Ambio
DOI 10.1007/s13280-017-0923-9

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

REVIEW

Vulnerability and impacts of climate change on forest and freshwater wetland ecosystems in Nepal: A review

Pramod Lamsal, Lalit Kumar, Kishor Atreya, Krishna Prasad Pant

Received: 1 February 2017 / Revised: 18 April 2017 / Accepted: 25 April 2017

Abstract Climate change (CC) threatens ecosystems in both developed and developing countries. As the impacts of CC are pervasive, global, and mostly irreversible, it is gaining worldwide attention. Here we review vulnerability and impacts of CC on forest and freshwater wetland ecosystems. We particularly look at investigations undertaken at different geographic regions in order to identify existing knowledge gaps and possible implications from such vulnerability in the context of Nepal along with available adaptation programs and national-level policy supports. Different categories of impacts which are attributed to disrupting structure, function, and habitat of both forest and wetland ecosystems are identified and discussed. We show that though still unaccounted, many facets of forest and freshwater wetland ecosystems of Nepal are vulnerable and likely to be impacted by CC in the near future. Provisioning ecosystem services and landscape-level ecosystem conservation are anticipated to be highly threatened with future CC. Finally, the need for prioritizing CC research in Nepal is highlighted to close the existing knowledge gap along with the implementation of adaptation measures based on existing location specific traditional socio-ecological system.

Keywords Climate change · Forest ecosystem · Freshwater wetland ecosystem · Impact · Socio-ecological adaptation · Vulnerability

INTRODUCTION

Climate change (CC) is an emerging problem with pervasive potential consequences not yet fully understood. Both the developed and developing countries are witnessing serious impacts of CC on their natural ecosystems and resource base. CC is gaining worldwide attention among researchers and policy makers due to its irreversible detrimental consequences on ecosystems and their biota. There is widespread consensus that the greenhouse effect will lead to a global rise in air temperature, with mean surface temperatures increasing 1.5–5.8 °C by the year 2100 (Houghton et al. 2001). A recent statement from World Meteorological Organization (WMO 2015) states that atmospheric concentration of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) reached new highs in 2013, and the year 2016 was the hottest year on record (LeComte 2017). CC affects distribution, diversity, and abundance of species in all types of ecosystems (Williams et al. 2012), and global CC is ongoing and will continue (Hansen et al. 2001; Harris et al. 2006; Nogues-Bravo et al. 2007). Diverse speculations are made in literature regarding CC impacts on ecosystems and biodiversity. For instance, IPCC (2007) forecasted an increased extinction risk of 20–30% of global plant and animal species if an increase in global average temperature exceeds 1.5–2.5 °C. Similarly, up to 43% of the world's endemic biota, mainly flora and vertebrate fauna, would face extinction risk by the end of the twenty-first century (Malcom et al. 2006). Novel climates could emerge that may have profound impacts on flora, fauna, and the ecosystems they inhabit (Pearson 2006; Williams et al. 2007; Loarie et al. 2009). Thus, CC poses considerable threats to ecosystems and their biota.

Being rich in biodiversity and harboring 35 vegetation types and 118 ecosystems (NBS 2002), Nepal sits in the Southern Himalayas which are considered as one of the most vulnerable regions of the globe to climate-related hazards like drought, flood, and heat stress. Highly varied topography and a large elevation gradient over a short latitudinal distance in Nepal have given rise to a distinct

Published online: 01 June 2017

climate over a small area, producing several physiographic zones (Fig. 1), with larger variation in precipitation pattern (Tamrakar and Alfredsen 2013). Southeasterly monsoon arriving from the Bay of Bengal dominates overall climate of Nepal, providing 80% of annual precipitation during summer months from June to September (Shrestha and Aryal 2011). The summer monsoon is more active in the east and middle regions of the country, while winter rain originating from the Arabian Sea is active during winter in the western region, especially on the leeward side of the northern highland (Shrestha 2000; Sigdel and Ikeda 2012). The biota in such distinct climates has special survival requirements, and therefore, a slight climatic alteration could be detrimental to their survival, as Sigdel and Ma (2015) recently projected an increase of mean annual rainfall by 14% by 2050.

Variability in temperature, rainfall, and retreat of glaciers has already been observed in Nepal. A 30-year study (1976–2005) revealed a general increasing trend in temperature all over Nepal, with maximum temperature increasing at a faster rate (0.05 °C/annum) than minimum temperature (0.03 °C/annum) (Practical Action 2009). Sharma et al. (2009) reported an annual temperature increase of 0.01–0.04 °C in the second half of the twentieth century, while Agrawala et al. (2003) and Rupa Kumar et al. (2006) projected it to increase by 3 and 4 °C, respectively, at the end of the twenty-first century. Changes in local climate system have a relevance to regions as the effect of such national change could have severe impact at regional level. For instance, snow melt and glacier retreat in Nepal Himalaya have been observed unexpectedly faster than the past from recent warming (Chaulagain 2009; Shrestha and Aryal 2011). This could alter hydrology and flow regime of the catchment of Nepal (Bharati et al. 2014) as well as other large river basins within Asia such as Ganges and Brahmaputra (Xu et al. 2009; Immerzeel et al. 2010), affecting agro-production systems and food security of millions of downstream population in India and Bangladesh. Range shift of both biome and species (MoPE 2004; Zomer et al. 2014; Thapa et al. 2016) is feared in Nepal Himalaya with future warming and unpredictable rainfall that could lead to noble climatic eco-regions with overhaul of species composition, giving rise to new biotic interactions. Considering habitat loss and consequent risk to its endangered species from CC, Nepal is identified as a highly vulnerable country (Giam et al. 2010); however, it lacks required social, economic, scientific, and institutional resource base to cope with such

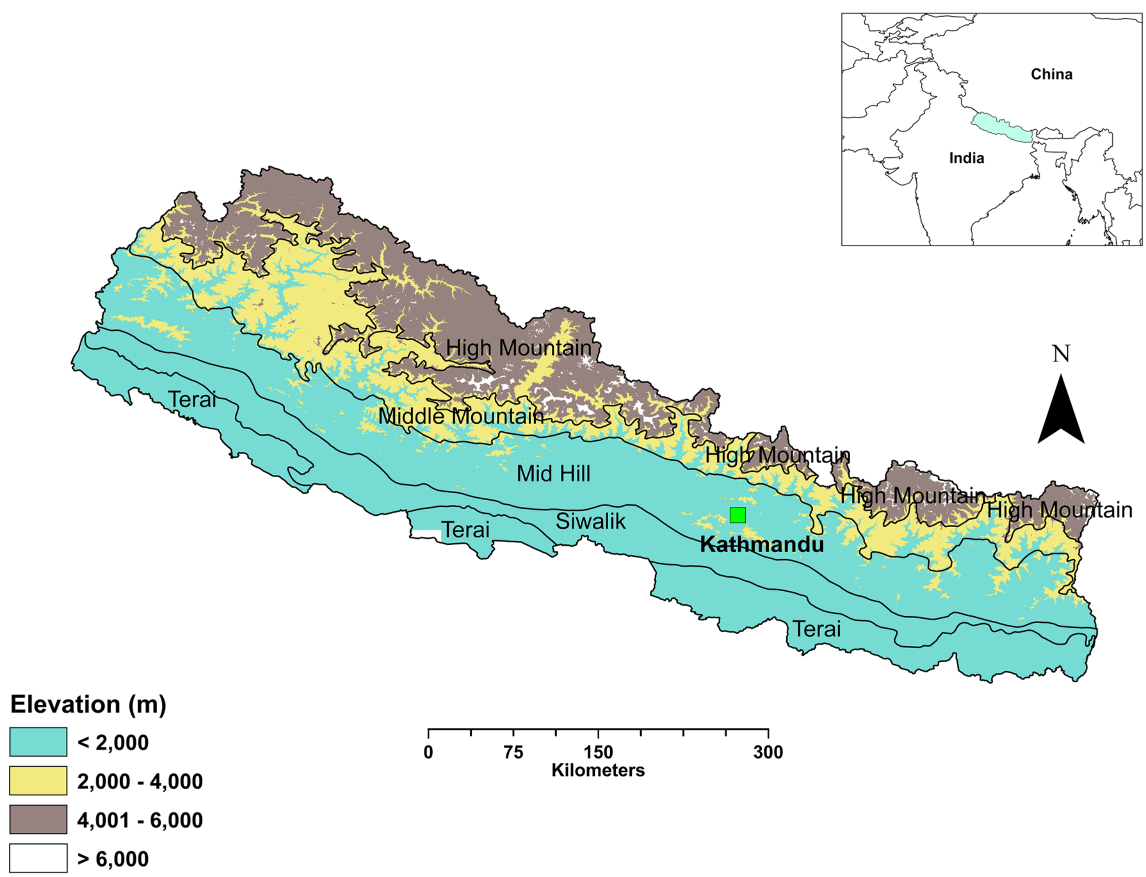

Fig. 1 Physiographic zones and elevation gradient of Nepal Himalaya with *inset* showing its location in South Asia

vulnerability (Agrawala et al. 2003; Regmi and Bhandari 2013). Thus, CC is a serious and pressing issue for Nepal in the context of its fragile Himalayan ecosystems and that demands to have appropriate adaptive mechanisms.

Vulnerability to CC comprises of exposure, sensitivity, and weak adaptive capacity (Kelly and Adger 2000; McCarty 2001). Vulnerability and impacts of CC on ecosystems and biota have been investigated extensively across different geographic regions, mostly in developed countries. The magnitude of climate-related threats are more severe in least developed countries (Turner et al. 2010), such as Nepal, where scientific studies are very limited and fragmented. Here we review existing knowledge base on CC vulnerability and impacts on forest and freshwater wetland ecosystems and their biota across regional and national scales and then identify research gaps and likely implications of resulting threats for Nepal, followed by recommendations emphasizing on the socio-ecological adaptive measures. This paper first briefly introduces the broader regional themes before delving into Nepal's case incorporating existing adaptation response to CC.

BRIEF OVERVIEW OF CC VULNERABILITY AND IMPACTS ACROSS REGIONS

Global CC is the primary driver of ecosystem degradation (MEA 2005), and three decades of increased temperature at the end of last century has changed the way ecosystems used to exist before (Walther et al. 2002). Response of ecosystems to CC has many dimensions (Walther 2010). Through extensive reviewing of published literature, we found changes in the forest and freshwater wetland ecosystem in terms of structure, function, and habitat (Fig. 2) across different geographic regions viz. Asia, Europe, Africa, North America, South America, and Australia.

In the forest ecosystems, we found changes in

- plant and animal phenology (Both et al. 2006; Clausen and Clausen 2013; Klaus and Lougheed 2013; Thackeray et al. 2016),
- species migration and population range shift (Kaplan and New 2006; Peh 2007; Feehan et al. 2009; Dolezal et al. 2016),
- new assemblages of plant species (Halloy and Mark 2003; Thuiller et al. 2005; Lawler et al. 2009; Nogues-Bravo et al. 2016),
- expansion and contraction of habitat and population (Gomez-Mendoza and Arriaga 2007; Coetzee et al. 2009; Dullinger et al. 2012; Gottfried et al. 2012; Schloss et al. 2012; Songer et al. 2012; Tuanmu et al. 2013; Zhang et al. 2014; Alamgir et al. 2015),
- species invasion (Early et al. 2016; Kuebbing and Nunez 2016), and
- extinction (Thuiller et al. 2005; Molur 2008; Feehan et al. 2009; Nogue et al. 2009; Alamgir et al. 2015).

Likewise, in the freshwater wetland ecosystems, we found changes in

- thermal stratification and water level fluctuation (Winder and Schindler 2004; Mooij et al. 2005; Verburg and Hecky 2009),
- areal extent of wetlands (Chu and Fischer 2012; Ouyang et al. 2013),
- alteration in aquatic vegetation composition and range shift (Lou et al. 2015),
- habitat degradation (Simmons et al. 2004; Thompson et al. 2005; An et al. 2013; Dubey et al. 2013; Froyd et al. 2014),
- bird migratory patterns (Walther et al. 2002; Lehikoinen et al. 2013), and
- biota extinction (Thuiller et al. 2006; Heino et al. 2009; Traill et al. 2010; Werner et al. 2013).

These studies suggest that climatic threats exist over different geographic regions of the world and have affected forest and freshwater wetland ecosystems in all climatic conditions ranging from tropical and sub-tropical to temperate and alpine.

CC VULNERABILITY AND IMPACTS IN NEPAL

High altitudinal variations in Himalayan terrain within a small latitudinal extent characterize Nepal (Fig. 1) with diversity in physiographic, elevation, and climatic zones (Table 1). Nepal represents 0.1% area of the global terrestrial surface, however hosts up to 3.2 and 1.2% of world's flora and fauna, respectively, including 5.2% of world's known mammals, 9.5% of birds, 5.1% of gymnosperm, and 8.2% of bryophytes (GoN 2014a). The reason for such a high biodiversity level is its location within two bio-geographical realms, the Indo-Malayan and the Palaearctic realms, and existing diverse climates such as hot monsoon and tropical in lowlands to alpine and tundra in high mountains (CEPF 2005). Despite high diversity, CC could have increased the ecosystem vulnerability and has impacted the flora and fauna therein; however, literature is very scant.

CC impacts in forest ecosystem

Change in plant phenology

Plant phenological changes are the earliest visible response to global CC (Corlett and Lafrankie 1998; Xu et al. 2009).

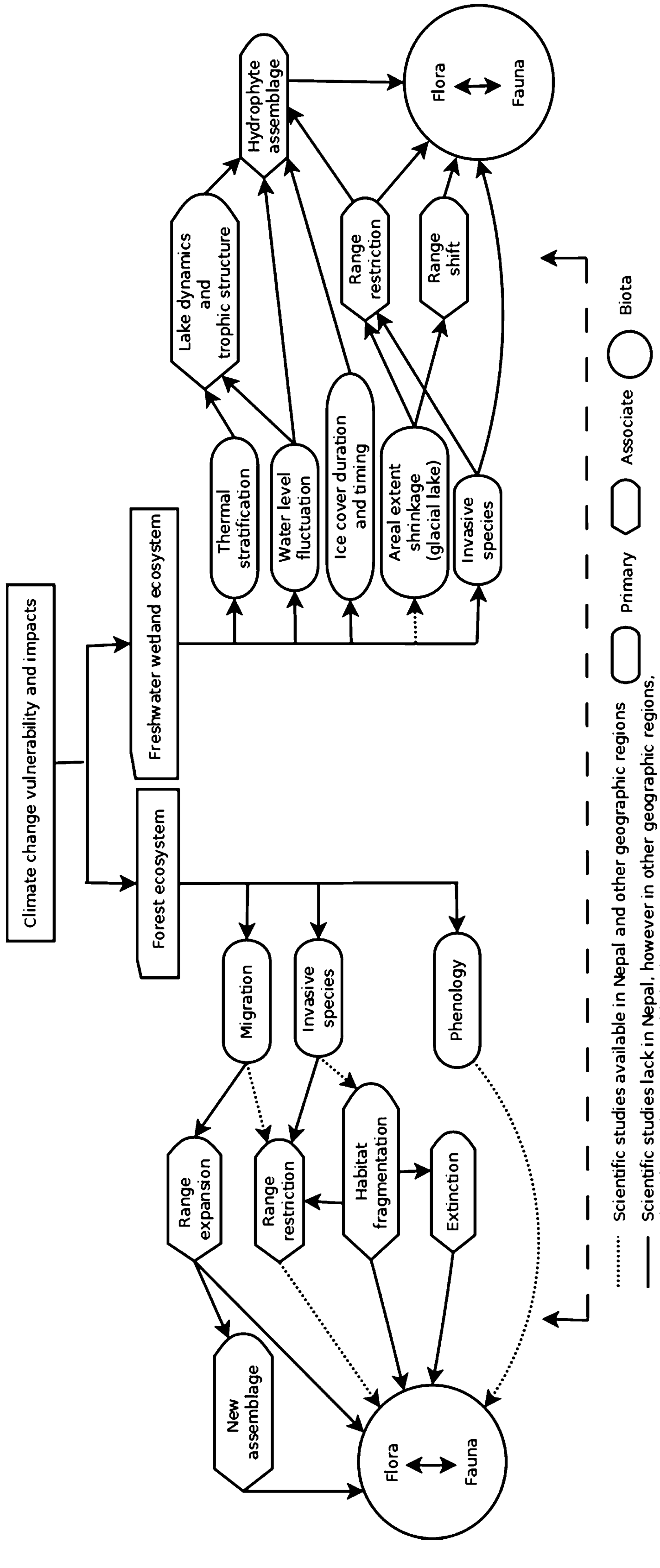

Fig. 2 Schematic diagram illustrating vulnerability and impacts of CC on forest and freshwater wetland ecosystems and research gaps in Nepal

Table 1 Physiographic zones of Nepal. *Source* MFSC (2014) (with modifications)

Physiographic zones	Surface area (%)	Elevation (m)	Climate
High Mountain	23	Above 5000	Tundra type and Arctic
Middle Mountain	20	4000–5000	Alpine
		3000–4000	Sub-alpine
Mid-Hill	30	2000–3000	Cold temperate monsoon
		1000–2000	Warm temperate monsoon
Lowland (Terai and Siwalik)	27	500–1000	Hot monsoon and Sub-tropical
		Below 500	Hot monsoon and tropical

In Nepal, Gurung and Bhandari (2009) found early flowering of *Ficus religiosa* and *Bombax ceiba* across the tropical lowlands. Likewise, Chaudhary and Bawa (2011) reported phenological changes for mid-hill trees such as *Magnolia* sp., *Michelia champaca*, *Chrysanthemum indicum*, *Tagetes* sp., *Prunus persica,* and *Prunus cerasoides*. Alamgir et al. (2014) mentioned that increased winter temperature in the mid-hills of Nepal has led to advance fruit ripening by two weeks along with decrease in fruit size of *Myrica esculenta*. Chettri (2008), Xu et al. (2009), and Chaudhary and Bawa (2011) also reported advancement of flowering season of *Rhododendron* sp. by around one month in mid-hills and middle mountains across Nepal from mid-April and May to mid-March and April. Likewise, Lamsal et al. (2017b) reported changes in flowering time of *R. arboreum* advanced by 2–3 weeks in the central sub-alpine middle mountains; and delayed by 3–6 weeks in the western sub-alpine middle mountains. Similarly, Mohandass et al. (2015) observed phenological changes of three specialized perennial alpine herbaceous flora due to warming temperature: late flowering of *Roscoea alpinia* and *R. capitata* by 8–30 days, while early flowering of *R. purpurea* by 22 days. Such early shifting of flowering time of native alpine plants has also been observed in Canada where Beaubien and Hamann (2011) reported that plants such as *Populus tremuloides* and *Anemone patens* flowers two weeks earlier than past. Therefore, climate change could have paramount influence on seasonality, causing extensive phenological desynchronization (Thackeray et al. 2016), that has overall effect on ecosystem functioning and productivity (Feehan et al. 2009), mainly through creating temporal and spatial mismatches in plant–pollinator interactions (Hegland et al. 2009).

Upward ecological range shift

High-altitude species such as *Rhododendron arboreum* could shift its existing range with future warming in Eastern Himalayan region because of its better coping mechanism in such extreme climates (Ranjitkar et al. 2013). Gaire et al. (2014) and Chhetri and Cairns (2015) reported upslope migration of alpine tree *Abies spectabilis* by 0.17 m and 2.6 m per year at eastern and central Nepal, respectively, while Aryal et al. (2014) and Lamsal et al. (2017b) in addition to *Abies* sp., also reported *Betula utilis*, *Juniperus indica*, *Rhododendron* sp., *Berberies* sp., and *Alnus nepalensis* to upslope migration in central and western sub-alpine middle mountain of Nepal. Similar migration phenomena of *Abies* sp. has also been reported in Arunanchal State of India (Bharali and Khan 2011). Likewise, Telwala et al. (2013) found that 87% out of 124 endemic montane flora of Sikkim Himalaya bordering eastern Nepal have shifted their natural habitat further upward at a rate of 28 ± 22 m per decade. Dolezal et al. (2016) also reported similar phenomena of some vascular plants in arid north-west Himalaya of India. Such alpine flora migration has also been documented in the European Alps (Pauli et al. 1996; Gottfried et al. 2012). An increase in temperature in the mountain regions could result in an upward shift of the snowline as well as the biota it holds, as there is a widespread assumption that an average of 1 °C rise in temperature may cause most species to extend their distribution upwards by 300 meters (Gopal 2013). This is a concern for Nepal, which has 23% of land mass in the high-altitude mountain region, spanning from east to west at the northern border, and containing many endangered and endemic montane flora (MFSC 2014). The resultant changes in diversity from such shift could alter the abundance of other species found in such regions that helps to control ecosystem processes such as modification of pathways of energy and material flow, leading to further changes in community composition and vulnerability to invasion (Chapin et al. 2000). The mid-hills of Nepal, which possess moist deciduous and temperate forest, has also witnessed an upward shift of species such as *Castanopsis hystrix*, *Schima wallichii*, *Eurya acuminata*, *Ficus roxburghii*, *Alnus nepalensis*, *Saurauia nepaulensis*, and *Albizia lebbeck* (Chaudhary and Bawa 2011).

Increased vulnerability of avifauna and megafauna

Of the 867 bird species recorded in Nepal, 17% are under the nationally threatened, of which 53 species are critically endangered, 48 species are endangered, and 47 species are vulnerable (Inskipp et al. 2013). Based on the projected changes of the climate and forest vegetation in central and western lowland Nepal, Thapa et al. (2016) predicted that around 20 bird species from lowland and 10 species from mid-hills that also contain many important bird areas (IBAs) are at greater risk through human-induced habitat fragmentation and likely altered climatic condition. A similar situation has been found in the Southern belt of Africa where Coetzee et al. (2009) reported that 62% of the 50 endemic bird species could lose climatically suitable areas while 77% of the existing IBAs would likely observe 50% species turnover by 2100. CC could have even more threats through range contraction where Jetz et al. (2007) predicted 20% of world's 8750 terrestrial birds to be directly affected. In Nepal, there are only a handful of researches investigating on possible disturbance of climatic impact on avifauna habitat as the country harbors many endangered and nationally threatened bird species.

Many fauna in forest ecosystems are reported to be vulnerable to CC in Nepal. For example, a cold-loving species snow leopard (*Uncia uncia*) that survives in the high mountains (Jackson and Ahlborn 1989; Ale et al. 2007) is vulnerable to ecological changes in its habitat through warming. A habitat suitability index model and cross verification of predator–prey relationship suggests an estimated population of the snow leopard to be around 195–416 in the middle and high mountains of Nepal (Snow Leopard Network 2014). Forrest et al. (2012) predicted northward shift due to 40% loss in the habitat of the snow leopard in Nepal by 2050 as a result of tree line shift which is supposed to be occupied by other mammals such as common leopard (*Panthera pardus*) and Asiatic wild dog (*Cuon alpinus*). Lovari et al. (2013) also reported similar findings of upward tree line shift in central Asia that restrict habitat range of snow leopard while expansion of common leopard habitat, causing the former to become vulnerable due to reduction in habitat range and wild prey availability. This range shift and invasion of non-territorial species could affect predator–prey relationships and could disrupt the functioning of such fragile high-altitude ecosystems.

Change in bio-climate and community assemblage

Based on the Canadian Climate Center Model (CCCM) and Geophysical Fluid Dynamics Laboratory (GFD3) global circulation models, and Holdridge model, MoPE (2004) projected that tropical wet forests and warm temperate rain forests of mid-hill Nepal would completely disappear, while cool temperate vegetation of the same region would turn into warm temperate vegetation by 2100. Rain forests that currently do not exist will emerge in the tropical and sub-tropical regions of lowlands under double CO_2 emission conditions. The same study further revealed that sub-alpine and alpine regions of middle mountains might face more intense warming compared to the lowlands and the existing vegetation in those regions could ascend 500-m upwards. Such high-altitude regions support many threatened and endemic biota. Therefore, considerable overhaul of forest ecosystem in Nepal extending from lowland to highland could be anticipated with future warming climate. However, existing biota responses to such overhaul remains largely unknown. Thapa et al. (2016) modeled and predicted temperate broadleaved and sub-alpine conifer forest representing montane ecosystem of Eastern Himalayan region to become more resilient to climate impact in the future. They further reported the vulnerability of lowland forests to climatic impact that includes vegetation such as sub-tropical broadleaved and *Shorea robusta* forest that currently support the habitat of many megafauna of Nepal. Zomer et al. (2014) projected significant shift in the bio-climate of Kailash Sacred Landscape (KSL) of western Himalaya lying within middle and high mountain where Nepal shares about 43% of its area that represents diverse eco-regions and contains two montane protected areas (PAs) viz. Khaptad National Park and Api Nampa Conservation Area. The likely alteration in such bio-climates is worrisome as these eco-regions and the PAs therein harbor numerous endangered flora such as *Rauvolfia serpentina*, *Neopicrorhiza scrophulariiflora*, *Dactylorhiza hatagirea*, and *Nardostachys grandiflora*; and fauna such as snow leopard, Tibetan antelope (*Pantholops hodgsonii*), Asiatic wild dog, and Red Panda (*Ailurus fulgens*) (Chaudhary et al. 2010). This is comparable with the finding of Rashid et al. (2015) who also projected significant overhaul of adjacent Kashmir Himalaya eco-region with substantial alteration in temperate and sub-alpine forest ecosystem by 2100. Such changes in bio-climatic conditions and reorganization of plant communities could disturb the existing ecological integrity within the country, making the ecosystems lying both within and outside of the nature reserves more vulnerable to warming and leading to uncertain future of their biota.

Increased species invasion

CC and invasive species are two key drivers of ecosystem degradation and biodiversity loss (Burgiel and Muir 2010), and with combined interaction, climatic stress further compounds the devastating effect of invasive species on the ecosystems through its adaptability to disturbance in wide bio-geographic and environmental conditions

(Mainka and Howard 2010). Global Invasive Species Program (GISP), with secretariat office currently headquartered in Nairobi, Kenya, describes invasive alien species as "organisms that have been moved from their native habitat to a new location where they cause significant harm to the environment, economic systems and/or human health." All the species that appear outside of its territorial range are considered as alien species. However, those species become invasive and emerge as a new dominant one once they increase their abundance at the expense of native species of the region (Davis 2003) and displace them through competition for limited resources, prey upon native species to the point of extinction, or alter the habitat and make persistence for natives impossible (Richardson and Rejmanek 2011). Many globally endangered megafauna such as *Panthera tigris*, *Rhinoceros unicornis*, *Bubalus arnee*, and *Elephas maximus* roam around the lowland tropical and sub-tropical forest and savannah grassland in Nepal, mostly within protected area systems (Paudel and Heinen 2015). Though warming in this region has not been fully established yet, the recent infestation of invasive species and extended drought are linked to the warming phenomena (Rai and Scarborough 2012). Alamgir et al. (2015) predicted the loss of substantial habitat range of Asian elephants in Bangladesh by 2070 due to CC and its associated stresses such as forest fragmentation. Invasive species such as *Parthenium hysterophorus*, *Mikania micrantha*, *Lantana camara*, *Chromolaena odorata,* and *Ageratina adenophora* are invading forest ecosystems. The menace of an invasive weed *P. hysterophorus* has been reported in lowlands such as Chitwan National Park (Shrestha 2012; Adkins and Shabbir 2014) and other parts of the country, causing alteration in soil nutrients and species composition of plants (Shrestha et al. 2015). One sixth of global land surface is highly alien species invaded, mostly in areas having biodiversity hotspots (Early et al. 2016). The invasion in Chitwan National Park could have negative effects on the habitat of some endangered species such as one-horned rhinoceros, Asian elephant, and Bengal tiger. For example, *Rhinoceros* prefers alluvial grassland habitats in the natural riparian vegetation of lowlands in Nepal; however, invasion of *M. micrantha* and *L. camara* could have negative impacts on the habitat of this mega herbivore (Amin et al. 2006) as both of these invasive species could suppress and dominate grasslands with future warming climate, causing direct risk to the survival of *Rhinoceros*. Similarly, of the less than 3600 remaining adult tigers within 13 countries in the world, around 2000 are thought to be surviving in the forests of the Indian subcontinent (Seidensticker 2010), of which Nepal shares around 200 individuals in its lowland tropical forests. As discussed above, the likely invasion of *P. hysterophorus*, *M. micrantha*, and *L. camara* in the lowland of Nepal could degrade and fragment the habitat of the tiger, and this may disrupt predator prey relationships and overall food in the existing lowland forest ecosystems.

The warming trend in Nepal's Himalayan region has been faster compared to any equivalent period in the last century (Diodato et al. 2012), and as a result, many restricted habitat fauna could be vulnerable from habitat degradation due to invasion by exotic invasive plants. For instance, *Neofelis nebulosa* and *Ursus thibetanus* in the mid-hill temperate forests, and *Ursus arctos*, *A. fulgens*, *Bos mutus*, and *Mustela altaica* in the sub-alpine and alpine forests of middle mountains are just a few examples of restricted habitat fauna and thus could be vulnerable to CC. Bourdot et al. (2012) forecasted likely invasion of *Nassella neesiana* in Nepal, which is a temperate grassland weed, and has potential to harm pasture and grassland biodiversity by outcompeting native flora in middle mountain ecosystems (Csurhes 2008). Shrestha et al. (2015) projected that high-altitude regions of Nepal could be climatically suitable habitat for the expansion of invasive species *Parthenium hysterophorus* with the increased warming of +3 °C, and is obvious as Rangwala and Miller (2012) reported increased future warming with altitude. This risks the habitat of other fauna of middle mountains, such as *Canis lupus*, *Moschus* spp., *Equus kiang*, and *Ovis ammon* through altering existing ecosystems either by directly reducing abundances of useful species via predation and competition or by altering controls on critical ecosystem processes. Alamgir et al. (2014) reported that the impact of recent warming increased the abundance of invasive plant species such as *A. adenophora* and *Mimosa rubicaulis* in the mid-hill forest of Nepal. Similarly, Chettri (2008) reported the invasion of grazing pasture land by low-altitude exotic species such as *Circium* sp. in the high-altitude regions. The rapid upward shift and colonization of invasive *A. adenophora* with the advent of accelerated warming in recent time in the temperate and sub-alpine forest of mid-hills and middle mountain of central Nepal has been reported (Lamsal et al. 2017b), threatening the habitat of *A. fulgens* and *Moschus chrysogaster*, the two endangered fauna. This suggests that serious habitat degradation from invasive species is inevitable with future warming climate in Nepal as this species colonize an area rapidly and forms a dense thicket thereby outcompeting the native species through capturing soil nutrients and sunlight. Kuebbing and Nunez (2016) reported that the performance of non-native invasive species is five times higher to adjacent native than other non-native species. As the warming is more visible and increases with altitude (Shrestha and Aryal 2011), it is obvious that the fauna habitats in the temperate, sub-alpine, and alpine regions are at risk of substantial changes. Potential threat of invasive plant species, around 160 species recorded so far, to the biodiversity and ecosystem function in Nepal is poorly understood (Bhattarai et al. 2014).

CC impacts in freshwater wetland ecosystem

Freshwater habitats occupy 0.8% of the earth's surface, and supports high species diversity per unit area (MEA 2005), nurturing around 6% of the earth's species (Dudgeon et al. 2006). Global CC is one of the primary direct drivers for global wetland biodiversity loss (MEA 2005) that acts along with other anthropogenic stressors. The systematic study of wetlands in Nepal is very recent with their exact distribution, number, and supporting biota still unaccounted. Wetlands cover 5.6% of the total area in Nepal and ten freshwater wetlands have been listed in the Ramsar sites of international importance (Lamsal et al. 2017a). Apart from these Ramsar sites, there are numerous other freshwater wetlands supporting habitat of many endangered biota. For instance, Bhuju et al. (2010) compiled a total of 5358 freshwater wetlands in Nepal of which 52% are located in the lowland, 7% in mid-hill, and 42% in high-altitude Himalayan region. Impact assessment on climatically and geographically differed wetlands is almost non-existent in South Asia (Gopal et al. 2010). Glaciers are a perennial source of water for most of the wetlands in lowlands, mid-hills, and middle mountains and play a major role in their existence (MoEnv 2012). A total of 3252 glaciers and 2323 glacial lakes have been identified in the country. However, the volume of glaciers has been rapidly decreasing and consequently affecting the extent of such glacial lakes (Xu et al. 2009; Shrestha and Aryal 2011). The retreat of glaciers, less snowfall, and rapid snow melt from increased warming have degraded the habitat of alpine medicinal flora such as *N. scrophulariiflora* (Shrestha and Jha 2009) and *Ophiocordyceps sinensis* (Shrestha and Bawa 2015). Chaulagain (2009) predicted that water availability in the rivers and streams of Nepal would increase by 2030, then decrease by 2100 due to rapid glacier retreat in the highlands. As most of the Ramsar and non-Ramsar wetlands in lowlands and mid-hills of Nepal are fed by or depend upon either glacier melt or riverine flood, these changes in water flow and availability could affect those wetlands through changes in water level. The fluctuation in water level triggers changes, such as new planktonic and hydrophyte assemblages (Lou et al. 2015), as well as shrinkage in wetland area (Ouyang et al. 2013), which together could degrade numerous wetland-dependent micro- and macro-fauna. Shrinkage of wetland area coverage could endanger many freshwater wetland-dependent endangered fauna in the lowland and mid-hill regions. Some species such as *Crocodylus palustris*, *Kachuga kachuga*, and *Gavialis gangeticus* are only a few examples which have very poor dispersal capacity and nowhere to go as most of the wetlands in lowlands and mid-hills of Nepal are in isolated locations. Further, these wetlands support breeding ground for many endangered and threatened migratory and resident avifauna; as Carey (2009) reported that both migratory and resident avifauna could be drastically restructured through extinction and habitat range shift in wetland ecosystems. The changes in trophic and planktonic community structures as discussed here could threaten the ecology of micro- and macroinvertebrates on which higher trophic wetland fauna depend. Though this review has highlighted a few regional studies of altered trophic impacts on phytoplankton, wetland birds and other fauna, information for wetlands of the Nepal Himalaya is very limited, as illustrated in Fig. 2.

EXISTING POLICIES AND ADAPTATION RESPONSE TO CC IMPACT

As a signatory to the UNFCCC, Kyoto Protocol and Nagoya Protocol, Nepal has identified immediate adaptation needs through National Adaptation Program of Action (NAPA), in 2010, which assesses the climate-induced vulnerability and impacts on six thematic areas and on the livelihood of people. The thematic areas include agriculture and food security, forest and biodiversity, climate-induced disasters, water resources and energy, public health, and urban settlements and infrastructures. The NAPA emphasizes on community-based adaptation planning and utilization of traditional skill, knowledge, and practices of local communities for climate change adaptation to enable the country to respond strategically to the challenges and opportunities posed by CC. It is a comprehensive document prepared after rigorous consultation with multiple stakeholders and is under implementation through formulation of Local Adaptation Plan for Actions (LAPA) at local government level. Formulation of LAPA is guided by the National Framework for LAPA 2011. The LAPA follows bottom-up approach of planning with active involvement of communities and local-level actors who are potential victims of CC impacts. NAPA framework has identified broad sectors as its priority areas for climate assessment among which biodiversity and ecosystem management is one of the major components. The formulation of NAPA and LAPA should be viewed as a significant step for Nepal that has the objective of integrating CC vulnerability and impacts into the national- and local-level development planning. NAPA and LAPA are strong frameworks in Nepal, in addition to Climate Change Policy 2011, Environmental Protection Act 1996, and Environmental Protection Rules 1997 as well as many different inter sectoral acts and policies which have direct connections to environment, and have therefore opened up future research opportunities to look at climate impact on ecosystems in Nepal. Recently, the Nepal Government, through the Climate Change Policy 2011, mandates 80% of the resources to be channeled to local level for CC response/adaptation so that vulnerable communities are able to build adaptive capacity from climatic impact (NAST and OPML 2016). Here we argue that, given the diverse nature of demographic, geographic, cultural, and economic factors, strengthening socio-ecological system as a location-specific mechanism for adaptation could be a best fit for Nepal to ensure long-term sustainability of the resource base and the dependent vulnerable community.

Based on diverse culture and way of life, promotion of non-timber forest products and ecotourism to save flora and fauna, biological flood control measures to reduce flood and landslide risks, social fencing for effective forest protection, and rotational grazing management as well as existing Kipat system,[1] Nawa system,[2] and Mukhiya system[3] are some of the common indigenous knowledge and practices found in Nepal (GoN 2014b). Although adaptation measures are integrated using such traditional coping strategies against CC impact on forest and wetland ecosystems, they are becoming less effective in the context of complex and unpredictable climate change scenario (Regmi et al. 2015). In Nepal, low income people, accounting almost 1.9 million that depend on natural resources to sustain their livelihood, are in a highly vulnerable state while another 10 million are increasingly at risk to climate change (GoN 2010). For instance, Gentle and Maraseni (2012) reported that drought together with limited winter rain and snowfall affected forest- and pasture-based ecosystem services in the remote region of Jumla district that has in turn impacted livestock rearing and non-timber forest product (NTFPs) collection, which are the major sources of income to sustain livelihood. A study in Kali Gandaki river basin (Pandey and Bardsley 2015) found that the households with agro-based livelihood system that depend on pasture- and forest-based resource across three geographical regions viz. lowland, mid-hill, and mountain are climate sensitive and subjected to CC vulnerability. Likewise, Regmi and Bhandari (2013) and Gentle et al. (2014) reported that CC vulnerability in the mid-hill Nepal varies according to wellbeing status of household, with low income household suffering the most because of the least adaptive capacity in terms of poor socio-demographic status, limited livelihood diversification strategies, and a weak social network. In the Koshi Tappu floodplain basin of the southern lowland, Sharma et al. (2015) calculated ecosystem services worth US$16 million per year, equivalent to US$982 per household where provisioning services accounted almost 85%. CC could have long-term consequences in the absence of adaptive mechanisms. However, Dulal et al. (2010) found very weak adaptive capacity of local community people who depend on Koshi Tappu floodplain for agri-livestock production and natural resources, mainly due to lack of capital assets and required institutional support that make them resilient against climatic hazards such as floods and droughts. Similarly, Gurung and Bhandari (2009) reported that local communities in Chitwan district have adopted few adaptation measures to tackle CC impact on ecosystem and biodiversity, for example reforestation and afforestation in the upstream watershed. Lack of climate knowledge and essential financial resources are the hurdles for them to develop long-term adaptation strategies against CC impacts. As per Berkes et al. (2000), scientific ecology and traditional ecological knowledge are complementary to each other, and therefore could be used for effective ecosystem management against diverse natural threats. Such traditional knowledge results in effective and sustainable adaptation strategies if incorporated into CC policies (Robinson and Herbert 2001). Strengthening of traditional socio-ecological system as a mechanism for adaptation therefore could be an ideal practice in a data-deficient developing country such as Nepal, which is also strongly encouraged by the relevant policies such as NAPA and LAPA. For instance, NAPA already listed out broad-scale priority adaptation options required for the forest and biodiversity sectors of Nepal through identification of areas of CC impact and their possible adaptation response (GoN 2010, p 74).

Socio-ecological adaptation measures are mostly documented for agro-ecosystems compared to forest and wetland ecosystems. Nepal has already established community-based management system in the form community forestry user group (CFUG), which is a noble example of socio-ecological management system that has evolved through local knowledge-based initiatives. This prevailing management system can be considered as a strong grass root institutional and resource base, and an opportunity for ongoing and future CC adaptation intervention program, which is supported by Khatri et al. (2013) and Niraula and Pokharel (2016) who found such management system to enhance adaptive capacity of local

[1] Kipat is a system of land management under which the state recognized the land owned by the ethnic Limbu people of eastern Nepal; under this system, the right to use the land was given to a member of a Kipat-owning ethnic group. Some CFUG in the eastern regions are reported to use Kipat along with other traditional practices.

[2] Nawa system is a traditional institution of the ethnic Sherpa community that controls the use of village land and forest for the purpose of agriculture and animal husbandry.

[3] Mukhiya system, also called village chief or headman, is practiced mostly in the highland of central Nepal in ethnic Thakali people to implement the indigenous system of forest and pasture land management as per the rules framed by their community.

community against the impact of CC. It should be noted however that understanding the community perspective of environmental change is crucial for planning future adaptation that ensures such approach being sustainable and in accordance with community priorities (Ireland 2012). To support NAPA and LAPA policies, three large-scale adaptation programs have been recently implemented by the Government of Nepal with support from international development agencies, viz. Strategic Program for Climate Resilience (SPCR), Nepal Climate Change Support Program (NCCSP), Pilot Project for Climate Resilient (PPCR), and Hariyo Ban (Fisher and Slaney 2013), where Hariyo Ban program (2011–2016) especially focused on society, ecosystem, and biodiversity—a concept of socio-ecological system as a mechanism for adaptation. The same study further reported that as of 2013, almost 70 LAPAs were formulated, identifying 3000 activities to address climate change impact in 14 districts of mid and far western region of the country. In addition, a global initiative pilot program on CC mitigation, viz. reducing emissions from deforestation and forest degradation (REDD+), is being implemented and could strengthen adaptive capacity of the society through providing direct financial benefit through carbon trade. On the other hand, as most of the climate change programs in Nepal and other developing countries are run with technical and financial support from international development agencies, the long-term success of CC adaptation measure will be governed by the ability and willingness of those external actors to evolve their practices by paying attention to the local communities who are the most vulnerable (Ireland 2012). In this context, integrated interventions based on the co-management principle together with providing technological support to enhance existing socio-ecological systems could be a good alternative for speeding up effective CC adaptation in Nepal and other developing countries (Regmi et al. 2015). As such, CC knowledge perceived by local people should be collected and prioritized as it builds up a base for scientific hypothesis to climate research, and also helps in the formulation of mitigation and adaptation measures suited to local context, especially for a data-deficient country (Chaudhary and Bawa 2011) such as Nepal. Transboundary cooperation is inevitable in some areas of riverine floodplain wetlands such as Koshi Tappu. Koshi basin is a part of a larger river basin of South Asia called Ganges that is shared by neighboring four countries—Nepal, India, China, and Bangladesh. Dulal (2014) reported that even though the Ganges basin supports several ecosystem services for half a billion people in the region, effectiveness of existing climate information systems, infrastructure, and institutions—three pillars required for successful climate change adaptation—is insufficient and thus necessitate close regional cooperation at broader transboundary scale. Similar cooperation for combined adaptation is needed in KSL of western Himalayan region between Nepal, India, and China to formulate effective adaptation measures to offset ecological disaster as Zomer et al. (2014) projected.

CC RESEARCH GAPS AND IMPLICATIONS FOR NEPAL

Considerable research gaps on CC impact on forest and freshwater wetland ecosystems exist in Nepal. The outcome of our current review (Fig. 2) shows different nature of vulnerability and impacts that CC may cause on these two types of ecosystems in Nepal and across selected geographic regions around the world. The major impacts are mostly on phenology, species migration and population range shift, expansion and contraction of habitat and population in the forest ecosystem. Similarly, thermal stratification and water level fluctuation; areal extent alteration, vegetation composition and range shift; habitat degradation; change in migratory pattern and extinction are the possible impacts on the freshwater wetland ecosystems. Kappelle et al. (1999) also reported comparable impacts on ecosystems that arise from recent CC. The regional studies have investigated ecosystem vulnerability and resultant impacts using various modeling techniques. In the context of Nepal, little is known so far, though ecosystem vulnerability and impacts from climate variability, as we show in Fig. 2, are either existing or equally likely to occur in the future if we consider rapidity of ongoing climatic alteration owing to the country's exposed geography and climate. For example, research gaps exist in Nepal on identifying relationship between CC, range expansion and new assemblage; however, few studies are available on range restriction (Gaire et al. 2014; Chhetri and Cairns 2015), habitat fragmentation (Thapa et al. 2016), and phenology (Xu et al. 2009; Chaudhary and Bawa 2011). Here, it should be noted that not only Nepal but as per IPCC (2007), the whole Himalayan region is severely data deficient in terms of CC vulnerability and impacts observation on their ecosystems.

Least developed countries have contributed negligible amounts of greenhouse gas (GHG) emission, but are at the most vulnerable from its effect mostly due to their least adaptive capacities, shortage in resources and funds for undertaking climate research, and implementing the outcomes (Huq et al. 2003). For example, Nepal is a least emitter of GHG, accounting for only 32 MT CO_2 in 2010, which is less than 0.1% of global emission[4]; however, warming impacts could be extensive on its ecosystem due to the highly variable elevational range and climatic

[4] http://climateactiontracker.org/countries/nepal.html.

condition (Table 1) within a short latitudinal extent, and therefore could be the worst victim of CC. Nepal ranks 4th of the most vulnerable countries in the world (Maple Croft 2010). Further, IPCC (2007) stated that the living condition of rural and low income population in least developed countries are being affected by CC, which creates variability and uncertainty of the natural system, for instance forest and freshwater wetlands, upon which they maintain their livelihood.

We view likely impacts on ecosystem services as a societal and landscape-level conservation as an ecological consequence among others as a foremost concern for Nepal arising from CC. Ecosystem functioning is linked with ecological services that bear far-reaching effects on societies in the twenty-first century (Jentsch and Beierkuhnlein 2008). Impacts of CC on the forest ecosystem in the country have been evidenced through decreasing trend of forest area and density, biodiversity, potential for sustainably harvesting products while increasing incidence of pests and diseases, fire, and invasive species (MFSC 2014). The country has agriculture-based economy, and 80% of the population lives in rural and semi-urban settings and are highly dependent on the provisioning services of forest and freshwater wetland ecosystems to sustain livelihoods (Maren et al. 2013; Lamsal et al. 2015, 2017a). Zomer et al. (2014) reported that by 2050, there will be significant biological overhaul in the montane climate throughout KSL that risks both forest and wetland biodiversity and threatens livelihood and survival of local communities. Therefore, timely recognition of landscape-level ecosystems that are vulnerable to climatic impact and at the same time those that have high potential of delivering important ecosystem services to communities are imperative for proper management.

Similarly, climate impact could threaten the management of protected area (PA) systems in the country. More than 20 PAs have been established so far in Nepal, covering an area of 34 312 sq. km (23% of total land area) (DNPWC 2015) with the aim of restoration and conservation of diverse forest and freshwater wetland ecosystems and their biota. These PAs represent all physiographic zones (seven in lowland, three in mid-hill, and ten in middle and High Mountain) and become pioneered landscape-level conservation strategies for the protection of many endangered and vulnerable flora and fauna (Shrestha et al. 2010). With the identified and unaccounted vulnerability to the climatic impacts that we discussed here, the future of these protected areas is uncertain, mainly because these are static, having artificially designated boundaries with criteria other than ecological whereas climate systems, ecosystems, and species ranges are dynamic, failing to buffer species from ongoing climate impact (Monzon et al. 2011). For instance, Araujo et al. (2004) predicted disappearance of up to 11% of the flora from the current European PAs by 2050 and suggested to look for a new way of PA selection methods in the context of future CC. Krupnick (2013) also agreed on non-effectiveness of current conservation philosophy. Management of current or establishment of future PAs for the conservation of climate-sensitive landscape of Nepal though seems costly but is unavoidable. Hannah et al. (2007) suggested that these PAs are and will remain important conservation strategies for future climate scenarios and prompt action is more effective and less costly than inaction or delayed action.

CONCLUSION, AND MANAGEMENT AND POLICY RECOMMENDATION

CC has become a reality as vulnerability and impacts of CC threatening forest and freshwater wetland ecosystems and their biota are evident across different geographic regions. Scientific studies in other parts of the world have confirmed this. Nepal has also witnessed such threats in recent time, however, due to the lack of extensive empirical research on climate science, the extent of such impacts is still largely unknown. However, as such ecological impacts are global in nature, Nepal will not be spared and thus it should prepare itself to guard against detrimental consequences. Such threats will not only degrade Nepal's ecosystems but also affect livelihood of dependent communities and threaten landscape conservation efforts due to insufficient capital assets that are essential to develop strong adaptive capacity. As CC research is very low despite having high vulnerability, there is an urgent need to identify and verify the likelihood of such impacts at the landscape ecosystem level, and prioritize national-level research programs to minimize existing knowledge gaps. Nonetheless, Nepal has supportive climate-related acts and policies that encourage research and development, and implementation of adaptation activities. We suggest that identification and verification of threats are important before commencing such adaptation activities. Given the diverse nature of demographic, geographic, and economic factors, adaptation measures based on existing traditional socio-ecological systems that are also emphasized by existing policies will be the best fit for Nepal, which truly reflects the need of vulnerable communities and ensures sustainability in the long term. To make this happen, proper coordination among concerned stakeholders that range from local community people to governmental and international non-governmental organizations is crucial.

Acknowledgements We thank three anonymous reviewers for their helpful comments and suggestions.

REFERENCES

Adkins, S., and A. Shabbir. 2014. Biology, ecology and management of the invasive parthenium weed (*Parthenium hysterophorus* L.). *Pest Management Science* 70: 1023–1029. doi:10.1002/ps.3708.

Agrawala, S., V. Raksakulthai, P. Larsen, J. Smith, and J. Reynolds. 2003. *Development and climate change in Nepal: Focus on water resources and hydropower*. Paris: OECD.

Alamgir, M., J. Pretzsch, and S.M. Turton. 2014. Climate change effects on community forests: Finding through user's lens and local knowledge. *Small-scale Forestry* 13: 445–460. doi:10.1007/s11842-014-9264-8.

Alamgir, M., S.A. Mukul, and S.M. Turton. 2015. Modelling spatial distribution of critically endangered Asian elephant and Hoolock gibbon in Bangladesh forest ecosystems under a changing climate. *Applied Geography* 60: 10–19. doi:10.1016/j.apgeog.2015.03.001.

Ale, S.B., P. Yonzon, and K. Thapa. 2007. Recovery of snow leopard *Uncia uncia* in Sagarmatha (Mount Everest) National Park, Nepal. *Oryx* 41: 89–92.

Amin, R., K. Thomas, R.H. Emslie, T.J. Foose, and N.V. Strien. 2006. An overview of the conservation status of and threats to rhinoceros species in the wild. *International Zoological Yearbook* 40: 96–117. doi:10.1111/j.1748-1090.2006.00096.x.

An, S., Z. Tian, Y. Cai, T. Wen, D. Xu, H. Jiang, Z. Yao, B. Guan, et al. 2013. Wetlands of northeast Asia and high Asia: An overview. *Aquatic Science* 75: 63–71. doi:10.1007/s00027-012-0281-4.

Aryal, A., D. Brunton, and D. Raubenheimer. 2014. Impact of climate change on human–wildlife–ecosystem interactions in the Trans-Himalaya region of Nepal. *Theoritcal and Applied Climatology* 115: 517–529. doi:10.1007/s00704-013-0902-4.

Araujo, M.B., M. Cabeza, W. Thuiller, L. Hannah, and P.H. Williams. 2004. Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. *Global Change Biology* 10: 1618–1626. doi:10.1111/j.1365-2486.2004.00828.x.

Beaubien, E., and A. Hamann. 2011. Spring flowering response to climate change between 1936 and 2006 in Alberta, Canada. *BioScience* 61: 514–524. doi:10.1525/bio.2011.61.7.6.

Berkes, F., J. Colding, and C. Folke. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications* 10: 1251–1262. doi:10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2.

Bharali, S., and M.L. Khan. 2011. Climate change and its impact on biodiversity: Some management options for mitigation in Arunachal Pradesh. *Current Science* 101: 855–860.

Bharati, L., P. Gurung, P. Jayakody, V. Smakhtin, and U. Bhattarai. 2014. The projected impact of climate change on water availability and development in the Koshi Basin, Nepal. *Mountain Research and Development* 34: 118–130. doi:10.1659/MRD-JOURNAL-D-13-00096.1.

Bhattarai, K.R., I.S. Maren, and S.C. Subedi. 2014. Biodiversity and invasibility: Distribution patterns of invasive plant species in the Himalayas, Nepal. *Journal of Mountain Science* 11: 688–696. doi:10.1007/s11629-013-2821-3.

Bhuju, U.R., M. Khadka, P.K. Neupane, and R. Adhikari. 2010. A map based inventory of lakes in Nepal. *Nepal Journal of Science and Technology* 11: 173–180. doi:10.3126/njst.v11i0.4141.

Both, C., S. Bouwhuis, C.M. Lessells, and M.E. Visser. 2006. Climate change and population declines in a long-distance migratory bird. *Nature* 441: 81–83. doi:10.1038/nature04539.

Bourdot, G.W., S.L. Lamoureaux, M.S. Watt, L.K. Manning, and D.J. Kriticos. 2012. The potential global distribution of the invasive weed *Nassella neesiana* under current and future climates. *Biological Invasions* 14: 1545–1556. doi:10.1007/s10530-010-9905-6.

Burgiel, S.W., and A.A. Muir. 2010. *Invasive species, climate change and ecosystem-based adaptation: Addressing multiple drivers of global change*. Washington, DC: Global Invasive Species Programme (GISP), 56 pp.

Carey, C. 2009. The impacts of climate change on the annual cycles of birds. *Philosophical Transactions of the Royal Society of London* 364: 3321–3330. doi:10.1098/rstb.2009.0182.

CEPF. 2005. Ecosystem Profile: Eastern Himalayas Region. WWF-US Asia Program, 100 pp.

Chapin, F.S., E.S. Zavaleta, V.T. Eviner, R.L. Naylor, P.M. Vitousek, H.L. Reynolds, D.U. Hooper, S. Lavorel, et al. 2000. Consequences of changing biodiversity. *Nature* 405: 234–242. doi:10.1038/35012241.

Chaudhary, P., and K.S. Bawa. 2011. Local perceptions of climate change validated by scientific evidence in the Himalayas. *Biology Letters*. doi:10.1098/rsbl.2011.0269.

Chaudhary, R. P., K.K. Shrestha, P. K. Jha, and K.P. Bhatta. 2010. *Kailash sacred landscape conservation initiative feasibility assessment report—Nepal*. Kathmandu: Central Department of Botany, Tribhuwan University, 213 pp.

Chaulagain, N.P. 2009. Climate change impacts on water resources of Nepal with reference to the glaciers in the Langtang Himalayas. *Journal of Hydrology and Meteorology* 6: 58–65. doi:10.3126/jhm.v6i1.5489.

Chettri, P.K. 2008. Dendrochronological analyses and climate change perceptions in Langtang National Park, Central Nepal. In *Climate change and disaster impact reduction*, ed. Komal Raj Aryal and Zaina Gadema, 28–32. Northumbria University.

Chhetri, P.K., and D.M. Cairns. 2015. Contemporary and historic population structure of *Abies spectabilis* at treeline in Barun valley, eastern Nepal Himalaya. *Journal of Mountain Science* 12: 558–570.

Chu, C., and F. Fischer. 2012. Climate change vulnerability assessment for aquatic ecosystems in the clay belt ecodistrict of Northeastern Ontario. Climate Change Research Report CCRR-30, Ministry of Natural Resources, 26 pp.

Clausen, K.K., and P. Clausen. 2013. Earlier Arctic springs cause phenological mismatch in long-distance migrants. *Oecologia* 173: 1101–1112. doi:10.1007/s00442-013-2681-0.

Coetzee, B.W.T., M.P. Robertson, B.F.N. Erasmus, B.J. Van Rensburg, and W. Thuiller. 2009. Ensemble models predict important bird areas in Southern Africa will become less effective for conserving endemic birds under climate change. *Global Ecology and Biogeography* 18: 701–710. doi:10.1111/j.1466-8238.2009.00485.x.

Corlett, R.T., and J.V. Lafrankie. 1998. Potential impacts of climate change on tropical Asian forest through an influence on phenology. *Climatic Change* 39: 439–453. doi:10.1023/A:1005328124567.

Csurhes, S. 2008. *Plant pest risk assessment: Chilean needle grass Nassella neesiana*. Brisbane: Queensland Government, Department of Primary Industries and Fisheries, 12 pp.

Davis, M.A. 2003. Biotic globalisation: Does competition from introduced species threaten biodiversity? *BioScience* 53: 481–489.

Diodato, N., G. Bellocchi, and G. Tartari. 2012. How do Himalayan areas respond to global warming? *International Journal of Climatology* 32: 975–982. doi:10.1002/joc.2340.

DNPWC. 2015. *Royal Chitwan National Park and Buffer Zone Management Plan: 2013–2017*. Kathmandu: Department of National Parks and Wildlife Conservation, 192 pp.

Dolezal, J., M. Dvorsky, M. Kopecky, P. Liancourt, I. Hiiesalu, M. Macek, J. Altman, Z. Chlumska, et al. 2016. Vegetation

dynamics at the upper elevational limit of vascular plants in Himalaya. *Scientific Report* 6: 24881. doi:10.1038/srep24881.
Dubey, S., D.A. Pike, and R. Shine. 2013. Predicting the impacts of climate change on genetic diversity in an endangered lizard species. *Climatic Change* 117: 319–327. doi:10.1007/s10584-012-0540-3.
Dudgeon, D., A.H. Arthington, M.O. Gessner, Z. Kawabata, D.J. Knowler, C. Lévêque, R.J. Naiman, A.D. Prieur-Richard, et al. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Review* 81: 163–182. doi:10.1017/S1464793105006950.
Dulal, H.B. 2014. Governing climate change adaptation in the Ganges basin: Assessing needs and capacities. *International Journal of Sustainable Development & World Ecology* 21: 1–14. doi:10.1080/13504509.2013.871657.
Dulal, H.B., G. Brodnig, H.K. Thakur, and C. Green-Onoriose. 2010. Do the poor have what they need to adapt to climate change? A case study of Nepal. *Local Environment: The International Journal of Justice and Sustainability* 15: 621–635. doi:10.1080/13549839.2010.498814.
Dullinger, S., A. Gattringer, W. Thuiller, D. Moser, N.E. Zimmermann, A. Guisan, and K. Hülber. 2012. Extinction debt of high-mountain plants under twenty-first-century climate change. *Nature Climate Change* 2: 619–622. doi:10.1038/nclimate1514.
Early, R., B.A. Bradley, J.S. Dukes, J.J. Lawler, J.D. Olden, D.M. Blumenthal, P. Gonzalez, E.D. Grosholz, et al. 2016. Global threats from invasive alien species in the twenty-first century and national response capacities. *Nature* 7: 12485. doi:10.1038/ncomms12485.
Feehan, J., M. Harley, and J. Minnen. 2009. Climate change in Europe. 1. Impact on terrestrial ecosystems and biodiversity. A review. *Agronomy for Sustainable Development* 29: 409–421. doi:10.1051/agro:2008066.
Fisher, S., and M. Slaney. 2013. *The monitoring and evaluation of climate change adaptation in Nepal: A review of national systems*. London: International Institute for Environment and Development, 29 pp.
Forrest, J.L., E. Wikramanayake, R. Shrestha, G. Areendra, K. Gyeltshen, A. Maheshwari, S. Majumdars, R. Naidoo, et al. 2012. Conservation and climate change: Assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya. *Biological Conservation* 15: 129–135. doi:10.1016/j.biocon.2012.03.001.
Froyd, C.A., E.E.D. Coffey, W.O. van der Knaap, J.F.N. van Leeuwen, A. Tye, and K.J. Willis. 2014. The ecological consequences of megafaunal loss: Giant tortoises and wetland biodiversity. *Ecology Letters* 17: 144–154. doi:10.1111/ele.12203.
Gaire, N.P., M. Koirala, D.R. Bhuju, and H.P. Borgaonkar. 2014. Treeline dynamics with climate change at Central Nepal Himalaya. *Climate of the Past* 10: 1277–1290. doi:10.5194/cpd-9-5941-2013.
Gentle, P., and T.N. Maraseni. 2012. Climate change, poverty and livelihoods: Adaptation practices by rural mountain communities in Nepal. *Environmental Science & Policy* 21: 24–34. doi:10.1016/j.envsci.2012.03.007.
Gentle, P., R. Thwaites, D. Race, and K. Alexander. 2014. Differential impact of climate change on communities in the middle hill region of Nepal. *Natural Hazard* 74: 815–836. doi:10.1007/s11069-014-1218-0.
Giam, X., C.J.A. Bradshaw, H.T.W. Tan, and N.S. Sodhi. 2010. Future habitat loss and the conservation of plant biodiversity. *Biological Conservation* 143: 1594–1602. doi:10.1016/j.biocon.2010.04.019.
Gomez-Mendoza, L., and L. Arriaga. 2007. Modeling the effect of climate change on the distribution of oak and pine species of Mexico. *Conservation Biology* 21: 1545–1555. doi:10.1111/j.1523-1739.2007.00814.x.
GoN. 2010. *National Adaptation Programme of Action (NAPA) to climate change*. Kathmandu: Ministry of Environment, Government of Nepal, 96 pp.
GoN. 2014a. *Nepal national biodiversity strategy and action plan 2014–2020*. Kathmandu: Ministry of Forest and Soil Conservation, Sighadurbar, 226 pp.
GoN. 2014b. *Mainstreaming climate change risk management in development*. Ministry of Science, Technology and Environment, ADB TA 7984—Indigenous Research, 271 pp.
Gopal, B. 2013. Future of wetlands in tropical and subtropical Asia, especially in the face of climate change. *Aquatic Science* 75: 39–61. doi:10.1007/s00027-011-0247-y.
Gopal, B., R. Shilpakar, and E. Sharma. 2010. Functions and services of wetlands in the Eastern Himalayas: Impacts of climate change. Technical Report 3, Climate change impact and vulnerability in the Eastern Himalaya. ICIMOD, Kathmandu.
Gottfried, M., H. Pauli, A. Futschik, M. Akhalkatsi, P. Barancok, B. Alonso, and G. Grabherr. 2012. Continent-wide response of mountain vegetation to climate change. *Nature Climate Change* 2: 111–115. doi:10.1038/nclimate1329.
Gurung, G.B., and D. Bhandari. 2009. Integrated approach to climate change adaptation. *Journal of Forest and Livelihood* 8: 91–99.
Halloy, S.R.P., and A.F. Mark. 2003. Climate change effects on alpine plant biodiversity: A New Zealand perspective on quantifying the threat. *Arctic, Antarctic and Alpine Research* 35: 248–254. doi:10.1657/1523-0430(2003)035[0248:CEOAPB]2.0.CO;2.
Hannah, L., G.F. Midgley, S. Andelman, M.B. Araujo, G. Hughes, E. Martinez-Meyer, R.G. Pearson, and P.J. Williams. 2007. Protected area needs in a changing climate. *Frontiers in Ecology and the Environment* 5: 131–138. doi:10.1890/1540-9295(2007)5[131:PANIAC]2.0.CO;2.
Hansen, A.J., R.P. Neilson, V.H. Dale, C.H. Flather, L.R. Iverson, D.J. Currie, S. Shafer, R. Cook, and P.J. Bartlein. 2001. Global change in forests: Responses of species, communities, and biomes. *BioScience* 51: 765–779.
Harris, J.A., R.J. Hobbs, E. Higgs, and J. Aronson. 2006. Ecological restoration and global climate change. *Restoration Ecology* 14: 170–176. doi:10.1111/j.1526-100X.2006.00136.x.
Hegland, S.J., A. Nielsen, A. Lazaro, A.L. Bjerknes, and O. Totland. 2009. How does climate warming affect plant–pollinator interactions? *Ecology Letters* 12: 184–195. doi:10.1007/s10750-014-2166-0.
Heino, J., R. Virkkala, and H. Toivonen. 2009. Climate change and freshwater biodiversity: Detected patterns, future trends and adaptations in northern regions. *Biological Review* 84: 39–54. doi:10.1111/j.1469-185X.2008.00060.x.
Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, and V. Xiaosu (Eds.) (2001). *Climate Change 2001: The Scientific Basis*. Intergovernmental Panel on Climate Change: Working Group I. Cambridge: Cambridge University Press, 881 pp.
Huq, S., A. Rahman, M. Konate, Y. Sokona, F. Crick, and H. Reid. 2003. *Mainstreaming adaptation to climate change in Least Developed Countries (LDCs)*. International Institute for Environment and Development, 42 pp.
Immerzeel, W.W., L.P.H. van Beek, and M.F.P. Bierkens. 2010. Climate change will affect the Asian water towers. *Science (New York, NY)* 328: 1382–1385. doi:10.1126/science.1183188.
Inskipp, C., H.S. Baral, T. Inskipp, and A. Stattersfield. 2013. The state of Nepal birds 2010. *Journal of Threatened Taxa* 5: 3473–3503. doi:10.11609/JoTT.o3276.933.
IPCC. 2007. Climate Change 2007: Synthesis Report. In *Contribution of Working Groups I, II and III to the Fourth Assessment Report*

of the Intergovernmental Panel on Climate Change, ed. R.K. Pachauri, and A. Reisinger, 104. Geneva: IPCC.

Ireland, P. 2012. Nepalganj, the centre of the world: Local perceptions of environmental change and the roles of climate-change adaptation actors. *Local Environment* 17: 187–201. doi:10.1080/13549839.2012.660907.

Jackson, R.M., and G. Ahlborn. 1989. Snow leopards (*Panthera uncia*) in Nepal: Home range movements. *National Geographic Research* 5: 161–175.

Jentsch, A., and C. Beierkuhnlein. 2008. Research frontiers in climate change: effects of extreme meteorological events on ecosystem. *Comptes Rendus GeoScience* 340: 621–628. doi:10.1016/j.crte.2008.07.002.

Jetz, W., D.S. Wilcove, and A.P. Dobson. 2007. Projected impacts of climate and land-use change on the global diversity of birds. *PLoS Biology* 5: 1211–1219. doi:10.1371/journal.pbio.0050157.

Kaplan, J.O., and M. New. 2006. Arctic climate change with a 2 °C global warming: Timing, climate patterns and vegetation change. *Climatic Change* 79: 213–241. doi:10.1007/s10584-006-9113-7.

Kappelle, M., M.M.I. Van Vuuren, and P. Baas. 1999. Effects of climate change on biodiversity: A review and identification of key research issues. *Biodiversity and Conservation* 8: 1383–1397. doi:10.1023/A:1008934324223.

Kelly, M., and N. Adger. 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climate Change* 47: 325–352. doi:10.1023/A:1005627828199.

Khatri, D.B., R. Bista, and N. Gurung. 2013. Climate change adaptation and local institutions: How to connect community groups with local government for adaptation planning. *Journal of Forest and Livelihood* 11: 14–28. doi:10.3126/jfl.v11i1.8610.

Klaus, S.P., and S.C. Lougheed. 2013. Changes in breeding phenology of eastern Ontario frogs over four decades. *Ecology and Evolution* 3: 835–845. doi:10.1002/ece3.501.

Krupnick, G.A. 2013. Conservation of tropical plant biodiversity: What have we done, where are we going? *Biotropica* 45: 693–708. doi:10.1111/Btp.12064.

Kuebbing, S.E., and M.A. Nunez. 2016. Invasive non native plants have a greater effect on neighboring natives than other non-natives. *Nature Plants*. doi:10.1038/NPLANTS.2016.134.

Lamsal, P., K.P. Pant, L. Kumar, and K. Atreya. 2015. Sustainable livelihoods through conservation of wetland resources: A case of economic benefits from Ghodaghodi Lake, western Nepal. *Ecology and Society* 20: 10. doi:10.5751/ES-07172-20011.

Lamsal, P., K. Atreya, K.P. Pant, and L. Kumar. 2017a. People's dependency on wetlands: South Asia perspective with emphasis on Nepal. In *Wetland science: Perspective from South Asia*, ed. B.A.K. Prusty, R. Chandra, and P.A. Azeez, 407–419. Springer. doi: 10.1007/978-81-322-3715-0.

Lamsal, P., L. Kumar, and K. Atreya. 2017b. Historical evidence of climatic variability and changes, and its effect on high-altitude regions: insights from Rara and Langtang, Nepal. *International Journal of Sustainable Development and World Ecology*. doi:10.1080/13504509.2016.1198939.

Lawler, J.J., S.L. Shafer, D. White, P. Kareiva, E.P. Maurer, A.R. Blaustein, and P.J. Bartlein. 2009. Projected climate-induced faunal change in the Western Hemisphere. *Ecology* 90: 588–597. doi:10.1890/08-0823.1.

LeComte, D. 2017. International weather highlights 2016: Record heat, El Niño, a wacky tropical cyclone season. *Weatherwise* 70: 20–27. doi:10.1080/00431672.2017.1299473.

Lehikoinen, A., K. Jaatinen, A.V. Vahatalo, P. Clausen, O. Crowe, B. Deceuninck, R. Hearn, C.A. Holt, et al. 2013. Rapid climate driven shifts in wintering distributions of three common water bird species. *Global Change Biology* 19: 2071–2081. doi:10.1111/gcb.12200.

Loarie, S.R., P.B. Duffy, H. Hamilton, G.P. Asner, C.B. Field, and D.D. Ackerly. 2009. The velocity of climate change. *Nature* 462: 1052–1057. doi:10.1038/nature08649.

Lou, Y., K. Zhao, G. Wang, M. Jiang, X. Lu, and H. Rydin. 2015. Long-term changes in marsh vegetation in Sanjiang Plain, northeast China. *Journal of Vegetation Science* 26: 643–650. doi:10.1111/jvs.12270.

Lovari, S., M. Ventimiglia, and I. Minder. 2013. Food habits of two leopard species, competition, climate change and upper treeline: A way to the decrease of an endangered species? *Ethology Ecology and Evolution* 25: 305–318. doi:10.1080/03949370.2013.806362.

Mainka, S.A., and G.W. Howard. 2010. Climate change and invasive species: Double jeopardy. *Integrative Zoology* 5: 102–111. doi:10.1111/j.1749-4877.2010.00193.x.

Malcom, J.R., C. Liu, R.P. Neilson, L. Hansen, and L. Hannah. 2006. Global warming and extinctions of endemic species from biodiversity hotspots. *Conservation Biology* 20: 538–548. doi:10.1111/j.1523-1739.2006.00364.x.

Maple Croft. 2010. Climate change risk report 2009/10. Retrieved November 12, 2015, from http://maplecroft.com/about/news/ccvi.html.

Maren, I., K.R. Bhattarai, and R.P. Chaudhary. 2013. Forest ecosystem services and biodiversity: The resource flux from forests to farms in the Himalayas. Technical report, Kathmandu, Nepal.

McCarty, J.P. 2001. Ecological consequences of recent climate change. *Conservation Biology* 15: 320–331. doi:10.1046/j.1523-1739.2001.015002320.x.

MEA. 2005. *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.

MFSC. 2014. *Nepal National Biodiversity Strategy and Action Plan (2014–2020)*. Singhdurbar, Kathmandu: Ministry of Forests and Soil Conservation.

MoEnv. 2012. Mountain Environment and Climate Change in Nepal: National Report prepared for the International Conference of Mountain Countries on Climate Change, 5–6 April 2012, Kathmandu: Ministry of Environment, Government of Nepal, 56 pp.

Mohandass, D., Y.M. Zhao, M.J. Campbell, and Q.J. Li. 2015. Increasing temperature causes flowering onset time changes of alpine ginger *Roscoea* in the central Himalayas. *Journal of Asia Pacific Biodiversity* 8: 191–198. doi:10.1016/j.japb.2015.08.003.

Molur, S. 2008. South Asian amphibians: Taxonomy, diversity and conservation status. *International Zoological Yearbook* 42: 143–157. doi:10.1111/j.1748-1090.2008.00050.x.

Monzon, J., L. Moyer-Horner, and M.B. Palamar. 2011. Climate change and species range dynamics in protected areas. *BioScience* 61: 752–761. doi:10.1525/bio.2011.61.10.5.

Mooij, W.M., S. Hulsmann, L.N. De Senerpont Domis, B.A. Nolet, P.L.E. Bodelier, P.C.M. Boers, L.M.D. Pires, H.J. Gons, et al. 2005. The impact of climate change on lakes in the Netherlands: A review. *Aquatic Ecology* 39: 381–400. doi:10.1007/s10452-005-9008-0.

MoPE. 2004. Initial National Communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change. A report submitted to UNFCCC, 181 pp.

NAST and OPML. 2016. *Understanding demand and supply of climate change knowledge management in Nepal*. Nepal Academy of Science and Technology, Nepal and Oxford Policy Management Limited, India, Action on Climate Today Initiative, 72 pp.

NBS. 2002. *Nepal Biodiversity Strategy*. Kathmandu: Ministry of Forests and Soil Conservation, Government of Nepal, 132 pp.

Niraula, R., and B.K. Pokharel. 2016. Community forest management as climate change adaptation measure in Nepal's Himalaya. In

Climate change adaptation strategies—An upstream-downstream perspective, ed. N. Salzmann, C. Huggel, S.U. Nussbaumer, and G. Ziervogel. Uitgever: Springer. doi:10.1007/978-3-319-40773-9_6.

Nogue, S., V. Rull, and T. Vegas-Vilarrubia. 2009. Modeling biodiversity loss by global warming on Pantepui, northern South America: Projected upward migration and potential habitat loss. *Climatic Change* 94: 77–85. doi:10.1007/s10584-009-9554-x.

Nogues-Bravo, D., M.B. Araujo, M.P. Errea, and J.P. Martinez-Rica. 2007. Exposure of global mountain systems to climate warming during the 21st century. *Global Environmental Change* 17: 420–428. doi:10.1016/j.gloenvcha.2006.11.007.

Nogues-Bravo, D., S. Veloz, B.G. Holt, J. Singarayer, P. Valdes, B. Davis, S.C. Brewer, J.W. Williams, et al. 2016. Amplied plant turnover in response to climate change forecast by Late Quaternary records. *Nature Climate Change*. doi:10.1038/NCLIMATE3146.

Ouyang, Z., R. Beckar, and J.C. Wade Shaver. 2013. Evaluating the sensitivity of wetlands to climate change with remote sensing techniques. *Hydrological Processes* 28: 1703–1712. doi:10.1016/j.gloenvcha.2006.11.007.

Pandey, R., and D.K. Bardsley. 2015. Social–ecological vulnerability to climate change in the Nepali Himalaya. *Applied Geography* 64: 74–86. doi:10.1016/j.apgeog.2015.09.008.

Paudel, P.K., and J.T. Heinen. 2015. Think globally, act locally: On the status of the threatened fauna in the Central Himalaya of Nepal. *Geoforum* 64: 192–195. doi:10.1016/j.geoforum.2015.06.021.

Pauli, H., M. Gottfried, and G. Grabherr. 1996. Effects of climate change on mountain ecosystems—Upward shifting of alpine plants. *World Resource Review* 8: 382–390.

Pearson, R.G. 2006. Climate change and the migration capacity of species. *Trends in Ecology & Evolution* 21: 111–113. doi:10.1016/j.tree.2005.11.022.

Peh, K.S.H. 2007. Potential effects of climate change on elevational distributions of tropical birds in Southeast Asia. *The Condo* 109: 437–441. doi:10.1650/0010-5422(2007)109[437:PEOCCO]2.0.CO;2.

Practical Action. 2009. *Temporal and spatial variability of climate change over Nepal (1976–2005)*. Kathmandu: Practical Action Nepal Office.

Rai, R.K., and H. Scarborough. 2012. Valuing the damage caused by invasive plant species in a low income community in Nepal. SANDEE Working Paper No. 74-12, 40 pp.

Rangwala, I., and J.R. Miller. 2012. Climate change in mountains: A review of elevation-dependent warming and its possible causes. *Climatic Change* 114: 527–547. doi:10.1007/s10584-012-0419-3.

Ranjitkar, S., E. Luedeling, K.K. Shrestha, K. Guan, and J. Xu. 2013. Flowering phenology of tree rhododendron along an elevation gradient in two sites in the Eastern Himalayas. *International Journal of Biometeorology* 57: 225–240. doi:10.1007/s00484-012-0548-4.

Rashid, I., S.A. Romshoo, R.K. Chaturvedi, N.H. Ravindranath, R. Sukumar, M. Jayaraman, T.V. Lakshmi, and J. Sharma. 2015. Projected climate change impacts on vegetation distribution over Kashmir Himalayas. *Climatic Change* 132: 601–613. doi:10.1007/s10584-015-1456-5.

Regmi, B.R., C. Star, A. Paudyal, and R.C. Karki. 2015. Strengthening climate change adaptation in Nepal: Needs and perspective. In *Climate change in the Asia-Pacific region*, ed. W. Leal Filho, 245–262. Cham: Springer. doi:10.1007/978-3-319-14938-7_15.

Regmi, B.R., and D. Bhandari. 2013. Climate change adaptation in Nepal: Exploring ways to overcome the barriers. *Journal of Forest and Livelihoods* 11: 43–61. doi:10.3126/jfl.v11i1.8612.

Richardson, D.M., and M. Rejmanek. 2011. Trees and shrubs as invasive alien species—A global review. *Diversity and distribution* 17: 788–809. doi:10.1111/j.1472-4642.2011.00782.x.

Robinson, J., and D. Herbert. 2001. Integrating climate change and sustainable development. *International Journal of Global Environmental Issues* 1: 130–148.

Rupa Kumar, K., A.K. Sahai, K. Krishna Kumar, S.K. Patwardhan, P.K. Mishra, J.V. Revadekar, and K. Kamala. 2006. High-resolution climate change scenarios for India for the 21st century. *Current Science* 90: 334–345.

Schloss, C.A., T.A. Nunez, and J.J. Lawler. 2012. Dispersal will limit ability of mammals to track climate change in the Western Hemisphere. *Proceedings of the National Academy of Sciences* 109: 8606–8611. doi:10.1073/pnas.1116791109.

Seidensticker, J. 2010. Saving wild tigers: A case study in biodiversity loss and challenges to be met for recovery beyond 2010. *Integrative Zoology* 5: 285–299. doi:10.1111/j.1749-4877.2010.00214.x.

Sharma, B., G. Rasul, and N. Chettri. 2015. The economic value of wetland ecosystem services: Evidence from the Koshi Tappu Wildlife Reserve. *Nepal. Ecosystem Services* 12: 84–93. doi:10.1016/j.ecoser.2015.02.007.

Sharma, E., K. Tsering, N. Chettri, and A. Shrestha. 2009. *Biodiversity in the Himalayas—Trends, perceptions, and impacts of climate change*. Proceedings of the international mountain biodiversity conference, 16–18 November 2009, Kathmandu, Nepal.

Shrestha, M.L. 2000. Inter annual variation of summer monsoon rainfall over Nepal and its relation to southern oscillation index. *Meteorology Atmospheric Physics* 75: 21–28. doi:10.1007/s007030070012.

Shrestha, B.B. 2012. Parthenium weed in Chitwan National Park, Nepal. *International Parthenium News* 5: 6–7.

Shrestha, A.B., and R. Aryal. 2011. Climate change in Nepal and its impact on Himalayan glaciers. *Regional Environmental Change* 11: 65–77. doi:10.1007/s10113-010-0174-9.

Shrestha, U.B., and K.S. Bawa. 2015. Harvesters' perceptions of population status and conservation of Chinese caterpillar fungus in the Dolpa region of Nepal. *Regional Environmental Change* 15: 1731–1741. doi:10.1007/s10113-014-0732-7.

Shrestha, B.B., and P.K. Jha. 2009. Habitat range of two alpine medicinal plants in a trans-Himalayan dry valley, Central Nepal. *Journal of Mountain Science* 6: 66–77. doi:10.1007/s11629-009-0209-1.

Shrestha, U.B., S. Shrestha, P. Chaudhary, and R.P. Chaudhary. 2010. How representative is the protected areas system of Nepal? *Mountain Research and Development* 30: 282–294. doi:10.1659/MRD-JOURNAL-D-10-00019.1.

Shrestha, B.B., A. Shabbir, and S.W. Adkins. 2015. *Parthenium hysterophorus* in Nepal: A review of its weed status and possibilities for management. *Weed Research* 55: 132–144. doi:10.1111/wre.12133.

Sigdel, M., and M. Ikeda. 2012. Seasonal contrast in precipitation mechanisms over Nepal deduced. *Nepal Journal of Science Technology* 13: 115–123. doi:10.3126/njst.v13i1.7450.

Sigdel, M., and Y. Ma. 2015. Evaluation of future precipitation scenario using statistical downscaling model over humid, subhumid, and arid region of Nepal—A case studies. *Theoretical and Applied Climatology*. doi:10.1007/s00704-014-1365-y.

Simmons, R.E., P. Barnard, W. Dean, G.F. Midgley, W. Thuiller, and G. Hughe. 2004. Climate change and birds: Perspectives and prospects from southern Africa. *Ostrich* 75: 295–308. doi:10.2989/00306520409485458.

Snow Leopard Network. 2014. *Snow leopard survival strategy*. Revised 2014 Version. Seattle: Snow Leopard Network, 145 pp.

Songer, M., M. Delion, A. Biggs, and Q. Huang. 2012. Modeling impacts of climate change on giant panda habitat. *International Journal of Ecology*. doi:10.1155/2012/108752.

Tamrakar, B., and K. Alfredsen. 2013. Satellite based precipitation estimation for hydropower development. *Hydro Nepal* 12: 52–58. doi:10.3126/hn.v12i0.9033.

Telwala, Y., B.W. Brook, K. Manish, and M.K. Pandit. 2013. Climate-induced elevational range shifts and increase in plant species richness in a Himalayan biodiversity epicenter. *PLoS ONE* 8: e57103. doi:10.1371/journal.pone.0057103.

Thackeray, S.J., P.A. Henrys, D. Hemming, J.R. Bell, M.S. Botham, S. Burthe, P. Helaouet, D.G. Jones, et al. 2016. Phenological sensitivity to climate across taxa and trophic levels. *Nature* 535: 241–245. doi:10.1038/nature18608.

Thapa, G.J., E. Wickramanayake, S.R. Jnawali, J. Oglethorpe, and R. Adhikari. 2016. Assessing climate change impacts on forest ecosystems for landscape scale spatial planning in Nepal. *Current Science* 110: 345–352. doi:10.18520/cs/v110/i3/345-352.

Thompson, R., C. Kamenik, and R. Schmidt. 2005. Ultra-sensitive alpine lakes and climate change. *Journal of Limnology* 64: 139–152. doi:10.4081/jlimnol.2005.139.

Thuiller, W., O. Broennimann, G. Hughes, J.R.M. Alkemade, G.F. Midgley, and F. Corsi. 2006. Vulnerability of African mammals to anthropogenic climate change under conservative land transformation assumptions. *Global Change Biology* 12: 424–440. doi:10.1111/j.1365-2486.2006.01115.x.

Thuiller, W., S. Lavorel, M.B. Araujo, M.T. Sykes, and I.C. Prentice. 2005. Climate change threats to plant diversity in Europe. *Proceeding of the National Academy of Sciences of United States of America* 102: 8245–8250. doi:10.1073/pnas.0409902102.

Traill, L.W., C.J.A. Bradshaw, S. Delean, and B.W. Brook. 2010. Wetland conservation and sustainable use under global change: A tropical Australian case study using magpie geese. *Ecography* 33: 818–825. doi:10.1111/j.1600-0587.2009.06205.x.

Tuanmu, M.N., A. Vina, J.A. Winkler, Y. Li, W. Xu, Z. Ouyang, and J. Liu. 2013. Climate-change impacts on understorey bamboo species and giant pandas in China's Qinling Mountains. *Nature Climate Change* 3: 249–253. doi:10.1038/nclimate1727.

Turner, W.R., B.A. Bradley, L.D. Estes, D.G. Hole, M. Oppenheimer, and D.S. Wilcove. 2010. Climate change: Helping nature survive the human response. *Conservation Letters* 3: 304–312. doi:10.1111/j.1755-263X.2010.00128.x.

Verburg, P., and R.E. Hecky. 2009. The physics of the warming of Lake Tanganyika by climate change. *Limnology and Oceanography* 54: 2418–2430. doi:10.4319/lo.2009.54.6_part_2.2418.

Walther, G. 2010. Ecosystem and community responses to recent climate change. *Philosophical Transactions of the Royal Society B* 365: 2019–2024. doi:10.1098/rstb.2010.0021.

Walther, G., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, and F. Bairlein. 2002. Ecological response to recent climate change. *Nature* 416: 389–395. doi:10.1038/416389a.

Werner, B.A., W.C. Johnson, and G.R. Guntenspergen. 2013. Evidence for 20th century climate warming and wetland drying in the North American Prairie Pothole Region. *Ecology and Evolution* 3: 3471–3482. doi:10.1002/ece3.731.

Williams, J.W., S.T. Jackson, and J.E. Kutzbach. 2007. Projected distributions of novel and disappearing climates by 2100 AD. *Proceeding of the National Academy of Sciences of United States of America* 104: 5738–5742. doi:10.1073/pnas.0606292104.

Williams, J.W., A. Ordonez, M. Notaro, S. Veloz, and D. Vimont. 2012. *Climatic analogs, climate velocity, and potential shifts in vegetation structure and biomass for Wisconsin under 21st century climate-change scenarios*. Environmental and Economic Research and Development Program, The University of Wisconsin-Madison, 41 pp.

Winder, M., and D.E. Schindler. 2004. Climate change uncouples trophic interactions in an aquatic ecosystem. *Ecology* 85: 2100–2106. doi:10.1890/04-0151.

WMO. 2015. *WMO statement on the status of the global climate in 2014*. Geneva: WMO, 24 pp.

Xu, J., R.E. Grumbine, A. Shrestha, M. Eriksson, X. Yang, Y. Wang, and A. Wilkes. 2009. The melting Himalayas: Cascading effects of climate change on water, biodiversity, and livelihoods. *Conservation Biology* 23: 520–530. doi:10.1111/j.1523-1739.2009.01237.x.

Zhang, M.G., Z.K. Zhou, W.Y. Chen, C.H. Cannon, N. Raes, and J.W.F. Slik. 2014. Major declines of woody plant species ranges under climate change in Yunnan, China. *Diversity and Distribution* 20: 405–415. doi:10.1111/ddi.12165.

Zomer, R.J., A. Trabucco, M.J. Metzger, M. Wang, K.P. Oli, and J. Xu. 2014. Projected climate change impacts on spatial distribution of bioclimatic zones and ecoregions within the Kailash Sacred Landscape of China, India. *Nepal. Climatic Change* 125: 445–460. doi:10.1007/s10584-014-1176-2.

AUTHOR BIOGRAPHIES

Pramod Lamsal (✉) is a Ph.D. candidate at The University of New England, Australia. His research interests include climate change impact and species distribution modeling.
Address: School of Environmental and Rural Science, The University of New England, Armidale, NSW 2351, Australia.
e-mail: plamsal@myune.edu.au; pramod_lamsal@yahoo.com

Lalit Kumar is a Professor at The University of New England, Australia. His research interests include climate change impacts on biodiversity and Small Island states, mainly in the Pacific and the Himalayan region, remote sensing, spatial modeling, spatial ecology, and species distribution modeling.
Address: School of Environmental and Rural Science, The University of New England, Armidale, NSW 2351, Australia.
e-mail: lkumar@une.edu.au

Kishor Atreya is an agricultural and environmental health expert at Asia Network for Sustainable Agriculture and Bioresources (ANSAB), Nepal. His research interests include environment-human health/livelihood nexus; biodiversity, ecosystem services and climate change; health risk assessment; social cost-benefit analysis; and economic valuation of environmental resources/pollution.
Address: Asia Network for Sustainable Agriculture and Bioresources (ANSAB), P.O. Box 11035, Kathmandu, Nepal.
e-mail: k.atreya@gmail.com

Krishna Prasad Pant is an agricultural and environmental economist and visiting faculty at Kathmandu University, Nepal. His research interests include climate change adaptation and food security in developing countries, wetland livelihoods, and environmental economics.
Address: School of Arts, Kathmandu University, P.O. Box 6250, Lalitpur, Nepal.
e-mail: Krishna.Pant@ku.edu.np; kppant@yahoo.com