusa unicolor*), muntjac (*Muntiacus muntjac*), wild pig, and grey langur have a higher frequency (Pradhan et al. 2004) than other mammals of significance, such as the Himalayan black bear (*Selenarctos thibetamus*), common leopard (*Panthera pardus*), red panda (*Ailurus fulgens*), and red fox (*Vulpes vulpes*) (RSPN 2007). In a 2011 survey, several animals such as the sambar, muntjac, crab-eating mongoose (*Herpestes urva*), and Asiatic wild dog (*Cuon alpinus*) were encountered, together with scats of lesser carnivores and scats, pugmarks, and scratching and rubbing marks of the jungle cat (*Felis chaus*) (Pradhan 2011). Alpine meadows within PCA are home to many small mammals such as marmots (*Marmota* sp.), Himalayan pika (*Ochotona himalayana*), and stone martens (*Martes foina*). Broadleaf forests host a range of faunal species, including a large number of insects such as the Asian giant hornet (*Vespa mandarinia*), rock bees (*Apis dorsata*), and common bees (*Apis cerana*) (Pradhan et al. 2004; Pradhan 2011).

Threatened species

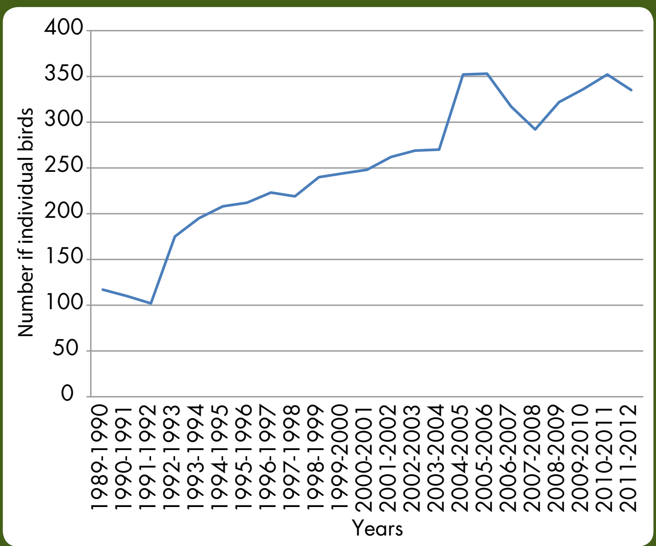
The Black-necked crane is the most well-known of vulnerable species in Phobjikha. Another critically endangered bird in the larger area of the PLCA is the white-bellied heron (*Ardea insignis*); there are only about four individuals

Figure 4: **Roosting and feeding habitat of Black-necked crane within PCA**



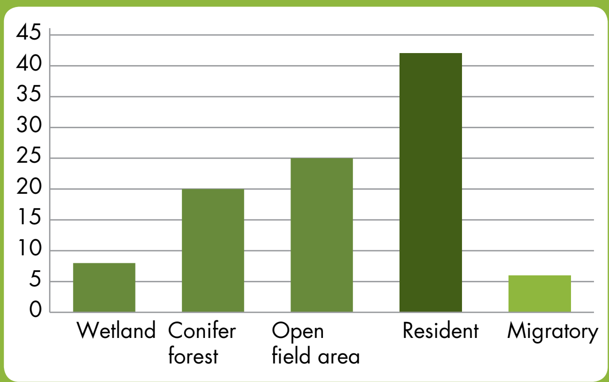
Source: RSPN

Figure 5: **Trend of growth in the number of Black-necked cranes arriving in the Phobjikha Valley from 1986-2012**



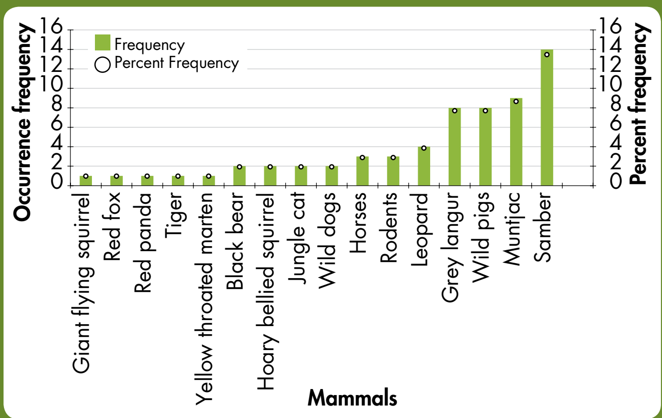
Source: RSPN 2012a

Figure 6: **Number of bird species in PCA**



Source: RSPN 2007

Figure 7: **Preliminary list of wild mammal species and their frequency of distribution in PCA**



Source: Pradhan et al. 2004

in Berti, Zhemgang Dzongkhag and 26 in the Punatsangchu basin, Wangduephodrang Dzongkhag, according to the RSPN (2012b). Likewise, the crane count (2010-2011) lists about 347 cranes in PCA, about 60 in Bumdeling, about five in Khotkha and Lhuntse, and four in Chuzagang, Gelephu (RSPN 2012c). The tiger is another endangered species being monitored in PCA (Pradhan et al. 2004). Tiger monitoring is a priority action for the government, as it feeds into Bhutan's greater tiger conservation strategy.

Invasive species

Not much is known on invasive species in the Phobjikha Valley except for some *Trifolium repens* growing together with *Yushania*. *T. repens* is an introduced fodder species that is invasive under the right conditions. *T. repens* is growing rapidly in the wetland core area, next in dominance only to *Yushania*. As a legume and perennial herb, it may have a comparative advantage in terms of rapid growth and spread.

Ecosystem types

PCA has four major types of ecosystems: forest ecosystem, grassland ecosystem, freshwater ecosystem, and agro-ecosystem. The dominating forest ecosystem covers about about 62% of PCA's total land area. This ecosystem is mainly comprised of gymnosperms such as *P. walliciana, Juniperus recurva, Larix giffithiana, and Tsuga dumosa*. There are also some broadleaf species, such as *Sorbus microphylla, Rhododendron cinnabarinum*, and *Rhododendron campylocarpum*. Grassland is the second most significant ecosystem, covering 24% of the total area and mostly made up of *Yushania microphylla*. The wetland ecosystem encomphases 8% of PCA's total area. Two significant streams, the Lolephage Chu and the Gau Chu, enter the Phobjikha Valley from the east. In the central part of the valley, the cascading Nake Chu River bisects the valley and runs north-southeasterly. Some marshes lie at the catchment and the central part of the valley. About 6% of PCA is under cultivation, with potato cultivation comprising the majority.

Overview of ecosystem goods and services

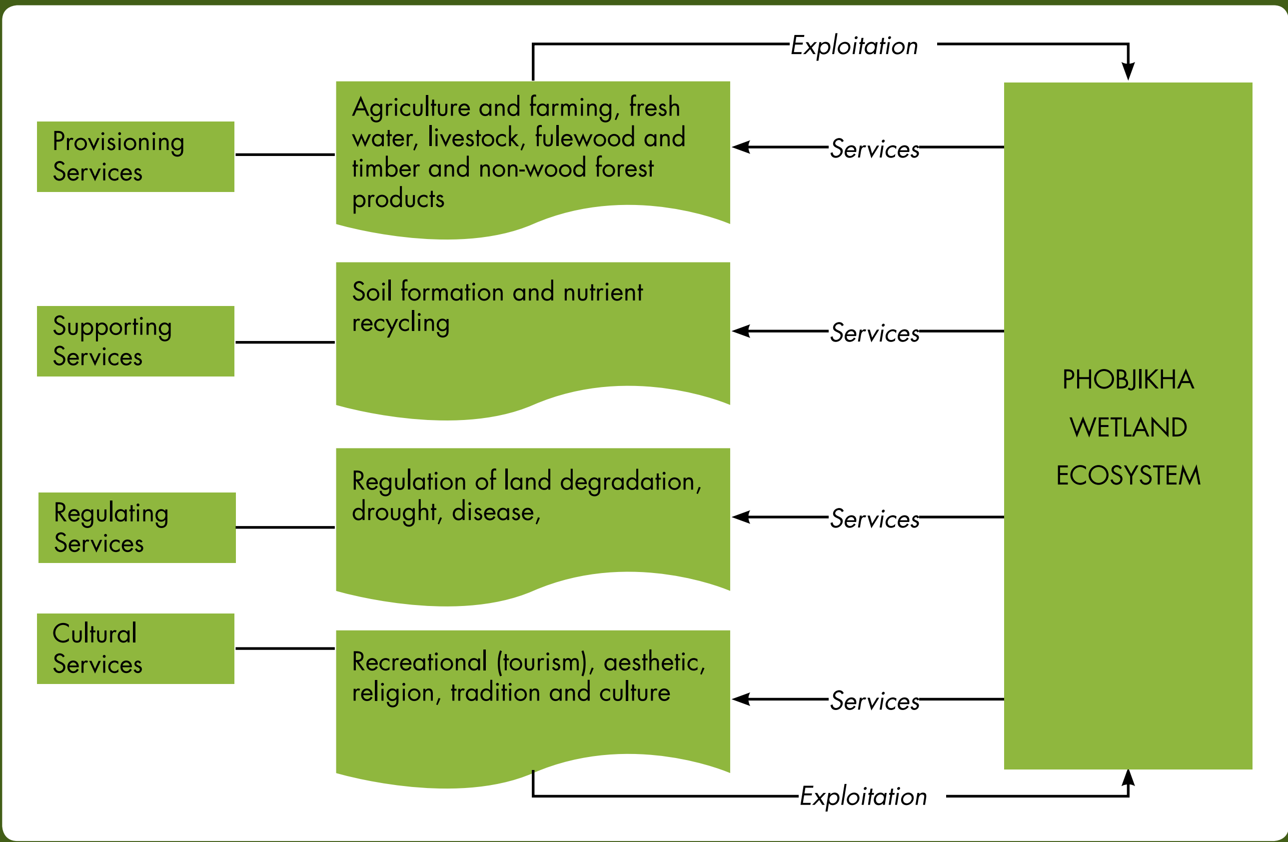
A brief framework of ecosystem services (Figure 8) reflects interlinkages among provisional, supporting, regulating, and cultural services, as well as the wellbeing of the Phobjikha wetland ecosystem (Phuntsho 2010b). Cultural services are growing in prominence. With its ecologically significant scenic landscape and rich cultural heritage, PCA is becoming a popular destination for both domestic and international tourists. In 2009 alone, 6,975 international tourists visited the valley (RSPN 2010). Local people considered the most highly valued ecosystem services to be recreation and tourism, the valley's intrinsic and existence values, freshwater provision, water regulation, and the provision of food and fuelwood. Contingent valuation of Phobjikha (Dorji and Tobgay 2003) suggests benefits from conservation of the Black-necked crane are considered aesthetic rather than monetary. This indicates, however, that people are beginning to consider opportunity costs and to acknowledge economic opportunities and gains from non-provisional ecosystem services.

Ecosystem services provided by PCA, notably provisioning and cultural services, are immensely important to people's livelihoods and wellbeing; the moral and aesthetic value associated with the Black-necked crane is especially prominent (Dorji and Tobgay 2003). Figure 9 enumerates the proportions of provisional, cultural, regulating, and supporting services provided by different land-use types, as per the recent ecosystem services assessment. The highest value was given to provisioning services, followed by cultural services.

Value of provisioning services

Table 6 shows the annual value of different provisioning services per household, as well as the aggregated values for all dependent households residing in PCA. The aggregate annual economic value of provisioning services estimated for all dependent households in the valley is more than Bhutanese ngultrum (BTN) 69 million (about USD 1.3 million), equivalent to USD 80/ha/year. In other words, an average household derives USD 2,610 worth of annual economic benefit from provisioning services from the valley. The net benefit from potato farming is the

Figure 8: **Schematic diagram of ecosystem services provided by Phobjikha Wetland**

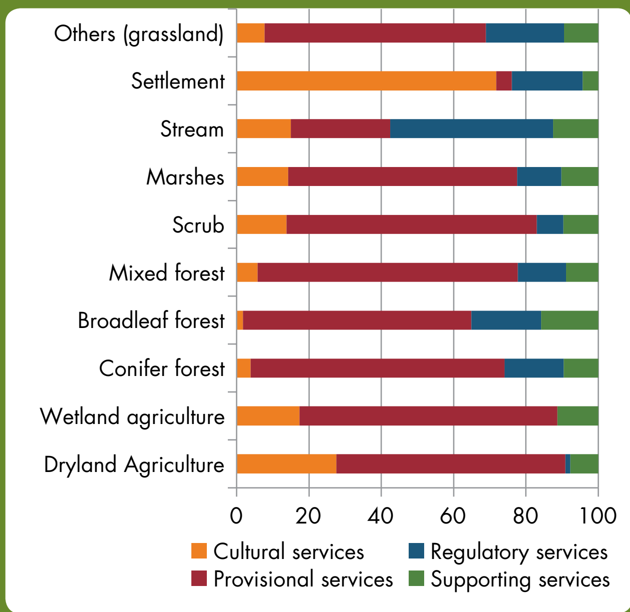


Source: Phuntsho 2010b

most dominant provisioning service, accounting for 84% of the total estimated value of provisioning services considered in this study; the remaining 16% is made up by other directly used wetland resources, even when these benefits are not immediately visible in terms of direct household income. A discussion of the economic value of each type of provisioning services, and their relative contribution to the total value of provisioning service as well as to that of total economic value, follows.

Potato farming: The local economy of PCA has long been heavily reliant on large-scale potato farming. Over half of PCA's cultivated area is estimated to be under potato cultivation. The valley boasts one of the highest rates of potato productivity in the country (about 8 tonnes/ha), and PCA produces over 41% of Bhutan's total potato production. According to survey data collected in 2012, an average household derives an annual net income of BTN 124,847 from potato farming after deducting cultivation cost – assumed to be 35% of the total gross return. With the estimated total number of households dependent on this livelihood, the total annual net

Figure 9: **Value of different types of ecosystem services to communities in villages across PCA (in %)**



Source: Ecosystem Services data 2012

Table 6: **Estimated annual total economic value of provisioning services**

	Average value per household (BTN/year)	% HH dependent	Total households	Total value for all dependent households (BTN/year)	Total value USD/yr	Total value USD/ HH/year	Total value per USD/ha / year	% share Total Economic Value	% share Provisioning Services
Potato	124,847	93.6	498	58,180,792	1,093,798	2,196.4	67.5	30.3	84.1
Timber	24,697	29.4	498	3,610,792	67,883	136.3	4.2	1.9	5.2
Fuelwood	4,101	95.0	498	1,939,459	36,462	73.2	2.3	1	2.8
Pole	2,664	44.5	498	590,345	11,098	22.3	0.7	0.3	0.9
Leaf litter	1,107	89.9	498	495,479	9,315	18.7	0.6	0.3	0.7
Fodder	1,612	61.5	498	493,386	9,276	18.6	0.6	0.3	0.7
Bamboo	10,273	27.5	498	1,408,084	26,472	53.2	1.6	0.7	2.0
Mushroom	5,172	24.3	498	626,132	11,771	23.6	0.7	0.3	0.9
Medicinal plant	41,875	3.67	498	765,333	14,388	28.9	0.9	0.4	1.1
Domestic water	2,131	97.5	498	1,034,711	19,453	39.1	1.2	0.5	1.5
Total provisioning service				**69,144,511**	**1,299,917**	**2,610.3**	**80.2**	**36.1**	**100**

Note: Exchange rate used refers to average value of 2012 (1 BTN = 0.0188 USD; 1 USD = 53.191 BTN); Inflation values have been taken from the International Monetary Fund World Economic Outlook database, April 2010 and exchange rates from www.oanda.com/currency/historical-rates.

benefit generated from potato cultivation in Phobjikha is estimated to be around BTN 1 million; this accounts for 84% of the total value of provisioning services and 30% of the total economic value. However, a past study showed that potato yield has increased from 2,615 tonnes in 2000 to 5,388 tonnes in 2008. It was reported that 1.8 acres of dry land produced 130 quintals of potato each year, worth BTN 182,000 (USD 3,956) (Phuntsho 2010a). This figure is exceptionally high compared with national per capita income, which was about USD 1,900 as per World Bank's 2009 figure. The study further indicates that almost 91% of farmers' income is generated from the sale of potato in PCA; the remaining income comes from other sources such as livestock (5%), kitchen gardening and shops (3%), and remittances and tourism (1%) (Phuntsho 2010a). Income generated from the sale of potato was enough to sustain livelihoods for the whole year, and the increase in income allowed farmers to buy more fertilizer, farm machinery, and other agricultural support tools. Chemical fertilizers such as urea (nitrogen), suphala (nitrogen phosphate with potash), and single super phosphorous are the most commonly used fertilizers.

Fuelwood: Bhutan's per capita fuelwood consumption is one of the highest in the world, perhaps because of the country's cold climatic conditions combined with fuelwood's abundance, proximity, and the absence of other cheaper alternative sources of energy. Based on estimates form the last decade, the average annual household fuelwood consumption in PCA was about 31,158 kg; required annual fuelwood for all households in the valley was estimated at 15,516.83 tonnes (Dorji et al. 2004). Available information further indicates that, an average household consumes close to two back-loads of dried wood per day for domestic purposes. For a long time, PCA was not connected to grid electricity, as people feared that electricity poles and lights would impact the flight of Black-necked cranes.

Timber: The construction of traditional Bhutanese houses requires a lot of timber. People also use timber to build cow sheds and tractor sheds and for the renovation of houses. On average, over 200 trees of varying size were used to build new houses, however, efficient sawing equipment, such as power chain saws, have somewhat reduced timber requirements compared with the past (Phuntsho 2010a). Based on the prevailing price of different loads of timber, the average annual value of timber extracted from the wetland is estimated at BTN 24,697 per household. This translates to an annual total value of BTN 3.6 million (USD 67,883) for all timber-dependent households in the valley, representing 5% of the estimated total value of provisioning services (Table 6).

Bamboo and timber poles: Based on household survey data, about 45% of households in PCA depend on poles for construction needs. The average annual quantity collected per household and their prices vary by the types of load. For example, a sample household reported collecting poles in eight different loads with their average prices ranging from BTN 6 per kg to BTN 65,000 per truckload. The average annual value of poles collected from the wetland is estimated at BTN 2,668 per household. This translates to an annual total value of BTN 590,345 (USD 11,098) for all pole-dependent households in the valley, representing 3% of the estimated total value of provisioning services (Table 6).

Livestock fodder: The average annual quantity of fodder collected amounted to nearly 56.2 tonnes, with an estimated annual average value of BTN 1,612 per household. When multiplied by the estimated total number of fodder-dependent households in the valley, this gives an annual value worth BTN 493,386 per year (USD 9,276/year) derived from the use of wetland resources in Phobjikha Valley. This value represents less than 1% of the total value of provisioning services. Other details are provided in Table 6.

Leaf litter: A vast majority of the households in the valley (88%) rely on leaf litter for cattle bedding, though the quantity used is believed to be lower than in the past due to the availability of fertilizer. The fern and leaves of blue pine and oak make valuable cattle bedding, which can later be used as organic manure. The average annual value of leaf litter collected from the wetland is estimated to be BTN 1,107 per household. This translates to an annual total value of BTN 495,479 (USD 9,315) for all the leaf-litter dependent households in the valley and represents 3% of the estimated total value of provisioning services (Table 6).

Bamboo: Dwarf bamboo grows all over PCA, especially in open spaces where there are no trees, playing a significant role in protecting vegetation and controlling erosion. The bamboo is used as fodder for livestock animals and crafted into marketable products. The dwarf bamboo zone, like the wetland zone, also serves as pasture land for livestock animals. About 28% of sample households reported collecting bamboo. Its annual value is estimated at BTN 10,273 per household. This translates to an annual total value of BTN 1,408,084 (USD 26,472) for all dependent households in the valley, representing 2% of the estimated total value of provisioning services (Table 6).

Mushrooms: Mushrooms are among the main valuable non-timber forest products in PCA. Local people collect several types of mushrooms from the forest during summer months. Available information suggests mushrooms collected for consumption include jili namchu (*Auricularia auricula*), sisi shamu (*Cantherellus cibarius*), taa shamu (*Polyporus sulphureus*) etc. Based on survey data, about one-quarter of sample households collect mushrooms from the forest. The average quantity collected was 6.6 kg, and the average price was BTN 794 per kg. The average annual value of mushrooms collected was BTN 5,172 per household. This gives a total annual value of BTN

626,132 (USD 11,771) for all dependent households in the valley, although its contribution to total economic value is insignificant (less than 1%).

Medicinal plants: A very small proportion of sample households (about 4%) reported harvesting medicinal plants from wetland forest resources. Among the various types of medicinal plants harvested, dwarf rhododendron species such as *Rhododendron anthopogon, Rhododendron setosum*, and *Juniperus recurva* were greatly preferred as a valued incense source. Though locally made medicines are rarely used today, people still commonly practise a number of medicinal plants the to cure many types of disease. The average annual value of medicinal plants harvested from the valley is estimated at BTN 41,875 per household, which translate to BTN 765,333 (USD 14,388) for all dependent households in the valley (Table 6).

Domestic water supply: Water is a very important provisioning service provided by PCA. The vast majority of households used piped water as the most common source of drinking water. PCA's water is believed to have originated from the hillock where Gangtey Goenpa is built; it is believed that there are 128 different sources of water surrounding the hillock that gradually recharge the wetland. In the absence of information on domestic water supply benefit for wetlands in Bhutan, this study uses unit transfer value from the domestic water supply benefit estimated by Emerton and Kekulandala (2003) for a wetland in Sri Lanka. This gives the inflation adjusted unit transfer value of USD 40.06 per household in 2012 prices. With almost 97% of households using piped water originating from wetland sources in PCA, the total domestic water supply benefit from Phobjikha wetland ecosystem is estimated at BTN 1.034 million per year (USD 19,453). This value represents roughly 2% of the total value of provisioning services provided by the wetland ecosystem in PCA (Table 6).

Value of regulating services

Carbon sequestration: With no comparable carbon sequestration estimate available for wetlands in Bhutan, the present study relies on the commonly used default transfer value based on the CSI provided by Pagiola et al. (2007), which gives values for different land-use types according to their capacity to sequester stable carbon in soil and hardwood. The value of carbon sequestration is then calculated as the CSI adjusted areas multiplied by the unit price of USD 75. The total value of carbon sequestered by these four types of land in PCA is BTN 46.52 million per year (USD 874,739 per year), or USD 54.3/ha/year. This represents nearly one-quarter of the total economic value of the valley (Table 7).

Value of cultural services

PCA's wetland ecosystem provides the important recreational service of tourism through its unique landscape, rich cultural heritage, religious sites, and rich biodiversity, particularly the globally endangered Black-necked crane. PCA has become one of the most popular tourist destinations in Bhutan, designated as a preferred destination by travel agents. In 2009, a total of 6,975 tourists visited and spent bed nights in PCA. Based on the information obtained from private tour operators, the total number of tourist bed nights in five different hotels in Phobjikha in 2011 was 8,988. When multiplied by hotel-specific room rates, this gives a total revenue of BTN 114.18 million (USD 2.42 million) in 2011 prices. Without information on the actual number of tourists spending bed nights in PCA and revenue generated for 2012, the 2011 value was inflated to BTN 121.13 million in 2012 prices using the CPI factor. Further. assuming a flat rate of 35% of the gross value as the cost of management, the total annual net benefit generated from tourism services provided by PCA is estimated at BTN 78.73 million (USD 1.48 million). This represents nearly 40 % of the estimated total value of major wetland ecosystem services provided by PCA (see Table 7). This estimation reflects the lowest range under a pessimistic scenario as it included only the revenue generated by hotel per night without considering royalties (visa fee and tax) paid by tourists to the government in addition to the tariff.

Aggregated economic values from ecosystem services

The overall economic benefit generated from the major types of provisioning, regulating, and cultural services considered in this study amounts to around BTN 191.72 million (USD 3.6 million) per year (Table 7). This is around

Table 7: **Estimated aggregate value of major wetland ecosystem services in the Phobjikha Valley**

	Total value for all dependent HH (BTN/year)	Total value (USD/yr)	Total value (USD/HH/yr)	Total value (USD/ha/yr)	% share total value
Total provisioning service	69,144,511	1,299,917	2,610.3	80.2	36.1
Regulating service – Carbon sequestration	46,528,648	874,739	1,756.5	54.0	24.3
Cultural service – Tourism	76,051,048	1,429,759	2,871.0	88.3	39.7
Overall economic value	191,724,207	3,604,415	7,237.8	222.5	100.0

USD 22.5/ha considering an area of 162,000 ha. Revenue generated from recreational services (tourism) ranks first in terms of its contribution to total economic value, followed by provisioning services (36%), and regulating services from carbon sequestration (Figure 10). Since carbon sequestration and tourism account for 64% of the total value, a large share of the benefit generated goes outside the local economy. This suggests there is huge potential to mobilize resources for financing conservation and development needs by creating value, for example, through carbon trading and payment for environmental services.

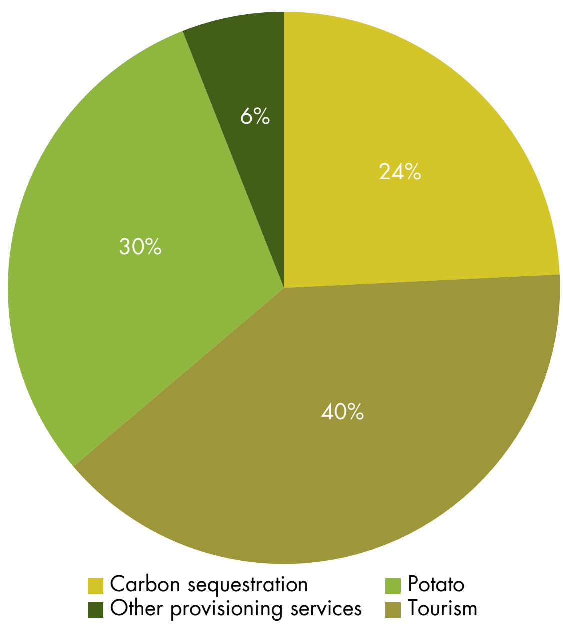
Even though many ecosystem services do not directly affect household income, the finding that over one-third of the total value of wetland ecosystem services is contributed by provisioning services is a clear manifestation of their vital importance for local livelihoods. The results show that the forest ecosystem in the study area provides significant economic benefits to local people and that people are highly dependent on forest ecosystem services for subsistence and wellbeing.

Overview of socioeconomic profile

Demographic profile

The LAT survey revealed that Ngalop is the predominant ethnic group in the study area. About 42.4% of households were headed by a female member. The mean size of households was 5.5 members, with a dependency ratio of 76 dependents per 100 persons aged between 15 and 64 years old. Around 17.4% of the households did not have any literate member aged 6 years and above. The illiteracy rate was somewhat higher for women (39.1%) than for men (34.8%) (Figure 11).

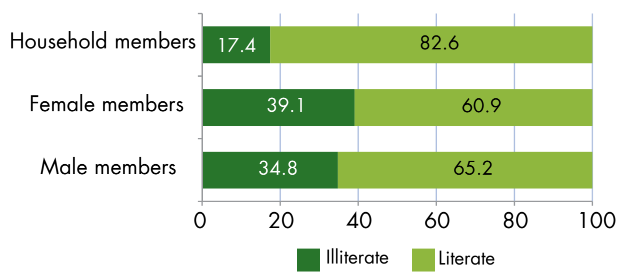
Figure 10: **Percentage share of economic value of ecosystem services in Phobjikha**



Socioeconomic profile

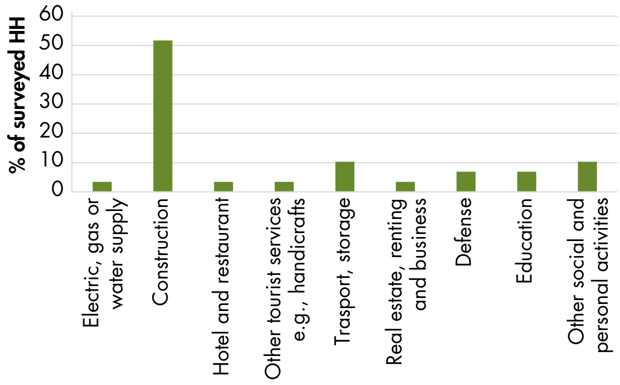
The economy of PCA is dominated by cash crop production. Almost all people in PCA are engaged in farming, with 87.6% dependent on a single cash crop, the potato. Raw exports of potato to India total about 2,770 tonnes annually. The average household produces 6 tonnes of potato, and it seems that households that produce more than 9 tonnes fare better economically. Based on quantities sold at auction in 2006, the highest quantity of potato is produced in PCA, followed by Naja in Paro (Roder et al. 2007). Other cash crops grown by farmers (on which there is a cumulative dependence of about 4%) included summer maize, barley, turnip, and radish (Table 8). Yaks, cows, horses, sheep, pigs, and poultry constitute major livestock.

Figure 11: **Percentage of households with at least one literate household member aged 6 years and above**



Household members N = 218 hh, Female member N = 207 hh
Male members N = 215 hh, 100%; data source: LAT 2011

Figure 12: **Engagement of household members in non-agricultural occupationss**



Source: LAT (2011)

Livelihood strategies

A total of 23 households, (10.6% of total households), had members managing or running a non-agricultural business. Of these households, most were involved in wholesale or retail trade and transport, storage, or communication. Only 26 households had at least one member employed in non-agricultural occupations (Figure 12), most were involved in construction.

Around 65.1% of households were exclusively dependent on primary income sources. Mean contribution of the primary income source to total yearly household income was about USD 84.7. It was slightly higher in female-headed households (USD 88.5) than in male-headed households (USD 81.9). Mean contributions from secondary and tertiary income sources were approximately USD 15.3. Income from remittances was only around 4%. The mean amount of remittance received from within the country by a household during the 12 months preceding the survey was USD 6.2, whereas the mean amount coming from outside the country by a household was USD 0.80 (Table 9). Although less than 2% of households had members either employed or engaged in managing nature-based tourism business in Phobjikha Valley, tourism has progressed over the last decade with the opening of new hotels and lodges (mostly owned by people not native to the area) and an increase in tourism-related activities like the crane festival and bird watching. Tourist arrivals increased from a few hundred tourists visiting the valley annually in the late 1990s to 6,975 in 2009. The LAT revealed, however, very limited tourism benefits or opportunities for local communities.

People generally perceive their standard of living as having improved compared to the past 20 years (Phuntsho 2010a). This is primarily attributed to revolutions in potato cultivation, which have not only increased household incomes, but also other material assets. This economic growth is differential, however. Farmers with large landholdings reaped the advantages of large-scale potato cultivation; poor farmers with fragmented lands could not benefit much from cultivation.

Table 8: **Kinds of cash crops grown by households during the 12 months preceding the survey (in %)**

Cash crop type	Phobjikha Valley
Summer potato	87.61
Summer maize	0.46
Barley	0.46
Turnip	0.46
Radish	0.46
Others	0.80

N=218 HH, 100%; data: LAT 2011.

Table 9: **Household dependency on different income sources**

Sole dependence on primary income source (in %)	Yes	65.1
	No	34.9
Contribution of primary income to total HH income (mean value) (in USD)	Male-headed HH	81.9
	Female-headed HH	88.5
Contribution of secondary and tertiary income to total HH income (mean value) (in USD)	Male-headed HH	18.1
	Female-headed HH	11.5
Mean remittance (in USD)	From within Bhutan	6.2
	From abroad	0.80

Dependency on ecosystem services

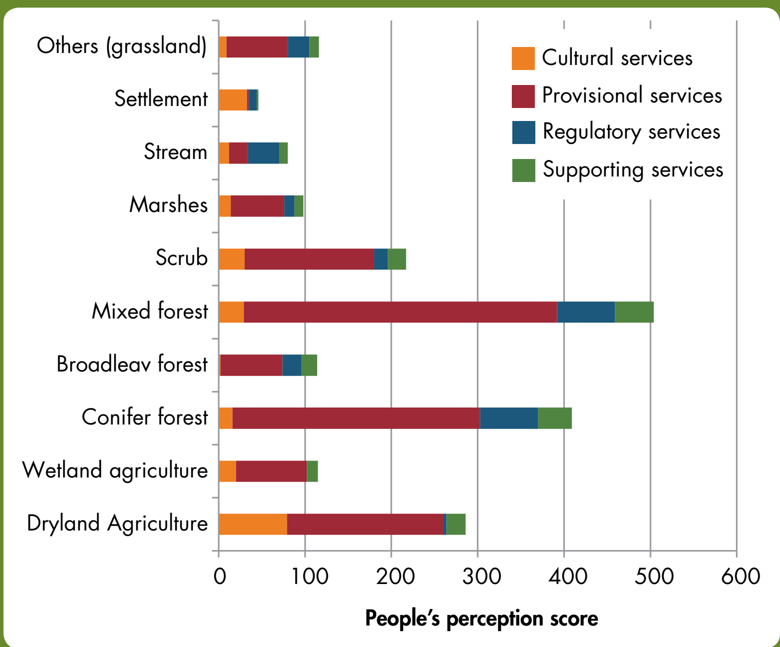
Local people value each of the land cover types within the PCA according to their dependence on different types of services. The Ecosystem Services survey revealed that for provisional services local people depend comparatively more on mixed forest, followed by conifer forest, dryland agriculture, and scrub. Interestingly, people are dependent on the majority of PCA's ecosystems, though by dfferent proportions. The four most important land-use types in relation to services were reported to be mixed forest, conifer forest, dryland agriculture, and scrub (Figure 13).

To understand the dependency on ecosystem services, several indicators for provisions and perceived importance of ecosystem services were used. These provisions included: primary construction material of exterior walls and roofs of houses, primary fuel source for cooking and heating, primary water supply for domestic use and agriculture, use of compost manure, constraints to agricultural production, grazing patterns, fish catching and breeding, collection of timber and non-timber products, dependency on primary sector income sources, employment or business dependent on nature-based tourism, wildlife-related shocks, and dependency on watersheds.

Local livelihoods in PCA are primarily sustained by agriculture and animal husbandry (Dorji and Tobgay 2003). Major crops include potato, radish, and wheat. Yields of potato – the main cash crop – vary greatly, from 250 to 6,250 kg per acre. Phobjikha currently accounts for a large proportion of the potatoes produced in Wangduephordrang District. The value of potato represented over 80% of agricultural production and accounted for nearly 100% of agricultural products sold by people in Phobjikha and Gangtey (Roder et al. 2008). Yield is affected by varying levels of soil fertility, quality and quantity of seed, the level of agricultural inputs, and differences in cropping practices (Dorji et al. 2004).

As a high-altitude landscape, fuelwood for heating is one of the major privisions derived from watershed forests in PCA. In the past, people depended on forest resources for all basic necessities. These included resin for fire and making torches, construction materials, wild edibles, non-timber forest products (NTFPs), and cultural amenities such as poles and prayer flag posts (Phuntsho 2010b). The most important provisions to date are timber and fuelwood. The survey conducted by RSPN in 2004 found that, on average, each household consumed about 40 m^3 of fuelwood per year, equivalent to approximately 20 big trees (RSPN 2007). According to the LAT, PCA provides a number of ecosystem goods and services to local communities (Table 10). Annually, local communities collect approximately 2,000 kg of dry leaf for cattle breeding, 716 kg of fuelwood, 12.4 m^3 of timber, and 385 kg of grass and forage as essential provisions. The traditional method of timber use requires chopping around the log, causing a lot of wood wastage and raising concerns over the excessive number of trees used (RSPN 2007). Blue pine is a major source of timber for building houses. Timber is also used for fencing to prevent wild boars and free grazing cattle from entering farmlands. According to the LAT, households still collected used wood, as well as sawdust, grass, and other natural materials from nearby forests and wetland areas, for cooking (33.9%) and heating (97.7%). The the primary fuel source for light, however, was electricity from solar (56.4%); efforts have also been made to supplement energy through micro-hydel stations, which are not yet functioning. Some households also harvested bamboo from the forests for making baskets, cattle sheds, and fencing.

Figure 13: **Important land cover types as per the value given to different kinds of ecosystem services**



Source:Ecosystem Services data 2012

Another major service from the PCA landscape are resources for livestock. Ground vegetation, dominated by Yushania microphylla, is the most important area for grazing and foraging for cattle, horses, sheep, and especially the Black-necked crane (Joseph et al. 2004). The contiguous pastures from Lowla in the north to Zizi in the south provide ample grazing grounds for local livestock, particularly cattle, yak, sheep, and horses. A number of yaks and sheep from adjoining Sephu and Kumbu also use pasture and shrubland along the slopes of the core area. The entire watershed is also important for other provisions such as wild vegetables, wild edible fruits, ferns, mushrooms, dried fallen leaves, grass, fodder, bamboo, medicinal aromatic plants, poles, and crabs. Blue pine needles are used for cattle bedding; mushrooms (Cantharellus sp) are a delicacy extracted from conifer forests.

Table 10: **Products and their quantity collected by households in the12 months preceding the survey**

Products collected by HH	Number of HH	Quantity mean (kg, except for timber)	Total quantity collected (kg)
Timber (in m^3)	218	12.4	2,706
Fuelwood	218	716.2	1,56,140
Wild edible vegetables	218	1.6	352
Wild edible fruits	218	39.4	8,600
Dried/fallen leaves	218	1,961.9	4,27,690
Grass/forage	218	385.5	84,035
Fodder	218	200.3	43,655
Bamboo	218	8.3	1,815
Medicinal aromatic plants	218	3.7	8124
Poles	218	22.5	4,901
Crab	218	0.4	94

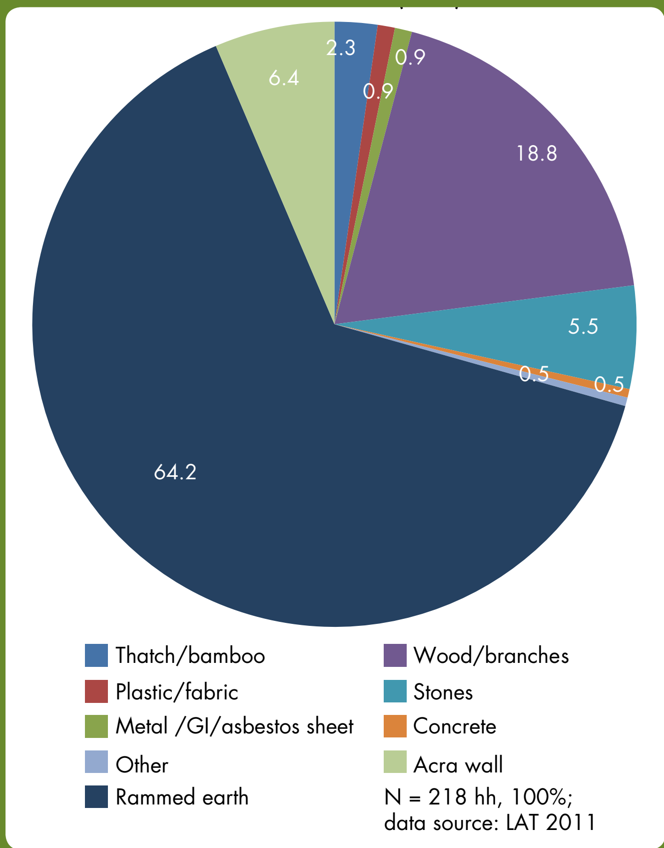
Source: LAT 2011

The LAT also indicated the primary material used to construct the exterior wall of houses, which included rammed earth (64.2%), wood or branches (19.0%), acra wall (6.4%), stones (5.5%). These were all derived from ecosystems around PCA (Figure 14). Similarly, wood or planks (33.5%) were an important primary construction material for the roof (Figure 15).

Ecologically, the Phobjikha wetland is a nutrient sink with vegetation dynamics influenced by grazing and movement of livestock, as well as by spatial variability of soil moisture. As a buffer area between farmlands and the central stream, the wetland plays a significant role in filtering nutrients and pollutants entering the streams from farmland. It also provides excellent habitat for endangered species and forms a roosting and nesting ground for the Black-necked crane and some skylarks. About 80% of the alpine meadows in PCA are a freshwater reservoir. The broadleaf forest ecosystem provides habitat for several animals, birds, and medicinal and ornamental plants, creating a dynamic system of ecological interactions.

Yushania and Spagnum mosses that cover the wetland help regulate the water cycle by controlling evaporation processes and retaining ground moisture. Water conservation, water filtration, and soil erosion control are other underrecognized ecological benefits of the wetland ecosystem in PCA. Water table depth varies across the wetland, and there are micro-topographical changes. Water is at the surface in some places while deeper than 1 m at others. In areas with surface water, puddles made by cattle hooves provide microhabitats for several insects such as dragonfly nymphs, mosquito larvae, and gnats (Phuntsho 2010b). Cattle appear to influence

Figure 14: **Primary construction material for the exterior wall of houses (in %)**



micro-drainage in these areas. Reddish-brown tinged grass grows predominantly in areas where water is flowing on the surface; wet areas with grass (without surface water) have balls of small reddish earthworms in the root zone (Dorji et al. 2004). The Phobjikha Valley has been studied extensively in terms of soil development and landscape evolution (Caspari 2009). These studies suggest that human activities such as deforestation, grazing, and arable agriculture together with strong along-valley winds, frequent freeze-thaw cycles, extensive dry periods, and sparse vegetation cover have given rise to the silty-clay and stone-free texture of the valley's soil. This strongly relates to the availability of soil types that sustain the kind of natural biomass and agricultural produce present in the valley (Caspari n.d).

According to the LAT, the households perceived significant services of the watershed during the ten years preceding the survey as domestic water supply (97.6%), timber (92.0%), livestock use (89.2%), non-timber forest products (83%), and religious/cultural/recreational activities (80.7%). Almost 87.6% of the households had enough water to meet their needs and for livestock for all 12 months. On average, households in the valley had enough water for crops for 11.3 months and livestock for 11.4 months during the 12 months preceding the survey. While irrigation services from the watershed were considered important by 49.1% of households, most did not perceive the importance of the watershed in providing services like fish breeding or catching, collection of crabs or snails, or game animals (Figure 16).

Water piped inside the house was the main source of drinking water for most households during rainy season (81.7%), dry season (80.7%), and most of the year (81.7%). Water from ponds, streams, rivers, canals, and public standpipes were also used by some households (Table 11).

Community dependency on institutions

Phobjikha's local population is mostly comprised of farmers, with their local economy entirely dependent on commercial potato farming. According to LAT, in times of distress people turned to financial institutions, the national government, local government, the monastery, and local foundations (for example, Kidu Foundation) for household support. Assistance during times of shock or stress was commonly received from family (71.9%), friends (64.3%), and community members (32.6%) (Figure 17). Notably, a higher percentage of male-headed households (14.1%)

Figure 15: **Primary construction material of the roof of the houses (in %)**

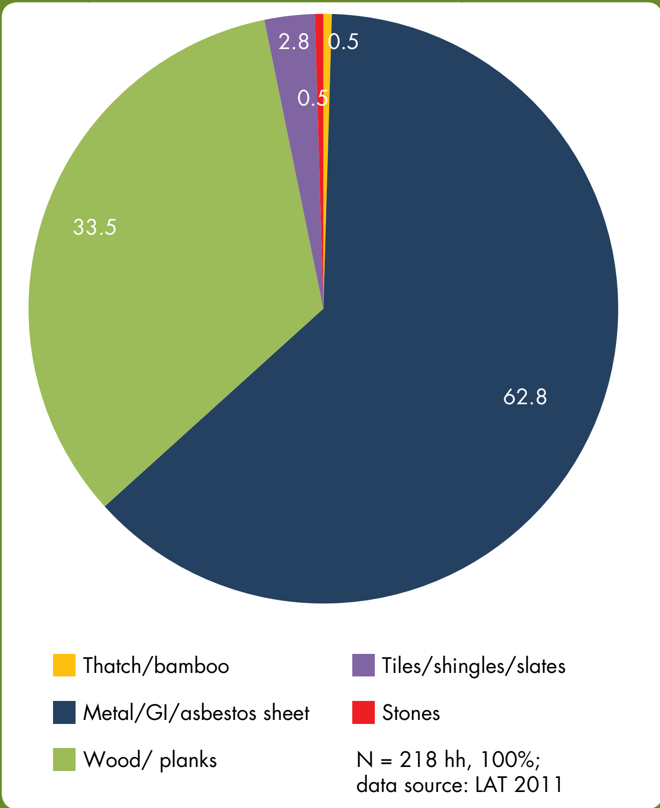
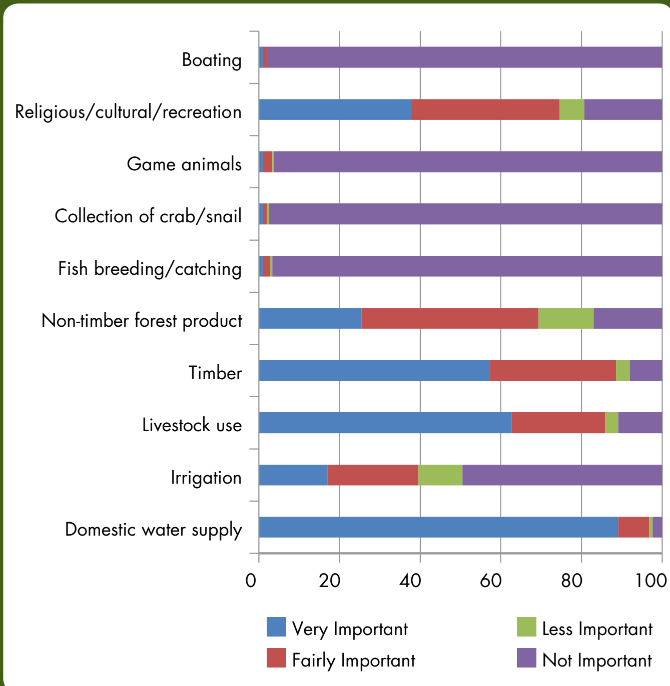
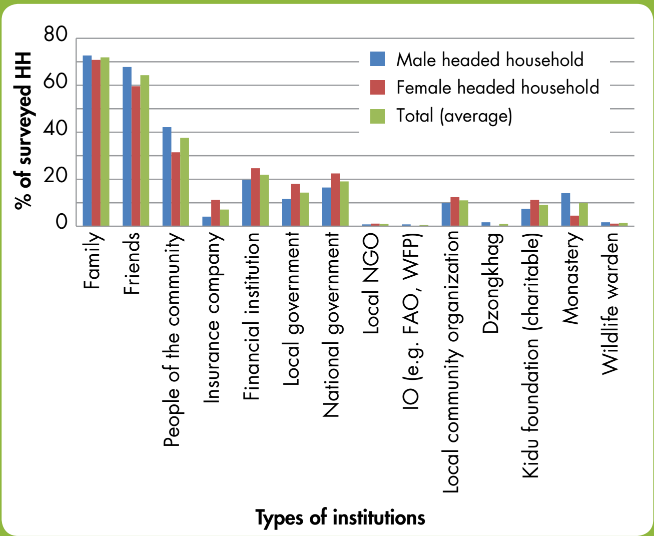


Figure 16: **Perceived importance of ecosystem services provided by the watershed during the ten years preceding the survey (in %)**



Source: LAT 2011

Figure 17: **Assistance received from various institutions by the households in PCA during shocks/stress in the 12 months precedings the survey**



Source: LAT 2011

Table 11: **Primary source of drinking water (in %)**

Source of drinking water	During rainy season	During dry season	Most of the year
Unprotected dug well	0.0	0.5	0.0
Unprotected spring	3.7	3.2	3.2
Protected spring	0.9	1.4	0.9
Pond, stream, river, canal	6.0	6.9	6.0
Public standpipe	4.6	4.6	4.6
Piped water inside house	81.7	80.7	82.0
Piped water inside the community	3.2	2.3	3.2
Other	0.0	0.5	0.0
Total	**100**	**100**	**100**
N	218	218	217

100%; data: LAT 2011.

reported receiving assistance from the monastery than female-headed households (4.5%). A higher percentage of female-headed than male-headed households reported receiving assistance from financial institutions, the national government, local government, and insurance companies.

Drivers of change and community perceptions

Climate variability and future scenarios

As a high-altitude wetland, Phobjikha is directly influenced by changes in climatic parameters. Climate change impacts are especially significant considering how closely Phobjikha's economy is tied to the climate-sensitive agriculture sector. Climate change and other non-climatic stressors such as poverty, urbanization, and changes in land use impact biodiversity structure, functions, and ecosystem services, and consequently the lives and livelihoods of local people.

The average temperature recorded for the past eleven years (2001-2011) in the PCA was 8.2°C. The mean maximum temperature (July) was 14.7°C, while mean minimum temperature (January) was 0.2°C (Figure 18a). Precipitation is strongly influenced by topography and elevation; average monthly rainfall rises from March to October with June, July, and August receiving the most annual precipitation due to the monsoon. Phobjikha's mean total annual rainfall for the past 12 years (1992-2003) was 1,411.4 mm. The maximum rainfall was in July (323.3 mm), followed by August (307.1 mm), and minimum was in December (4 mm), followed by January (10.3 mm) (Figure 18b). The arrival of Black-necked cranes in Phobjikha also indicates transboundary weather change.

The analysis from the downscaled data used from PCA showed that the model captures the annual cycles of both maximum and minimum temperatures (Figure 19a,b). However, some cold and warm biases are present in monthly estimations of both maximum and minimum temperature. For maximum temperature, the downscaling model simulates slightly warmer than observed temperatures in spring and summer months, and slightly cooler than observed in autumn and winter months. For minimum temperature, the model simulates slightly warmer than observed temperatures from February to June, and slightly cooler than observed the remaining months. In general, the small amount of bias in the simulations indicates that good reliability of the SDSM temperature calibration process was achieved. Likewise, annual cycles of observed and NCEP simulated monthly precipitation from Phobjikha during the independent verification period (1997-2003) underestimate precipitation throughout the year, except in winter months (Figure 19c). The significant magnitude of these biases in summer explains the lower reliability of the SDSM precipitation calibration process in the PCA.

Figure 18: **Climatic background of Phobjikha: (a) average, maximum, and minimum temperatures (°C), (b) average mean temperature (°C) and annual total rainfall (mm)**

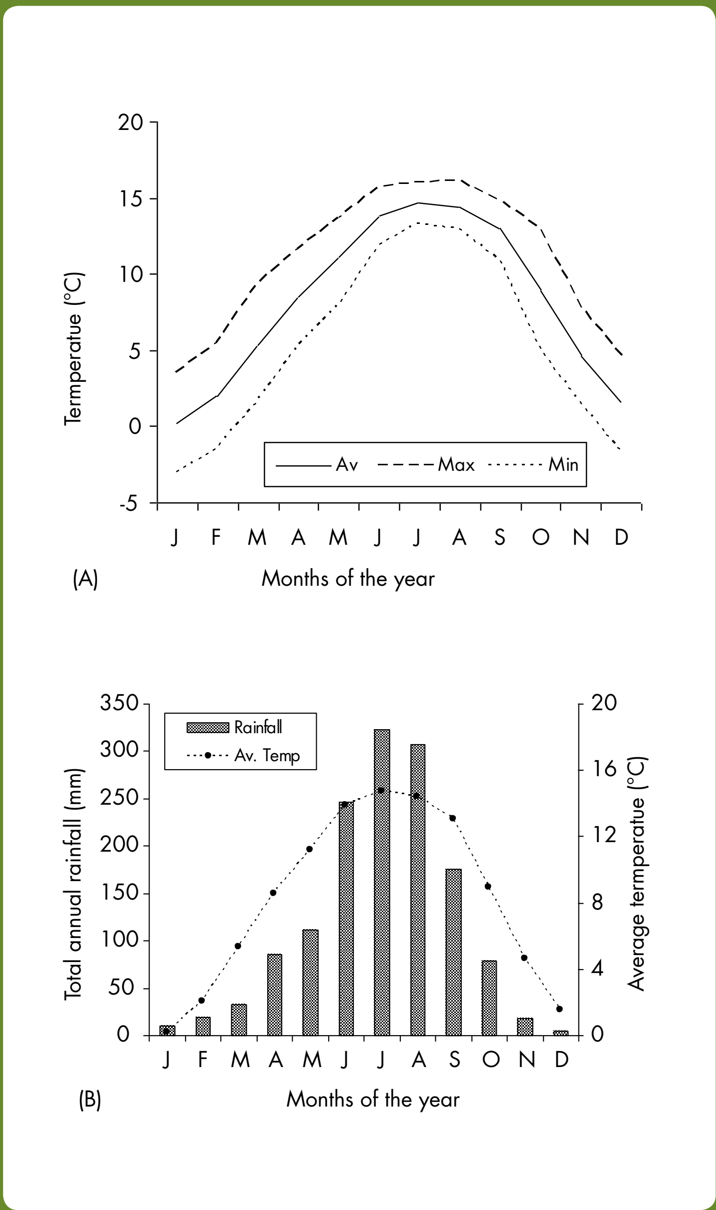
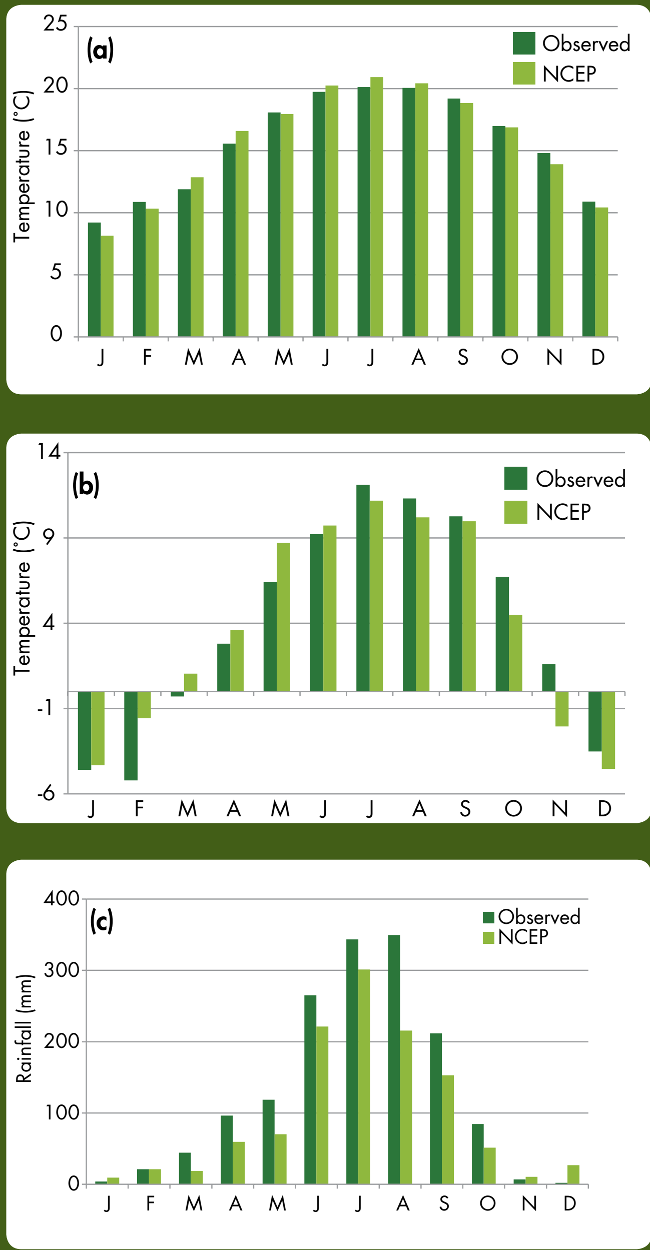
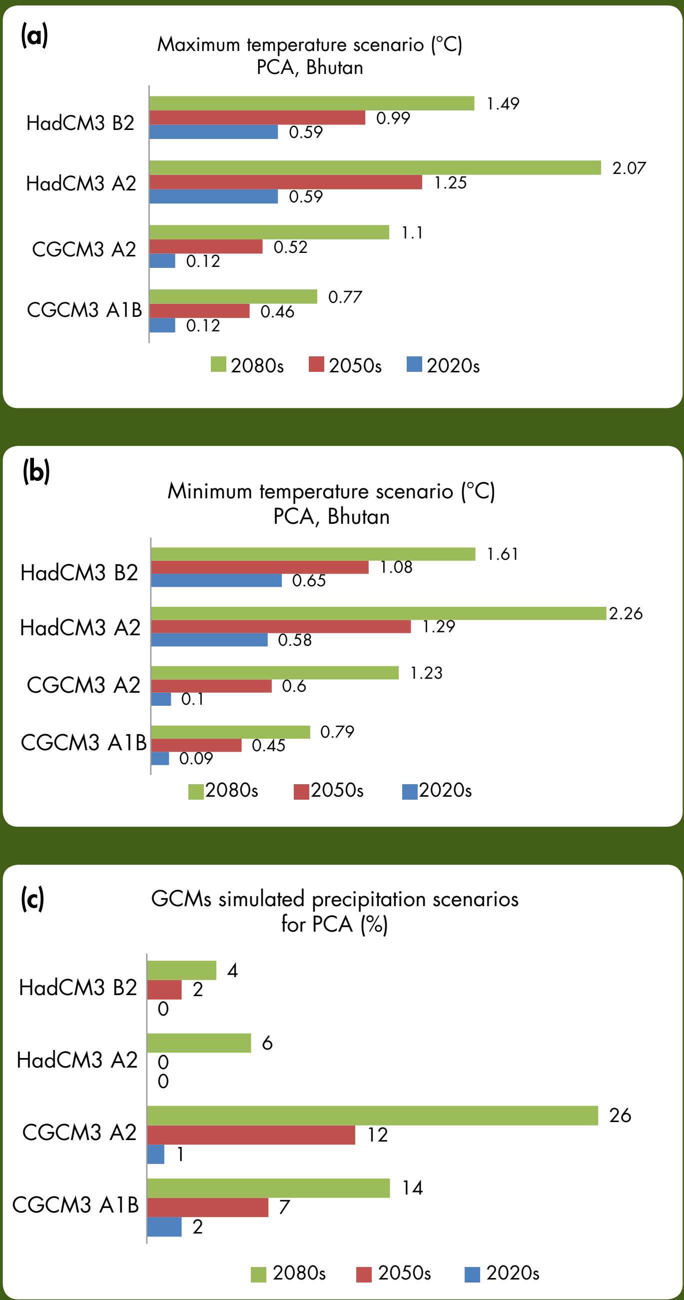


Figure 19: **Observed and NCEP simulated cycles of (a) monthly maximum temperatures, (b) minimum temperatures, (c) precipitation at Phobjikha (1997-2003)**



Climate change scenarios (2020s, 2050s, 2080s) developed through GCM for maximum and minimum temperatures (Figure 20a,b) based on the 1961-1990 baseline showed an increasing trend in both minimum and maximum temperature. The projection for 2080 maximum temperature against different scenarios (CGCM3 – A1B and A2; HadCM3 – A2 and B3) ranged from 0.77°C to 2.07°C. The implications of this increase could be significant for a high-altitude wetland like Phobjikha. The impact on PCA wetland ecosystems as a result of this rise in temperature could be aggravated by other drivers of change such as land use and land cover change and socioeconomic development. Likewise if we consider the GCM's (2020s, 2050s, and 2080s) simulated annual precipitation scenario (Figure 20c), CGCM3 models project a very wet scenario compared to HaDCM3 models, which project a moderately wetter PCA in the future. In general, CGCM3 projects a consistent increase in seasonal precipitation for both A1B and A2 emission scenarios throughout the twenty-first century. However, the model projects inconsistent trends in future seasonal precipitation changes only for autumn for 2020s (A1B), and winter for

Figure 20: **NCEP simulated (a) maximum temperature (b) minimum temperature, and (c) precipitation future scenarios for PCA**



2020s and 2050s (A2). Similarly, HadCM3 projects a consistent increasing trend of seasonal precipitation in summer and autumn, and a consistent decrease in precipitation in winter for both A2 and B2 emission scenarios throughout the twenty-first century. However, the model projects inconsistent trends in future seasonal precipitation change in autumn, for both A2 and B2. See tabulated data for NCEP (1961-1990) and GCMs scenarios for temperature and precipitation (Annex VI).

Land use and land cover change

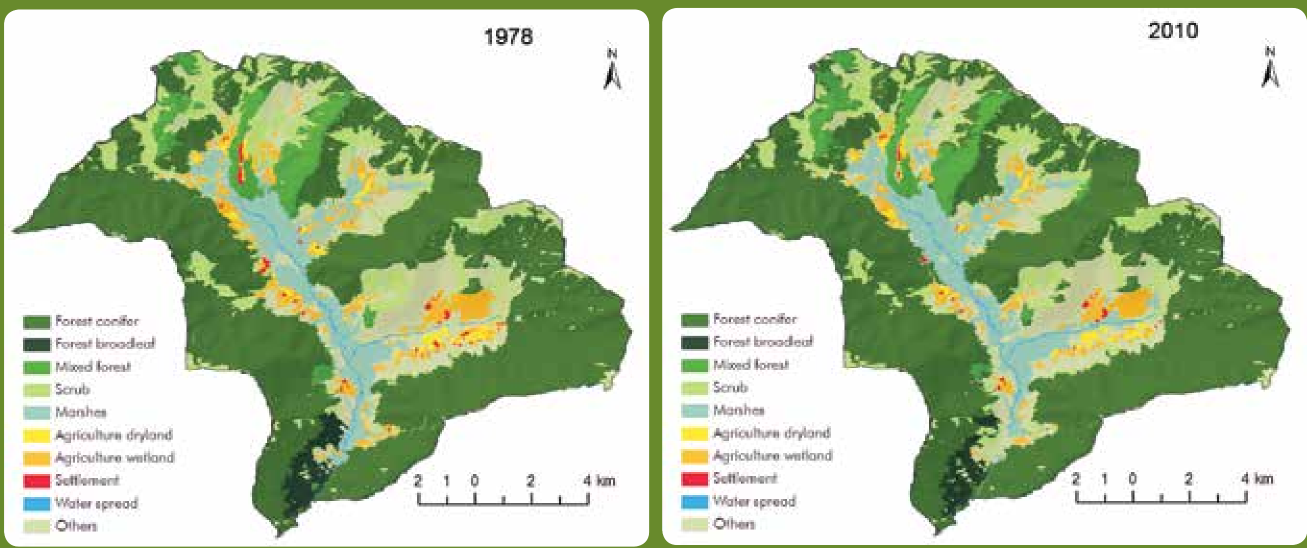
PCA's major land-cover types include agriculture, forests (mixed, coniferous, and broadleaf), bare areas, shrubland, water bodies, pastures, and settlements (Table 12). Forests covers 60% of the total area, followed by grassland (12%), and scrubland (11%). Agriculture accounts for only about 6% of the total area; however, communities are mostly agrarian and have taken to extensive potato cultivation, using even rocky areas within and on the edge of farmlands as well as patches of land previously considered unproductive by transhumance communities (Phuntsho 2010b). From 1978 to 2010, PCA experienced changes in land uses and land cover (Table 12, Figure 21), specifically increases in agriculture and settlements and decreases in marshes. Agricultural lands grew as lucrative potato cultivation was introduced to the valley and accessibility to markets increased through road construction to Phobjikha. The gentle slopes of the agricultural area also encouraged mechanized farming. As populations in PCA grew from an inflow of migration from nearby gewogs, government employees (teachers, extension agents, and health workers), and hoteliers (Phutsho 2010b), as well as the end of traditional migration by some Phobjikha natives, pressure increased on conifer forests, especially for timber and fuelwood. Changes in land cover were further exacerbated by the location of the settlement zone between the forest and wetland and the government's allocation of new lands to landless and fragmented families through the 'Kidu system'. After the mid-1990s, Phobjikha's cultural and aesthetic significance gained prominence and tourism started to flourish; this resulted in increased dependency on the forest, wetland, and water resources, and their decreasing area coverage.

From 1978 to 2010, coverage of conifer forests dropped by about 2% (from 9,194 ha to 8,905 ha), marshland decreased by about 1% (from 1,339 ha to 1,244 ha), and other land-cover types experienced subtle increases. More recently, between 2002 and 2010, both mixed and conifer forests, agricultural wetland, and settlements increased, which is reflected in satellite imagery (Figure 22). Although dry agricultural area decreased over the last eight years (2002-2010), agriculture is becoming more mechanized and cash crop driven (Pradhan 2011). According to local accounts, the Phobjikha Valley has experienced great change in the last ten years, and especially rapid change in the last few years due to increasing developmental activities, social transformation,

Table 12: **Land cover change in PCA between 1978 and 2010**

Land-cover types	Area in ha				% change from 1978-2010
	Year 1978	Year 1990	Year 2002	Year 2010	
Agricultural dry land	135	154	281	160	0.15
Agricultural wet land	556	703	594	739	1.13
Conifer forest	9,194	8,967	8,707	8,905	-1.78
Broadleaf forest	219	252	282	282	0.38
Mixed forest	815	877	820	858	0.26
Marshland	1,339	1,423	1,256	1,244	-0.58
Water spread	53	58	58	58	0.03
Settlement	31	46	58	62	0.19
Others (grass)	1,980	1,849	2,090	1,994	0.08
Scrubland	1,862	1,855	2,039	1,881	0.11
Total	**16,184**	**16,184**	**16,184**	**16,184**	

Figure 21: **Land use and land cover change between 1978 and 2010**



and modernization. The changes in land use, especially along the slopes of the valley, pose a serious threat to the watershed and the services it provides (Phuntsho 2010b). In recent years, unplanned development and a growing number of vehicles and hotels continue to threaten the fragile habitat of PCA. Villages lie on the eastern and western side of the river that runs through the middle of the wetland; tractors transporting farm produce and people often travel through the wetland instead of using the poorly laid stone roads (RSPN 2007).

Human-wildlife conflict, pests, and diseases

Dramatic increases in animal attacks on crops are a major concern, particularly red-billed choughs (birds) that eat sown seeds and wild boars that dig up tubers. Respondents from Taphu reported a larger impact from bird attacks as pigs could be chased away, but birds kept returning during the sowing season. Leopards and other predators sometimes attack livestock and pets as well. Animal attacks were limited prior to the start of large-scale commercial potato farming.

Figure 22: **Comparative satellite images of different parts of PCA from 2000 and 2011**

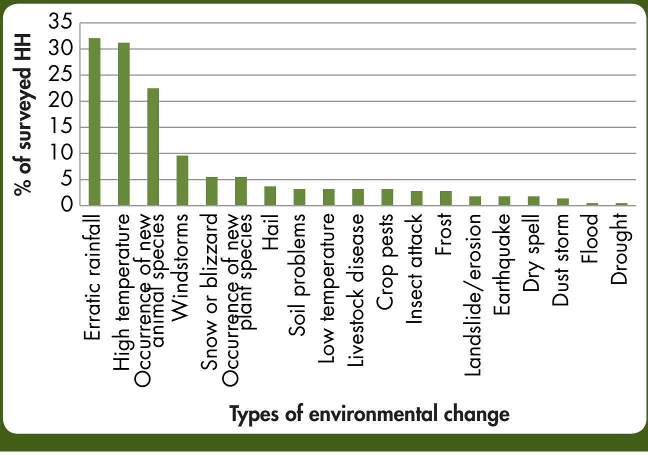
The increase in the incidence of pests is of critical concern. Residents of Drang noted that these pests have been increasing for 10 to 15 years. Pesticides are only applied to potato crops to encourage high commercial yields; turnips and radishes are cultivated without any pesticides for household use. Respondents from Gangtey noticed that the increase in pests only started when commercial potato cultivation began. Pest incidence appears to be inversely related to the amount of annual snowfall. Every household reported using various pesticides. Insecticides often destroyed everything (including the potato plant itself), leaving only the potatoes underground. Residents of Drang mentioned mixing chemical fertilizers and pesticides with cow dung and manure and applying it to fields. Communities reported distress that harvests could be reduced up to 50% due to pests, even with heavy pesticide use. Though local communities did not report use of inorganic pesticides, it was observed that they are widely used on farmland now and are detrimental to the wetlands as the chemicals flow into marshes. With additional chemicals applied every year to deal with the increasing incidence of pests and lower yields, this could be a maladaptive practice with serious consequences for the sustainability of agriculture in the Phobjikha Valley.

Community perceptions of environmental change

According to LAT, around 53.7% of households mentioned that they observed changes in temperature patterns, and 56% reported noticing changes in precipitation patterns in the ten years preceding the survey. Other major changes observed were erratic rainfall (33%), high temperatures (31.7%), the arrival of new animal species (22.5%), windstorms (9.6%), the occurrence of new plant species (5.5%), and snow or blizzards (5.5%) (Figure 23).

Communities expressed worry about changing weather events and erratic and unpredictable weather conditions damaging their crops, especially potato. In PCA, ideal potato cultivation requires adequate snowfall. As one of the most important environmental factors in potato production, snow retains moisture in the soil and also appears to limit the occurrence of pests in the crop. Previously heavy snowfall appears to be decreasing both in intensity and duration. In the past, the ground remained covered by snow for the whole winter, but now it melts in just one or two days. Communities noted that the lack of snow correlates to a decrease in potato harvest. For example, fields

Figure 23: **Environmental changes perceived by the HH in PCA during the 10 years preceding the survey that had not occured before**



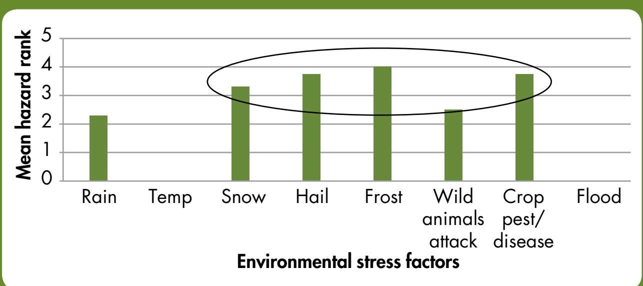
yielding 15,000 kg of potato now produce only 6,000 kg. Snowfall has currently given way to heavy rainfall in many places and communities perceived an increase in rainfall duration and intensity, in addition to new periods of rainfall. Changes in rainfall patterns have also negatively impacted the production of crops by eroding vital topsoil and nutrients, as well as affecting the roads, thus limiting the timely sale of the annual harvest. PCA residents stated that in the past few years, there has been a break in precipitation with little rainfall in September followed by untimely heavy rainfall in October. Rain during the harvesting months in mid-September to October causes potatoes to rot, severely reducing the harvest (up to 50%) and also delays the sowing of wheat (only grown in Drang). Irrigation is unnecessary for potato cultivation, and rainfall provides enough moisture for food crops such as radish and turnip. Only the community from Drang required irrigation because of wheat cultivation; for this they created canals that received sufficient water.

Other weather events, such as frost and hailstones, were also perceived to impact crop production. The change in the timing of the frost is problematic for farmers – as long as the potatoes are underground and unharvested, frost does not affect the yield. However, if frost occurs post-harvest, one rotting potato can ruin an entire harvest during storage. Early frost, too, can destroy the shoots of the potato plant, decimating the yield. The changes in timing also affect buckwheat cultivation, which is still practised in some places. Remarkably, rising temperatures are considered positive as warmer temperatures appear to limit the occurrence of frost and its consequent negative impacts. The erratic nature of weather events is also seen in changes in the timing of hailstorms; if they occur when potato shoots are growing or crops are flowering, they can also greatly reduce the final yield.

Through a hazard ranking exercise (Figure 24), communities listed and ranked each of their environmental concerns on the basis of impact.

The main concerns (circled above) communities identified in PCA were changes in snowfall, hailstorms, and frost as well as the increase in wild animal attacks, crop pests, and diseases, which mostly affected the potato cultivation. A respondent from Moll compared frost and wild pigs saying, “They destroy the field once and disappear”. Unseasonable rainfall and higher temperatures affect agricultural activities, delaying the sowing and harvesting of crops and changing the length of the growing season with immediate impacts. Pest incidence and the decrease in snowfall reduce harvest quality with the amount of snow affecting the incidence of pests, which either reduce the size of the potatoes and/or ruin part of the harvest and, subsequently, household incomes. Other weather events interact, eventually reducing overall production and affecting the living standards of communities that get by on a year-by-year basis (Figure 25).

Figure 24: **Environmental stress factors compared by their hazard rankings based on community hazard ranking excercise**



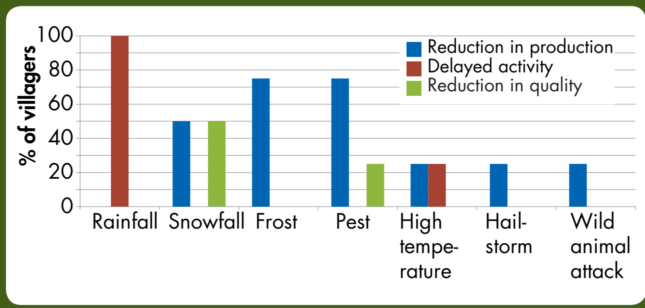
Impact assessment

Over the last 30 years, PCA has experienced changes in land-use patterns as seasonal grazing land is converted to agricultural land. Development activities brought roads, electricity, and tourism to the valley, and invited an flux of settlers from outside the valley in search of economic oppprtunities. The valley also saw changes in climate variability with increasing trends in precipitation and temperature. Projections revealed that the trend of rising temparture will continue. Such changes are challenging the ecosystem integrity and values of PCA, and will likely continue to do so. In the following section, potential impacts on ecosystem services, biodiversity, and human wellbeing have been analysed.

Impacts on biodiversity

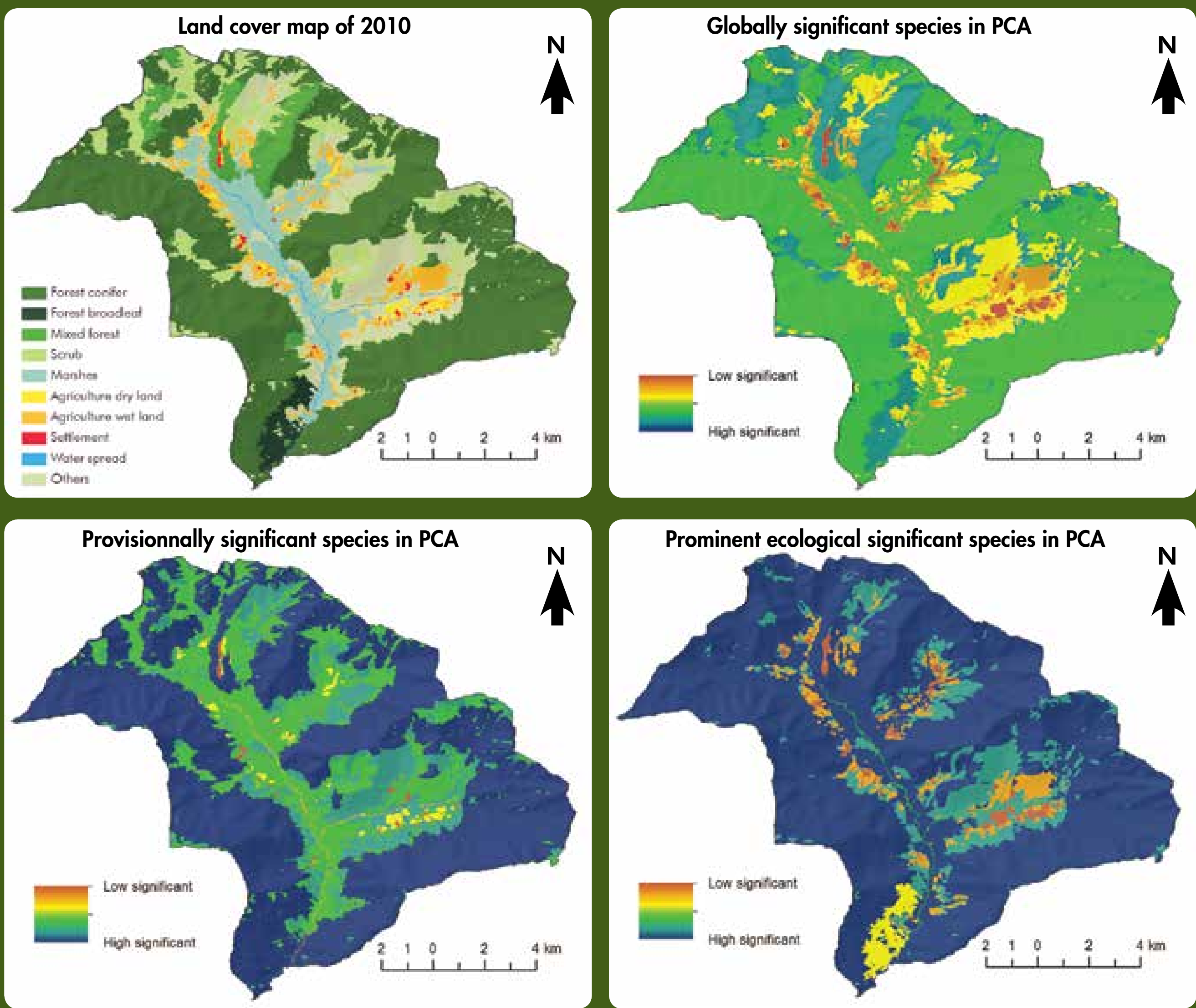
Analysis of land cover (2010) against the habitat of selective globally significant species (Annex V-A), selective provisionally important species (Annex V-B), and selective ecologically significant species (Annex V-C) from the PCA highlighted that all forest types (conifer, broadleaf, and mixed forests) are highly significant in terms ecosystem services. Varied services range from daily provisions for communities, to habitat for a large number of ecologically or economically significant species. The wetland ecosystem, comprising marshes, scrub, and grasses, is equally significant in terms of aesthetic and ecological value (Figure 26). The analysis points to the fact that ecosystems that provide significantly for people are equally significant as habitats for globally significant species. Several ecological species help regulate and keep the ecosystem functional to sustain these services in the future.

Figure 25: **Specific impacts of each environmental concern on crop production**



Source: Field data

Figure 26: **Significance of different land-cover types with regards to globally significant, provisionally significant, and ecologically important species**



Though there have been some positive developments in economic development and ecosystem enhancement over the last 30 years, climate change trends and projections indicate future challenges for both natural and modified ecosystems, both significant for PCA's flagship species, the Black-necked crane. The crane's major roosting area is along the wetland core area at the centre of the Phobjikha Valley, where Nake Chu flows and there is adjacent open water (Figure 5). The cranes mostly feed on used scrub (Yushania bamboo), followed by agricultural fields, marshes, and pastures, depending on the availability of food (Wangmo et al. 2011). Any developmental activities near these areas – and even the projected rise in temapterature – may change the fate of these habitats and the species composition. This is especially important considering the significance of this fragile area for globally threatened species, ecologically significant species, and ecosystems with high levels of human dependency.

Impacts on ecosystems and ecosystem services

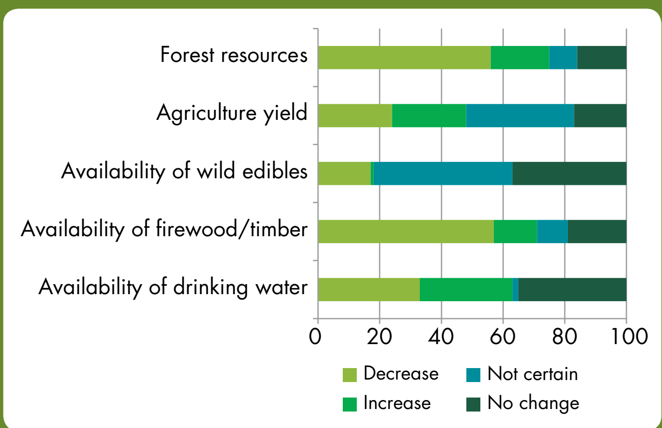
The communities in PCA perceived that the periodic changes in land use, together with changes in climatic variability, soil conditions, and socioeconomic development, have affected the availability and supply of various ecosystem goods and services. These perceptions, however, were not very clear. While some services have increased positively, 57% of the local community indicated that the availability of fuelwood or timber in the surrounding forest has decreased and 56% of the community felt that forest resources had decreased (Figure 27). There were mixed results on services such as the availability of drinking water and agricultural yield.

The flowering of dwarf bamboo (Yushania) and its natural death raises concerns of ecological changes. Yushania microphylla started flowering throughout Bhutan in 2011, raising questions for ecological succession, such as what species will take over and how this could change species composition in the Yushania dominated wetland. The main purpose of establishing plots during the rapid biodiversity survey along the Nalagang series was to monitor such changes annually and determine the effect of grazing, climate change, and natural phenomena in the valley.

People perceived increasing threats to agriculture, the primary basis of livelihoods in PCA, due to erratic rain and snowfall, windstorms, hail, and frost. Likewise, livestock grazing is under stress from changing weather patterns and land uses. There is also the perception that intensive farming-based livelihood practices are not conducive given the limited space for agriculture between the interface of wetland and forests. This can have implications on the core wetland area, a winter roosting habitat for the Black-necked crane requiring protection. In addition, the use of cross-contour lines from uphill to downhill to ease water drainage for potato growing has induced soil erosion and resultant loss of soil nutrients. The decrease in soil fertility has prompted some households to either practise shifting cultivation or apply chemical fertilizers. Among the households engaged in agriculture, the majority reported using chemical fertilizers and pesticides. However, most reported a decrease in the use of fertilizer due to high costs. A survey by RSPN in 2003 indicated that these households use more than 160 tonnes of different kinds of chemical fertilizer each year for potato cultivation. Local people have limited knowledge on the preparation and use of organic manure; most farmers in the valley own cows, but cow dung is rarely used as fertilizer. Increased use of chemical fertilizers has led to eutrophication of the wetlands at many patches, prompting changes in plant succession patterns.

Other critical concerns for ecosystem services are the fading traditional and cultural values associated with the wetland and the decreasing significance people feel towards the cranes. This lack of connection could lead to insensitive development and a rapid degradation of Black-necked crane habitat (Lhendup and Webb 2009). The agriculture-

Figure 27: **People's perceptions of changes in ecosystem services over the last ten years in PCA (in %)**



Source: Ecosystem Assessment Report 2012 livestock grazing cycle that people traditionally practised was closely linked to Black-necked crane survival. When people left for summer pastures in winter, they left open farms and marshes in which the cranes would roost. Now, changes in wetland shrub vegetation and increasing sedentary farming threaten the population of resident and migratory birds. Other important factors affecting ecosystem services include land use and land cover change through increased settlements and agricultural expansion, together with pressure from livestock grazing, hunting, tourists, noise pollution from vehicles, and the nuisance created by a rising number of stray dogs. According to the LAT, communities in Phobjikha are distressed by wildlife-related damages in the form of crop raiding and livestock depredation by wildlife, mainly wild boars (79.8%), big wild cats (35.3%), deer (26.1%), and wild dogs (21.1%). The extent of the damages to household incomes and to the ecological structure, function, and values of the ecosystem needs further analysis; this could play an important role in the development of a comprehensive management plan.

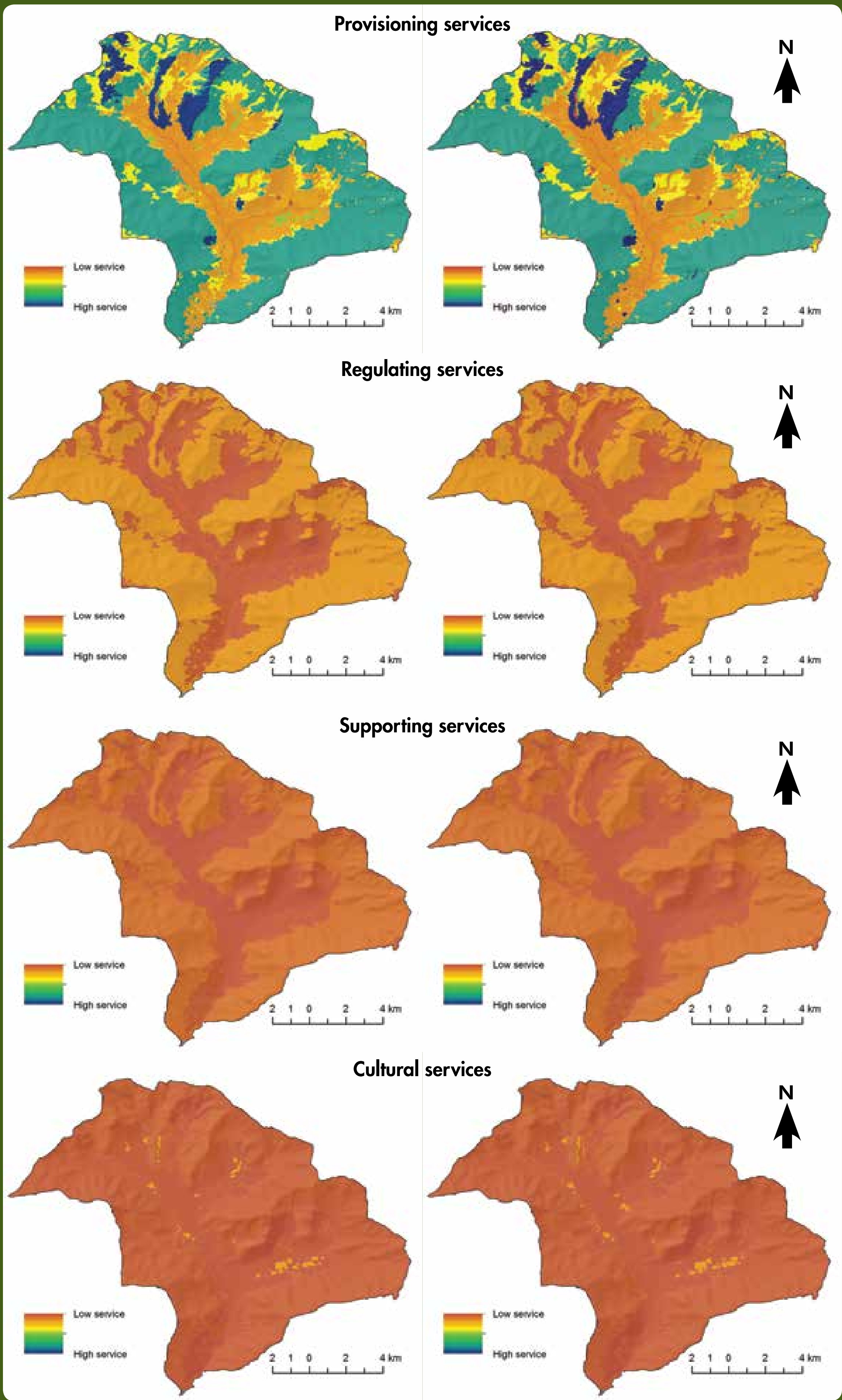
The effects on provisional services and cultural services are especially evident when comparing changes perceived by people with actual land cover change between 1978 and 2010 (Figure 28). During the 32-year span, dependency increased on the catchment areas around the wetland, the scrubland at the interface of the core wetland, and forest ecosystems mainly for provisions such as fuelwood, fodder, and NTFPs. Cultural services, particularly along the southern face of PCA, seem to be decreasing in significance in terms of aesthetic and non-material benefits. The role the entire landscape plays in recreation, tourism, aesthetic appreciation, and inspiration for culture and traditions, as well as the spiritual existence of the place itself, should be prioritized and strengthened in the future. Maintaining the habitat or supporting services of PCA, which underpin all other services, is even more crucial. PCA's ecological importance as a habitat for the Black-necked crane must be kept intact; protecting a habitat means maintaining everything a species needs to survive, including food, water, shelter, and interactions. The regulatory services provided by different forest and wetland ecosystems in PCA need particular attention as they ultimately influence a host of processes including local climate; air, water, and soil quality; carbon storage and sequestration; moderation of extreme events; removal of pollutants from chemical pesticides and fertilizers; prevention of pests and vector-borne diseases through sheltering natural controls; pollination; and maintainance of soil fertility in farmlands. It is also necessary to balance, agricultural practices, grazing cycles, and wintering and roosting cycles of Black-necked cranes.

Impacts on crop and food production

Results from the LAT indicated that about 94% of the total population living in the PCA depend on freshwater resources for drinking water supply, and 38% depend on these resources for irrigating their farmlands. Respondents indicated the availability of drinking water has increased over the past few years, but they were uncertain about changes in water for irrigation. Climate change is expected to affect water volume in the PCA through changes in precipitation patterns and the amount and availability of freshwater for domestic consumption, agriculture, and energy production. A comparison of perceptions with the GCM's (2020s, 2050s, and 2080s) simulated annual precipitation (Figure 19c) suggests that as PCA gets wetter with the increasing trend of seasonal precipitation, the availability of water for the maintenance of core wetland ecosystems, and for people's use will not be limited. However, if the trend in agricultural intensification for potato cultivation continues, together with increased use of fertilizers and pesticides, this may eventually lead to degradation of the wetland in terms of surface and subsurface water quality, eventually threatening the survival of wetland vegetation.

As per the LAT, several factors, particularly low market prices of crops (84.4%), shortages of labour (83.5%), wildlife related shocks (79.4%), and insufficient cash investments (78.4%), had constrained farming activities during the 12 months preceding the survey (Table 13). A considerable percentage of male-headed households claimed shortages of labour (84.8%), low market prices of crops (81.6%), insufficient cash investments (81%), wildlife related shocks (78.1%), lack of investment (56.2%), and pests and diseases (50.5%) to be major constraints for faming. Though challenges to farming confronted by female-headed households were similar, they reported low market prices for crops (89.2%), shortages of labour (83.1%), wildlife related shocks (81.9%), and insufficient cash investments (73.5%) as major problems. An overarching threat is the fragmentation of farmland and the dependence on a single crop economy.

Figure 28: **Comparison of four kinds of ecosystem services by land-cover change in PCA between 1978 (left) and 2010 (right)**



Impacts on tourism

Tourism has been on the rise since PLCA's establishment, and especially after the development of Bhutan's tourism industry. The number of visitors increased from 817 in 1996/97 to 4,660 in 2010/2011. Phobjika Valley's aesthetic ambience and the endangered migratory crane are major tourist attractions. But unless ecosystem services and development interventions are carefully monitored and managed, tourism may be negatively impacted as climate variability and other drivers of change influence land use and wetland vegetation. The combined effects of drivers of change may also affect the production and supply of tourism supply chain products such as food, vegetables, and handicrafts (Sedai 2012), in turn affecting local lives and livelihoods. Given Phobjikha's increasing number of tourists, and the national priority given to managing the landscape conservation area, tourism prospects look promising. RSPN also maintains an information centre in Phobjikha to spread awareness to visitors and communities about the importance of the landscape. As tourism infrastructure is developed, care should be taken to closely link it with communities' culture and values, and to consider how to ensure benefits from tourism reach the community.

Table 13: **Perception of households (HH) on issues constraining farming activites during the 12 months precding the survey**

Issues	Yes (% HH)	No (% HH)
Low market prices for crops	84.4	15.6
Shortages of labour	83.5	16.5
Wildlife related shocks	79.4	20.6
Insufficient cash investments	78.4	21.7
Pests and diseases	55.2	44.8
Lack of instruments or tools	50.8	49.2
Infertile soil	30.9	69.1
Natural hazards	26.6	73.4
Lack of techniques or knowledge	18.8	81.3
Soil erosion	8.3	91.7
Lack of water	6.2	93.8

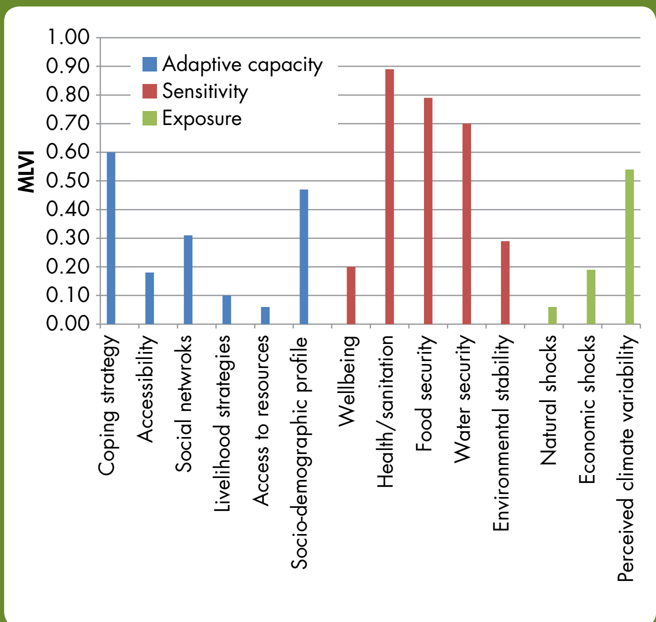
Source: LAT 2011

Impacts on people and their livelihoods

In analysing the sub-dimensions and sub-components of the mountain livelihoods vulnerability index of the PCA, the sensitivity to health or sanitation, and food and water security ranked higher than exposure to perceived climate variability, and natural and economic shock (Figure 29). Adaptive capacity, in terms of the presence of coping strategies and social networks, is high, however, access to resources remains low. Community organizations, which provide self help through soft loans and loans from banks have helped enhance the adaptive capacity of households. However, adaptive capacity in rural mountains is also influenced by access to health, education, and information facilities, as well as access to services, inequitable access to productive assets, and options for livelihood diversification. In Phobjikha, mountain livelihoods vulnerability is high given the heavy dependence on potato monoculture, which is highly weather-dependent. Pests and wildlife attacks remain the main concerns, for which high quantities of pesticides and chemical fertilizers are applied. This coping strategy could be maladaptive in the long run, as chemical fertilizers and pesticides affect soil quality, a fact noted by several of the communities.

Communities' proximity to institutions and their accessibility to social networks are key to increasing adaptive capacity. Though there are few institutions in place in Phobjikha, communities indicated a high level of satisfaction with the quality of services provided. Free health and education services are guaranteed

Figure 29: **Mountain specific livelihood vulnerability index (MLVI) for the PCA**



Source: LAT 2011

by the government, however these facilities are located far away. Government restrictions on forest resource use were respected as the residents were aware of overexploitation. Eight community forest management groups in Phobjikha have been instituted by the government and supported by NGOs, such as RSPN. One major concern was the processing time required time for loan applications through the Bhutan Development Bank Limited, the primary rural development loan provider. If loans are not available on time, the purchase of vital agricultural inputs, such as seeds and fertilizer, is delayed, affecting planting times and reducing harvests.

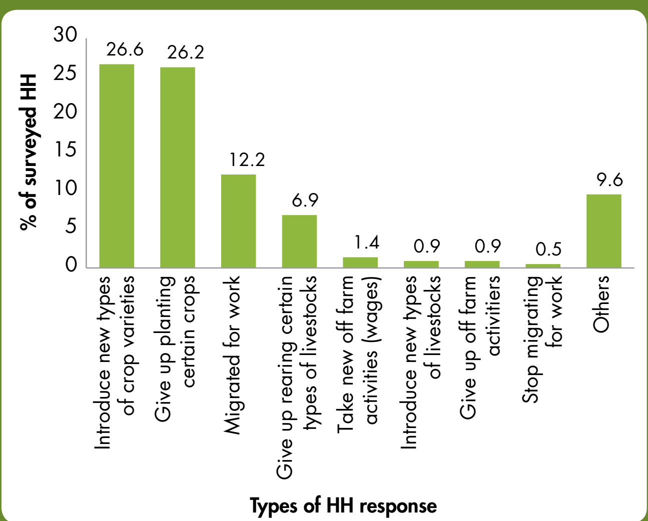
Coping and adaptation strategies

Like other rural mountain communities in the Himalayan region, the communities living in PCA are highly dependent on the natural environment for food and other ecosystem services. Watersheds and forests are directly relevant to their household economy: 78% of households indicated their dependency on PCA's watershed. Socioeconomic changes are inevitable given the changing environmental and development perspectives. Residents of PCA appear to practise a wide range of coping strategies in the context of natural, social and economic shocks or stress. The majority of households are dependent on credit and reduction of expenditure (Figure 31). For communities in PCA, changing patterns of temperature and precipitation mean adopting new farming technologies (for example, new varieties, tractors, and fertilizers) and cropping patterns. The survey found that 26.1% of households had given up planting certain kinds of crops, while 26.6% had introduced new crop varieties. Livestock rearing was also affected, though less so than agriculture. Around 7% of households gave up rearing certain livestock; interestingly, 11.2% of female-headed households gave up rearing certain livestock types, while only 4.1% of male-headed households did. Another consequence of changes in temperature and precipitation patterns was a shift to non-farm activities; members of 12.8% of the households surveyed migrated as a response to these changes. Overall, only a small percent of households made changes in their lives and livelihoods as a response to temperature and precipitation changes (Figure 30).

Conservation and management practices

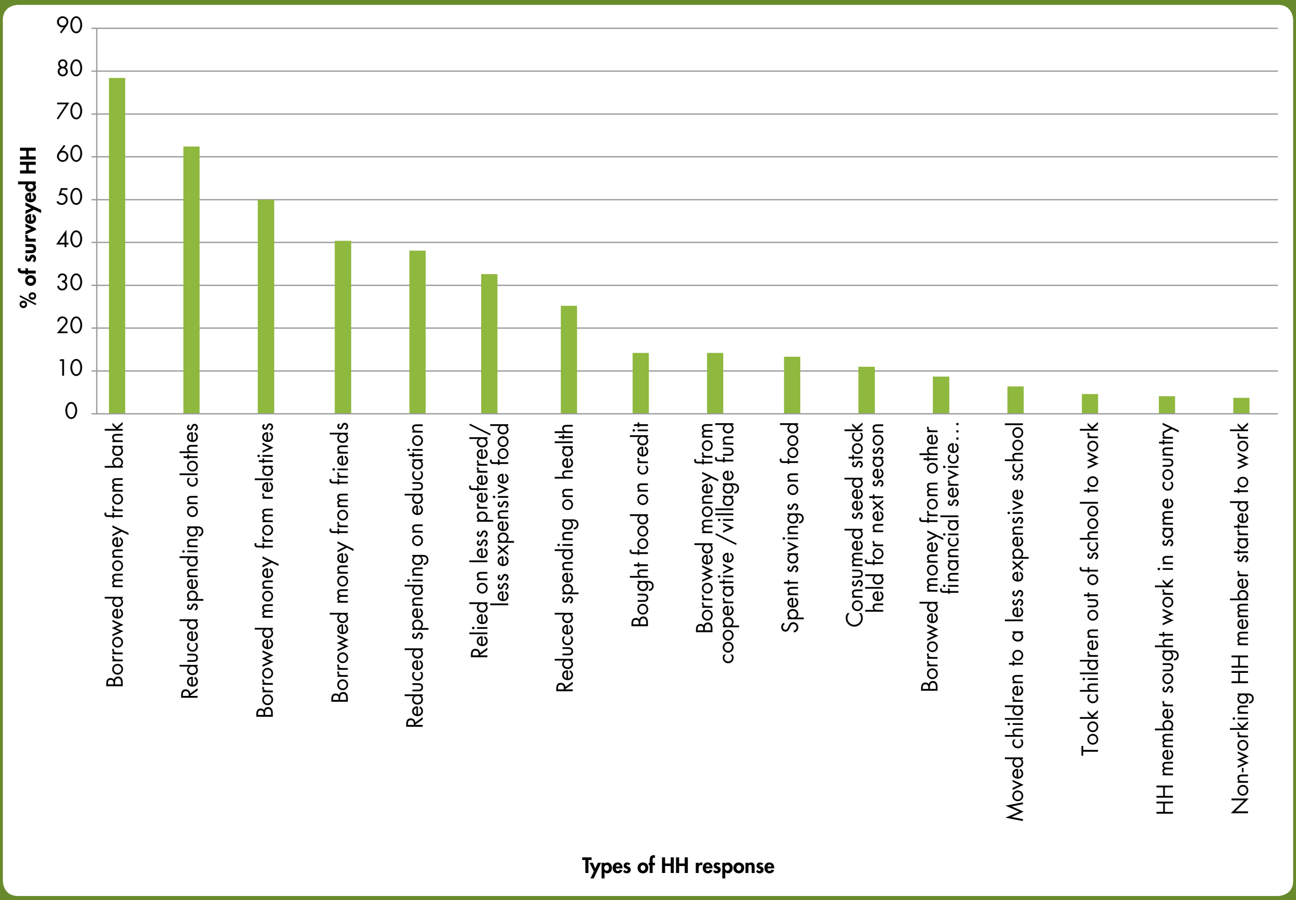
The history of conservation interventions in PCA started with an interest in understanding the linkages between conservation and development (Dorji 1998), which led to the establishment of RSPN in 1987. This non-governmental conservation organization has played an important role in conservation of the endangered Black-necked crane in the Phobjikha Valley. Efforts were made to increase their count by managing the valley as a protected area, with a limited number of community-based interventions. Gradually, the focus shifted to a participary approach, emphasizing raising awareness about the crane and its habitat. An interpretation centre was established and communities were involved in outreach and dissemination of information about the crane. Research also became an important element. The focus of research included vegetation changes in the valley; the relationships between the wetland ecosystem and neighbouring ecosystems, the wetland and agriculture, and the crane and the people. Some research also focused on the crane's role in culture and tradtion, and how this role influences its habitat. The rich cultural traditions associated with the Phobjikha wetland received careful consideration with national policy interventions highlighting these interrelationships, such as the Forest and Nature Conservation Act of Bhutan, 1995. Various studies were conducted in PCA to incorporate scientific information in the management of the areas, as well as in decision-making systems. A number of permanent plots were also designated to monitor changes in individual flora and fauna. Conservation was discussed not only in terms of protection of the

Figure 30: **Household responses to changes in temperature and precipitation patterns during the 10 years preceding the survey**



Source: LAT 2011

Figure 31: **Household responses to natural or social or economic shock/stresses in the 12 months preceding the survey**



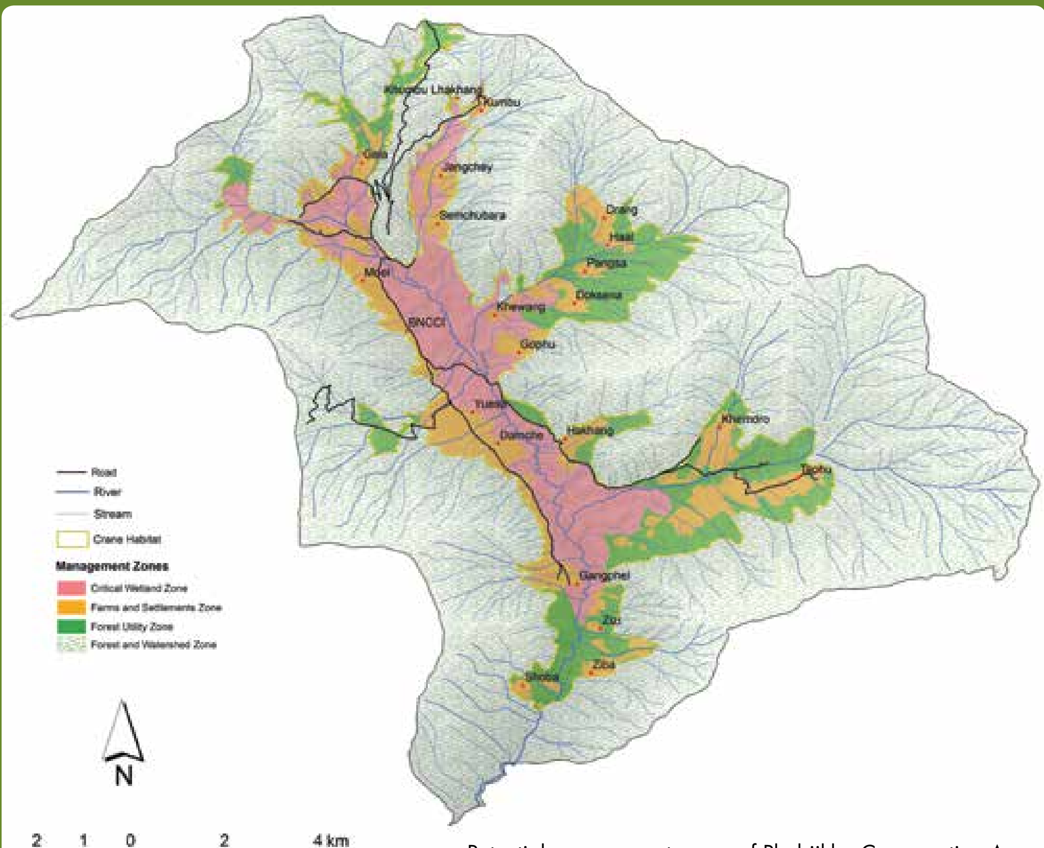
Source: LAT 2011

crane and its habitat, but also considering the other services the landscape delivers. This study is one such effort to understand the conservation of biodiversity from socioeconomic, sociocultural, environmental, and development perspectives. PLCA is a concept meant to broaden the perspectives of conservation from a protection to a wise-use approach. The draft management programme for PLCA (Dorjee et al. 2004) is in place, which advocates for four different management zones: critical wetland zone, critical forest and watershed zone, forest utility zone, and farms and settlement zone (Figure 32). This concept creates a win-win situation for both the landscapes rich biodiveristy and people. The PLCA Management Programme aims to further strengthen actions for Phobjikha landscape management. A PLCA Programme Committee has also been formed to address community concerns and local needs, and to sensitize the wider community to the conservation of cranes and management of their habitat (RSPN 2007).

Conservation and development opportunities

PCA offers a unique opportunity for implementing an ecosystem approach to biodiveristy conservation and management, linking the conservation of biodiversity with the farming system adopted by local communities, as well as creating linkages to their culture and traditions (Pradhan 2011). The proposed management zonation scheme can promote the differentiation of ecosystem services from each zone and their maintenance accordingly. For example, the wetland zone would serve as an important habitat not only for the endangered Black-necked crane, but also for the people and communities in terms of provision of water supply, regulation of water balance, water purification, waste management, microclimate stabilization, and carbon sequestration. Likewise, the forest and watershed zone would be important not only as habitat for many rare and endangered species (e.g., tiger, red panda), but also in terms of aquifer recharge and regulation for the wetland and the provision of a continuous water supply to surrounding farmland. The forest utility zone and farms and settlement zone would focus more on provisional services – largely meant for community use and benefit, the enhancement of appropriate sociocultural and infrastructural development, and the maintainence of the spiritual, religious, cultural, educational, recreational

Figure 32: **Potential management zones of PCA**



Potential management zones of Phobjikha Conservation Area

Source: RSPN

aspects of the landscape. The open dwarf bamboo zone, which is comparatively drier than the core area of the wetland, is not only used as pasture for local livestock. It also plays an important role as a catctment area of the landscape. Locals appreciate its ecological and conservation value of controlling soil erosion and landslides, as well as maintaining water flow to the wetland core area. This serves as the main grazing area during summer when the valley floor gets waterlogged.

Regarding development opportunities in PCA, there is huge potential for ecotourism, particularly low-volume, high-value tourism. The private sector and other international development partners could also be tapped to support ecotourism infrastructure development. Potato farming, the valley's central livelihood activity, can benefit from value addition through organic certification and links to sustainable soil and water management technologies. The government's conscious effort to build underground grid electricity and pilot electricity from solar voltaic cells can open opportunities for adopting renewable energy options in houses and lodges.

Recommended strategies for building resilience

Directly dependent on natural resources for their livelihoods, communities in PCA are vulnerable to any changes in natural systems. One major concern is the change in the wetland habitat, as well as the challenges this poses to the survival of the vulnerable Black-necked crane and other globally threatened species that interact with a range of habitats, from natural wetlands to agriculture. The impacts of climate variability on lives and livelihoods in PCA are further compounded by several non-environmental factors identified by communities, such as the lack of instituted markets, transport facilities, and roads, the quality of education, and the distance to schools. Reducing vulnerability for PCA ecosystems and communities therefore requires a holistic approach in which adaptation strategies are considered alongside strategies for poverty alleviation, biodiversity conservation, and community development. This calls for a landscape approach to address intersectoral vulnerabilities. A landscape approach may also help strengthen dialogues for transboundary conservation, for example, between Bhutan and China for Black-necked crane conservation, as well as the enhancement of regional tourism services.

Management and adaptation strategies that may help sustain PCA's ecosystem services and build people's resilience to socioeconomic and ecological vulnerabilities are suggested below:

Improve understanding of climate uncertainty and continuously monitor changes: Much literature indicates that the degradation of ecosystems harms the world's poorest, many of whom are highly dependent on resources from weather-dependent ecosystems (IPCC 2001; MEA 2005; Agrawal and Perrin 2008). A degree of uncertainty exists about the future direction and magnitude of change in the eastern Himalayan region (Singh et al. 2011) and consequences for mountain ecosystems and people (Kohler et al. 2010). Strategies should be implemented that increase the flexibility of ecological and socioeconomic systems to cope with future changes, address drivers of vulnerability, build response capacity, and reduce risks (Gbetibuou 2009; Chaudhary et al. 2011). Climate change scenarios in the PCA show trends of increasing temperature and higher precipitation, which will significantly impact ecosystems, ecosystem services, and the livelihoods of people living in the area. Local people have also perceived changes in climate and resultant impacts on different ecosystems, including agriculture. Changes in the state of ecosystems, climate, and livelihood patterns should be continuously assessed and monitored to better inform future action and responses.

Improve social protection services: Major hazards impacting the livelihoods of communities in the PCA include weather-related factors such as frost, hail, and snow; environmental stresses such as crop pests and diseases; and socioeconomic factors such as market linkages and development infrastructure. Improving capacity in terms of innovative farming practices and low cost soil and water management technologies should help. It would also be useful to improve agricultural subsidy mechanisms for poor farmers with small and fragmented land holdings and for nomadic herders who abandon their fields in PCA during the winter for the cranes. Wood scraps from traditional chopping of timber for house construction and excess pine leaves could be used to produce alternative energy products such as bio-briquettes. Enhanced support services, including those from the government, such as education and health, access to credit, crop and livestock insurance, better access to agriculture expansion, new agriculture technologies, and cooperatives may improve quality and access to social protection services. Special focus should be given to women and other disadvantaged groups, as well as to nomadic herders. Strengthening existing local institutions could also be useful, including reviving the functional traditions of having community nominated forest guards or 'resups'. Likewise, the 'women in environment' group established in Phobjikha needs strengthening in terms of their proactive involvement in the Phobjikha Conservation Development Committee for both conservation and development activities.

Diversify livelihood options to reduce poverty and social inequality: The majority of households in the PCA are dependent on agriculture, specifically a single cash crop – the potato. During the Livelihoods Assessment Tool (LAT) survey, households mentioned erratic rainfall, changes in snowfall duration, and intensity of frost and hail affecting potato productivity. Households have differentially adopted coping strategies: some benefitted from services from local institutions, while some could only mobilize coping within their own households. To address the differential coping situation, livelihood diversification must be a part of major adaptation strategies for PCA and must be promoted over economic dependence on potato monoculture. One option is the promotion of nature-based tourism. It is essential to link communities to the tourism supply chain (for food and other products such as handicrafts). This will add greater value and utility to ecosystems, thus encouraging community-driven conservation and promoting positive attitudes toward retaining the landscape's cultural, natural, and religious value.

Strengthen adaptive strategies by building on short-term coping strategies: Many households in the study area responded to stress with short-term coping strategies such as borrowing, reducing living expenditures, and buying food on credit. Such strategies not only deplete a household's livelihood asset base, but may actually render it more vulnerable to future shocks and stress. Spontaneous responses to short-term shock events must be translated into planned and strategic long-term actions that increase the resilience in the mountain landscape, increase robustness despite uncertainty, enhance the flexibility of both ecological and socioeconomic systems, and guarantee equity with regard to resource use and benefits. Emphasizing literacy, formal or informal education and awareness programmes, gender empowerment, the creation of income generation opportunities, and the development of appropriate physical infrastructure and market linkages could be a basis for adaptation. Households with better education and awareness would be better able to diversify their livelihoods and income sources, thus reducing their vulnerability.

Manage natural ecosystems for sustained ecosystem goods and services: Careful zoning and the preparation of zone-specific management plans and programmes are essential to maintaining the PCA's natural ecosystems. Maintaining the relationship between the wetland ecosystem and the communities that live in adjacent areas would help encourage sustainable farming practices, integrated soil and water management, enterprise-based conservation interventions, and greater economic value given to ecosystem goods and services. This would also encourage the maintenance of entire ecosystems, including microhabitat conditions for crane survival in PCA, as indicated by Wangmo et al. (2011). The majority of communities perceived that the forest extent and availability of fodder, fuelwood, and other non-timber forest products have decreased over the last ten years due to population growth and the overconsumption of forest resources. This calls for better enforcement and greater awareness of government rules, more clearly defined management zones, and the promotion of the equitable allocation of resources and benefits from ecosystem services to the communities in the PCA.

Promote and strengthen an integrated conservation and development approach through conducive policies and institutions: PCA is facing mounting challenges in maintaining its ecosystems and providing opportunities to local communities for integrated development. An integrated approach to conservation and development interventions is inevitable. For such, it is important to understand the landscape characteristics and address issues related to summer and winter farming, and the linkages between dryland farms in Phobjikha and wetland farms in Ada. It is similarly necessary to manage the conifer forests in Phobjikha and broadleaf forests in Ada as a contiguous forest patch used a single habitat by several flagship species such as tigers, cranes, and herons. Most importantly, an integrated approach will ensure large, intact habitats in and around protected areas, and will help long-term sustenance of ecosystems and their services. This will increase the resilience of both ecosystems and people, and create mechanisms for adaptation, moving beyond short-term coping strategies. Policy interventions should therefore focus primarily on addressing the underlying causes of vulnerability and communities' limited adaptive capacity. It will also be necessary to bridge the gap in understanding between local institutional mechanisms and external institutions (public and private). This can be achieved by identifying mechanisms for sharing information across institutional and sectoral boundaries and strengthening the capacity of the staff responsible for policy development for better coordination and effective management of resources

Raise awareness of the ecological and cultural significance of the landscape: There is a critical need to raise stakeholder awareness of the importance of designating the entire Phobjikha watershed and landscape as a Community Conserved Area. This will inform to what extent the ecological, cultural, and religious value of the Black-necked crane can support the conservation and maintenance of the landscape and reduce the risk of wetland habitat degradation. The value of the wetland must be assessed, explored, and highlighted in terms of its regional and global significance. Mechanisms for sharing information on crane monitoring activities through systematic data management and the dissemination of information to a wider audience, including training staff or community members as necessary, will be crucial. The further development and promotion of the Black-necked Crane Visitor Center, which serves as a crane observatory, would help facilitate enhanced understanding about the PCA among tourists, students, and local communities, as well as facilitate crane-related research.

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Annexes

Annex I: Mountain Specific Livelihoods Vulnerability Index (MSLVI) Framework

The table below describes a set of major components and sub-components of the MSLVI framework which capture 'mountain specificities' as defined by Jodha (1992). (Weights are in brackets.)

Main dimensions	Sub-dimensions	Indicators
Adaptive capacity	Socio-demographic profile (.8)	▪ Dependency ratio (1) ▪ Female-headed HHs (y/n) (.5) ▪ Educational attainment of HH head (1)
	Access to resources (.5)	▪ Agricultural land per head (1) ▪ Livestock per head (1)
	Livelihood strategies (1)	▪ Secondary and tertiary sector livelihood diversification index (1) ▪ Primary sector livelihood diversification index (.75) ▪ Total amount of annual remittances per head (.75) ▪ Cash crop diversity index (.75)
	Social networks (.7)	▪ No. of institutions assisting HH in time of stress)/total No. of networks (1) ▪ HH has difficulties borrowing money (y/n) (.5)
	Accessibility (.8)	▪ Accessibility factor (time in minutes) to next hospital, bus stop, paved road, market centre, agricultural centre, bank, post office (1)
	Coping strategies (1)	▪ No. of livelihood diversification strategies (.5) ▪ No. of decreased investments as coping strategies (-.5) ▪ Average time to recover from shocks (months)/combined severity (-1) ▪ No. of adaptation strategies implemented (.5)
Sensitivity	Wellbeing (-1)	▪ Extent of indebtedness (-.5) ▪ Durable goods factor (No. of TVs, dish antennas, radios, mobiles, motor vehicles) (.75) ▪ Total per head consumption (1)
	Health/sanitation (-1)	▪ Frequency of serious illnesses (1) ▪ Access to improved sanitation (.5) ▪ Access to improved source of drinking water (.5) ▪ Perceived quality of drinking water (.75)
	Food security (-1)	▪ HH is food self-sufficient (1) ▪ No. of months HH has sufficient food (1) ▪ Food crop diversity index (.3) ▪ Average no. of months food stocks feed all HH members (.5)
	Water security (-1)	▪ Time to water resource (min) (.8) ▪ No. of months with water sufficiency for HH needs (1) ▪ Severity of water conflicts (within community and between communities) (.75) ▪ No. of months of water sufficiency for crops and livestock (1)
	Environmental stability (-1)	▪ HH with sloping terrain (y/n) (-.5) ▪ HH with irrigated land (y/n) (1) ▪ Degree to which dwelling can withstand strong winds, severe rain, snow, or hail without significant damage (.5) ▪ Quality of wall material of dwelling (.5)
Exposure	Natural shocks (1) Economic shocks (1)	No. of natural shocks during the past 12 months (.5) Combined damage caused by natural shocks (1) No. of economic shocks during the past 12 months (.5) Combined damage caused by economic shocks (1)
	Perception of climate variability (.5)	HH experienced changes in frequency of certain climatic events (y/n) (1) HH experienced changes in severity of certain climatic events (y/n) (1) HH experienced new climatic or environmental conditions over the past 10 years (y/n) (.5) HH reported changes in temperature over the past 10 years (y/n) (.5) HH reported changes in precipitation over the past 10 years (y/n) (.5)

Annex II: Preliminary checklist of plant species in PCA

Latin name	Family	Habit
Taxus baccata	Taxaceae	Tree
Abies densa	Pinaceae	Tree
Picea spinulosa	Pinaceae	Tree
Pinus wallichiana	Pinaceae	Tree
Tsuga dumosa	Pinaceae	Tree
Juniperus recurva	Cupressaceae	Tree
Juniperus squamata	Cupressaceae	Tree
Juniperus pseudosabina	Cupressaceae	Tree
Juniperus sp.	Cupressaceae	Tree
Juniperus sp.	Cupressaceae	Tree
Schisandra grandiflora	Schisandraceae	Shrub
Magnolia campbellii	Magnoliaceae	Tree
Lindera heterophylla	Lauraceae	Tree
Lindera neesiana	Lauraceae	Tree
Lindera pulcherrima	Lauraceae	Shrub
Persea fructifera	Lauraceae	Tree
Piper suipigua	Piperaceae	Herb
Agrostis micrantha	Gramineae	Herb
Agrostis nervosa	Gramineae	Herb
Agrostis petelotii	Gramineae	Herb
Arundinaria racemosa	Gramineae	Herb
Arundinella bengalensis	Gramineae	Herb
Arundinella hookeri	Gramineae	Herb
Blymus compressus	Gramineae	Herb
Borinda grossa	Gramineae	Herb
Deschampsia caespitosa	Gramineae	Herb
Elymus sikkimensis	Gramineae	Herb
Eulalia quadrinervis	Gramineae	Herb
Festuca leptopogon	Gramineae	Herb
Festuca polycolea	Gramineae	Herb
Festuca rubra	Gramineae	Herb
Festuca stapfii	Gramineae	Herb
Setaria palmifolia	Gramineae	Herb
Yushania microphylla	Gramineae	Herb
Aletris pauciflora	Melanthiaceae	Herb
Skkimia laureola	Smilacaceae	Shrub
Smilax elegans	Smilacaceae	Shrub
Smilax ferox	Smilacaceae	Shrub
Smilax menispermoidea	Smilacaceae	Shrub
Smilax minutiflora	Smilacaceae	Shrub
Smilax myrtillus	Smilacaceae	Shrub
Paris polyphylla	Trilliaceae	Herb
Northolirion bulbuliferum	Liliceae	Herb
Cephalanthera longifolia	Orchidaceae	Herb

Latin name	Family	Habit
Chusua nana	Orchidaceae	Herb
Gymnadenia orchidis	Orchidaceae	Herb
Hebenaria intermidia	Orchidaceae	Herb
Hebenaria sp	Orchidaceae	Herb
Ione bicolor	Orchidaceae	Herb
Bulbophyllum rolfei	Orchidaceae	Herb
Zeuxine goodyeroides	Orchidaceae	Herb
Maianthemum fuscum	Asparagaceae	Herb
Ophiopogon bodinieri	Convallariaceae	Herb
Ophiopogon clarckii	Convallariaceae	Herb
Ophiopogon wallichianus	Convallariaceae	Herb
Polygonatum hookeri	Convallariaceae	Herb
Polygonatum kansuense	Convallariaceae	Herb
Polygonatum verticillatum	Convallariaceae	Herb
Juncus brachystigma	Juncaceae	Herb
Juncus grisebachii	Juncaceae	Herb
Carex nubigena	Cyperaceae	Herb
Carex rara	Cyperaceae	Herb
Cyperus cyperoides	Cyperaceae	Herb
Cyperus myosurus	Cyperaceae	Herb
Cyperus squarrossus	Cyperaceae	Herb
Frimbristylis complanata	Cyperaceae	Herb
Isolepis setacea	Cyperaceae	Herb
Kyllinga brevifolia	Cyperaceae	Herb
Pycreus flavidus	Cyperaceae	Herb
Brachypodium sylvaticum	Poaceae	Herb
Calamagrostis emodensis	Poaceae	Herb
Calamagrostis lahulensis	Poaceae	Herb
Calamagrostis scabrescens	Poaceae	Herb
Eragrostis nigra	Poaceae	Herb
Eragrostis ferruginea	Poaceae	Herb
Eragrostis nubigena	Poaceae	Herb
Muhlenbergia himalayensis	Poaceae	Herb
Poa annua	Poaceae	Herb
Poa rajbhandarii	Poaceae	Herb
Sporobolus fertilis	Poaceae	Herb
Thamnocalamus spathiflorus	Poaceae	Herb
Cyanotis vaga	Commelinaceae	Herb
Roscoea alpina	Zingiberaceae	Herb
Cathcartia villosa	Papavaraceae	Herb
Holboellia latifolia	Lardiazabalaceae	Shrub

Latin name	Family	Habit
Berberis insignis	Berberidaceae	Shrub
Berberis aristata	Berberidaceae	Shrub
Berberis cooperi	Berberidaceae	Shrub
Aconitum laciniatum	Ranunculaceae	Herb
Clematis buchananiana	Ranunculaceae	Herb
Clematis montana	Ranunculaceae	Shrub
Clematis montana	Ranunculaceae	Herb
Thalictrum chelidonii	Ranunculaceae	Herb
Thalictrum foetidum	Ranunculaceae	Herb
Corydalis latfolia	Fumariaceae	Herb
Sarcococca hookeriana	Buxacaceae	Shrub
Daphniphyllum himalense	Daphniphyllaceae	Tree
Ribes acuminatum	Grossulariaceae	Shrub
Saxifraga brunonis	Saxifragaceae	Herb
Saxifraga filicaulis	Saxifragaceae	Herb
Euonymus elongatus	Celastraceae	Shrub
Euonymus frigidus var. elongatus	Celastraceae	Shrub
Euonymus grandiflorus	Celastraceae	Shrub
Euonymus longiflora	Celastraceae	Shrub
Toricellia tiliifolia	Celastraceae	Shrub
Oxalis corniculata	Oxalidaceae	Herb
Hypericum choisianum	Clusiaceae	Shrub
Hypericum elodeoides	Clusiaceae	Shrub
Viola bulbosa	Violaceae	Herb
Viola biflora	Violaceae	Herb
Viola pilosa	Violaceae	Herb
Parochetus communis	Fabaceae	Herb
Piptanthus nepalensis	Fabaceae	Shrub
Trifolium repens	Fabaceae	Herb
Betula utilis	Betulaceae	Tree
Cotoneaster bacillaris	Rosaceae	Shrub
Cotoneaster microphylla	Rosaceae	Shrub
Fragania nubicola	Rosaceae	Herb
Neillia thyrsiflora	Rosaceae	Shrub
Potentilla arbuscula	Rosaceae	Herb
Potentilla sp	Rosaceae	Herb
Prunus cornuta	Rosaceae	Tree
Prunus nepalensis	Rosaceae	Tree
Prunus rufa	Rosaceae	Tree
Rosa sericea	Rosaceae	Shrub
Rubus thomsonii	Rosaceae	Shrub
Rubus alexeterius	Rosaceae	Shrub
Rubus calycinus	Rosaceae	Herb
Rubus fockeanus	Rosaceae	Shrub
Rubus splendidissimus	Rosaceae	Shrub

Latin name	Family	Habit
Rubus treutleri	Rosaceae	Shrub
Rubus wardii	Rosaceae	Shrub
Sorbus arachnoidea	Rosaceae	Tree
Sorbus microphylla	Rosaceae	Tree
Sorbus sp. (unid)	Rosaceae	Tree
Sorbus thibetica	Rosaceae	Tree
Spiraea arcuata	Rosaceae	Shrub
Spiraea bella	Rosaceae	Shrub
Elaeagnus parvifolia	Elaeagnaceae	Shrub
Ficus pubigera	Moraceae	Shrub
Elatostema sessile	Urticaceae	Herb
Elatostema grandidentatum	Urticaceae	Herb
Elatostema pusillum	Urticaceae	Herb
Laportea terminalis	Urticaceae	Herb
Pilea symmeria	Urticaceae	Herb
Quercus glauca	Fagaceae	Shrub
Quercus griffithii	Fagaceae	Tree
Quercus oxyodon	Fagaceae	Tree
Quercus semecarpifolia	Fagaceae	Tree
Quercus thomsoniana	Fagaceae	Tree
Quercus thomsonii	Fagaceae	Shrub
Corylus ferox	Betulaceae	Tree
Geranium nepalense	Geraniaceae	Herb
Geranium polyanthes	Geraniaceae	Herb
Geranium procurrens	Geraniaceae	Herb
Acer campbellii	Sapindaceae	Tree
Acer cappadocicum	Sapindaceae	Shrub
Acer caudatum	Sapindaceae	Tree
Acer pectinatum	Sapindaceae	Tree
Acer sikkimensis	Sapindaceae	Tree
Acer sterculiaceum	Sapindaceae	Tree
Toddalia asiatica	Rutaceae	Shrub
Daphne bholua	Thymelaeaceae	Shrub
Thlaspi andersonii	Cruciferae/ Brassicaceae	Herb
Taxillus kaempferi	Loranthaceae	Shrub
Drosera peltata	Droceraceae	Herb
Aconogonum molle	Polygonaceae	Herb
Bistorta microphylla	Polygonaceae	Herb
Polygonum nepalensis	Polygonaceae	Herb
Spergula arvensis	Caryophyllaceae	Herb
Hydrangea heteromalla	Hydrangeaceae	Tree
Impatiens stenantha	Balsaminaceae	Herb
Impatiens dipyrena	Balsaminaceae	Herb
Impatiens discolor	Balsaminaceae	Herb

Latin name	Family	Habit
Bryocarpum himalaica	Primulaceae	Herb
Lysimachia prolifera	Primulaceae	Herb
Primula denticulata	Primulaceae	Herb
Eurya cavinervis	Theaceae	Shrub
Symplocos dryophila	Symplocaceae	Tree
Symplocos glomerata	Symplocaceae	Tree
Symplocos lucida	Symplocaceae	Tree
Symplocos paniculata	Symplocaceae	Tree
Agapetes hookeri	Ericaceae	Shrub
Chimaphila japonica	Ericaceae	Herb
Enkianthus deflexus	Ericaceae	Tree
Gaultheria nummularioides	Ericaceae	Shrub
Gaultheria semi-infera	Ericaceae	Herb
Lyonia ovaliferia	Ericaceae	Shrub
Rhododendron arboreum	Ericaceae	Tree
Rhododendron barbatum	Ericaceae	Tree
Rhododendron campylocarpum	Ericaceae	Tree
Rhododendron ciliatum	Ericaceae	Shrub
Rhododendron cinnabarinum	Ericaceae	Tree
Rhododendron griffithianum	Ericaceae	Tree
Rhododendron griffithii	Ericaceae	Shrub
Rhododendron hodgsonii	Ericaceae	Tree
Rhododendron kesangiae	Ericaceae	Tree
Rhododendron keysii	Ericaceae	Tree
Rhododendron lanatum	Ericaceae	Shrub
Rhododendron lepidotum	Ericaceae	Shrub
Rhododendron thomsonii	Ericaceae	Shrub
Rhododendron wightii	Ericaceae	Shrub
Vaccinium glauco-album	Ericaceae	Herb
Vaccinium nummularia	Ericaceae	Shrub
Vaccinium retusum	Ericaceae	Shrub
Vaccinium sikkimense	Ericaceae	Shrub
Actinidia callosa	Actinidaceae	Shrub
Rapanea capitellata	Myrsinaceae	Tree
Galium aparine	Rubiaceae	Herb
Galium elegans	Rubiaceae	Herb
Galium hoffmeisteri	Rubiaceae	Herb
Galium sikkimense	Rubiaceae	Herb
Rubia manjit	Rubiaceae	Herb
Crawfordia speciosa	Gentianaceae	Shrub
Gentiana capitata	Gentianaceae	Herb
Helenia elliptica	Gentianaceae	Herb

Latin name	Family	Habit
Swertia bimaculata	Gentianaceae	Herb
Jasminum humile	Oleaceae	Shrub
Ligustrum confusum	Oleaceae	Shrub
Osmanthus suavis	Oleaceae	Tree
Plantago erosa	Plantaginacea	Herb
Rhynchoglossum obliquum	Schrophulariaceae	Herb
Hemiphragma heterophyllum	Schrophulariaceae	Herb
Veronica himalensis	Schrophulariaceae	Herb
Ajuga lobata	Lamiaceae	Herb
Ajuga vulgaris	Lamiaceae	Herb
Labiatae sp	Lamiaceae	Herb
Origanum vulgare	Lamiaceae	Herb
Stachys scaberula	Lamiaceae	Herb
Elsholtzia ciliata	Lamiaceae	Herb
Elsholtzia densa	Lamiaceae	Herb
Orobanche solmsii	Orbanchaceae	Herb
Pedicularis sp1	Orbanchaceae	Herb
Pedicularis sp2	Orbanchaceae	Herb
Strobilanthus sp	Acanthaceae	Shrub
Strobilanthes oligocephala	Acanthaceae	Herb
Strobilanthes sp.	Acanthaceae	Shrub
Corallodiscus cooperi	Gesneriaceae	Herb
Ilex crenata	Aquifoliaceae	Shrub
Ilex dipyrena	Aquifoliaceae	Tree
Ilex macropoda	Aquifoliaceae	Shrub
Cirsium falcneri	Astaraceae/ Compositae	Herb
Euparorium mairei	Astaraceae/ Compositae	Herb
Picris hieracioides	Astaraceae/ Compositae	Herb
Ainsliaea aptera	Astaraceae/ Compositae	Herb
Ainsliaea latifolia	Astaraceae/ Compositae	Herb
Anaphalis busua	Astaraceae/ Compositae	Herb
Anaphalis contorta	Astaraceae/ Compositae	Herb
Anaphalis cooperi	Astaraceae/ Compositae	Herb
Anaphalis sp	Astaraceae/ Compositae	Herb

Latin name	Family	Habit
Anaphalis triplinervis	Astaraceae/ Compositae	Herb
Artemisia vulgaris	Astaraceae/ Compositae	Herb
Artemisia moorcroftiana	Astaraceae/ Compositae	Herb
Aster albescens	Astaraceae/ Compositae	Herb
Carpesium nepalense	Astaraceae/ Compositae	Herb
Senecio diversifolia	Astaraceae/ Compositae	Herb
Senecio raphanifolius	Astaraceae/ Compositae	Herb
Senecio scandense	Astaraceae/ Compositae	Herb
Senecio wallichii	Astaraceae/ Compositae	Herb
Synotis acuminata	Astaraceae/ Compositae	Herb
Synotis wallichii	Astaraceae/ Compositae	Herb
Aralia cachemirica	Araliaceae	Shrub
Gamblea ciliata	Araliaceae	Tree
Hedera nepalensis	Araliaceae	Shrub
Pantapanax sp. (unid)	Araliaceae	Tree
Pentapanax fragrans	Araliaceae	Tree
Pentapanax racemosus	Araliaceae	Shrub
Centella asiatica	Apiaceae	Herb
Cortia depressa	Apiaceae	Herb
Oenanthe hookeri	Apiaceae	Herb
Sanicula elata	Apiaceae	Herb
Acronema bellum	Umbelliferae	Herb
Leycesteria formosa	Caprifoliaceae	Shrub
Lonicera acuminata	Caprifoliaceae	Shrub
Lonicera lanceolata	Caprifoliaceae	Shrub
Lonicera myrtillus	Caprifoliaceae	Shrub
Sambucus adnata	Caprifoliaceae	Herb
Viburnum mullaha	Caprifoliaceae	Tree

Source: RSPN 2007

Annex III: Checklist of bird species in PCA (Source: Pradhan 2011)

Common name	Latin name	Family	IUCN status	CITES category
Hill Partridge	*Arborophila torqueola*	Phasianidae	LC	
Satyr Tragopan	*Tragopan satyra*	Phasianidae	NT	III
Bar-headed Goose	*Anser indicus*	Anatidae	LC	
Ruddy Shelduck	*Tadorna ferruginea*	Anatidae	LC	
Gadwall	*Anas strepera*	Anatidae	LC	
Eurasian Wigeon	*Anas penelope*	Anatinae	LC	
Red-crested Pochard	*Rhodonessa rufina*	Anatidae	LC	
Common Hoopoe	*Upupa epops*	Upupidae	LC	
Eurasian Cuckoo	*Cuculus canorus*	Cuculidae	LC	
Lesser Cuckoo	*Cuculus poliocephalus*	Cuculidae	LC	
Red-breasted Parakeet	*Psittacula alexandri*	Psittacidae	LC	II
Tawny Owl	*Strix aluco*	Strigidae	LC	
Spotted Owlet	*Athene brama*	Strigidae	LC	
Rock Pigeon	*Columba livia*	Columbidae	LC	
Snow Pigeon	*Columba leuconota*	Columbidae	LC	
Oriental Turtle Dove	*Streptopelia orientalis*	Columbidae	LC	
Black-necked Crane	*Grus nigricollis*	Gruidae	VU	
Northern Lapwing	*Vanellus venellus*	Charadriidae		
Red-wattled lapwing	*Vanellus indicus*	Charadriidae	LC	
Himalayan Griffon	*Gyps himalayensis*	Accipitridae	LC	II
Hen Harrier	*Circus cyaneus*	Accipitridae	LC	II
Eurasian Sparrowhawk	*Accipiter nisus*	Accipitridae	LC	II
Changeable Hawk Eagle	*Spizaetus cirrhatus*	Accipitridae		II
Common Kestrel	*Falco tinnunculus*	Falconidae	LC	II
Cattle Egret	*Bubulcus ibis*	Ardeidae	LC	
Brown Shrike	*Lanius cristatus*	Laniidae	LC	
Yellow-billed Blue Magpie	*Urocissa flavirostris*	Corvidae	LC	
Black-billed Magpie	*Pica pica*	Corvidae		
Spotted Nutcracker	*Nucifraga caryocatactes*	Corvidae	LC	
Red-billed Chough	*Pyrrhocorax pyrrhocorax*	Corvidae	LC	
Large-billed Crow	*Corvus macrorhynchos*	Corvidae	LC	
Long-tailed Minivet	*Pericrocotus ethologus*	Corvidae	LC	
Scarlet Minivet	*Pericrocotus flammeus*	Campephagidae	LC	
Brown Dipper	*Cinclus pallasii*	Cinclidae	LC	
Chestnut-bellied Rock Thrush	*Monticola rufiventris*	Muscicapidae	LC	
Blue Whistling Thrush	*Myiophonus caeruleus*	Turdidae	LC	
White-collared Blackbird	*Turdus albocinctus*	Turdidae	LC	
Dark-throated Thrush	*Turdus ruficollis*	Muscicapidae	LC	
Dark-sided Flycatcher	*Muscicapa sibirica*	Muscicapidae	LC	
Ferruginous Flycatcher	*Muscicapa ferruginea*	Muscicapidae	LC	
Rufous-gorgetted Flycatcher	*Ficedula strophiata*	Muscicapidae	LC	
Snowy-browed Flycatcher	*Ficedula hyperythra*	Muscicapidae	LC	
Ultramarine Flycatcher	*Ficedula superciliaris*	Muscicapidae	LC	

Common name	Latin name	Family	IUCN status	CITES category
Orange-flanked Bush Robin	*Tarsiger cyanurus*	Muscicapidae	LC	
Rufous-breasted Bush Robin	*Tarsiger hyperythrus*	Muscicapidae	LC	
Hodgson's Redstart	*Phoenicurus hodgsoni*	Muscicapidae	LC	
White-throated Redstart	*Phoenicurus schisticeps*	Muscicapidae	LC	
Daurian Redstart	*Phoenicurus auroreus*	Muscicapidae		
Blue-fronted Redstart	*Phoenicurus frontalis*	Muscicapidae	LC	
White-capped Water Redstart	*Chaimarrornis leucocephalus*	Muscicapidae	LC	
Plumbeous Water Redstart	*Rhyacornis fuliginosus*	Muscicapidae		
Beautiful Nuthatch	*Sitta formosa*	Sittidae	VU	
Wallcreeper	*Tichodroma muraria*	Sittidae	LC	
Eurasian Treecreeper	*Certhia familiaris*	Certhiidae	LC	
Rusty-flanked Treecreeper	*Certhia nipalensis*	Certhiidae	LC	
Winter Wren	*Troglodytes troglodytes*	Certhiidae	LC	
Rufous-vented Tit	*Parus rubidiventris*	Paridae		
Coal Tit	*Parus ater*	Paridae	LC	
Green-backed Tit	*Parus monticolus*	Paridae	LC	
Yellow-browed Tit	*Sylviparus modestus*	Paridae	LC	
Rufous fronted tit	*Aegithalos iouschistos*	Aegithalidae		
Black Bulbul	*Hypsipetes leucocephalus*	Pycnonotidae	LC	
Spotted-Bush Warbler	*Bradypterus thoracicus*			
Brown Bush Warbler	*Bradypterus luteoventris*	Sylviidae		
Tickell's Leaf Warbler	*Phylloscopus affinis*	Sylviidae	LC	
Buff-barred Warbler	*Phylloscopus pulcher*	Sylviidae	LC	
Ashy-throated Warbler	*Phylloscopus maculipennis*	Sylviidae	LC	
Lemon-rumped Warbler	*Phylloscopus chloronotus*	Sylviidae	LC	
Large-billed Leaf Warbler	*Phylloscopus magnirostris*	Sylviidae	LC	
Golden-spectacled Warbler	*Seicercus burkii*	Sylviidae	LC	
Whistler's Warbler	*Seicercus whistleri*	Sylviidae	LC	
White-throated Laughing Thrush	*Garrulax albogularis*	Timaliidae	LC	
Spotted Laughing Thrush	*Garrulax ocellatus*	Timaliidae	LC	
Black-faced Laughing Thrush	*Garrulax affinis*	Timaliidae	LC	
Chestnut-crowned Laughing Thrush	*Garrulax erythrocephalus*	Timaliidae	LC	
Red-faced Liocichla	*Liocichla phoeniceus*	Sylviidae	LC	
Slender-billed Scimitar Babbler	*Xiphirhynchus superciliaris*	Timaliidae	LC	
Scaly-breasted Wren Babbler	*Pnoepyga albiventer*	Timaliidae	LC	
Rufous-capped Babbler	*Stachyris ruficeps*	Sylviidae/ Mucicapidae	LC	
Red-billed Leiothrix	*Leiothrix lutea*	Timaliidae	LC	II
Chestnut-tailed Minla	*Minla strigula*	Timaliidae	LC	
Red-tailed Minla	*Minla ignotincta*	Timaliidae	LC	
Chestnut headed Tit-Babbler	*Alcippe castaneceps*	Sylviidae	LC	
White-browed Fulvetta	*Alcippe vinipectus*	Sylviidae		

Common name	Latin name	Family	IUCN status	CITES category
Rufous Sibia	*Heterophasia capistrata*	Timaliidae	LC	
Whiskered Yuhina	*Yuhina flavicollis*	Sylviidae	LC	
Stripe-throated Yuhina	*Yuhina gularis*	Sylviidae	LC	
Rufous-vented Yuhina	*Yuhina occipitalis*	Sylviidae	LC	
Brown Parrotbill	*Paradoxornis unicolor*	Timaliidae	LC	
Oriental Skylark	*Alauda gulgula*	Alaudidae		
Fire-breasted Flowerpecker	*Dicaeum ignipectus*	Nectariniidae	LC	
Mrs. Gould's Sunbird	*Aethopyga gouldiae*	Nectariniidae	LC	
Russet Sparrow	*Passer rutilans*	Passeridae	LC	
Olive-backed Pipit	*Anthus hodgsoni*	Motacillidae	LC	
Rosy Pipit	*Anthus roseatus*	Passeridae		
Rufous-breasted Accentor	*Prunella strophiata*	Prunellidae	LC	
Yellow-breasted Greenfinch	*Carduelis spinoides*	Fringillidae	LC	
Common Rosefinch	*Carpodacus erythrinus*	Fringillidae	LC	
Red-headed Bullfinch	*Pyrrhula erythrocephala*	Fringillidae	LC	
Collared Grosbeak	*Mycerobas affinis*	Fringillidae	LC	
Spot-winged Grosbeak	*Mycerobas melanozanthos*	Fringillidae	LC	
White-winged Grosbeak	*Mycerobas carnipes*	Fringillidae	LC	

Annex IV: Checklist of mammal species in PLCA (Source: modified after Pradhan 2011)

S.No	Common Name	Scientific Name
1.	Barking Deer	*Muntiacus* sp.
2.	Asian Palm Civet	*Paradoxurus hermaphroditus*
3.	Jungle cat	*Felis chaus*
4.	Common Leopard	*Panthera pardus*
5.	Crab eating mongoose	*Herpestes urva*
6.	Dhole	*Cuon alpinus*
7.	Goral	*Naemorhedus goral*
8.	Himalayan Black Bear	*Ursus thibetanus*
9.	Orange-bellied Squirrel	*Dremomys lokriah*
10.	Bhutan giant flying squirrel	*Petaurista nobilis*
11.	Himalayan Pika	*Ochotona himalayana*
12.	Three stripe Himalayan Squirrel	*Dremomys* sp.
13.	Wild Pigs	*Sus scrofa*
14.	Yellow-throated Marten	*Martes flavigula*
15.	Otter	*Lutra sp.*
16.	Indian crested porcupines	*Hystrix indica*
17.	Tiger	*Panthera tigris*
18.	Grey Langur	*Semnopithecus entellus*
19.	Red Fox	*Vulpes vulpes*
20.	Red Panda	*Ailurus fulgens*
21.	Sambar	*Rusa unicolor*
22.	Sheep	*Ovis* sp.
23.	Stone Martens	*Martes foina*
24.	Marmots	*Marmota* sp.

Annex V: Species habitat matrix of some of the ecologically and economically important species used for analyzing ecosystem services against different land-cover types in PCA

A. Habitat matrix of selective globally significant species in PCA

Species	Significance	Land cover types									
		Agricultural dry land	Agricultural wet land	Conifer forest	Broad leaved forest	Mixed forest	Marshes	Water spread	Settlement	Others (grass)	Scrub
Grus nigricollis (Black-necked crane)	Endangered migratory bird	X	X				X	X	X	X	X
Ardea insignis hume (White-bellied Heron)	Rare bird species		X				X	X			
Ailurus fulgens (Red panda)	Endangered mammal species			X	X	X					
Ochotona himalayana (Himalayan Pika)	Threatened mammal under stress from climate change			X	X	X				X	X
Rhododendron kesangiae	Endemic species			X	X	X	X				X
Rhododendron bhutanense	Endemic species			X	X	X	X				X
Panthera tigris (Tiger)	Keystone species				X	X				X	X
Total		1	2	4	5	5	4	2	1	3	5

B. Habitat matrix of selective provisionally important species in PCA

Species	Significance	Land cover types									
		Agricultural dry land	Agricultural wet land	Conifer forest	Broad leaved forest	Mixed forest	Marshes	Water spread	Settlement	Others (grass)	Scrub
Quercus semecarpifolia	Firewood				X	X					
Yushania microphylla (Dwarf bamboo)	Dominant fodder species			X			X	X		X	X
Pinus wallichiana (Blue pine)	Timber/ cattle bedding (leaves)			X		X					
Larix griffithiana	Timber			X	X	X					
Panax pseudo ginseng	Medicinal plant			X	X	X					
Plantago depressa	Medicinal plant	X	X	X	X	X				X	X
Paris polyphylla	Medicinal plant			X	X	X	X				
Cantharellus sp	Mushroom- important NTFP			X	X	X					
Solanum tubersoum (Potato)	Major cash crop	X	X								
Carex/Juncus species	Rapidly colonizing fodder species		X				X	X		X	
Domesticated cattle	Integral to farming system	X	X	X	X	X	X		X	X	X
Pterdium revolutum (Fern)	Cattle bedding, fodder			X	X	X				X	X
Total		3	4	9	8	9	4	2	1	5	4

C. Habitat matrix of selective ecologically significant species in PCA											
Species	Significance	Land cover types									
		Agricultural dry land	Agricultural wet land	Conifer forest	Broad leaved forest	Mixed forest	Marshes	Water spread	Settlement	Others (grass)	Scrub
Grus nigricollis (Black-necked crane)	Endangered migratory bird	X	X				X	X	X	X	X
Ardea insignis hume (White-bellied Heron)	Endangered bird species		X				X	X			
Yushania microphylla (Dwarf bamboo)	Dominant species of core wetland			X			X	X		X	X
Pinus wallichiana (Blue pine)	Major canopy tree, pure stand present			X		X					
Sphagnum sp.(moss)	Wet ground vegetation for controlling moisture		X	X	X	X	X	X		X	X
Usnea sp	Pollution indicator species, medicinal plant, fodder species			X	X	X					X
Berberis cooperii (Berbery)	Indicators of drier habitat			X	X	X	X			X	X
Herpestes urva (Crab eating Mongoose)	Shares roosting habitat of BNC			X			X	X		X	
Yellow Barn Hornet	Pollinators				X	X	X				X
Gueldenstaedtia himalaica	Nitrogen fi1tration					X					
Juniperus recurva (Juniper)	Pioneer species in severe cold areas			X		X				X	X
Carex nigra and other hydrophilic species species	Preferred for roosting by BNC		X				X	X			
Muntiacus munjac (Muntjac)	Common prey species		X	X	X	X		X		X	X
Felis bengalensis (Leopard cat)	Predator species			X	X	X	X			X	X
Total		1	5	9	6	9	9	7	1	8	9
Cumulative Total		5	11	22	19	23	17	11	3	16	18

Annex VI: Downscaling of GCMs for PCA: Tabular data

		CGCM3 A1B			CGCM3 A2			HADCM3 A2			HADCM3 B2		
	Base	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
Winter	9.55	0.11	0.26	0.59	0.12	0.47	0.91	0.39	0.84	1.22	0.46	0.58	0.96
Spring	15.69	0.21	0.74	1.01	0.20	0.60	1.49	0.79	1.37	2.43	0.64	1.16	1.65
Summer	19.94	0.08	0.41	0.64	0.08	0.45	0.86	0.64	1.45	2.35	0.59	1.20	1.74
Autumn	16.32	0.10	0.41	0.85	0.09	0.54	1.12	0.53	1.33	2.28	0.69	1.00	1.59
Annual	15.40	0.12	0.46	0.77	0.12	0.52	1.10	0.59	1.25	2.07	0.59	0.99	1.49

Annex VI (a): NCEP (1961-1990) and GCMs (2020s, 2050s and 2080s) simulated seasonal and annual maximum temperature scenarios at Phobjikha

		CGCM3 A1B			CGCM3 A2			HADCM3 A2			HADCM3 B2		
	Base	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
Winter	-3.84	0.07	0.32	0.66	0.10	0.52	1.10	0.24	0.68	1.29	0.34	0.67	1.00
Spring	4.22	0.05	0.33	0.48	0.08	0.34	0.79	0.68	1.15	2.10	0.55	0.96	1.39
Summer	10.66	0.11	0.64	1.01	0.14	0.85	1.57	0.55	1.30	2.21	0.57	1.11	1.62
Autumn	4.29	0.13	0.50	1.00	0.09	0.69	1.45	0.84	2.03	3.44	1.13	1.56	2.42
Annual	3.87	0.09	0.45	0.79	0.10	0.60	1.23	0.58	1.29	2.26	0.65	1.08	1.61

Annex VI (b): NCEP (1961-1990) and GCMs (2020s, 2050s and 2080s) simulated seasonal and annual minimum temperature scenarios at Phobjikha

		CGCM3 A1B			CGCM3 A2			HadCM3 A2			HadCM3 B2		
	Base	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
Winter	51	10	3	15	-3	-18	6	-8	-21	-21	-21	-27	-18
Spring	148	2	9	14	2	14	32	-5	0	2	-5	3	-2
Summer	732	2	4	11	0	8	19	2	1	10	1	4	6
Autumn	198	-1	16	22	4	27	46	1	2	5	6	4	6
Annual	1132	2	7	14	1	12	26	0	0	6	0	2	4

Annex VI (c): NCEP (1961-1990) and GCMs (2020s, 2050s and 2080s) simulated seasonal and annual precipitation scenarios at Phobjikha

About ICIMOD

The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalization and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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