PROJECT COMPLETION REPORT

DST-NMSHE: Task Force IV

2015 - 2020

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Department of Science & Technology
Ministry of Science & Technology
Government of India

NMSHE NATIONAL MISSION FOR SUSTAINING THE HIMALAYAN ECOSYSTEM

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Task Force IV: Micro Flora and Fauna and Wildlife and Animal Population

Assessment and Monitoring of Climate Change Effects on Wildlife Species and Ecosystems for Developing Adaptation and Mitigation Strategies in the Indian Himalayan Region

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Preface

In an era of rapid development, habitat loss and fragmentation due to the anthropogenic activities, the accelerating climate change is a nearly insurmountable challenge threatening the biodiversity of the earth. The climate-driven changes in phenology *viz.* earlier onset of spring, migration and lengthening of growing season have been observed throughout the globe. Considerable changes have also been detected in terrestrial biodiversity including range shift, changes in community composition and local extinctions. The climate impact on humans is in itself alarming, having direct or indirect impacts on health, economy, agricultural practices, increased population movement and unforeseen changes in food productivity. In view of the global economic challenges, India is likely to face major setback when majority of its population is exposed to poverty, food and livelihood insecurity.

On 30th June 2008, the Prime Minister released India's first National Action Plan on Climate Change (NAPCC) to address and mitigate the climate-impact effectively. The plan identified eight "national missions", to achieve solutions and key goal in the context of climate change. One of the key missions "The National Mission for Sustaining the Himalayan Ecosystem (NMSHE)" is a cross-cutting mission developed to contribute towards sustainable development of the country under a paced up climate change. This was planned to be implemented by addressing climate change impact and adaptation specifically for the Himalaya, an ecosystem highly vulnerable being a biodiversity hotspot and providing bio-resources to a significant proportion of India's population. Currently, the mission is working on achieving the appropriate policy measures to sustain the ecological resilience and key ecosystem services in the Himalayas.

Considering the impact of climate change, a science-based action plan is urgently required to address the threats which the entire country faces and to conserve its rich biodiversity. To begin with, the current level of scientific knowledge is scarce to meet the present and future challenges of climate change induced threats to terrestrial biodiversity and ecosystem services.

The present document is based on the research outputs from the project "*Assessment and Monitoring of Climate Change Effects on Wildlife Species and Ecosystems for Developing Adaptation and Mitigation Strategies in the Indian Himalayan Region*" which serve as a technical report describing our study design, assessment methodologies and recommendations for sustaining the Himalayan ecosystem. Apart from developing baseline data on distribution of wild flora and fauna of the Himalaya through intensive camera trapping and other taxa-specific sampling techniques in unexplored and inaccessible areas, we also developed spatially-explicit model based predictions for the current and future distributions of the priority aquatic and terrestrial species.

We anticipate further escalating our efforts by long-term monitoring to generate trends and address several climate-wildlife challenges, including operationalization of climate adapted planning, conservation of highly sensitive species, management of climate refugia and also catchment/basin scale characterization by downscaled high resolution climate data.

Acknowledgements

The study would not have been possible without the support from the Department of Science and Technology (DST), Ministry of Science and Technology, Government of India (GOI) who gave us the responsibility to coordinate and implement the research work under task force IV. We acknowledge the continuous guidance and support from Dr. Akhilesh Gupta, Adviser/Scientist-G & Head SPLICE Division, DST, Dr. Nisha Mendiratta, Director/Scientist-G, Climate Change Programme (CCP), Dr. Susheela Negi, Scientist E and Dr. Rabindra Panigrahy Scientist D, SPLICE Division, for contributing through scientific inputs during the entirety of the project.

We thank our outstanding team of scientists and researchers who not only worked continuously in the tough terrains of the Himalaya but also brought new and cutting-edge scientific endeavors for this particular study in IHR. We are grateful to the field assistants who toiled hard in harsh field conditions and assisted us.

We thank the DST Committee that reviewed our project from time to time. We would also like to acknowledge Prof. S.P. Singh, Former Vice Chancellor, HNB Garhwal University, Srinagar, Uttarakhand, for guiding us to refine our research methodologies throughout the project tenure.

We are thankful to the State Forest Departments of Himachal Pradesh, Sikkim and Uttarakhand for granting permission and extending the necessary support for our work. Thanks are due to the PCCF cum CWLW, field officials and frontline staff who supported our research teams in various ways.

We thank the State Climate Change Cells in the Indian Himalayan Region for their valuable inputs. We also thank the Indo-Tibet Border Police for necessary permission and support. We also acknowledge the Department of Fisheries, Govt. of Himachal Pradesh for helping with the necessary permission for aquatic field sampling.

We also thank our partnering institutes, GB Pant Institute of Himalayan Environment and Development, Indian Institute of Tropical Meteorology, National Botanical Research Institute, Birbal Sahni Institute for Paleobotany, University of British Columbia, for their ever-lending support and assistance throughout the project duration.

Acronyms and abbreviations

AIC	Akaike Information Criterion
AR5	Fifth Assessment Report
AUC	Area under the ROC Curve
CART	Classification and regression tree analysis
CPUE	catch per unit effort
CSZs	Climate Sensitive Zones
DBMS	Database Management System
DEM	Digital Elevation Model
DMSP	Defence Meteorological Satellite Program
DNA	Deoxyribonucleic acid
DSS	Decision Support System
DST	Department of Science and Technology
GAM	Generalized additive modeling
GBM	Generalized Boosted Regression Model
GBPNHESD	Govind Ballabh Pant National Institute of Himalayan Environment and Sustainable Development
GCM	Global Climate Model
GHG	Green House Gas
GLM	General Linear Model
GNP	Gangotri National Park
GSI	Gonado-somatic indices
ICAR	Indian Council of Agriculture Research
IHR	Indian Himalayan Region
INCCA	Indian Network for Climate Change Assessment
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
IPCC-AR5	IPCC 5th Assessment Report
JNU	Jawaharlal Nehru University, Delhi
KOH	Potassium Hydroxide
LEVL	Landscape Ecology and Visualization Laboratory
LFT	Landscape Fragmentation Tool
masl	Mean Average Sea Level
MODIS	Moderate Resolution Imaging Spectroradiometer
MoEFCC	Ministry of Environment, Forest and Climate Change
NAPCC	National Action Plan on Climate Change
NDVI	Normalized Difference Vegetation Index
NGCC	National Geomatics Centre of China
NIH	National Institute of Hydrology
NVES	Nocturnal stream Visual Encounter Surveys
OTC	Open Top Chamber
PCA	Principal Component Analysis

PCNM	Principal Coordinate analysis of Neighbour Matrices
PCoA	Principal Coordinate Analysis
Ppm	Parts per million
QoL	Quality of Life
ROC	Receiver operator characteristic
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal
SOI	Survey of India
TITAN	Threshold Indicator Taxa Analysis
TSS	True Skill Statistic
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
VES	Visual Encounter Surveys
VIF	variance inflation factor
WIHG	Wadia Institute of Himalayan Geology
WII	Wildlife Institute of India

Contents

Executive Summary

The NMSHE Task Force-IV was commissioned to the Wildlife Institute of India (WII) with an idiosyncratic emphasis on climate change impacts on the wild fauna and microflora. Monitoring the climate impacts on the wildlife of Himalaya was a complete lacuna and the TF-4 was put forth to conduct research with the objectives of; (a) identifying landscape change drivers (b) conducting field research on wildlife aspects (terrestrial, aquatic, microflora and habitats) (c) Developing monitoring and Decision Support Systems (DSS) for indicator species in the IHR (d) Model building and visualization for climate change impacts on Himalayan wildlife (e) Spatial and inter-operable database generation and (f) Capacity building and sensitization. The extensive monitoring and research work was primarily focused on three major river basins- Beas (Himachal Pradesh) in North-western Himalaya, Bhagirathi (Uttarakhand) in Western Himalaya, and Teesta (Sikkim) in Eastern Himalaya which provided a strong basis to understand the climate-related impact and vulnerabilities. Based on rigorous fieldwork by the research personnel and dedicated team efforts, a large scale baseline data related to the distribution of many cryptic and abundant species apart from several new records, seasonal phenological trends, species-habitat requirements, potential climatic drivers, and socio-economic vulnerabilities have been collected and analyzed.

Considering the dearth of knowledge with respect to understating the climate related vulnerabilities in IHR, a large-scale date base have been developed which comprises a total of 5042 articles on wild fauna and microflora. This was developed to identify the knowledge gaps as well as an assembled knowledge base to initiate climate-wildlife research in IHR. Large scale spatial data related to land-use-landcover, fragmentation, disturbance, and bio-rich areas for all six IHR states viz. Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Northern Districts of West Bengal, and Arunachal Prades were also generated.

The project initiated, for the first time, a long term monitoring of data-loggers based air-temperature and humidity trends in the three selected river basins. More than 200 climate data-loggers have been deployed for fine-scale climate data generation in three Himalayan states viz. Himachal Pradesh, Uttarakhand, and Sikkim. Innovative technologies such as Open Top Chamber (OTC) based long term experimental setup has also been established for the charting of long-term spatial and temporal trends in activity patterns of the soil microbial and microfaunal communities. After two years of experimental warming significant difference found in the abundance of plants along with different soil parameters, inside and outside of the Open top chambers (OTCs) during both spring and summer. Activity of microbial extracellular enzymes such as β-glucosidase and per-oxidase, known for degrading labile and recalcitrant organic material respectively. Activity of both enzymes showed increasing trend inside OTCs in comparison to control plots.

Indicator based assessment of adaptive capacity and socio-economic vulnerability was also assessed in the Bhagirathi basin, Beas basin and Teesta basin of Indian Himalayan region. A total of 1345 households of 77 villages of the three basins were surveyed to get information on adaptive capacity, climate sensitivity and climate stress. The villages of Teesta Basin and Bhagirathi basin were more vulnerable in compare to the villages of Beas basin. Future Vulnerability also very high in the villages of Teesta basin and Bhagirathi basin in compare to Beas basin. A quality of life (QoL) index was formulated with variables on living condition, housing condition, availability of assets, education status and job availability. The comprehensive QoL index map provides a synoptic view of available and existing community assets and lays the groundwork for planning the appropriate mitigation measures which can interlinked with the real need of communities for climate change adaptation.

Driver of landscape change was assessed using NDVI as response variable and determinants like Human Footprint, Population, and different bioclimatic variables. The result shows Human footrpints, Annual precipitation, Precipitation of driest month, Precipitation of driest quarter, Precipitation of wettest month, Minimum temperature of coldest month, and Maximum temperature of warmest month were the maor deteminats of NDVI change. The entire landscape of the IHR has experienced varying levels of degradation and this degradation is driven by both human as well as natural factors. Anthropogenic factors were identified as primary drivers of decline in vegetation NDVI at the regional scales while the finer scales are more controlled by the seasonal extremes like heat waves and cold waves.

Given the intensity of threat due to climate change in this region, it is vital that the wildlife of IHR would be required to respond to these changes by shifting their distributional ranges to higher elevations. To address this question, robust climate envelope models have been generated based on different predictive algorithms Locations of suitable climate refugia across the IHR for two terrestrial (musk deer, Himalayan pit viper) and an aquatic species (snow trout) were identified based on different modeling approaches. For musk deer, the results emphasized that the contiguity is highly required among the Protected Areas (PA). Considering only the extreme emission scenario (RCP 8.5) we identified two major geographical zones with an extensive PA network which could serve as optimal potential refugia for the musk deer in the year 2050. This includes 15 PA networks in Western Himalaya and seven PA networks in the Eastern Himalaya.

We also identified potential future refugia for vulnerable freshwater species snow trout and predicted that the species range to increase towards higher elevation, while most habitats placed lower than 1000m would be concurrently lost, considering the intensity of different emission scenarios and time periods. The Himalayan pit viper was predicted to increase their distributional range in most of the distant and near future scenario. This increase in range is mostly observed in lower elevation zone. As it is known lower limits of Himalaya is much more populated by other reptilian species than upper limits.

In continuation with the research and data collection the NMSHE project also contributed in capacity building of the field personnel from Himachal Pradesh, Uttarakhand, and Sikkim forest department. Research personnel (68 no.) were also trained on species distribution modeling and vulnerability analysis using present and future climate scenarios. To create awareness about climate change education and sustainable living among young students, a program has been initiated through the school level Do-It-Yourself (DIY) Activity book “Climate Cool-Kit”. The research outputs from the NMSHE project would help in landscape prioritization, identify the fauna and flora most likely to be impacted, identify the trends in biotic/abiotic linkages and key ecosystem services to better plan the appropriate policy measures for mitigating the impacts of climate change in the Indian Himalayan Region.

Chapter 1

Global Climate Crisis: Implications on the Indian Himalayan Region (IHR)

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1.1 Introduction

Climate change and habitat loss are both key threatening processes driving the global loss in biodiversity (Mantyka Pringle 2011). Global biodiversity loss due to human activities since 1950s have been more rapid than at any time in the human history (MEA 2005; Dirzo et al 2014) Most of this loss has been driven by the anthropogenic pressures and will intensify along with the growing human population and increasing pressure on limited resources of ecosystem (MEA 2005, Carpenter et al 2009; Pereira et al 2012). Recent climate change and global warming is also acting as major drivers of biodiversity loss and availability of ecosystem services (IPCC

2014; Lister et al 2008; Travis 2003). Earth surface temperature have been successfully warmer than any decade since pre-industrial times and an increase of 0.85ºC in global average temperature was recorded since 1880 (IPCC 2013). In future the average increase is predicted to be more rapid and larger. There is also prediction of temporal changes of precipitation, increased frequency of extreme weather events Species is predicted to change their geographical ranges and seasonal activities in response to the changing temperature and rainfall patterns (IPCC 2014, Bellard et al 2012).

Climate change will affect a species in multiple way depending on the behavior of the species. Change in the geographic range and relative abundance is predicted for several species in response to changing temperature and rainfall patterns (IPCC 2014; Bellard et al 2012; Travis 2003). The change in spatial and temporal association between species will also lead to change in community composition and inter and intra specific interactions (Perreira et al 2010; Walther 2010; Parmesan 2006). It is important to understand the interlinkage between climate change and other threats for the ability to envision adaptation and mitigation measures through policy development and management. One of the critical issues in 21st century is to assess how multiple stressors interact and cumulatively impact ecosystem integrity and biodiversity (Vinebrooke et al., 2004; Brook et al., 2008; Crain et al., 2008). Climate change, habitat loss, invasive species, disease, pollution, and overexploitation are typically studied and managed in isolation, although it is becoming increasingly clear that a single stressor perspective is inadequate when ecosystems and species are threatened by multiple, co-occurring stressors (Sala et al., 2000; Darling et al., 2010; Cote et al 2016, Brooks et al 2019). most studies reporting effects of climate change (e.g. Williams et al., 2003; Miles et al., 2004; Parmesan, 2006) or habitat loss and fragmentation on biodiversity (e.g. Brooks et al., 2002; Fahrig, 2003; Cushman, 2006) have examined each in isolation. If the potential combined effects of these processes are greater than those estimated individually, then current estimates of habitat loss and fragmentation effects may be misleading (de Chazal & Rounsevell, 2009). Understanding relationships between biodiversity and drivers of change will facilitate the assessment of the impacts of land use decisions. However, current projections for biodiversity variables rarely incorporate multiple drivers or interactions (Sala et al 2000; Mora et al 2007) Interactions may be relatively unimportant where the effects of a single driver are very great (Brooks et al 2008). However, it is probably more often the case than multiple drivers act together to impact biodiversity (Tylianakis et al 2008; Stefanescu et al 2011).

From a more positive perspective, interactions between land use change and climate change present opportunities to lessen climate change impacts by adapting land use and management. Adaptation to climate change has become a major priority for conservation, it can be defined as '*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*' (IPCC 4th Assessment report Working Group 2 Glossary http://www.ipcc.ch/pdf/glossary/ar4-wg2.pdf). A wide range of high level principles for adaptation have been identified.74,181 Climate change adaptation can be viewed as a spectrum of responses from building resilience of existing ecosystems, populations, and communities to accommodating inevitable change, to promoting transformational change (Morecroft et al 2012)

In the few cases where studies examine both the importance of climate change and habitat loss, it is difficult to determine which stressor is the more important driver of long-term trends (e.g. Travis, 2003; Opdam & Wascher, 2004; Pimm 2008). At present knowledge base habitat loss and fragmentation are the major limiting factor for species and ecosystem stability, but the impact of climate change is expected to be the major determinants of species distribution in its ecological space (Sala et al 2000, Warren et al 2001, Franco et al 2006 Jetz et al 2007, Lemoine et al 2007) There is growing evidence to suggest that climate change will negatively interact with habitat loss and habitat fragmentation and synergistically contribute to the degradation of biological diversity at the species, genetic and/or habitat level (Schindler, 2001; McLaughlin et al., 2002; Opdam & Wascher, 2004; Pyke, 2004; Brook et al., 2008). Species in fragmented landscapes are more vulnerable to environmental drivers, such as climate change than those in continuous landscapes (Travis, 2003; Opdam & Wascher, 2004).

Over the last 10–15 years, key findings on the ecological effects of high temperatures and extended droughts in terrestrial ecosystems have accumulated (e.g. Davis & Shaw, 2001; Walther et al., 2002; Parmesan & Yohe, 2003; Root et al., 2003; Thomas et al., 2004; Bates et al., 2005; Parmesan, 2006; Allen et al., 2010). Evidence suggests that stressful conditions appear to drive local population dynamics; however, the responses of both flora and fauna to drought, heat and rain, can vary (Parmesan, 2006; Pearson, 2006). Species react differently to climate change depending on their life-history characteristics, individual thresholds and many environmental factors (Walther et al., 2002). It is also important to recognize that the threshold of climate change below which species extinction occurs or populations severely decline is likely to be determined by the pattern of habitat loss (Opdam & Wascher, 2004; Keith et al., 2008). A wide variety of studies have investigated the responses of biodiversity to past periods of climate change in the Earth's history (Bellard et al 2012, Jentsch et al 2007). Although climate changes are likely to be implicated in some mass extinction events,(Payne et al 2007) there appears to have been relatively few extinctions during the more recent glacial to interglacial transition periods of rapid climate change (Dawson et al 2011). Species are expected to have survived through combinations of shifting their distribution to track climate, persisting in climatic refugia and evolving tolerance to climate changes (Coope 2004; Willis et al 2009; Dawson et al 2011). However, future climate change could potentially occur at an unprecedented rate, and also against a backdrop of other drivers of change (e.g., heavily modified landscapes, pollution, eutrophication). Therefore, any generalities of extinction dynamics from ancient evidence need be contextualized within current pace of climate change and interactions between drivers need to be understood (Brook et al 2008).

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Based on the ability of species to cope with climate change effects predictions for future level of extinctions for several species have been published and accordingly conservation planning and policy were developed in many developed countries (Fischlin et al 2007, Buckley et al 2004; Hartley et al 2004; Thomas et al 2004; Thuiller et al 2004). Traditional conservation practices restricted to preserve species in its current space by conserving the habitat by establishment and maintenance of protected areas. But under climate change scenario change in management practice by shifting its perspective from preserving the present ecosphere to managing the dynamic responses of species and ecosystem to climate change, is required (Heller et al 2009; Huntly 2007; Lawler 2009). Where climate change is driving transition towards a new ecological state, focus may need to be on facilitating that transition by minimizing species loss and preserving key ecosystem functions and services, where possible (Lawler 2009; Willis et al 2010).

1.2 Potential risks to biodiversity and vulnerabilities in IHR

Mountains are among the most fragile environments on Earth (Tsering et al 2010). They are also rich repositories of biodiversity and water and providers of ecosystem goods and services on which downstream communities (both regional and global) rely (Xu et al 2019). Mountains are home to some of the world’s most threatened and endemic species, as well as to some of the poorest people, who are dependent on the biological resources (Rasul 2014). Realising the importance of mountains as ecosystems of crucial significance, the Convention on Biological Diversity specifically developed a Programme of Work on Mountain Biodiversity in 2004 aimed at reducing the loss of mountain biological diversity at global, regional, and national levels by 2010. Despite these activities, mountains are still facing enormous pressure from various drivers of global change, including climate change (Rasul 2014, Xu et al 2019). Under the influence of climate change, mountains are likely to experience wide ranging effects on the environment, natural resources including biodiversity, and socioeconomic conditions. Little is known in detail about the vulnerability of mountain ecosystems to climate change. Intuitively it seems plausible that these regions, where small changes in temperature can turn ice and snow to water, and where extreme slopes lead to rapid changes in climatic zones over small distances, will show marked impacts in terms of biodiversity, water availability, agriculture, and hazards, and that this will have an impact on general human wellbeing (Tsering et al 2010). But the nature of the mountains, fragile and poorly accessible landscapes with sparsely scattered settlements and poor infrastructure, means that research and assessment are least just where they are needed most.

And this is truest of all for the Himalayan region, with the highest mountains in the world, situated in developing and least developed countries with few resources for meeting the challenges of developing the detailed scientific knowledge needed to assess the current situation and likely impacts of climate change (Rasul 2014; Xu et al 2019).

Climate change and land use change interact to impact Himalayan biodiversity through a wide range of mechanisms (Behera et al 2019). Understanding these interactions will be necessary to more reliably project changes in biodiversity under different land use and climate scenarios and to manage habitats appropriately. There are also opportunities to reduce the negative impact of climate change on biodiversity through adaptation strategies (Mantyka Pringle 2011, and relatively simple actions such as increasing habitat quality and extent can simultaneously address multiple drivers. However, land use decisions can also have negative impacts on the ‘adaptive capacity’ of populations (Williams et al 2008). Land use is driven by socioeconomic and climatic factors, potentially with complex feedbacks; but if we cannot suitably address the negative impacts of land use change, then we close off our options for dealing with climate change


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(Hannah 2011).With a growing recognition of the existence of interactions between global change drivers, conservation strategies and biodiversity projections that only address a single driver are inadequate (Sala et al., 2000; Darling et al., 2010; Cote et al 2016, Brooks et al 2019). Future research needs to understand and quantify the major mechanisms by which global change drivers interact, in order to minimize risks and increase opportunities for the conservation of biodiversity.

1.3 National Action Plan for Climate Change

India is one of the most adversely affected country witnessing an average of 3579 deaths attributed by climate related events. According to the Global Climate Risk Index of 2018, published by German Watch, a nonprofit organization, India is the 12th most vulnerable country to climate change impacts. During the first decade of the 21st Century under the immense pressure of climate change related hazards and need of its mitigation and adaptation strategy to cope up with the climate stress Government of India constituted the prime Minister's Council on climate Change (PMCCC) in 2007. Before the G8 summit to be held in July 2008, National Action Plan for Climate Change was announced, that identifies measures that promote our development objectives while also yielding co-benefits for addressing climate change effectively. The action plan outlines a number of steps to simultaneously advance the development and climate change adaptation and mitigation strategies for future. The plan is having eight missions overseen by 10 ministries for its overall implementation. The major objectives of the NAPCC is

- To protecting the poor through an inclusive and sustainable development strategy, sensitive to climate change.
- Achieving the national growth and poverty alleviation objectives while ensuring the ecological sustainability
- Efficient and cost effective strategies for end use demand and management.
- Extensive and accelerated deploymeny of appropriate technologies for adaptation and mitigation.
- New and innovative market, regulatory and voluntary mechanisms for sustainable development.

- Effective implementation through unique linkages with civil society, LGUs and Public private partnerships.

The eight different missions are:

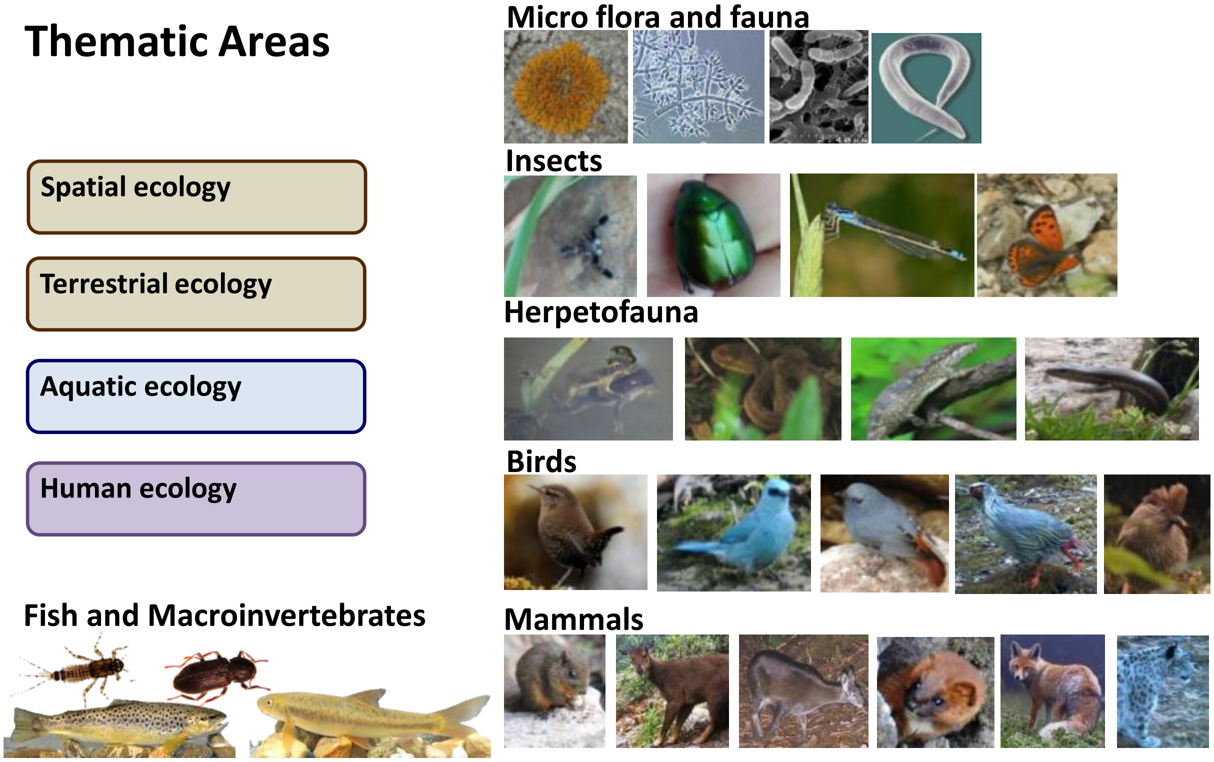
- National water mission (NWM)
- National Mission for Sustaining Himalayan Ecosystem (NMSHE) and National Mission for Strategic Knowledge on Climate Change (NMSKCC)
- National Solar Mission (NSM)
- National Mission for Enhanced Energy Efficiency (NMEEE)
- National Mission on Sustainable Habitat (NMSH)
- National Mission for Sustainable Agriculture (NMSA)
- Green India Mission (GIM)

1.4 National Mission for Sustaining Himalayan Ecosystem (NMSHE)

The Himalayan System, although being fragile and diverse, is vital to the ecological integrity of the Indian landmass. It provides important ecosystem services like providing forest cover, feeding perennial river used for drinking water, irrigation and hydropower, conserving biodiversity and so on. The Himalayan system is susceptible to climate change impacts and consequences are severe for different natural processes. The current level of scientific knowledge is inadequate to meet the present and future challenges of climate change induced threats to biodiversity and ecosystem services of the Himalaya. Among the many factors that have contributed to knowledge gap are lack of data, researched information and published studies; inadequate understanding of systems sensitivity and variability of systems responses to climate changes as reflected from resilience and adaptations in natural systems. The National Action plan for climate change (NAPCC) has enunciated the launch of National Mission for Sustaining Himalayan Ecosystem. The mission is multi-pronged and cross cutting initiative to enhance the understanding of climate change impact and formulate needful adaptation and mitigation strategies for sustaining the Himalayan ecosystem. The mission aims to address some key issues concerning

- Himalayan Glaciers and associated hydrological consequences
- Biodiversity conservation and Protection

- Wildlife Conservation and Protection
- Traditional knowledge societies and their livelihood and
- Planning for sustainability of the Himalayan Ecosystem



Representation of different thematic areas under NMSHE project

The primary objective of NMSHE is to develop sustainable national capacity to continuously assess the health status of the Himalayan Ecosystem and enable policy bodies in their policy formulation, functions and assist States in the Indian Himalayan Region with their implementation of actions selected for sustainable development. There are eight secondary objectives that have been proposed. The scientific work under NMSHE is structured under six thematic task forces, each with one coordinating institution.

Task Force	**Natural & geological wealth**	**Water, ice, snow, including glaciers**	**Forest resources & plant biodiversity**	**Micro flora and fauna and wildlife & animal populations**	**Traditional Knowledge Systems**	**Himalayan Agriculture**
Coordinating Institution	WIHG (DST)	NIH (MWR)	GBPNIHE (MoEFCC)	**WII (MoEFCC)**	JNU/DST	ICAR/ MoAgri

1.5 Task Force IV: Micro flora, fauna, wildlife and animal population

The Indian Himalayan Region (IHR) covers *ca.* 12% of the country's 3.3 million km^2 geographical area and is spread over six Indian States, *viz*., Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh and in northern portions of West Bengal (Rodgers et al. 2000). The IHR encompasses about half of India's forest cover and home to about 5800 plants, 980 birds (26% of which are endemic) and 241 mammals (Ghosh 1996; Chandra et al 2018). About 6% of Indian human population lives in the IHR, but the growing population and consequent anthropogenic pressures have exerted considerable influence on these ecosystems. Changing land use practices, unsustainable use of natural resources, and incompatible forms of civic and infrastructure developments have led to habitat loss/degradation, fragmentation and consequent; changes in species range, diversity and numbers, and even local extinctions. In addition to this, climate change induced impacts are predicted to affect the critical ecosystem goods and services provided by the Himalaya.

In spite of their high importance, mountains out of all the terrestrial regions are still inadequately studied because of the remoteness of the area and difficult terrains to work upon. Information on the effects of anthropogenic drivers on fauna in the IHR is limited to some investigations in the IHR (Mishra 2001, Bagchi et al. 2004, 2006, Kittur et al. 2010, Bhattacharya & Sathyakumar, 2011, Rajvanshi et al. 2012), and information on effects of climate change on fauna in the IHR is scanty (Bhattacharyya et al. 2009, Forrest et al. 2012). While the effects of global change on water availability and sustainability of river ecosystem services have received attention (Vorosmarty et al. 2000; Alcamo et al. 2003a; Milly et al. 2005; Schroter et al. 2005), the over lapping impacts of climate change and the impacts caused by dams and other human infrastructure have not been explored at global scales (Palmer et al. 2008). The diversity and endemism of fauna, their habitats in Himalaya is exceptional, however, scientific knowledge on many of these faunal species is still lacking. In context of declining forests and wildlife habitats in the Himalaya, comprehending the scale of rapid growing changes in land use patterns, climate change, and their synergistic effects along with hunting/poaching are likely to cause many species/taxa to reach their critical threshold levels (Geist and Lambin 2002, Brooks et al. 2006). How species have coped with these changes that lead to their extirpation is of concern, but such understandings have been ignored at the scale of the species range. An understanding of distribution range reduction and accompanied decline in numbers is vital for an understanding of the impacts of climate change and other human induced impacts for the preservation of biodiversity and these concerns are of fundamental interest to conservation biology (Simberloff 1986).

Although there is some information on status, distribution, abundance, and aspects of ecology of faunal and micro floral species and their habitats for some parts of the Himalaya, there are gaps in our knowledge on the above aspects from many areas in the IHR. Similarly, predictive and reliable species distribution and modelling of species/taxa with respect to different habitat, climate, and anthropogenic factors for the IHR are inadequate. There is very little information on ecosystems services provided by the IHR and also on impacts of anthropogenic drivers, particularly developmental projects.

In order to usefully inform conservation and climate policy, it is essential to reasonably attribute changes in populations and communities to climate and/or land use change. In order to do this, well designed experiments and analyses are required, which control for one driver while exploring the effects of another. A basic requirement is to have measurements of the degree to which land use and local climate has changed in any area, concurrent with measurements of biodiversity change. Sufficient independent samples are needed to allow statistical analyses which give an appropriate degree of confidence in associations. If these conditions are met, then researchers can potentially ascertain whether changes in biodiversity across a number of sites are primarily due to climate or land use change, including quantification of uncertainty in any conclusions. In some cases, clear significant effects of either land use change or climate change may be identified. However, in other cases it may be difficult to separate out effects of land use and climate change. The current level of scientific knowledge is inadequate to meet the present and future challenges of climate change induced threats to biodiversity and ecosystem services of the Himalaya. Among the many factors that have contributed to knowledge gap are lack of data, researched information and published studies; inadequate understanding of systems sensitivity and variability of systems responses to climate changes as reflected from resilience and adaptations in natural systems both, terrestrial and aquatic and their biotic components including micro flora, macro fauna, and palaeobotany.

1.7 Importance and account of NMSHE research work

The effects of climate change are pronounced in places such as the Himalaya, where the network of snow-clad mountains, ice-peaks, high intensity drainage and precipitation characterizes the bio-social landscape. Realizing the need for developing science-based action plans to address both the existing as well as emerging threats of climate change in the fragile mountain ecosystems of the IHR, the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) has been conceived and is expected to offer practical adaptation strategies based on inputs from various reputed Institutions. The Wildlife Institute of India (WII) an autonomous institution of the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India in the field of wildlife and natural resource conservation has been identified as a Nodal Institute under NMSHE. The goal of this project is to: Develop strategies to mitigate climate change effects on wild animal species and ecosystems in the IHR. The thematic areas identified under the research project area (A) Terrestrial System, (B) Aquatic System, (C) Human Ecology, and (D) Spatial Ecology, and include assessments of: (a) animal species/communities diversity, distribution, abundance (b) wildlife habitats, ecosystems, and ecosystem services; (c) anthropogenic and climate change impacts on wildlife and ecosystems through scenario building and visualization; (d) vulnerability of species / habitats to climate change; and prioritization of species/taxa and sites for monitoring. Tentatively, three project sites have been identified across IHR considering the river catchments as representative ecological units. The conceptual and methodological frameworks, budget outlay and the log frame for monitoring project progress have been developed. The WII team of Scientists and a Project Management Unit (PMU) with dedicated scientific and support staff would generate species specific data and conduct focused research and monitoring as per assigned tasks at various sites in the IHR and would also collaborate with relevant national and international institutions for building capacities at WII in modelling and projection of scenarios in climate change.

1.7 Major research objectives

The expected outputs/outcomes from this project are : Cohesive and inter-operable spatial database on fauna and their habitats, and ecosystems in the IHR; Vulnerability Indices for species (fauna), wildlife habitats and ecosystems in the IHR; Establishment of monitoring protocols for long-term climate change monitoring; Development of predictive modelling and projection scenarios in context of climate change and anthropogenic drivers including validated projections based on pilot studies, enhancement in research capacities of WII and collaborating partners; and Formulation of policy briefs and development of 'Wildlife Watch' for indicator/endangered species for regular monitoring by stakeholders. The project outputs would provide researched and collated information for use during current negotiations and future strategies in the IHR. The main goal of the project is to:

Develop strategies to mitigate climate change effects on wildlife species and their habitats in the IHR

To achieve the above goal, the following research /task components have been put forth:

I. Identify the drivers of landscape change (climatic and anthropogenic) in the IHR and their effects on the ecological and social systems.

II. Conduct focussed research on wildlife aspects (terrestrial and aquatic fauna, micro flora and their habitats) and human dimensions in IHR for framing evidence-based policy measures.

III. Develop monitoring and Decision Support Systems (DSS) for indicator species in the IHR.

IV. Undertake climate change scenario analyses and visualization for predicting potential effects on fauna and ecosystems as a strategy to communicate with stakeholders and to influence policy and decision making.

V. Develop spatial and inter-operable database to facilitate and policy decision making.

VI. Build capacities within WII and of other stakeholders for sensitization and development of action plans for climate change impact mitigation and to enhance capabilities for negotiations at the national and international forums.

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Chapter 2

Framework for Project Implementation and Action Plan

2.1 Introduction

The current level of scientific knowledge is inadequate to meet the present and future challenges of climate change induced threats to biodiversity and ecosystem services of the Himalaya. Among the many factors that have contributed to knowledge gap are lack of data, researched information and published studies; inadequate understanding of systems sensitivity and variability of systems responses to climate changes as reflected from resilience and adaptations in natural systems both, terrestrial and aquatic and their biotic components including micro flora, macro fauna, and palaeobotany. Realizing this need for data for developing science-based action plans to address the threats of climate change in the fragile mountain ecosystems of the IHR, a dedicated mission, NMSHE has been initiated as part of the NAPCC under the coordination of the DST. The NMSHE aims to understand the complex processes affecting the Himalayan ecosystem and evolve suitable management and policy measures for sustaining and safeguarding the Himalayan ecosystem.

The WII has been assigned the responsibilities for operating the Task Force on Fauna and Microflora by the Department of Science and Technology, Government of India. The goal of this project is to: Develop strategies to mitigate climate change effects on wild animal species and ecosystems in the IHR. The thematic areas identified under the research project area (A) Terrestrial System, (B) Aquatic System, (C) Human Ecology, and (D) Spatial Ecology, and include assessments of: (a) animal species/communities diversity, distribution, abundance (b) wildlife habitats, ecosystems, and ecosystem services; (c) anthropogenic and climate change impacts on wildlife and ecosystems through scenario building and visualization; (d) vulnerability of species / habitats to climate change; and prioritization of species/taxa and sites for monitoring. This is being envisaged by creating and building capacities in different domains through networking of knowledge institutions engaged in research for development of a coherent database on Himalayan ecosystem. Along with the Wildlife Institute of India, National Institute of Hydrology, Wadia Institute of Himalayan Geology, Jawaharlal Nehru University, Indian Council of Agriculture Research and GB Pant Institute of Himalayan Environment and Sustainable Development are also working as task force under the NMSHE project.

2.1 Addressing knowledge gaps between baseline and NMSHE objectives

Compared to other mountain systems of the world, the amount of literature or documented knowledge on the biodiversity of the Himalaya is not much. While baseline status for species/taxa are being established through surveys and studies in the recent past, consequences of climate change impacts on species could be better understood from historical information that presently lies scattered in various journals, books, expedition reports and gazetteers. In such a situation, even an expert will be able to access and acquaint with only a small fraction of available literature. To overcome this major constraint, the subject specialists and information scientists were able to find means of 'bibliographies' and 'databases' respectively.

In spite of their high importance, mountains out of all the terrestrial regions are still inadequately studied because of the remoteness of the area and difficult terrains to work upon. Information on the effects of anthropogenic drivers on fauna in the IHR is limited to some investigations in the IHR (Mishra 2011, Bagchi et al. 2004, 2006, Kittur et al. 2009, Bhattacharya & Sathyakumar, 2011, Rajvanshi et al. 2012), and information on effects of climate change on fauna in the IHR is scanty (Forrest et al 2012, Bhattacharyya et al. 2009, Chetri et al. 2008). While the effects of global change on water availability and sustainability of river ecosystem services have received attention, the over lapping impacts of climate change and the impacts caused by dams and other human infrastructure have not been explored at global scales (Palmer et al. 2008). The diversity and endemism of fauna, their habitats in Himalaya is exceptional, however, scientific knowledge on many of these faunal species is still lacking. How species have coped with these changes that lead to their extirpation is of concern, but such understandings have been ignored at the scale of the species range. An understanding of distribution range reduction and accompanied decline in numbers is vital for an understanding of the impacts of climate change and other human induced impacts for the preservation of biodiversity and these concerns are of fundamental interest to conservation biology.

Although there is some information on status, distribution, abundance, and aspects of ecology of faunal and micro floral species and their habitats for some parts of the Himalaya, there are gaps in our knowledge on the above aspects from many areas in the IHR. Similarly, predictive and reliable species distribution and modelling of species/taxa with respect to different habitat, climate, and anthropogenic factors for the IHR are inadequate. There is very little information on ecosystems services provided by the IHR and also on impacts of anthropogenic drivers, particularly developmental projects. The current level of scientific knowledge is inadequate to meet the present and future challenges of climate change induced threats to biodiversity and ecosystem services of the Himalaya. Among the many factors that have contributed to knowledge gap are lack of data, researched information and published studies; inadequate understanding of systems sensitivity and variability of systems responses to climate changes as reflected from resilience and adaptations in natural systems both, terrestrial and aquatic and their biotic components including micro flora, macro fauna, and palaeobotany.

2.2 Spatial and temporal account of baseline data

Considering the knowledge gaps and lack of baseline data in the IHR a ‘Bibliography on Fauna and Microflora of Indian Himalayan region’ has been compiled as part of this project. These references have beene categorised based on the scope of the articles and placed them under ten main taxa/group viz., Mammals, Birds, Herpetofauna, Fish, Butterflies, Odonates, Soil Nematodes, Soil Bacteria, Soil fungi and Lichen. WINISIS software was used for compilation of this bibliography and this includes publications from 1775 to 2016. However, majority of the references are of the period after 1900. The geographical coverage of the database as given in the title is restricted to the IHR i.e., Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh and West Bengal (northern hill districts only). In total, 5042 articles were compiled into a database on wild fauna and microflora of Indian Himalayan Region (Sathyakumar et al., 2016). The number of articles showed substantial rise in the last two decades. Basic ecology, distribution and taxonomy remains the major research topics for all the taxa. The dearth of studies on climate change impacts was observed for all the taxa. The state and taxa wise distribution of literatures are given in Fig. 1.

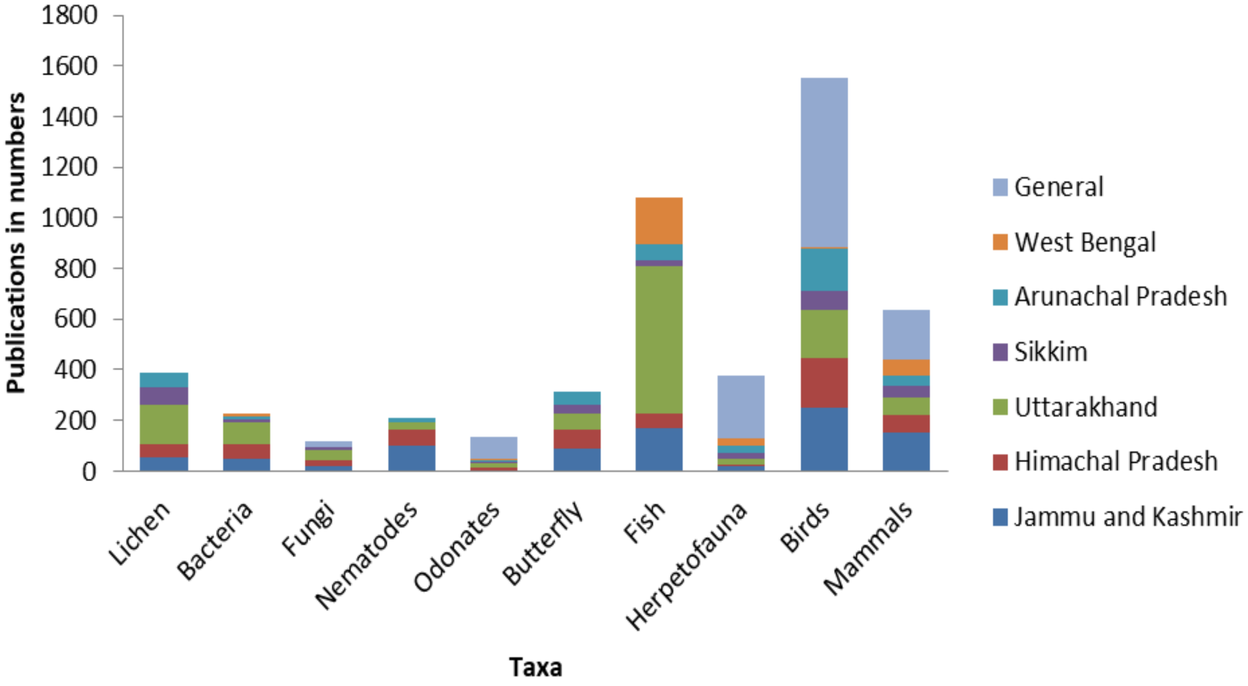

Fig. 1 State-wise and taxa wise distribution of literature in IHR

2.3 Methodology for assessment

Data collection under each thematic component was carried out in the selected study sites. The study sites also include a range of protection (National Park, Reserve Forest, and Community Forest) and human use levels (livestock grazing, forest produce collection, eco-tourism, pilgrimage and agriculture). The sampling design follows hierarchical framework (sub basins, rivers, grids, etc.) within the selected catchment such that the data on different components would be generated in same spatial/ecological sampling units for integration and appropriate inference (Fig 2).

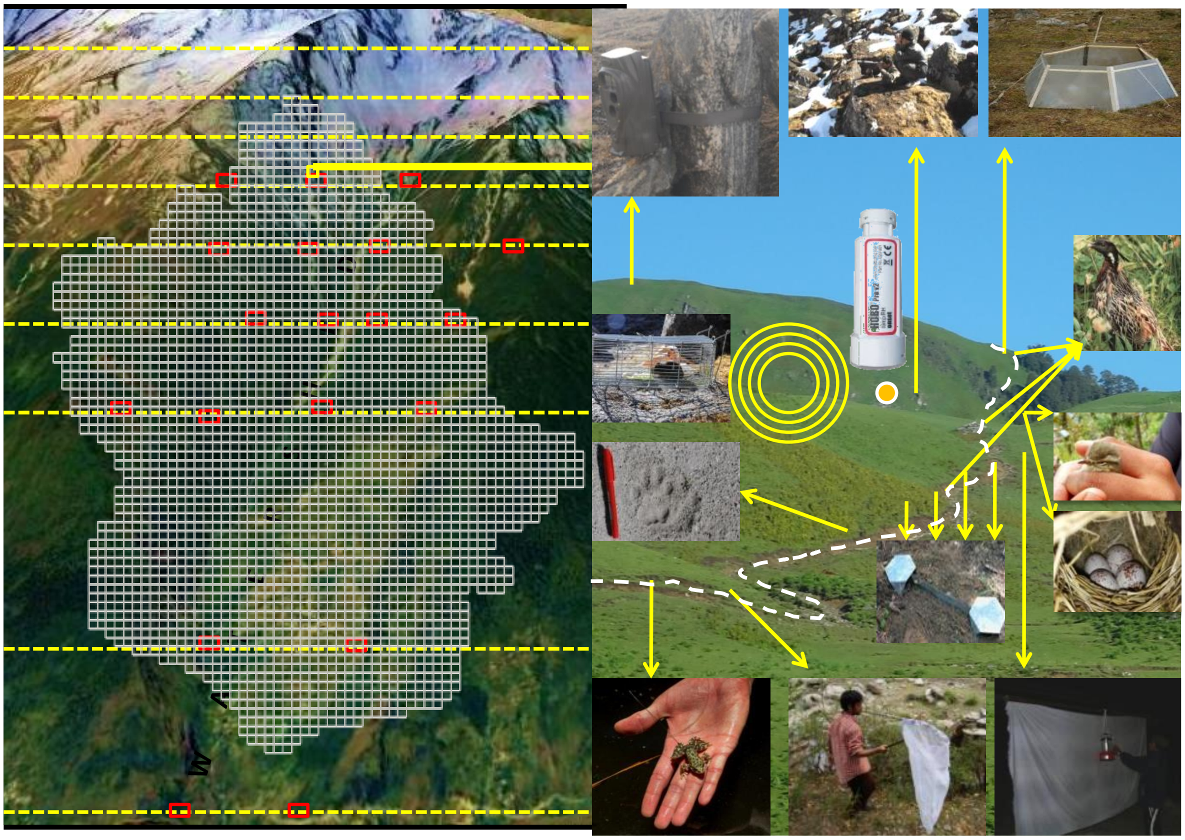

Fig. 2 Schematic representation of sampling framework in the selected sites of IHR

2.3.1 Study Area and Study Design

Biogeographically, the IHR has been categorized into seven biotic provinces (Rodgers et al. 2000, Kumar et al. 2017) in two biogeographic zones (Trans Himalaya and Himalaya) of India. They are: Ladakh Mountains (1A), Tibetan Plateau (1B & 1C), Northwest Himalaya (2A), West Himalaya (2B), Central Himalaya (2C) and Eastern Himalaya (2D). As the IHR falls under WII's research priority matrix, it has commanded considerable focus for research since 1980s. Tentatively it was envisaged that the project will include six project sites, (i.e. river basins) across the IHR considering the river catchments as representative ecological units. The current focus of the ongoing activities of the project focuses on three major river basin- Beas (Himachal Pradesh) in North Western Himalaya, Bhagirathi (Uttarakhand) in Western Himalaya and Teesta (Sikkim) in Eastern Himalaya (Fig. 3).

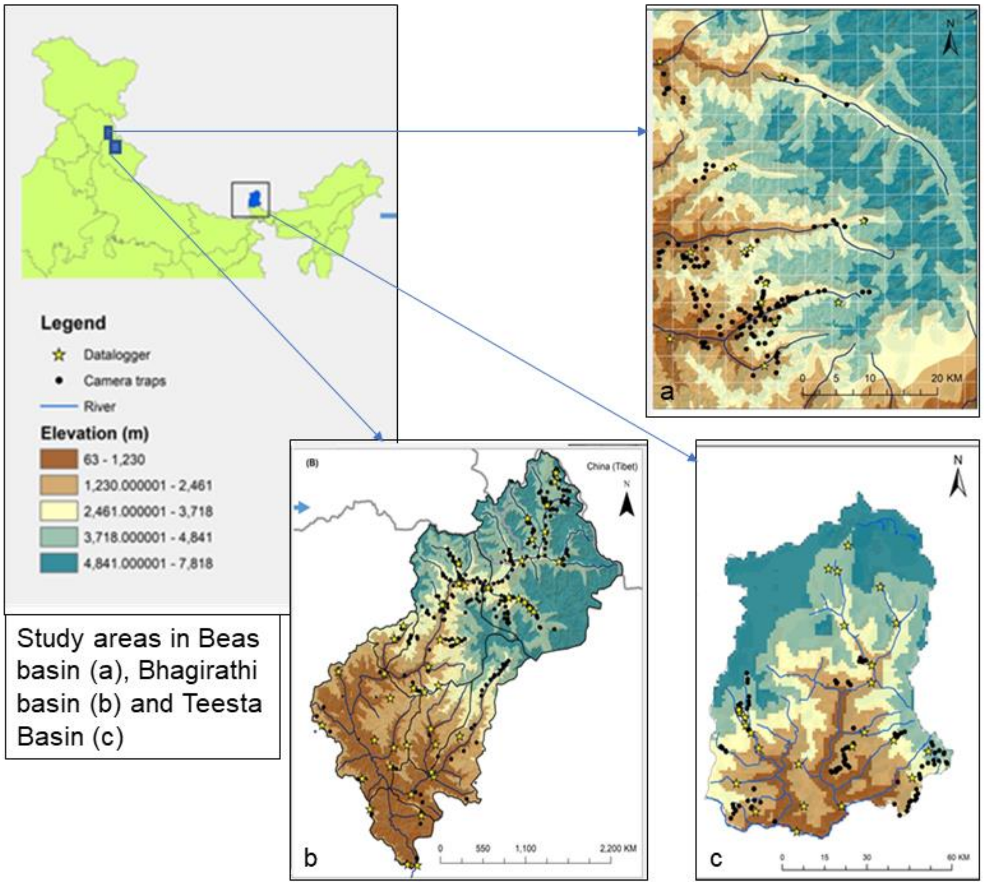

Fig. 3 Study areas selected under NMHSE phase I, Beas basin in North-western Himalaya, Bhagirathi basin in Western Himalaya and Teesta basin in Eastern Himalaya

An initial tentative identification of long-term monitoring sites within the Bhagirathi River Basin (catchments) representing the different Biogeographic provinces (1B, 2B and 1C), gradients (physical, anthropogenic), and conservation status has been done. The initial sampling locations have been chosen in seven different sub-basins such as Bhagirathi I, II, III and IV, Asiganga, Balganga and Bhilangana (Figure 2) covering approximately 7000 km^2 area and different land cover and land use patterns including human habitation, agricultural land, large and small water reservoirs, rivers, streams and wetlands, sub-tropical and temperate forests, alpine rangelands, glacial moraines, permafrost areas and trans-Himalayan cold deserts. Gangotri National Park is present within the study area covering an area of 2390km^2. The Gaumukh glacier, the origin of the river Ganges located inside the park and the northern boundary of the park is located along the Indo-China Border. The study area encompasses a wide range of elevation zones starting from 500m at sub-tropical forests to 5000m at trans-Himalayan cold deserts and accordingly represents a mosaic of several microclimatic regimes.

In the Beas river basin, the study area comprising the Great Himalayan National Park (GHNP) which is a UNESCO world heritage site located in the Kullu region of Himachal Pradesh in the Western Himalaya. A 90km² area of this park, was created Sainj Wildlife Sanctuary. Another protected area, known as Tirthan Wildlife Sanctuary 61km², was located in the southern edge of GHNP. In 2010, 710km² of the Parvati river catchment, contiguous to the northern boundary of GHNP, was instated as Khirganga National Park – adding further biological diversity, conservation value and physical protection to GHNP. The boundaries of GHNP are also contiguous with: the Pin Valley National Park in the Trans-Himalayan range (675km²); the Rupi-Bhabha Wildlife Sanctuary in the Sutlej watershed (503km²); and the Kanawar Wildlife Sanctuary in Parvati valley (107.29km²). Teesta basin in eastern Himalaya under the states of Sikkim consists of eight protected areas, with one National park and 7 Wildlife Sanctuaries. Khangchendzonga National Park is also a UNESCO mixed World Heritage Site inscribed in 2016.

In Teesta Basin, all the protected areas of the state of Sikkim were surveyed as part of the wildlife population monitoring along with the Department of Forest Environment and Wildlife Management. Sikkim with an area of 7,096 km^2 extends about 114 km from north to south and 64 km from east to west and is separated by Tibetan Plateau in the North, Chumbi valley of Tibet and the Kingdom of Bhutan in the east, Darjeeling and Kalimpong districts of West Bengal in the south and Nepal in the west. The State just covering 0.22% of the geographical area of the country has 26% of the country's total biodiversity and has been a part of the Eastern Himalaya biodiversity hot spot. According to Rodgers et. al. (2000), Sikkim is classified as a part of the Biogeographic province 2C (Central Himalayan), which in India includes the Darjeeling and Kalimpong districts of West Bengal with Temperate-Broadleaf biome, with the north of Sikkim as Biogeographic province 1C (Trans-Himalaya: Tibetan Plateau) with biota of Palaearctic affinity. The latter area is high-altitude cold desert in the rain-shadow of the main Himalayan range with typical flora and fauna. Sikkim is endowed with rich natural resources and biodiversity elements, which are of global significance.

Grid based sampling approach were opted for the collection of baseline species richness data. Bhagirathi basin was subdivided into 38 cells of 256 km^2 (16km x 16 km) according to the average home range of the largest mammal found in the area, the Himalayan brown bear (*Ursus arctos isabellinus*). Each of these 38 cells were further subdivided into 4 km x 4 km grids (Fig. 2) and sampling is ongoing in 3 to 4 such 4 km x 4 km grids within each 256 km^2 cells. Similarly, the Beas and Teesta basins were subdivided into 29 and 16 grids, each of 256 km^2 (Fig. 4, 5, 6) .

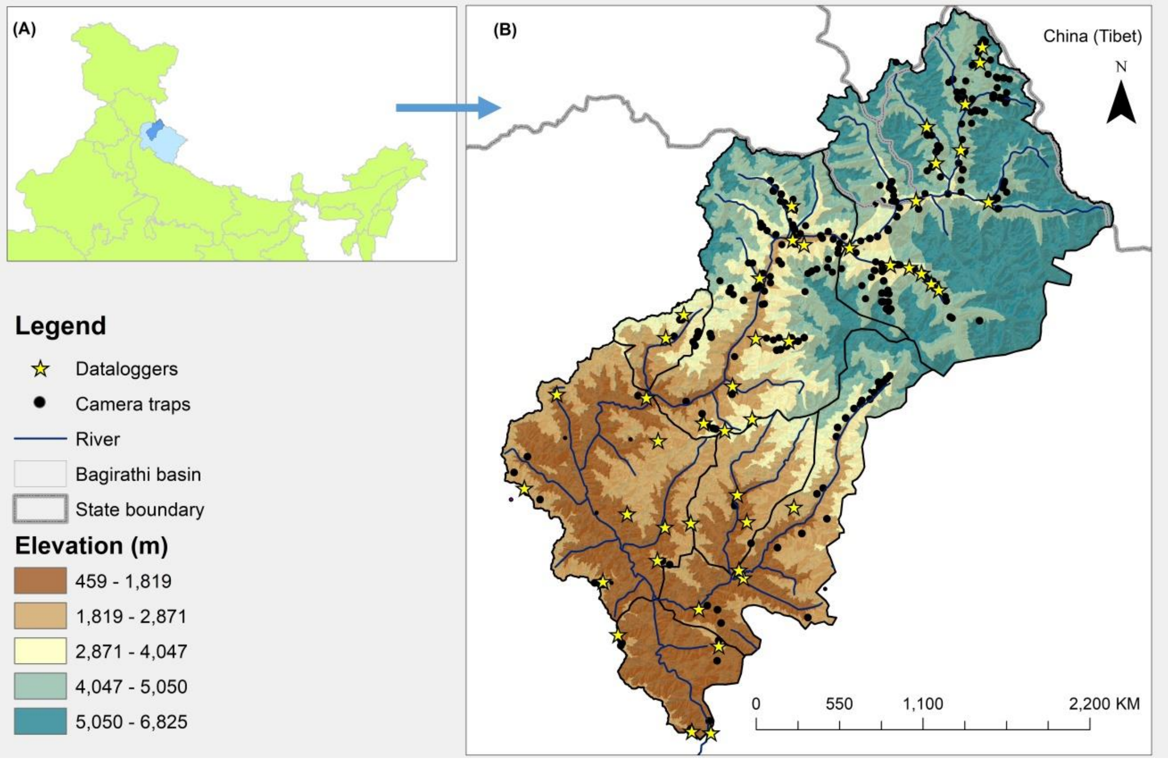

Fig. 4. Locations of the camera traps and data loggers deployed in Bhagirathi river basin, Uttarakhand

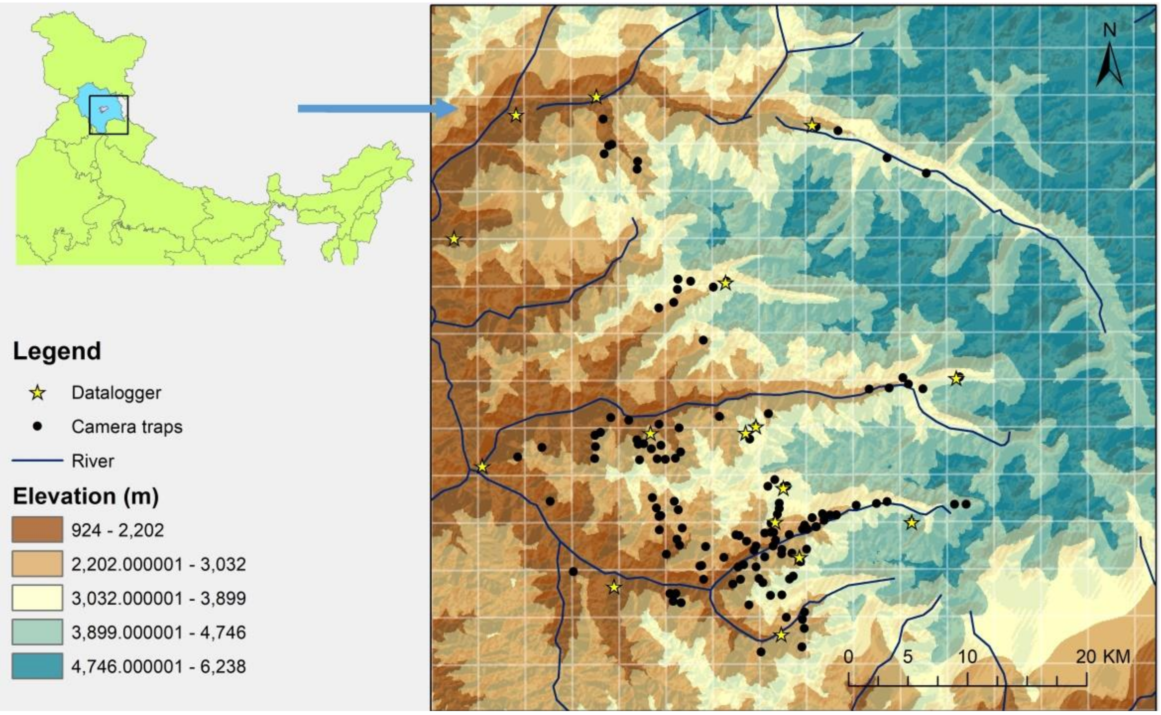

Fig. 4. Locations of the camera traps and data loggers deployed in GHNP, Himachal Pradesh

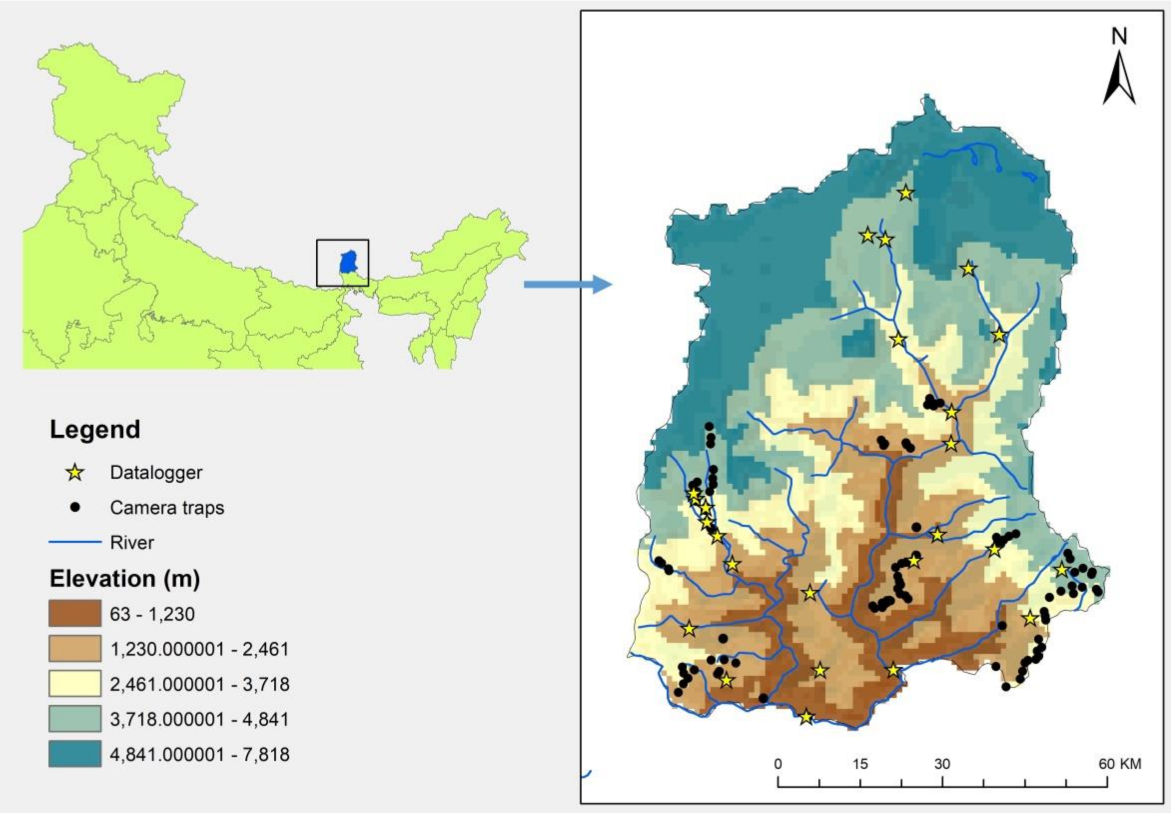

Fig. 5. Locations of the camera traps and data loggers deployed in Teesta river basin, Sikkim

2.3.2 Thematic groups and sampling methods

2.3.3 Terrestrial component

Mammals

The diversity and endemism of mammals in the Himalaya is exceptional, however, scientific knowledge on many of these mammals is still lacking in the Indian context. There are only three Himalayan species for which impact of climate change has been investigated. The proposed field methods and analytical approaches for the present study are presented here.

The Ganges river basin particularly the Bhagirathi basin in Uttarakhand is selected as the intensive study area for the initial two years, then the field work was extended in Teesta basin in Sikkim and Beas basin in Himachal Pradesh during the later phase of the study. The entire Bhagirathi basin (from Rishikesh to Gomukh and upwards to trans-Himalayan zones of Uttarakhand) is subdivided according to different watershed along the elevation gradient. Fieldwork according to order specific methodologies is being carried out within each sub-basin with spatial as well as temporal replicates. Different mammal group specific field methods are as follows:

a) Local interviews: During the initial one to two months, reconnaissance surveys were carried out in the sub-basins identified for the fieldwork. During this period, semi-structured interviews were conducted involving villagers, especially aged and experienced people who possess knowledge about locality-specific animal distribution, and may indicate about the changes in their status in comparison with the past. During this interview, colour photographs of mammals were shown to the participant to ensure proper identification of a species. This particular exercise helped to design the other order/species-specific field methods.

b) Sign survey: Sign survey was carried out on the forest trails (one to two km long) along the ridges or small streams covering the elevation gradients of the study area. During the sign survey, tracks and signs of ungulates, carnivores and small mammals were recorded and also searching for den sites of carnivores was carried out. Pugmarks/ tracks of felids, canids and ursids and hoof marks of ungulates were observed and the location was recorded. Similarly, scratch marks on trees and scrapes on the trails were recorded with geo-referencing. Location of carnivore scats were recorded and fresh scats were collected and preserved for further genetic analysis and identification of species. Direct sightings of mammals during sign survey were recorded with geo-referenced locations, habitat types and special observations if any.

c) Trail sampling: After the sign survey, several (at least three in each 500 m elevation difference covering each aspect) trails were selected for repeated survey. Direct sightings of mammals (particularly primates, ungulates and small mammals) were recorded. Number of individuals and the adjacent habitat features were recorded along with the geo-referenced location of the sighting. Encounter of pellets or scats or any other signs of mammals were recorded. Pellet or dung count for ungulates were carried out in a 20m x 2m belt transect at every 200 m interval along the trail. Once the pellet count is over, the pellet groups were removed from the plots to avoid repetition during the next count.

d) Scanning: Scanning from vantage points were carried out for open slope dwelling mountain ungulates such as the Himalayan Tahr, blue sheep and for goral in mid-elevation zones. Scanning an open meadow / cliff were carried out using spotting scopes or binoculars and sighting of ungulates are being recorded. Number of individuals, age, sex and other demographic parameters of a group were recorded. The habitat features were recorded as observed from the distance and/or if possible, by visiting the areas when the group is not there.

e) Camera trapping: Camera trapping for carnivores and elusive forest ungulates such as musk deer and serow were carried out following a 4 km x 4 km grid structure as according to the study design. The results of sign survey and trail sampling were used to select the camera location in each grid, and information on the habitat and climatic variables around the camera location are being collected. Cameras were placed using standard monitoring protocols (Sathyakumar et al. 2011) for mammals in mountains.

Herpetofauna

Nocturnal stream Visual Encounter Surveys (NVES) – which involves three, one-hour Visual Encounter Surveys (VES), formalized by Crump and Scott (1994) was carried out at each of the sites. Each site is a 100 m marked segment along stream courses. The sampling involved two people walking abreast with torches along the stream course looking for amphibians. Surveys were carried out post sunset between 18:30 – 21:00 hrs. The search does not involve active searching for amphibians and only those amphibians spotted by the torchlight will be recorded.

Similarly, in the high elevation Himalayan lakes, the same methods as mentioned above were followed to detect amphibians and reptiles. Diurnal VES (DVES) was conducted in each elevation zone (ca. 200 m bins), where two persons searched four to six belt transects (50 m x 2 m) for amphibians and reptiles by raking the leaf litter, turning logs and rocks, peeling bark and by opening fallen logs. This technique targets litter dwelling herpetofauna. The starting point of each belt positioned randomly between the edge of the water and 50 m up-slope in the riparian zone. In each belt, altitude, microhabitat features including soil pH, moisture and temperature were measured using a soil pH and moisture tester and a soil thermometer, respectively. Litter depth was measured with a metal ruler from the top of the soil to the top of the leaf litter. A canopy densiometer was used for measuring canopy cover. These microhabitat features were recorded at every 10 m interval along the belt.

A robust estimate of abundance and species richness were derived by utilizing count and presence data from transects and information on habitat co-variates to model site- and species-specific detection probabilities in an occupancy framework. With the predicted rise in temperature by 0.04 ^{o}C – 0.09 ^{o}C per year in the Himalaya, its herpetofauna is likely to provide a measurable negative response.

Invertebrates

A 16×16 km^2 grid is selected, which is further subdivided into 4×4 km^2 grid, for intensive sampling on at least 4 to 5 transects of 200 meter each by sweep net sampling, line transect sampling, kick net sampling, opportunistic sampling for both adults and larvae using stratified random sampling. The entire study area has been divided into different altitude classes as has been given in Table 1.

Table 1. Details of different elevation classes with ranges and code.

SL no.	Elevation Range (m)	Elevation Code	Elevation Type
1.	500-1000	LW	Low
2.	1000-1500	ML	Mid-low
3.	1500-2000	MD	Mid
4.	2000-2500	MH	Mid-high
5.	2500-3000	HG	High
6.	>3000	TH	Too High

Spreading larger Odonates in the field is time consuming and quickly leads to bulking up and presenting problem for future transport. However smaller Odonates can be spread effectively on fine foam plastic in shallow boxes that can be sealed with tape once the specimen is dry. The insects are pinned with micro-pins through the center of the thorax such that twice as much pin protrudes below as above, and the angle of the pin is slightly forwards above. The Odonates is then pinned into the foam with the pin vertical so that the body comes firmly up against the surface. The wings, and the legs if required are then be manipulated on either side into a roughly spread position. Permanent storage will be done in larger insect cabinets with glass top drawers and grooved sides for filling the naphthalene powder and then specimens are arranged in proper orientation. Male genitalia will also be dissected out and kept in 10% KOH solution for 12 hours, rinsed in distilled water for several times and are then preserved in 70% alcohol. The collected specimen ware identified and classified with the help of all available traditional taxonomic characters for the group.

The male genitalia also help in the process, especially for the discrimination of the species. The Odonates are then studied with the help of a camera-lucida and stereoscopic binocular microscope. The specimens are examined thoroughly and classified into different taxa or groups. Each taxon is then studied for further segregation on the basis of their general appearance and apparent characters. The identification of the individuals is taken up with the help of literature and the genera and species so identified are compared with the references collection available at the Zoological Survey of India, Kolkata and Dehradun. The traditional characters used for the identification of the Odonates are as per the keys of Fraser (1933, 1934, and 1936), Asahina (1981) and the species names were listed following Subramanian and Babu (2017). Field photographs and videography were taken using Canon Power-Shot SX50-HS advance point and shoot camera for further analysis.

2.3.4 Aquatic component

Aquatic fauna

Aquatic habitats in Beas (Himachal Pradesh), Bhagirathi (Uttarakhand) and Teesta (Sikkim) basins were sampled at a riverscape scale. An extensive sampling design was followed with a downstream to upstream approach starting at the confluence and moving onto the origin, conducting collections every 200 m for lower order streams (3rd and lower) and 500 masl for higher order streams (4th and higher). Within each sampling point 27 environmental parameters were recorded including 1) Geomorphological: total channel width, wetted channel width and altitude measured on field, distance from source, distance from confluence and stream length calculated by manual digitization on the google earth. 2) Hydrological: depth and flow (measured with the FP111- global water flow probe) 3) Physio-chemical: pH, alkalinity (ppm), water temperature (°C), total dissolved solids (ppm) and dissolved oxygen (mg/L) were measured using multiparameter water monitoring kit. Habitat: microhabitat (proportion of riffle, run, pool, rapid and cascade coded from 0-5) and substrate composition (% bedrocks, boulders, cobbles, gravels and sand). 4) Human Disturbance: proportion of none, low, medium and high coded from 0-5.

Fish sampling was done using cast (1 cm x 1 cm mesh size), drag and kick nets (500 µm x 500 µm mesh size). Number of persons, number of attempts and duration of attempts spent netting were noted as additional covariates to calculate catch per unit effort (CPUE). Morphometric characters and gonado-somatic indices (GSI) were noted on field with dissections of selected samples. Fish scales were collected from a uniform region below the dorsal fin and were stored in labelled envelopes for further age and grown analysis. The macroinvertebrate fauna was sampled using a nylon D frame dip net (30 cm diameter, 55 cm depth and 500 µm mesh size). Collections were made by kick sampling 10 × 0.1 m^2 replicates in 10% intervals of a 100 m long reach by disturbing the substrate for 30 seconds per replicate. Waterfalls were sampled by scouring the rock surfaces by hand, allowing the current to carry insects into the net. Along stream margins and in ponds, vegetation was swept with the D-net. Collections from all the replicates were transferred in a tray, the macroinvertebrates were hand-picked directly from the tray using forceps and hand-held magnifying lens to avoid further sorting in the laboratory. Samples were added into labelled vials and preserved with 95% ethanol, with the best estimations that organic debris, remaining water and body fluids bring the concentration to 70%. Identifications of macroinvertebrates in lab were made following standard keys.

A conceptual framework was developed on how to integrate the field data and secondary information collated to come out with comprehensive result on assessment of vulnerability of Indian Himalayan region and is given in Figure 6.

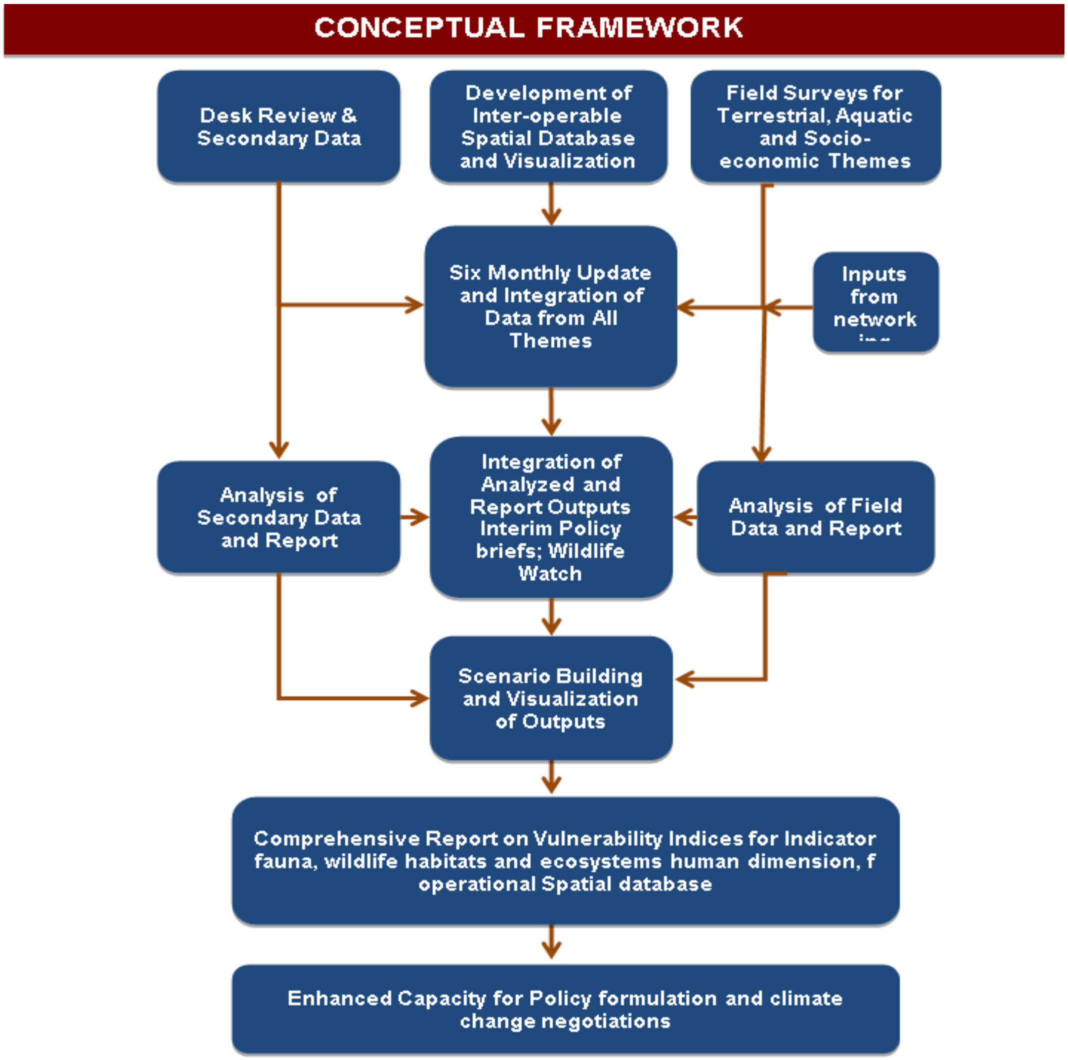

Fig. 6 Conceptual Framework for integrating the activity and come out with the comprehensive result on status and vulnerability of Himalayan Region.

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Chapter 3
Impacts on Terrestrial Environments

©WII Camera trap

3.1 Introduction

Climate and natural ecosystems are interwind for the stability of the system and its services (Sharma et al 2009). The race for modernization between the countries of the world has lead to the excess growth in industrialization, urbanization, transportation that is causing the destruction of the environmental balance through climate change. Mountains and uplands are aa major component of the global environment and is recognized under Chapter 13 of Agenda 21. The survival of the mountain ecosystem and biodiversity it sustains are now threatened by various drivers of change such as human activities like timber harvesting, intensive grazing and agricultural expansion into forest lands and above all the recent climate change. Problems associated with modernization like Green House Gas emission, air pollution, land use conversions, fragmentation, deforestation and land degradation have already crept into the HKH region. The landscapes and communities in the Indian Himalayan region are being simultaneously affected by rapid environmental and socioeconomic changes. Identification and understanding of key ecological and socio-economic parameters of the mountain ecosystems, including their sensitivities and vulnerabilities to climate changes, have become crucial for planning and policy making for environmental management and sustainable development of the mountain regions as well as the downstream areas.

3.2 Climate change overview on terrestrial taxa

The Himalayas, which literally mean the abode of snow, is the youngest and the highest range of Fold Mountains in the world. The Himalayas consist of three parallel ranges, the Greater Himalayas known as the Himadri, the Lesser Himalayas called the Himachal, and the Shivalik hills, which comprise the foothills. It extends between 28°N to 36°N latitude and 72°E to 96°E longitude run almost without break for about 2500 km. and with a width about 200-400 km. Biogeographically, the Himalayan mountain range straddles a transition zone between the Pale-arctic and Indo-Malayan realms (Myers et al., 2000). Species from both realms are represented in the hotspot. In addition, geological, climatic and altitudinal variations in the hotspot, as well as topographic complexity, contribute to the biological diversity of the mountains along their east-west and north-south axes (Chandra et al 2018). The flora and fauna of the Himalayas varies with rainfall, altitude, and soils. The climate ranges from tropical at the base of the mountains to permanent ice and snow at the highest elevations. The amount of yearly rainfall increases from west to east along the front of the range. This diversity of altitude, rainfall and soil conditions generates a variety of distinct plant and animal communities, or eco-regions.

Climate change is likely to have a number of impacts on biodiversity from ecosystem to species level. The most obvious impact is the effect that temperature and precipitation have on species, ranges and ecosystem boundaries. Any particular ecosystem consists of an assemblage of species, some of which will be near the edge of their ranges and others of which will not. Those at the edge of their ranges may need to move due to climate change (Lemoine and Böhning-

Gaese, 2003). The major proximate causes of species extinction are habitat loss and fragmentation etc, extremely accelerated by climate change through various ways.

The present study was concentrated on the three-river basin in the Indian Himalayan Region, The Beas Basin of Himachal Pradesh, the Bhagirathi Basin of Uttarakhand and the Teesta Basin of Sikkim. The survey includes intensive camera trapping and other field methods like trail sampling, nocturnal sampling, point sampling as per the need of data collection for various taxa. For survey of mammals and Galliformes, intensive camera trapping was done in nested grids of 4kmX4km (16 km^2) within 16kmX16km (256km^2).

3.3 Local scale biological characterization

3.3.1 Bhagirathi basin

The Bhagirathi river originates at an elevation of 3812 m from the Gangotri glacier in the Uttarkashi district of Uttarakhand state, India. The basin has a broad U-shape at higher elevations, characteristic of glacial origin, but at lower elevations, the river has cut a narrow V-shaped fluvial valley. The study area encompasses altitudes of 500–5,200 m (Fig. 1). The habitat types in the study area can be broadly classified (based on dominant vegetation) into four categories: (1) subtropical deciduous forest (500–2,000 m) characterized by broadleaved and needle-leaved species such as *Pinus roxburghii*, (2) temperate forest (2,000–3,500 m) with montane broadleaved and conifer species such as *Quercus semecarpifolia*, *Quercus floribunda*, *Abies pindrow*, *Cedrus deodara*, and *Pinus wallichiana*, (3) high altitude alpine and subalpine vegetation (3,500–5,000 m) with Rhododendron spp., *Betula utilis* and alpine herb and forb species, and (4) Trans-Himalayan landscape (3,500–5,200 m) with alpine dessert steppe plants such as *Eurotia sp., Caragana sp., Lonicera sp.* and *Rhamnus sp.* Summer (or monsoon, April–September) and winter (November–February) are more pronounced than the short autumn (October) and spring (March–April) seasons.

The region has one protected area, Gangotri National Park covering glaciated valleys of greater and Trans Himalayan region. Human presence in the lower and mid-altitude forests (500–2,500 m) of the Bhagirathi basin include livestock grazing, extraction of non-timber forest products and collection of fulewood, activities. Additionally, tourism, mountaineering, and pilgrimage attract numerous visitors during April–November. The northern boundary of the Bhagirathi basin also forms the international border with the Tibet region of China. Patrol camps and small settlements of the Indo-Tibetan Border Police and other security agencies are present in the area.

The previous reports on mammals from the Bhagirathi basin are restricted to few short term surveys (Uniyal & Ramesh 2004; Bhardwaj & Uniyal 2009; Negi 2002; Bhardwaj et al., 2010; (Rajvanshi et al., 2012). The distribution of mammals in this area has not yet been assessed with systematic sampling and robust scientific methods. Here, we summarize (1) the occurrence of mammal species along the gradient of habitat types and climate zones of Bhagirathi Basin, (2) the response of threatened mammal species to seasonal change and anthropogenic pressures and (3) new distribution records and notable findings.

3.3.1.1 Field sampling

After a three-month reconnaissance survey (July–September 2015), we conducted a camera-trap study at 209 locations, using Cuddeback C1 (Cuddeback, De Pere, USA), during October 2015–September 2017. We positioned camera traps along an elevation gradient (500–5,200 m) representing various habitats. To survey evenly we divided the basin into 38 grid cells of 256 km2 each (16 × 16 km), which corresponds to the average home range of the largest mammal in the area Himalayan brown bear *Ursus arctos isabellinus*. We subdivided these cells into 4 × 4 km cells and deployed camera traps in 3–4 of these smaller cells within each 256 km^2 cell (Fig. 1). In the fragmented forests of the lower areas with high human presence, frequent loss of camera traps prevented adequate sampling. From September 2017 to May 2019, intensive effort using camera traps (~130 sites) in 3×3 km grids were laid in the upper Bhagirathi basin.

We examined all camera-trap photographs of large and medium-sized mammals (except families Muridae and order Chiroptera) and identified species with the help of Prater (1980) and Menon (2014). Relative abundance (mean # photo-capture/ 100 days) of mammals in different habitat types were estimated using camera traps (N= 209, 33,057 trap days) from October 2015 to June 2017.

3.3.1.2 Effect of seasons and anthropogenic factors

To understand the distribution of threatened mammals along the gradient of elevation, season, and anthropogenic pressures, we used generalized linear mixed models (glmmTMB package Magnusson et al., 2017) in *R 3.6.2* (R Core Team, 2019). For analysis, we used cameras (124 locations, 12,558 trap nights) that were active in both seasons and either summer (April to September 2016) or and winters (November to February 2015–2016 and 2017). We used captures of species as the response variable and number of trap days (log-transformed) as offset to account for variation in the trapping effort between sites. Habitat features (elevation, ruggedness, slope) and anthropogenic pressures (capture rate of humans, dogs, and livestock) were used as predictor variables. The best model was decided based on Akaike's information criterion adjusted for sample size (AICc). The best-supported model was considered to be those with ΔAICc values < 2 units (Arnold, 2010). Multicollinearity between predictor variables was tested using the Pearson correlation, and correlated variables (Pearson correlation coefficient > 7.0) were not used in the same model. Suitable habitat for each species was decided based on the elevation range and habitats in which camera traps recorded them.

3.3.1.3 Results

3.3.1.4 Mammal diversity of Bhagirathi basin

The total number of camera-trap days was 66,757, with a mean of 108 trap days per camera. We recorded 41 species of mammals belonging to 13 families in five orders (Table 2). Carnivora was the most diverse order with 18 species, followed by Artiodactyla (9), Rodentia (5), Lagomorpha (4), and Primates (3). Of the 41 species recorded, nine are categorized as threatened (four Vulnerable, five Endangered), six as Near Threatened, and 26 as Least Concern on the IUCN Red List (IUCN, 2020).

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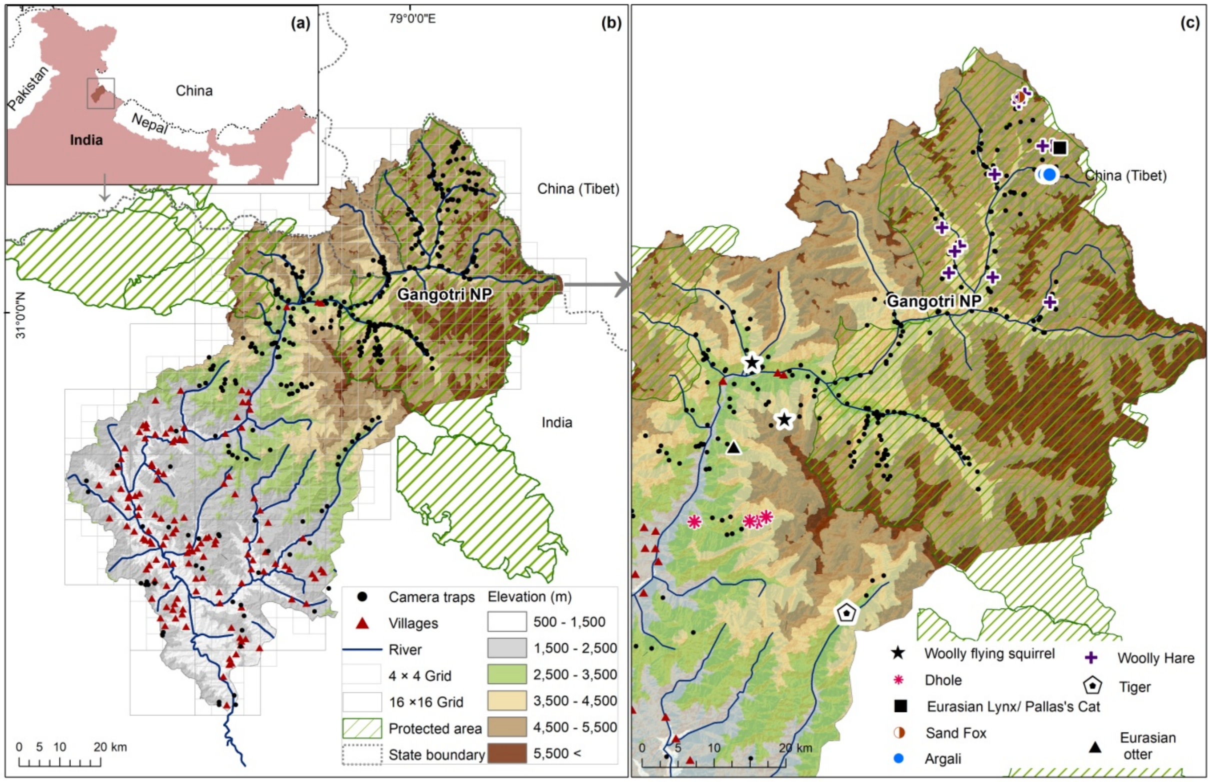


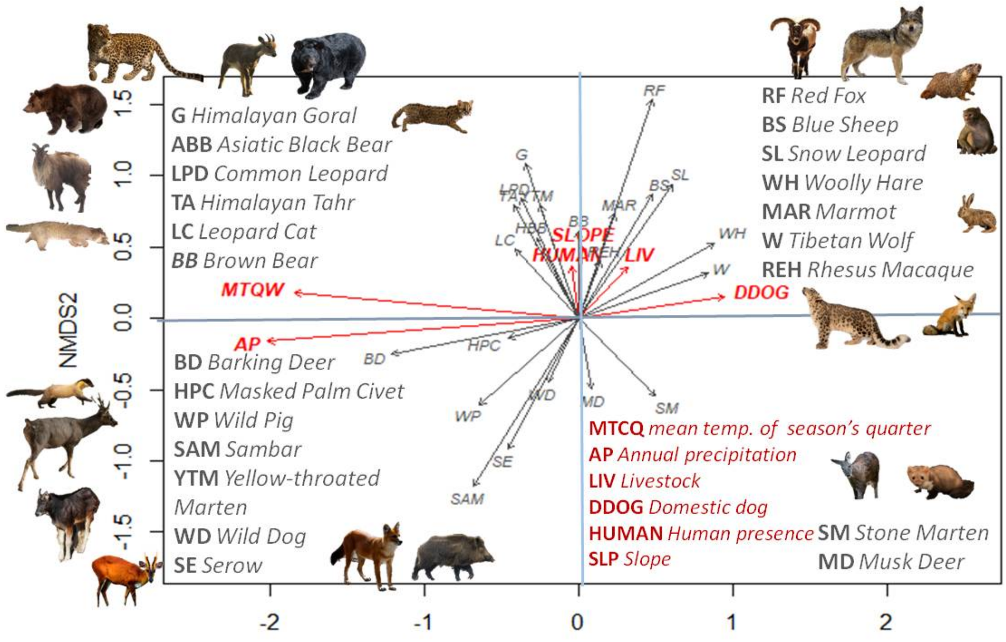
Fig. 1 (a) Bhagirathi basin in Uttarakhand state, Western Himalaya, India. (b) Camera-trap locations (October 2015-September 2017) and permanent human settlements along an elevation gradient in the Bhagirathi basin. (c) Location of some of the new records of species reported from the Bhagirathi basin

3.3.1.5 New distribution records

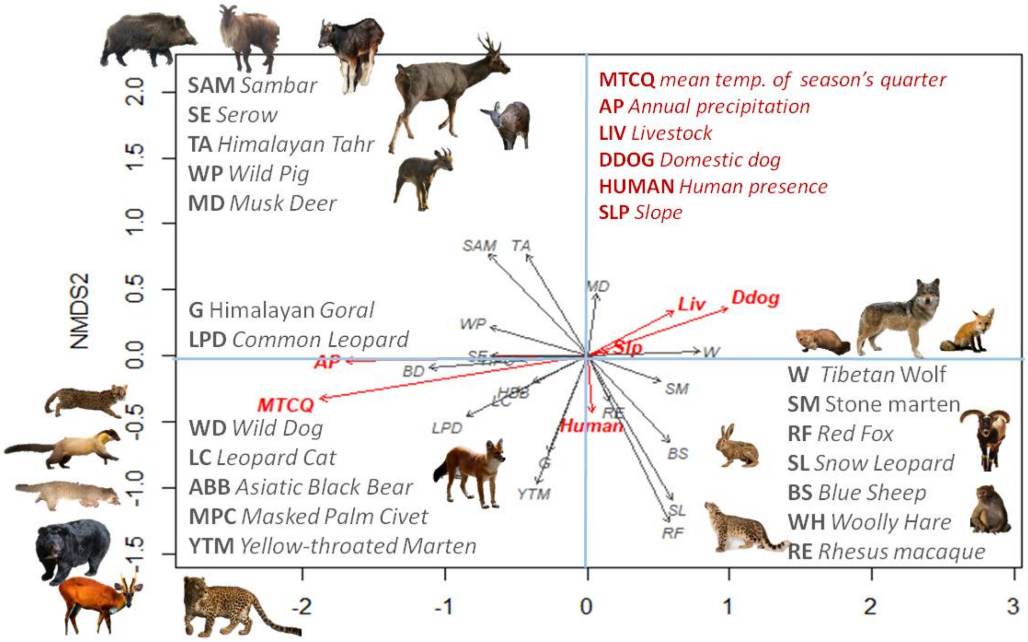
We recorded six mammal species (Fig. 1) that were hitherto not known to be present in Uttarakhand State: the argali *Ovis ammon*, Tibetan sand fox *Vulpes ferrilata*, woolly hare *Lepus oiostolus*, Eurasian lynx *Lynx lynx*, woolly flying squirrel *Eupetaurus cinereus, and* Pallas's cat *Otocolobus manual*. Argali, sand fox, woolly hare, Eurasian lynx, and Pallas's cat were recorded in the Trans-Himalayan landscape (4,000–5,200 m) of Nelong valley in Gangotri National Park. The woolly flying squirrel was captured at three locations in temperate (2700m) and alpine (4800m) and subalpine habitat (3000m) habitat. Apart from these new records, we also captured photographs of the dhole *Cuon alpinus* and tiger *Panthera tigris* and Eurasian otter *Lutra lutra*. A tiger was photographed only once, in February 2017 (at 2,910 m altitude) in subalpine broadleaved forest dominated by *Quercus semecarpifolia*. The Eurasian otter was captured twice near the Dabrani region, the meeting point of Jaulighad, and Songhad tributaries with Bhagirathi River. It was captured at an elevation of 2700m near the bank of Jualighad approximately 2 km away from confluence with the main river.

3.3.1.6 Response of mammals to abiotic and biotic pressures

Six threatened large mammals were captured regularly throughout the survey: the Himalayan brown bear, Asiatic black bear, snow leopard, common leopard, musk deer, and sambar. The analysis of factors influencing the distribution of species using GLMM models showed that sambar, common leopard, and Asiatic black bear occurred in areas with high levels of human disturbance. Asiatic black bears had lower capture rates in winter when they hibernate (Sathyakumar et al., 2013) or move to lower elevation areas. The sambar and Asiatic black bear are found in subtropical and temperate forest habitats and avoided steep slopes and rugged areas, respectively. Musk deer and brown bear were found in narrow elevation zones of subalpine habitats. In winter, musk deer capture rates declined with increasing elevation, which could be associated with snowfall at high altitudes. Snow leopards were recorded in greater and Trans Himalayan subalpine and alpine areas. Snow leopard presence in the areas was negatively influenced by the presence of seasonal headers in the area. They occurred at an altitude of 3,500–4,500 m and rarely occurred in the National Park's high elevation plateau habitat. Snow leopard capture rates were higher in winter when there were fewer disturbances by livestock and people (Fig. 3).



Summer



Winter

Fig. 3 Species assemblages across the gradient of abiotic (temperature, precipitation) and biotic factors (anthropogenic pressure; dog, human, livestock) seasons in Bhagirathi basin (method: Non-metric multidimensional scaling, stress value=0.15).

3.3.1.7 Other high elevation records

Rhesus macaque *Macaca mulatta*: Found in a range of habitats, rhesus macaque are associated with habitats such as temperate coniferous, moist and dry deciduous, and mixed forests, and around human habitations (Choudhury 2001; Srivastava and Mohnot 2001). The highest elevation recorded in earlier studies is at 4000 m from Qingghai province, China (Molur et al. 2003). We recorded rhesus macaque from 11 different locations in the trans-Himalayan landscape, alpine and sub-alpine habitat of Gangotri National Park. Rhesus macaque was photo captured in four occasions in winters of 2015 from the mix coniferous habitat (3100m to 3200m) of GNP and in 25 occasions in summer 2016 from alpine (7) (3700m to 4500m) and subalpine (11) (3000m to 3500m) and trans-Himalayan landscape(6) from the park. To our knowledge, these are by far the highest occurrence record for rhesus and first confirmed record of their presence in the trans-Himalayan landscape in India. We believe that rhesus movement to such high altitudes is partly mediated by high human presence (food resource) and partly by suitable abiotic conditions. In high elevation areas (>4000m), they were captured only in summer months and were not captured during winter months.

Sambar *Rusa Unicolor*: Sambar is known to adapt to a wide variety of forest types and environmental conditions (Timmins et al., 2015). In India, sambar is known to occur in the arid forest, moist and dry deciduous forest of peninsular India, evergreen or semi-evergreen forest of the northeast and western ghats and in pine and oak forest in the Himalayan foothill (Timmins et al., 2015). Sambar is also occasionally known to occurs up to at least 3,825 m on Siouguluan Mountain, the highest peak of the Central Mountains in Taiwan, but mostly they are found up till 3500m elevation (Timmins et al., 2015). In Bhagirathi basin, sambar was regularly photo captured up till a height of 3500m elevation and was sighted once at the height of 4000 m in the alpine meadow near Dokarani glacier.

Woolly flying squirrel *Eupetaurus cinereus*: The species was captured (5 October 2017, 7:25 PM) at 4800 m near Srikant glacier, Uttarkashi. It is higher than the described upper elevation range limit of any other flying squirrels found in mid to high elevation ranges (1500–4000 m) such as the Kashmir flying squirrel *Eoglaucomys fimbriatus* (1800–4000 m, Zahler and Karim 1999, Molur et al. 2005), the Chinese giant flying squirrel *Petaurista xanthotis* (3000 m, Smith and Xie 2008), the Siberian flying squirrel *Pteromys volans* (up to 2500 m, Shar et al. 2016).

Previous records of this species are from 2400 m to 3800 m (Zahler 2010). The alpine habitat devoid of any tree or woody vegetation where the squirrel was photo-captured was different from previously recorded habitats consisting of scattered conifers.

Jackal *Canis aureus:* Owing to the generalist omnivorous diet, the golden jackal is found in a wide variety of habitats (Hoffmann et al., 2018). In the high altitude areas, golden jackal has been recorded at 3800m in the Bale Mountains of Ethiopia (Ginsberg and Macdonald 1990). In India, they are known to occur up to 2000m in the temperate habitats (Prater 1980). In the Bhagirathi basin, Jackal was recorded (28 December 2017 1:55 AM) at an elevation of 4500m in the Trans-Himalayan area, Nelang valley of Gangotri National Park. The other species captured from the same site are snow leopard, Tibetan wolf, and red fox, woolly hare.

3.3.1.8 Density of snow leopard

Snow leopards can be identified individually based on their unique spot patterns, permitting estimation of their abundance and density using closed capture recaptures models. Individual capture histories of snow leopard were analyzed using secr package in R. The density was 1.4 /100 km2 ± 0.25 (SE) in summer and 2.07/100 ± 0.4 in winters. The number of unique individuals captured was also significantly different in summer (17) and winter (30). An increase in snow leopard numbers inside the park in winters can be associated with less human activity and heavy snowfall in the high reaches of the national park, which push snow leopards to use lower areas intensively. The good density of snow leopards has opened new scope for the conservation of this species in Gangotri National Park, a protected area can act as a refuge for the continued survival of this species.

3.3.1.9 Common leopard and snow leopard co-occurrence

Climate change has led to the upward shift of tree line and has created suitable habitat for common leopard habitat at the cost of snow leopard habitat (Lovari et al., 2013). Studies indicate that snow leopards may have to adjust their habitat use to avoid competition with common leopards (Ferretti & Lovari, 2016). In four years of camera trapping surveys, we recorded four instances (from four different sites) of occurrence of both snow leopards and common leopards at the same location. All the capture of the co-occurrence of leopard species was from below tree line (3000-3500m). The potential competition between these large cats may vary according to local richness and abundance of prey species (Lovari et al., 2013). Continuous monitoring is required to understand the resource overlap between leopard species and the potential for a competition that may increase in the changing climate scenarios.

3.3.1.10 A new approach for estimating density of mountain ungulate

Most of the currently available methods of estimating the density of ungulates are challenging to implement in the mountainous terrain. It has remained the major hurdle in developing management and conservation interventions. We tested the usefulness of the recent extension of the point-transect method using camera traps (Howe et al., 2017) for estimating density for two mountain ungulates: the group living Himalayan blue sheep or bharal (*Pseudois nayaur*) and the solitary Himalayan musk deer (*Moschus leucogaster*.). Camera traps were deployed randomly in 2017-18 for bharal (summer: 21; winter: 25 locations) in the Trans-Himalayan region (3000 to 5000m) and in 2018-19 for musk deer (summer: 30; winter: 28 locations) in subalpine habitat (2500 to 3500m) in Upper Bhagirathi basin, Uttarakhand, India. The distance-based camera trapping estimated bharal population 0.51 individuals/ km2 (±0.1, CV=0.31) in summer and 0.64 individuals/ km2 (±0.2, CV=0.36) in winter. For musk deer, the estimated density was 0.4 individuals/ km2 (±0.1, CV=0.34) in summer and 0.1 individuals/ km2 (±0.05, CV=0.48) in winter. Our analysis showed that camera-trapping based distance sampling could be a potential method for studying mountain ungulates. The camera trapping based distance method can overcome the logistic, terrain and weather constrain in estimating densities of mountain ungulates. One of the important advantages of this method over conventional distance sampling is the opportunity to monitor solitary, elusive, and nocturnal species such as musk deer.

3.3.1.11Discussion

Continuous monitoring using camera traps has contributed novel facts and new distribution records of several rare and threatened species. Our findings highlight the Bhagirathi basin's potential as a stronghold for several threatened and rare mammal species. We recorded four typical Trans-Himalayan mammals (argali, Tibetan sand fox, woolly hare, and Eurasian lynx) and the woolly flying squirrel in the Bhagirathi basin. The Near Threatened argali has declined significantly (Harris & Reading, 2008). Although categorized as Least Concern, the Tibetan sand fox occurs in low densities (Harris, 2014). The woolly hare has been assessed as Endangered in India (Molur et al., 2005). The Eurasian lynx population is declining, and the species is believed to be close to extinction in India (Breitenmoser et al., 2015). The woolly flying squirrel population is believed to have declined by 50% during the last decade, mostly because of deforestation and grazing pressure (Zahler, 2010). In addition to these threatened species, we recorded two large endangered carnivores, the dhole and tiger, which were hitherto unknown from the area. These new records and the high mammal diversity in the Bhagirathi basin are a result of a wide range of habitats, including many areas with low anthropogenic pressures. The persistence of species diversity can be attributed to the presence of remote, rugged, and undisturbed habitats and seasonal absence of people and livestock. Nonetheless, the distribution of threatened species overlaps with human activities both spatially and temporally, and thus these species remain vulnerable to anthropogenic pressures. The presence of these two Endangered carnivores in high-altitude forests emphasizes the need for regular monitoring of these areas over a more extended period. Long-term monitoring could elucidate if and how these species persist in these habitats and climatic conditions.

The sampling so far has recorded the occurrence of low elevation species in the alpine habitats such as common leopard (3500m), leopard cat (3500m), rhesus macaque (4500m), sambar (4000m) and jackal (4500m). The occasional presence of these species in high elevation areas can be linked with climate change or indicate the opportunistic behavior of moving to favorable microclimates. The continuous monitoring to generate data on species habitat use and fine-scale information on temperature will help us understand the underlying mechanism of species response to environmental variation.

The Bhagirathi basin has around 238 glaciers, which cover a glaciated area of 755 sq km and an ice volume of 67 cubic km (Anonymous 2014). The major glaciers in the region like Gangotri glacier, the source of Bhagirathi river and Dokriani glacier is retreating like other glaciers in Himalaya, and its volume and size are shrinking as well (Kumar et al., 2008; Dobhal et al., 2004). An analysis of snow cover area in October in different years in the Bhagirathi basin showed a steep decline of 45.8 % in the year 1972 to 22.6 % in 1999 (Anonymous 2014). Signatures of development of pro-glacial lakes in the Srikant glacier and others have started coming up in the region, which is another sharp evidence of the impact of global warming in the region (Anonymous 2014; field observation). Such changes are also causing changes in vegetation and habitat in the area. Pollen analysis near Gangotri glacier (Kar et al., 2002) shows that around 2000 years BP, open Juniperus–Betula forest occupied the area vacated by the glacier, revealing comparatively cooler and moist climate than the one prevailing at present. Around 850 years BP, there is a shift in the vegetation pattern, with a sharp increase in Ephedra and other steppe elements, notably Artemisia and Asteraceae. This reflects a trend towards drier climatic conditions, evidenced by a decrease in Ferns and Potamogeton. The subsequent increase of local arboreal taxa (Juniperus, Betula, Salix) and extra local elements (mainly Pinus) around 1700 years BP, indicates further amelioration of climate, i.e., increase of both precipitation and temperature in this region. Such changes and suitable abiotic conditions can create new opportunities for species from a lower elevation to move upwards. We believe the first one to do so will be the generalist species with wide niches like sambar, rhesus, and leopard cat. Further warming conditions may enhance the chances of co-occurrence among these low elevation species with typical high-altitude species. Such generalist species can act as an indicator of change in environmental conditions, and continuous monitoring is essential to monitor the subsequent effect of climate change.

3.3.2 Beas Basin

In the Beas basin the study was concentrated within the Great Himalayan National Park and Conservation area (GHNPCA). The Great Himalayan National Park (GHNP) forms a relevant part of the Western Himalayan Mountains of the Indian Himalayan Region (IHR) (Figure 4). It is situated in the Kullu district of the Himachal Pradesh and is an exemplar of typical Western Himalayan flora and fauna (Anon., 1999-2003). GHNP is stretched across 754 sq km and its boundaries are contiguous with the Pin Valley National Park (675 sq km) which is a part of Trans-Himalaya, the Rupi-Bhabha Wildlife Sanctuary (WLS) (503 sq km) in Sutlej watershed and the Kanawar WLS (61 sq km). The national park was inscribed as a UNESCO World Heritage Site in June 2014 which further ensured its importance and the flora and fauna inhabiting the park. Being surrounded by protected areas, GHNP receives an additional protection which further increases its conservation value and also serves as extended wildlife corridors. The total area which comprises of the National Park, the Wildlife Sanctuaries and the eco-zone is around 1171 sq km. This altogether, referred to as the Great Himalayan National Park Conservation Area (GHNPCA).

Regarding the fauna (mammals and pheasants) of the national park, few surveys were conducted by Gaston & Garson 1992, Vinod et al., 1997, Vinod et al., 1998, Garson 1998, Ramesh et al., 1999, in the Great Himalayan National Park. It was assessed that GHNP holds substantial populations of such faunal species which are globally significant such as Western Tragopan *Tragopan melanocephalus* , large carnivores like the Common leopard *Panthera pardus*, the endangered Himalayan Brown bear *Ursus arctos isabellinus*, Asiatic black bear *Ursus thibetanus* and mountain ungulates such as the Himalayan tahr *Hemitragus jemlahicus*, Blue sheep *Pseudois nayaur*, Musk deer *Moschus spp*. Recently, Snow leopard *Panthera unica* was also photo-captured, which marked the evident presence of this species in the park (Bandyopadhyay et al., 2019). Before that, there were just local people hinting about its presence without any concrete evidences.

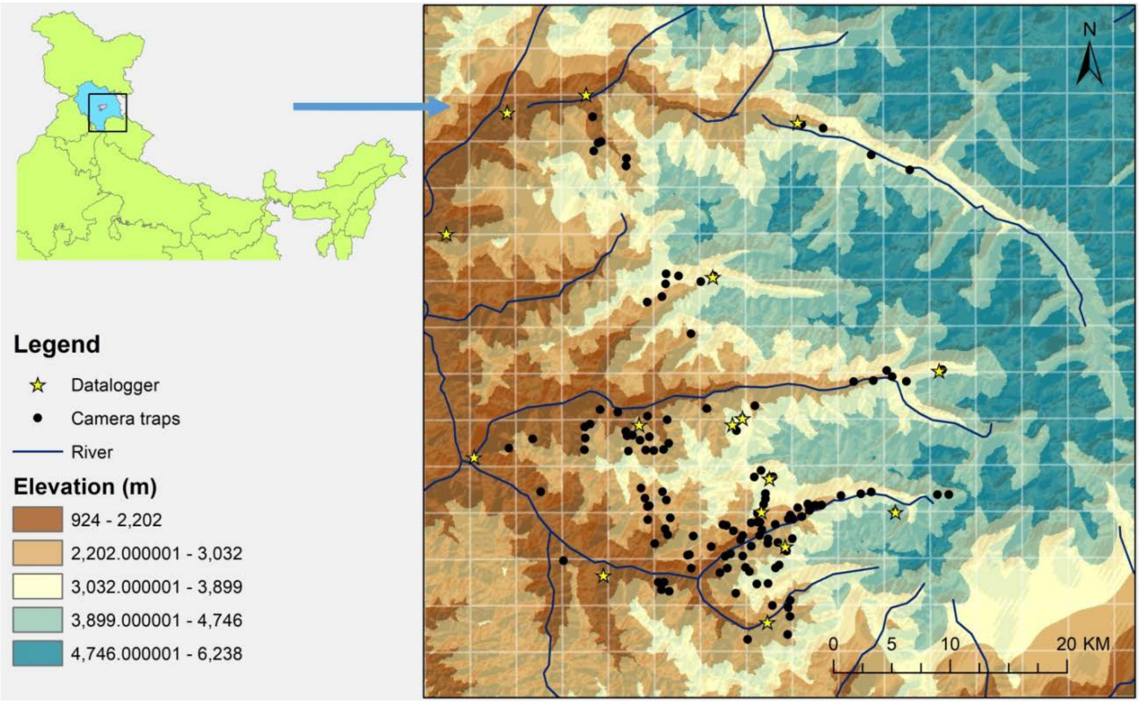


Fig.4. Map of the study area with the camera trap locations along the elevation gradient in GHNP, Himachal Pradesh

We did field surveys using sign surveys, trail monitoring, ridge walking, and camera trapping (Sathyakumar et al., 2011) in all the four valleys of the national park. The camera trapping began March 2017 following the nested 4kmx4km (16 km^2) grids. We deployed camera traps along the trails with a minimum of 1km distance between each camera trap. The trails were repeatedly monitored in different habitats such as in the temperate, subalpine and alpine habitats. Camera trapping was also initiated in other two valleys of GHNP viz *Jiwa* and *Parvati* in 2018. To assess the anthropogenic activities, (humans, livestock and domestic dogs), photo-capture rates (mean # photo-captures / 100 days) were calculated. Site occupancy and relative abundance of large carnivores were estimated based on sign survey and camera trap data (Fig.4). For occupancy modeling single season occupancy (Mackenzie et al., 2017) models were used to determine the influence of habitat types and anthropogenic activities on proportions of site utilization by different carnivores. Anthropogenic impacts were quantified by assessing the human activities and the resulting pressures on the habitat. Camera trapping was done in 65 sites (5595 trap nights in summer and 1849 trap nights in winter) covering Tirthan and Sainj, core-zone as well as eco-zone and parts of Jiwa and Parvati valley(s). Frequent loss of camera traps was a major constraint during the field surveys. The initial 84 sites were decreased to 65 sites due to theft issue.

3.3.2.1 Results

The pheasants which were photo-captured during the study were the “Western Tragopan”, *Tragopan melanocephalus* (0.16±0.11),“Himalayan Monal”, *Lophophorus impejanus* (5.03±2.11) alongwith the“Koklass”, *Pucrasia macrophola* (1.29±0.79), “Khalij” pheasant *Lophura leucomelanos* (4.87±1.94) and “Cheer” pheasant *Catreus wallichii* (0.01±0.01). Among the ungulates (Table 3), we photo captured the “Blue sheep (Bharal)”, *Pseudois nayaur*. “Himalayan Tahr”, *Hemitragus jemlahicus*, Barking deer *Muntiacus muntjak*,near threatened “Himalayan Serow”, *Capricornics tahr*, “Himalayan Goral”, *Naemorhadus goral*, and severely endangered “Musk deer”, *Moschus spp*. The highly endangered “Snow Leopard”, *Panthera uncia* have also been recently reported to be photo-captured for the first time from the National Park by the Wildlife Institute of India (Bandyopadhyay et al., 2019). The other large carnivores present in the park are “Common leopard”, *Panthera pardus*, “Asiatic black bear”, *Ursus thibetanus* and the endangered “Himalayan brown bear”, *Ursus arctos.*

3.3.2.2 Site occupancy by large carnivores

The site utilization patterns by leopard in both core as well as eco-zone were found to be frequently using areas with high anthropogenic disturbances (Fig. 5)**.** Similarly, in case of Asiatic Black bear, the result is somewhat similar and the species is found to be using areas with high human activities. Both the species being human-wildlife conflict species were found to be using areas with high anthropogenic activities. In case of Himalayan Brown bear, the animal is found to be mainly confined to the core area of the park.

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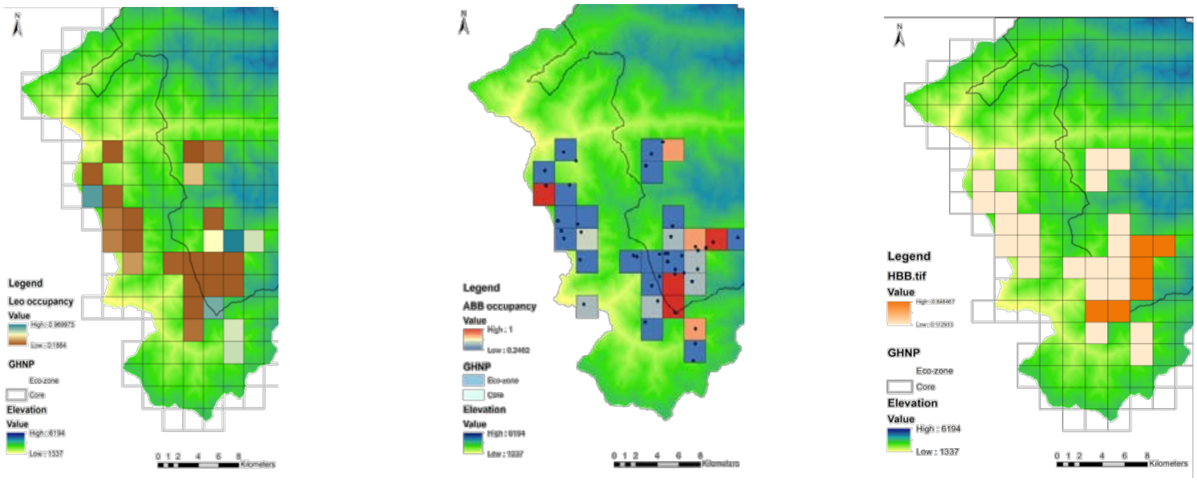

Fig.5.Site utilization by Common leopard, Black bear and Himalayan Brown bear (Summer 2017-2018)

Temporal overlap between Asiatic Black bear and Himalayan Brown bear

A significant temporal overlap (Δ=73) between two sympatric large carnivores present in the national park, Himalayan Brown bear and Asiatic black bear was observed (Figure 6). Such observations were recorded at multiple sites (n=10 sites.) from Kholipoyi in the Tirthan valley and Sainj valley, where the two species were photo-captured in the same location. In addition to that, the use of lower elevation habitat (2463m) by the Himalayan Brown bear indicates the presence of an alpine dwelling species in the temperate forests.

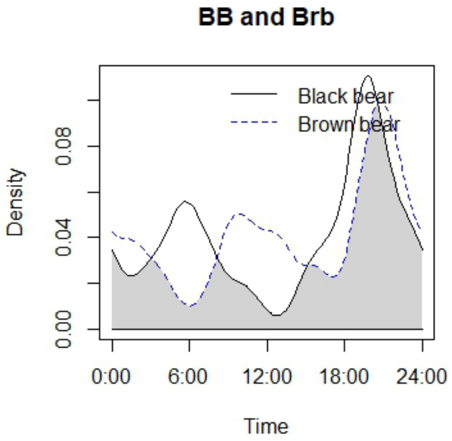

Fig. 6 - Temporal overlap between Asiatic Black bear and Himalayan Brown bear in summer

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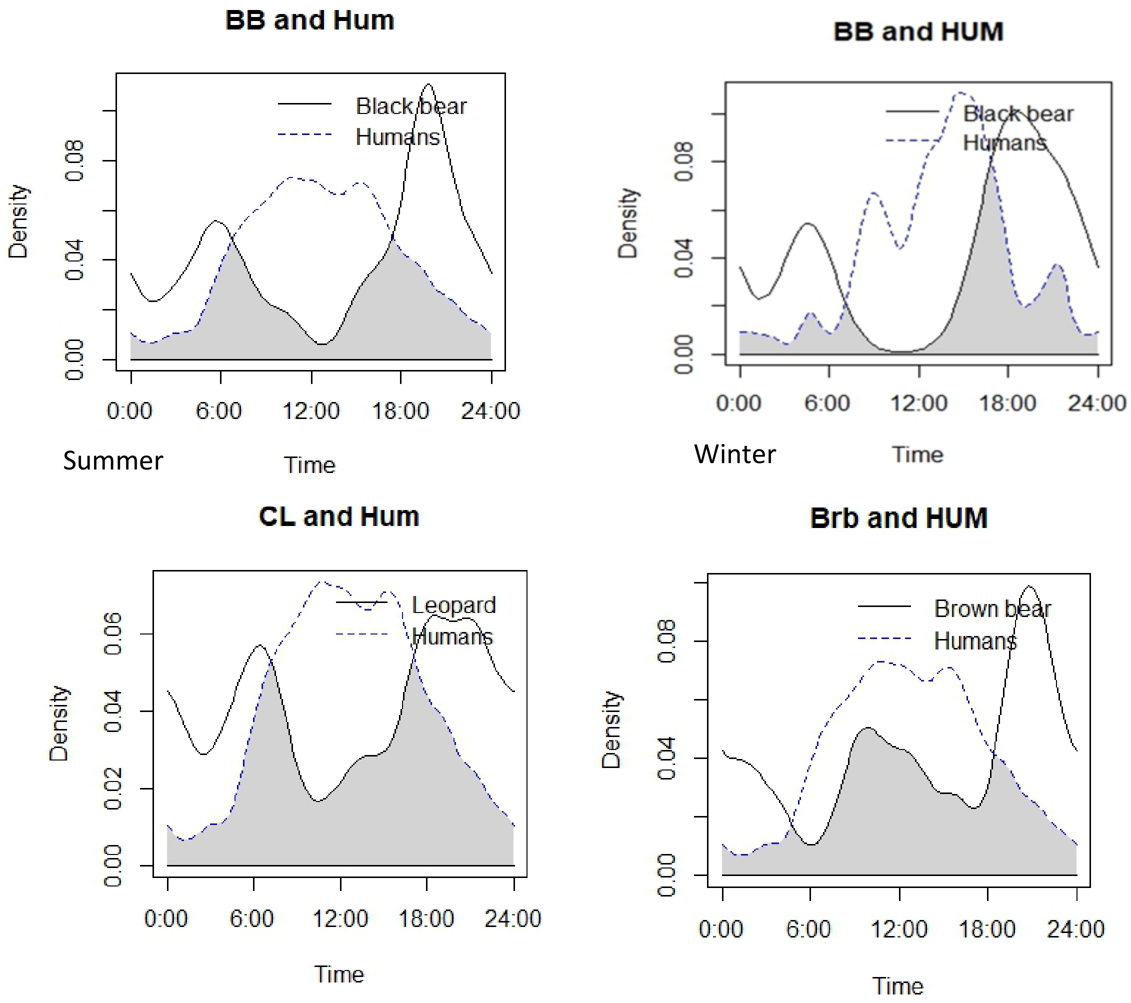

Fig.7 Overlap of activity between Human and Black bear, Brown bear and common leopard.

Analyzing the temporal activities seasonally, it was found that between Black bear and Humans it was 54% and between Leopard and humans it was also around 62-64 % in summer season**.** Similarly, the time activity overlap was found to be around 59% in case of common leopard and humans, between Black bear and humans was around 42 % in winter season (Fig. 7)**.**

3.3.2.3 Response of mammals to abiotic and biotic pressures

Himalayan tahr, Brown bear, Musk deer, and Blue sheep occur in areas with low human presence and high elevation areas (Fig.8). On the contrary, Barking deer, Leopard, Porcupine *Hystrix indica*, Macaque *Macaca mulatta* and Masked palm civet *Paguma larvata* co-occur with humans in low elevation of temperate habitats. Livestock and elevation were the most influencing variables.

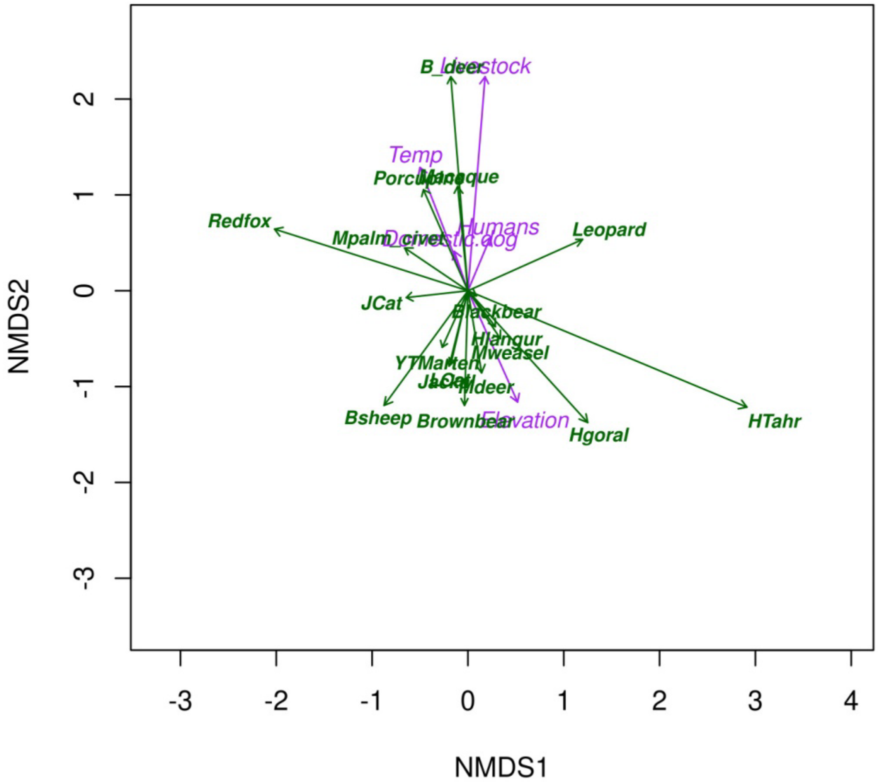

Fig. 8 -Species assemblages across the gradient of abiotic (Elevation, Temperature) and biotic factors (anthropogenic pressure; dog, human, livestock) in GHNP, Beas basin (method: Non-metric multidimensional scaling, stress value=0.08).

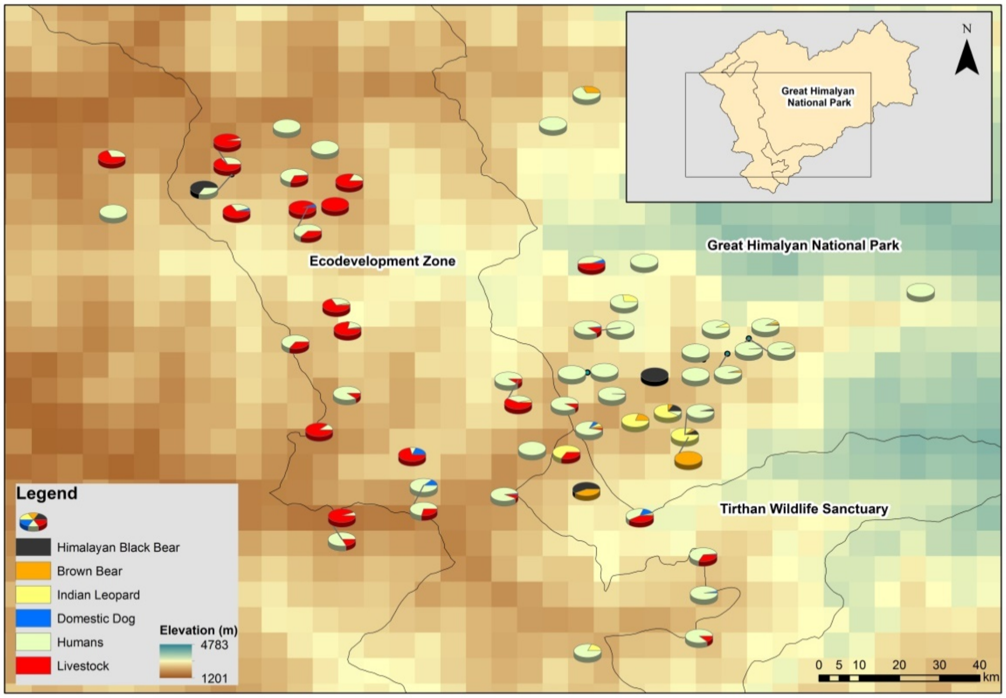

Fig. 9 – percentage abundance of large mammals and human in different areas of GHNPCA

3.3.2.4 Discussion

The study provided the recent information on the status of distribution and abundance of the large mammals present in the national park **(**Fig. 9**).** It highlighted that the major threat to the wildlife inside the park is high year around anthropogenic pressures. The major pressures observed in GHNP to be i) medicinal Herb collection ii) livestock grazing iii) unplanned tourism. Extensive human presence was observed in the months of April-July for medicinal plant collection. In the summer season, the higher reaches of the park including both alpine and subalpine regions, is used extensively by the local villagers resulting in tremendous pressure on the wildlife. Furthermore, the unchecked tourist activities contribute to the same. Such long term presence of humans inside the core area of the park, especially the higher altitudes might put the animals under constant stress and force them to move to other places or adjust their activity time period accordingly (Wong et al., 2015). Such modifications were observed in case of a high altitude dwelling large carnivore, the Himalayan Brown Bear. The species was frequently photo-captured inhabiting the temperate forests and overlapping with the niche of Asiatic Black Bear. Among the human conflict animals, the common leopard and the black bear, it was observed that they are evidently using the areas with human presence. This indicates towards the increasing human wildlife conflict which might increase many folds due to unchecked human presence. Furthermore, it was also observed that there is unchecked tourism pressure inside the national park. Not much attention is being paid to check the tourists moving inside and outside the park and hence further adding to the already existing disturbances inside the national park.

3.3.3 Teesta Basin

The Survey in Teesta Basin was done with the help of Forest Environment and Wildlife Management Department of Sikkim. The Basin encompasses the entire state of Sikkim. Sikkim with an area of 7,096 km^2 extends about 114 km from north to south and 64 km from east to west and is separated by Tibetan Plateau in the North, Chumbi valley of Tibet and the Kingdom of Bhutan in the east, Darjeeling and Kalimpong districts of West Bengal in the south and Nepal in the west. The State just covering 0.22% of the geographical area of the country has 26% of the country's total biodiversity and has been a part of the Eastern Himalaya biodiversity hot spot. The State nestled in the lap of Mount Khangchendzonga, the 3rd highest peak (8,586 m) in the world, with the altitude variation (*ca*. 300m - 8,586m) within a very short distance, elevation has played a major role in fashioning the various eco-regions. This is evident from the presence of the sub-tropical sal forest to temperate broad-leaved forest to temperate conifer forest to alpine grasslands beyond which lies the trans-Himalayan region (Rawat and Tambe 2011). According to Rodgers et. al. (2000), Sikkim is classified as a part of the Biogeographic province 2C (Central Himalayan), which in India includes the Darjeeling and Kalimpong districts of West Bengal with Temperate-Broadleaf biome, with the north of Sikkim as Biogeographic province 1C (Trans-Himalaya: Tibetan Plateau) with biota of Palaearctic affinity.

The State has 31% of its geographic area under PA network as compared to the national average of 4.8%. There is one National Park (NP), seven Wildlife Sanctuaries (WS) and one Biosphere Reserve (BR). The State is bestowed with the rich biodiversity of over 4,500 species of flowering plants, over 50 species of fishes, 690 species of butterfly, 16 species of amphibians, 78 species of reptiles, 550 species of birds, and 154 species of mammals (Arrawatia and Tambe 2011). Some of the threatened or vulnerable mammals in the State include the snow leopard (*Panthera uncia*), Asiatic black bear (*Ursus thibetanus*), Tibetan wolf (*Canis lupus chanco*), Red panda (*Ailurus fulgens*) and Musk deer (*Moschus* spp.). Scientific information on the abundance of these species was lacking due to their elusive behaviour and the complex habitats they inhabit. Therefore, to begin with some target species have been identified for population estimation exercise during 2016-17 in PAs of the State.

Apart from the baseline information generation on the distribution and abundance of snow leopard, co-predators and their prey in the Khangchendzonga Biosphere Reserve (Sathyakumar et. al. 2014) and wildlife surveys in North Sikkim (Shah 1994, Chanchani et. al. 2010) and a few other areas of the State, there has been no systematic population estimation exercise for mammals in the Sikkim. There was an urgent need to estimate population of major mammalian species in the State, particularly for the protected areas (PA). These are also the regions that encompass human habitations and experience various levels of human-wildlife negative interactions (conflict cases). Keeping in view the persisting situation, a scientific state level assessment of wildlife populations was proposed to be conducted in all the PAs of the State during 2016-17.

The target groups were large and medium size mammals. Amongst the carnivores, the survey emphasised on evidence detection and record of 16 carnivore species such as Snow leopard, Common leopard (*Panthera pardus*), Clouded leopard (*Neofelis nebulosa*), Golden cat (*Pardo felistemmincii*), Jungle cat(*Felis chaus*), Leopard cat(*Prionailurus bengalensis*), Pallas's cat (*Otocolobus manul*), Tibetan wolf (*Canis lupus chanco*), Red fox (*Vulpes vulpes*), Wild dog (*Cuon alpinus*), Jackal (*Canis aureus*), Asiatic black bear(*Ursus thibetanus*), Red panda(*Ailurus fulgens*), Himalayan yellow-throated marten (*Martes flavigula*), Large Indian civet (*Viverra zibetha*) and Himalayan masked palm civet (*Paguma larvata*). Among the ungulates, evidence detection and records of seven species such as Blue sheep (*Pseudois nayaur*), Musk deer (*Moschus spp.*), Himalayan tahr (*Hemitragus jemlahicus*), Himalayan serow (*Capricornis thar*), Himalayan goral (*Naemorhedus goral*), Barking deer (*Muntiaus muntjac*) and wild pig (*Sus scrofa*)were obtained.

During the survey, sighting of other wildlife (other than the above-mentioned species) such as small carnivores (weasels and stoat), rodents and lagomorphs (flying squirrels, marmot and pika) were recorded. Apart from mammals, visual encounters of galliformes such as Blood pheasant (*Ithaginis cruentus*), Himalayan monal (*Lophophorus impejanus*), Tibetan snowcock

(*Tetraogallus tibetanus*) and Snow partridge (*Lerwa lerwa*), Satyr tragopan (*Tragopan satyra*), Hill partridge (*Arborophila torqueola*), Kalij pheasant (*Lophuraleuco melanos*) and Red jungle fowl (*Gallus gallus*) were recorded.

3.3.3.1 Methods

To assess the distribution pattern and abundance of these species and to detect their presence in the wild, application of more sophisticated tools was required.

Camera trapping is one of the most popular quantitative tools for establishing wildlife presence and to estimate population status of different wildlife species in intricate Eastern Himalayan habitats, particularly the cryptic and solitary ones (Sathyakumar et. al. 2011, Bashir et. al. 2013a, 2013b, 2014). To carry out camera trap survey in each of the PA, the entire area of each of the PA was divided into 5x5 km grids and each of these grids (covering 25 km^2) served as a sampling unit of the survey (Fig. 10).

Total numbers of grids present in each of these PAs are given below:

Barsey Rhododendron Sanctuary– 11

FambhongLho Wildlife Sanctuary– 9

Khangchendzonga National Park and Biosphere Reserve– 127

Kitam Wildlife Sanctuary– 1

Kyongnosla Wildlife Sanctuary– 3

Maenam Wildlife Sanctuary– 4

Pangolakha Wildlife Sanctuary– 17

Shingba Rhododendron Sanctuary- 5

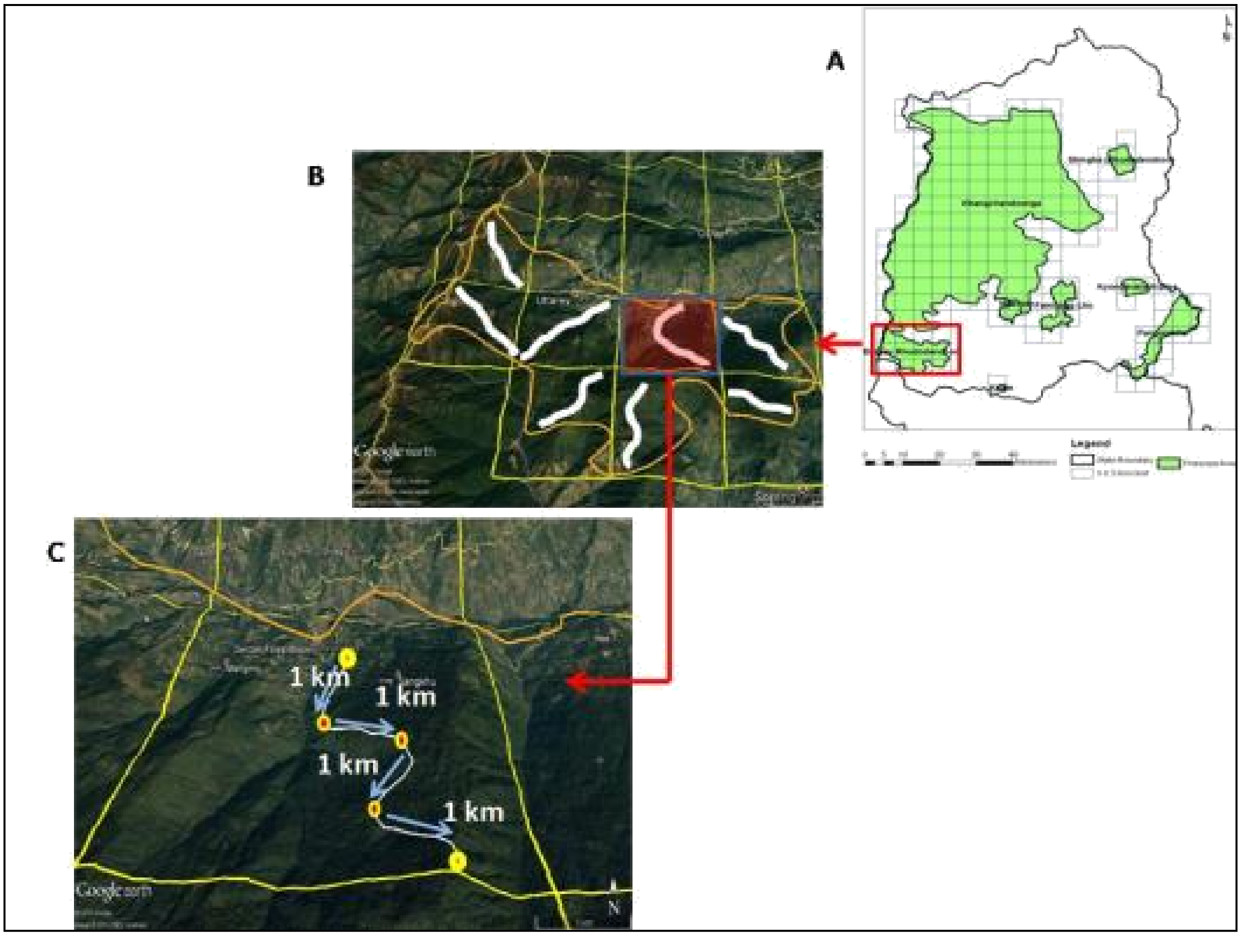

Fig. 10. Graphical representation of the survey design: A. 5x5 km grids on all the PAs; B. 5-6 km long trails in each grids of Barsey Rhododendron Sanctuary; C. One grid in Barsey Rhododendron Sanctuary with a 5 km long trail divided into five 1km segments.

Trail sampling was used for detection of carnivores and ungulates in different Protected Areas of the State. These trails were identified with slight modification from conventional transects for Himalayan terrain. Ridge walking and sign surveys along trails, ridges and streams were also carried out. In the Himalayas, trail sampling has been used to overcome the difficulties of working in an area having steep, rugged and inaccessible terrain.

Each 5x5 km grid was systematically surveyed by a team comprising of two to three forest/wildlife guards. In each grid, information on presence /absence of mammal species was recorded based on sampling of at least one trail (3-5 km long) covering all topographical and vegetation gradients within the grid. Species presence/ absence detection was based on visual encounters and secondary evidences such as calls, tracks, feeding / resting signs and other signs. In case of sightings and encounter of indirect evidences (scat, pellet group or hoof marks, pug marks), data on geographic location (using GARMIN etrex GPS), time of sighting, number of individuals, sex of the individuals were recorded. For habitat description data on major vegetation types, elevation, aspect and slope were recorded. Grid based camera trapping exercise also carried out during the survey method.

3.3.3.2 Results

The camera trapping exercise was carried out in eight PAs of Sikkim during Five months of winter from October 2018 to February 2019. In total 169 camera traps (CuddebackC1, Cuddeback attack, Moultire, and Reconyx) were deployed according to standard grid-based approach (5X5 km^2) (Fig. 11). Total effective camera traps days were 5618.

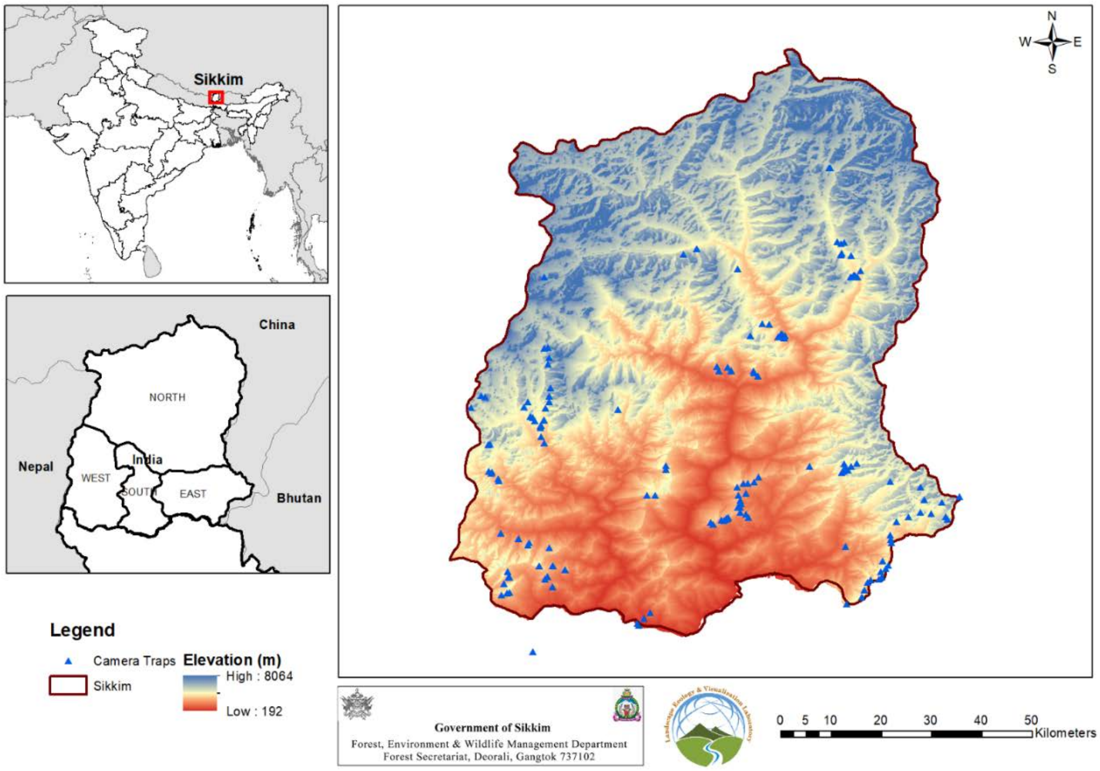

Fig. 11. Distribution of camera trap locations along the elevation gradient in different PAs of Sikkim 2018-19.

A total of 30 mammals' species (Table 1) was captured in the 2nd phase of wildlife population estimation of the PAs of Sikkim. Identification of squirrel, rodents, bat, and macaque species was not attempted as the black, and white photos limited the ability to identify species. Two new species were added to State list: Tiger and crab-eating mongoose. The species richness varied across the different elevation zones in Sikkim. The mid elevation camera traps (1500m to 2500m) captured diverse species whereas high elevation (>3000m) areas captured fewer but unique species of high-altitude areas. Camera locations at mid-elevation zones such as Fambhonglho Wildlife Sanctuary and Pangolakha Wildlife Sanctuary captured species characteristic to low elevation areas such as tiger, Asiatic black bear, leopard cat, yellow-throated marten and also species unique to high altitude areas such as snow leopard and musk deer. In high altitude camera traps locations of Khangchendzonga National Park and Kyongnosla Alpine Sanctuary, species like blue sheep and snow leopards were captured.

Table 1. Number of photo-captures and relative abundance (Mean photo-capture rate/100 days) of mammals in Protected Areas of Sikkim,2018-19. (Only no. of photo captures is mentioned for species with 5 or less captures)

S.No	Species	Mean Photo capture rate (#/100 days)	Standard Error	No of photo-captures
1	Barking deer	15.08	4.43	712
2	Wild pig	13.40	12.15	205
3	Himalayan serow	6.45	3.08	589
4	Macaque	5.13	2.84	316
5	Yellow-throated marten	1.38	0.45	82
6	Gaur	1.18	1.18	121
7	Musk deer	1.09	0.52	91
8	Blue sheep	0.81	0.81	87
9	Red fox	0.78	0.41	57
10	Himalayan brown goral	0.76	0.51	29
11	Leopard cat	0.56	0.21	24
12	Wild dog	0.39	0.33	11
13	Golden cat	0.35	0.26	14
14	Marbled cat	0.35	0.34	15
15	Red panda	0.30	0.19	28
16	Asiatic black bear	0.26	0.12	13
17	Clouded leopard	0.23	0.17	24
18	Large Indian civet	0.17	0.17	16
19	Snow leopard	0.12	0.08	11
20	Red giant squirrel	0.12	0.12	12
21	Squirrel	0.09	0.07	9
22	Jackal	0.08	0.08	8
23	Porcupine	0.08	0.06	8
24	Crestless porcupine	0.07	0.07	7

25	Tiger			5
26	Crab eating mongoose			3
27	Himalayan tahr			3
28	Small Indian civet			2
29	Weasel			1
30	Common leopard			1

Apart from these mammal species, 6 galliformes species were also photo captures among which Blood Pheasant was the most captured species (1.05 ±1.36, 161 photo- captures). Other pheasants caught are Himalayan monal *Lophophorus impejanus*, Satyr tragopan *Tragopan satyra*, Khalij *Lophuraleuco melanos*, Chukar *Alectoris chukar*, and Red jungle fowl *Gallus gallus* (Table 2). Other than these Galliformes, three more species were sighted during field session in Khangchendzonga National Park: Hill-partridge *Arborophila torqueola*, Tibetan snowcock *Tetraogallus tibetanus* and Snow partridge *Lerwa lerwa.*

Table 2. Relative abundance of galliformes in the Protected Areas of Sikkim, 2018- 2019. (Only no. of photo captures is mentioned for species with 5 and less captures).

Species	**No of photo-captures**	**Mean Photo capture rate (#/100 days) (Standard Error)**
Blood pheasant	161	1.5 (1.3)
Kalij	9	0.17 (0.1)
Red jungle fowl	1	---
Satyr tragopan	2	---
Himalayan Monal	59	0.5 (0.4)
Chukar	1	

3.3.3.3 Occupancy modelling of ungulates

Occupancy modelling was carried out only for four most captured ungulate species. These species are barking deer (n=712), wild pig (n=205), Himalayan serow (n=589), and musk deer (n=91). For each species, naïve occupancy, overall site occupancy, detection probability (Table 5), proportions of sites occupied in each PA (Table 6). For each of these four species, variations in the probability of site occupancy in the sampled grids are also prepared and are depicted here (Figure 12, 13, 14, 15).

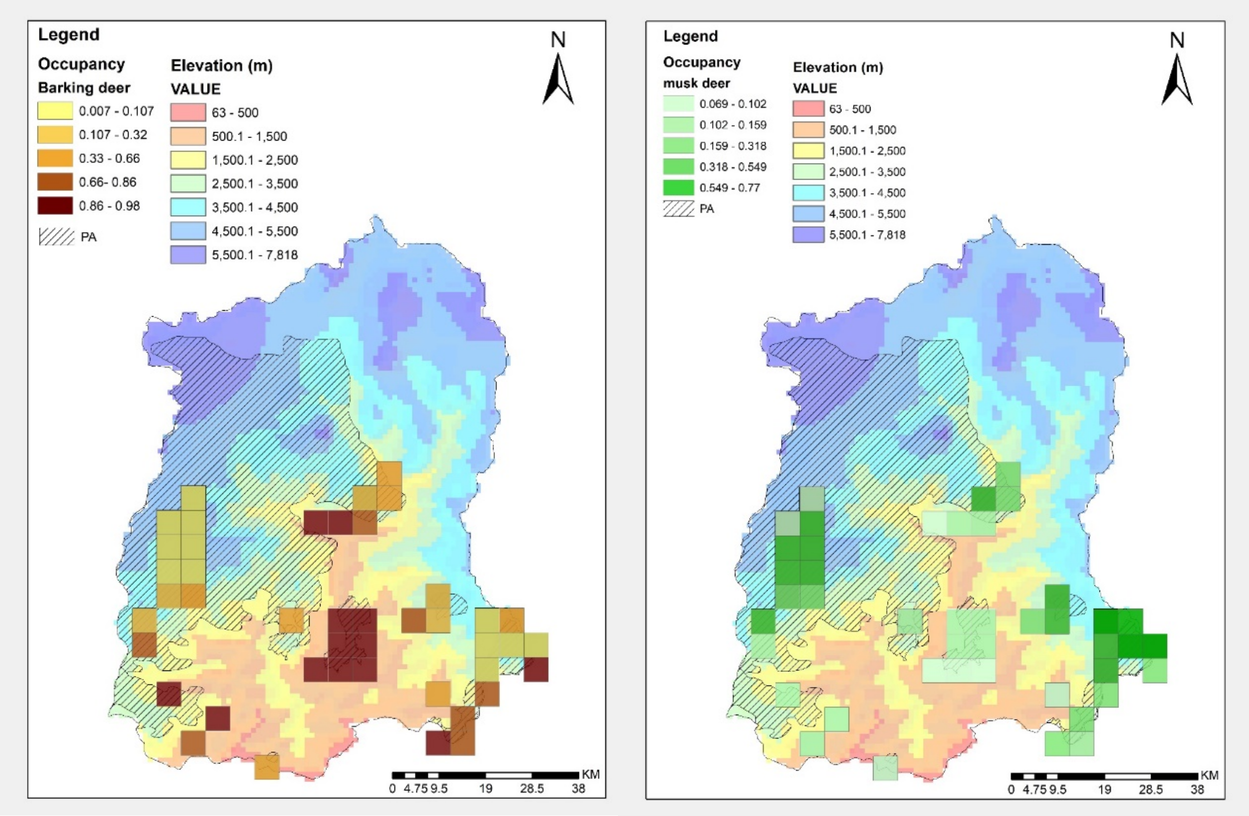

Fig. 12 and 13: Probability of site occupancy of barking deer and Musk deer in the sampled grids in all the PAs in Sikkim 2018-19

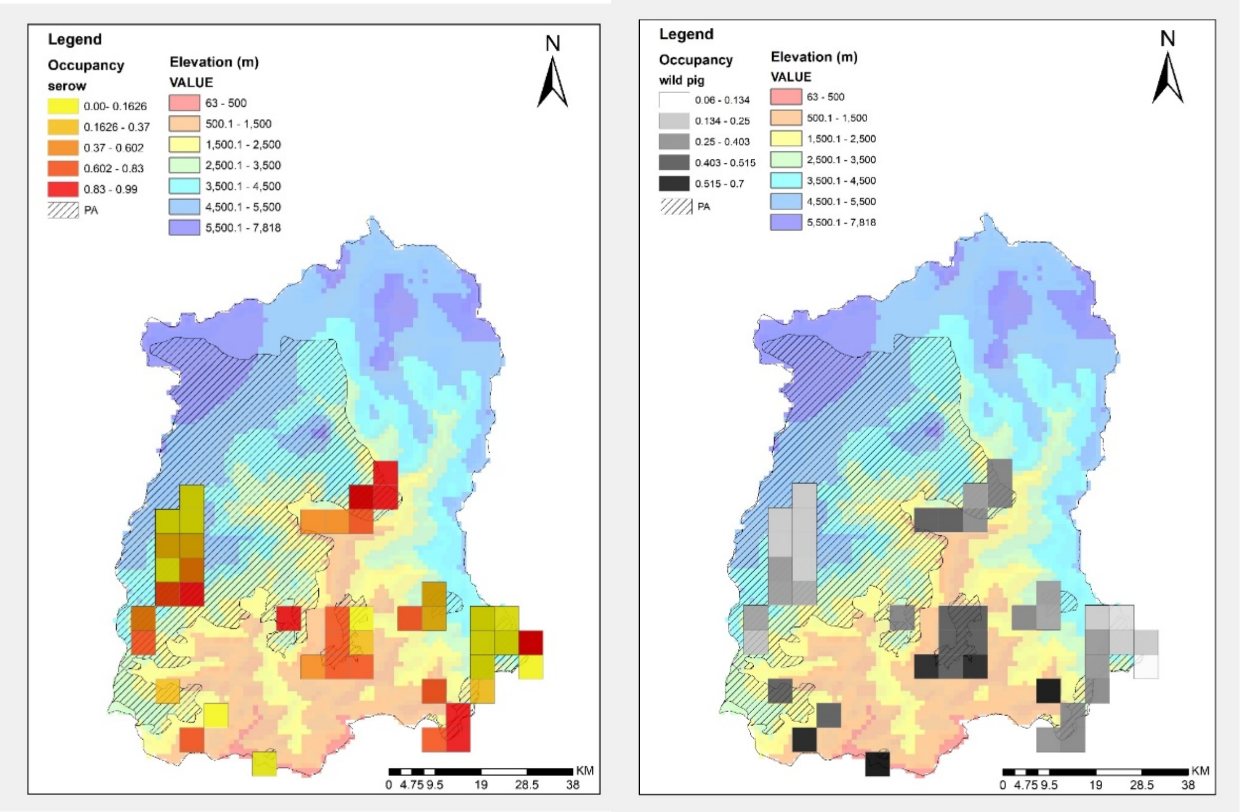

Fig. 14 and 15: Probability of site occupancy of Himalayan serow and wild Pig in the sampled grids in all the PAs in Sikkim (2018-19).

1/2/2019 4:22 PM

11/11/2018 2:13 PM

1/16/2019 3:44 PM

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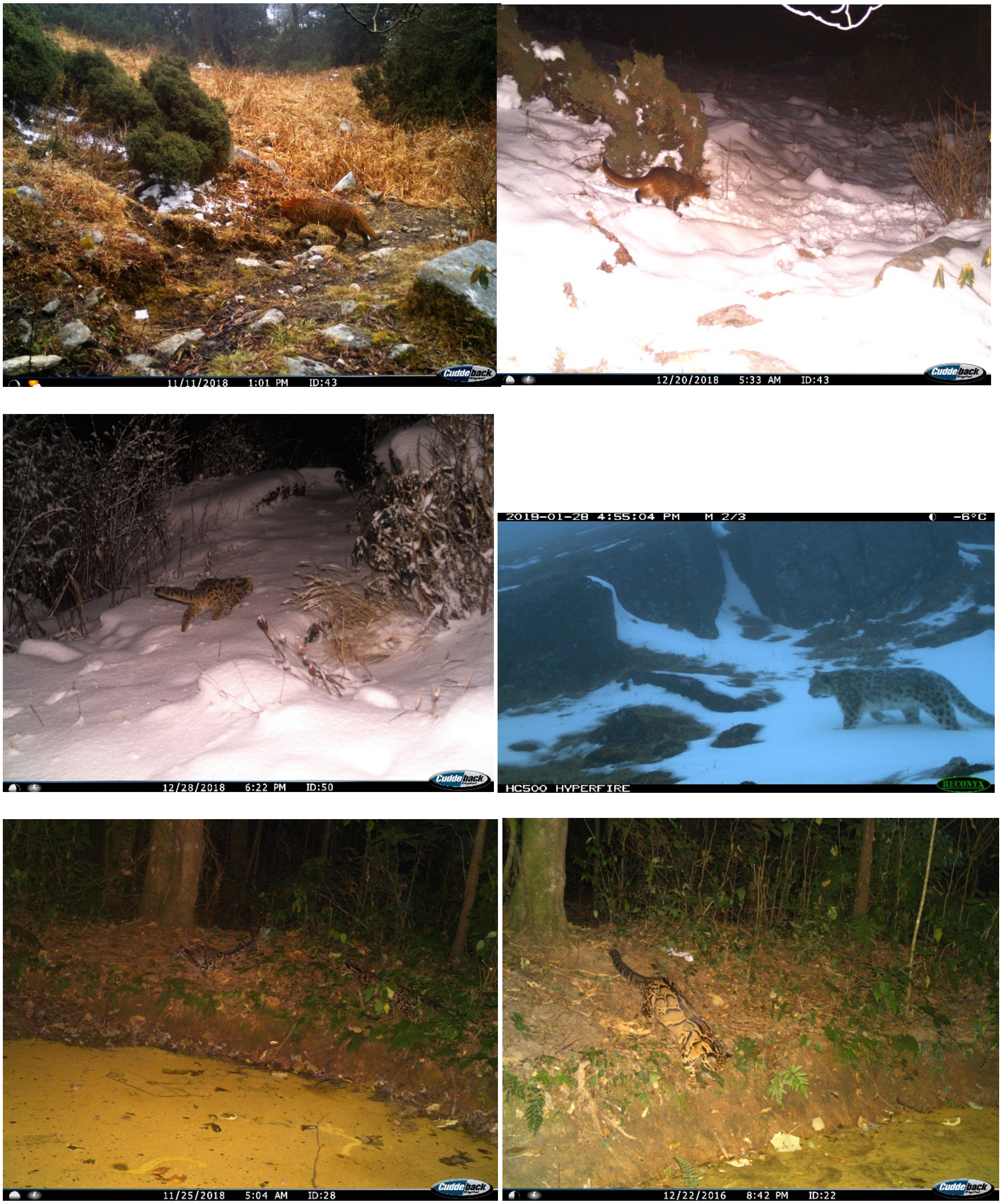
Carnivore diversity (*Felidae*) photo captured in Pangolakha Wildlife Sanctuary. (In clock-wise direction: Snow leopard, tiger. golden cat, clouded leopard)



Carnivore diversity (*Felidae*) photo captured during camera trapping in Protected areas of Sikkim.

3.3.3.4 Significant findings

As a result of intensive camera trapping presence of Tiger and Crab eating Mongoose was recorded for the first time from Sikkim (Figure 16). Tiger got photo captured from an elevation of 2,647m and 1430m in Pangolakha Wildlife Sanctuary. Tiger and Snow leopard was photo-captured from the same location in Pangolakha Wildlife Sanctuary near Gorujurey at an altitude of 1430 meter (Figure 17 and 18).

Figure 16 - First record Crab eating Mongoose *Herpestesurva* for Sikkim state from Fambonglho wild life Sanctuary.

Fig. 17 The first-ever photographic evidence of overlap between the Bengal Tiger and the Snow Leopard was recorded from Pangolakha Wildlife Sanctuary.

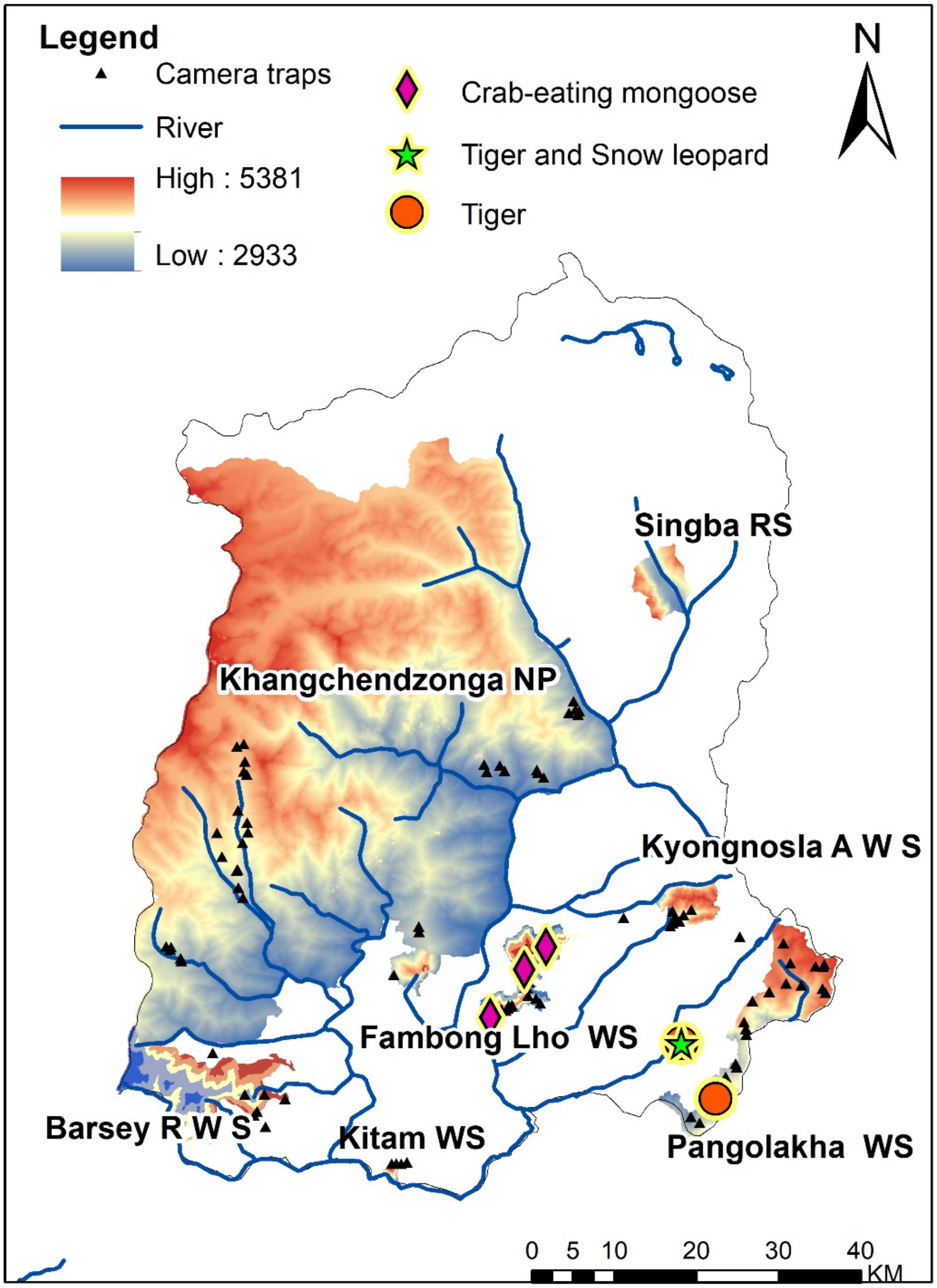


Fig. 18 Map showing capture locations of new records (tiger and crab-eating mongoose) and the location where first-ever photographic evidence of overlap between the Bengal Tiger and the Snow Leopard was recorded from Pangolakha Wildlife Sanctuary.

3.4 Environmental niche modeling and future scenarios

3.6 Impacts on mammals

3.5.1 The snow leopard

The snow leopard is a vulnerable species and is also an umbrella species for conservation of fragile alpine landscape in Asia. Climate change is a potential threat to snow leopard (McCarthy and Chapron, 2003; Forrest et al., 2012). As an apex predator of the high altitude of the Himalaya, the snow leopard is an ideal choice for monitoring the health of the high altitude ecosystems in the Himalaya. They inhabit the rugged and fragile and high altitude (3000m - 5000m) landscape of the Himalaya. Understanding the distribution is essential in the formulation of conservation policy, adaptation planning, and assessing the extent of vulnerability. Distribution studies done so far are based on abiotic factors largely ignoring biotic factors such as prey availability to look at snow leopard distribution in changing scenarios. Climate change will have a disruptive effect on interspecies interactions by changing resources availability. In Indian Himalayan region studies on diet of snow leopard have shown that blue sheep is the most common prey (Lyngdoh et al., 2014). Here we have mapped the current habitats of snow leopard in IHR by including information on prey distribution (blue sheep) with environmental, bioclimatic and topographic features.

3.5.1.1 Methods

The data on species occurrences were compiled from field surveys conducted at different times in wildlife Institute of India (2011-2018) in various localities of IHR. Presence points of snow leopards were collected using standard sampling techniques of scats collection, pugmarks and camera traps. Similarly, presence points of blue sheep were obtained by direct observation during field surveys and camera trap photos of NMSHE and other research projects. Only the landscape with known distribution of snow leopards were included in the analysis. Hence, the modelling was done for Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and western most parts of Arunachal Pradesh. A total of 237 presence points for snow leopard and 118 for blue sheep were used for modeling. The sampling area encompasses the entire snow leopard distribution range in India including the states of Jammu and Kashmir, Uttarakhand, Sikkim, and Arunachal Pradesh.

3.5.1.2 Environmental variables

We used 19 bioclimatic data obtained from WorldClim (www.worldclim.org) (Hijmans et al. 2005). Elevation layer for IHR was prepared from CartoSat DEM v3 at 30m resolution was downloaded from Bhuvan, the data dissemination portal of National Remote Sensing Centre (NRSC), Government of India. Slope, aspect, and ruggedness were calculated from the elevation layer in ArcGIS 10.1 (ESRI, Redlands, CA, USA). All raster layers were resampled to 30 arcsec (~1 km) resolution to correspond to the original resolution of the WorldClim data. Altogether, we used 19 bioclimatic, four topographic for blue sheep distribution (Table 3). We extracted each variables corresponding to the occurrence location of each species to observe multicollinearity between those variables, dropped highly correlated variables (Pearson's correlation coefficient, $r2 \geq 0.7$). First distribution map was made for blue sheep using nine variables (aspect, slope, ruggedness, annual mean temperature, annual precipitation, precipitation seasonality, max temperature of warmest month, min temperature of coldest month and mean temperature of wettest quarter). For, snow leopard eight variables (aspect, slope, ruggedness, annual mean temperature, annual precipitation, precipitation of driest month, temperature seasonality) variable along with blue sheep distribution information was used for snow leopard.

3.5.1.3 Methods

We used a maximum entropy (MaxEnt) species distribution model which is the most widely used species distribution tool (Kramer-Schadt et al. 2013) and is superior to other species distribution models in terms of performance (Elith et al. 2006; Wisz et al. 2008). We filtered localities with a minimum of 5 km distance and removed auto correlated occurrence points located within 5 km of each other using SDM toolbox, a python-based GIS toolkit. The spatial filter was limited to 5 km because of the high level of topographic heterogeneity in the Himalayan region (Anderson and Raza 2010; Aryal et al., 2016). We created a Gaussian kernel density map of the occurrence locations using sampling bias distance of 100 km for snow leopard and 50 km for blue sheep to represent an approximate habitat range for each species (Aryal et al., 2016) The density map was then rescaled to 1–10 value classes to prevent extreme down-weighting of highly sampled cells (Elith et al. 2011). We also used different regularization multiplier values (0.5, 1 (default), 1.5, 2, 3, 4, and 5). To avoid overfitting, we selected linear, quadratic, and hinge features. The best model was selected using AICc based evaluation method in ENM tool box (Table 4 & 5). To show the potential habitat suitability we rescaled maxent output from 0 to 1.

Table 3. Abiotic and biotic factors used in species distribution modeling.

Variables		**Description**
Abiotic	Temperature and Precipitation	19 Bioclimatic variables (worldclim)
Abiotic	Topographic variable	Elevation, aspect, slope and ruggedness
Biotic	Blue sheep distribution	Blue sheep potential habitat was used for predicting snow leopard habitat

3.5.2 Blue sheep

The potential habitat for blue sheep in the Indian Himalayan region was estimated to be 59,446 sq km (Fig. 19). Based on the Jackknife estimates, annual mean temperature influences potential habitats of blue sheep.

3.5.2.1 Conclusions

Changing climatic scenario can have a profound influence on species range. Global warming is predicted to continue and increase in the future. In response to the pressures of global climate change and habitat loss, there has been increasing interest in quantitative studies of factors predicting the distribution of species. These consequences are generally based on species relation to the environment variable and mapping it in past, present and future scenarios. Role of biotic interaction has largely neglected even though they play a major role in shaping species distribution. Distribution mapping of snow leopard solely build on an environment variable or abiotic factors can overestimate the area available to species. Higher consumers like Snow leopard are more affected by altered resource availability and species interaction due to climate change (Ockendon et al. 2014).

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We modeled and mapped the distribution of snow leopards under current climates by including biotic factors previously overlooked and found blue sheep presence was the most influential variable. As the availability of resource availability determines a species' distribution and abundance, it is not surprising that the predicted niche of a predator is most influenced by its prey distribution. In the case of blue sheep, the highest contribution of annual mean temperature to the model suggests that temperature is the most important variable.

The potential habitat for snow leopard in the Indian Himalayan region was estimated to be 37,034 sq km (Fig. 20). Blue sheep was found to be the most influencing factor in determining the potential habitats for snow leopard.

Table 4. Comparative performance of top 10 MaxEnt models (out of 46 models) in predicting species distribution of blue sheep. (ENMTool box).

Model	**Regularization multiplier**	**Log Likelihood**	**Parameter-s**	**AIC score**	**AICc score**	**BIC score**
Linear+ Quadratic	0.5	-483.50	10	987.00	994.10	1004.38
Linear+ Quadratic	1	-485.47	9	988.95	994.57	1004.59
Quadratic	0.5	-489.16	7	992.31	995.61	1004.48
Linear+ Quadratic	1.5	-487.48	9	992.95	998.58	1008.59
Linear+ Quadratic	2	-489.46	9	996.92	1002.55	1012.56
Quadratic	1	-491.54	7	997.08	1000.37	1009.24
Linear+Quadratic+ Hinge	2	-488.98	11	999.97	1008.77	1019.08
Quadratic	1.5	-494.00	7	1002.00	1005.29	1014.16
Linear+Quadratic+ Hinge	1.5	-486.28	15	1002.57	1021.03	1028.63

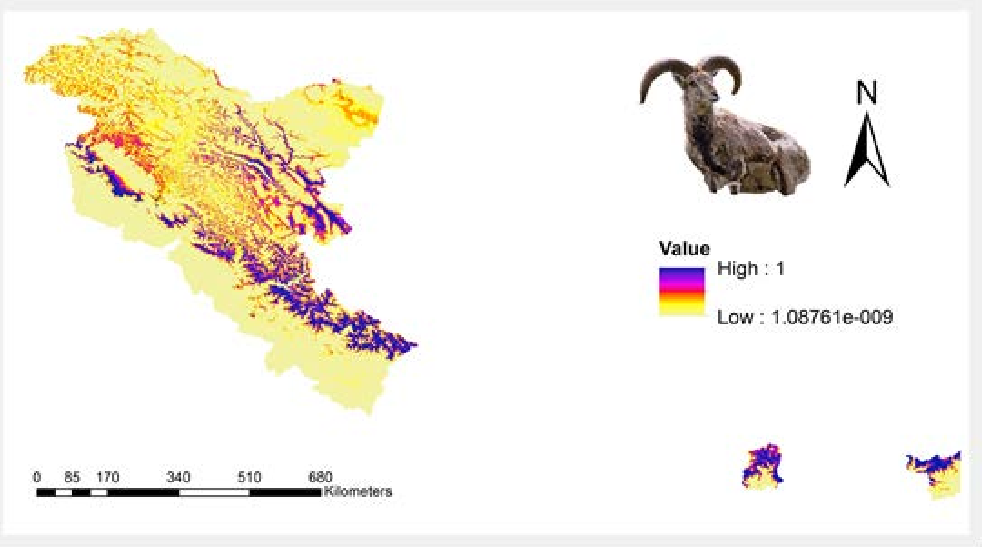

Fig. 19 - Predicted suitable habitats in Indian Himalayan region for blue ship

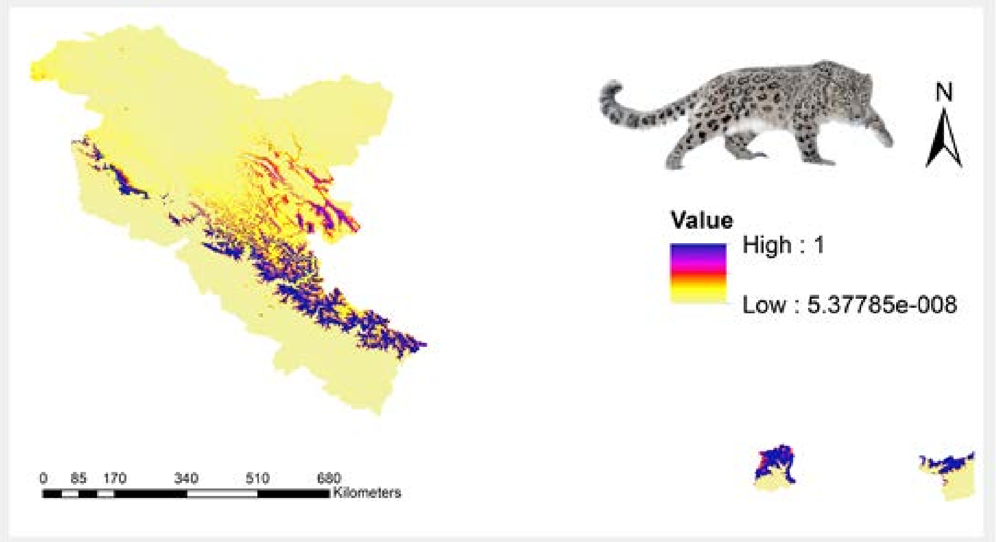

Fig. 20 Predicted suitable habitats in Indian Himalayan Region for snow leopard

Table 5. Comparative performance of top 10 MaxEnt models (out of 92 models) in predicting species distribution of snow leopard. (ENMTool box).

Model	**Regularization multiplier**	**Log Likelihood**	**Parameters**	**AIC score**	**AICc score**	**BIC score**
Linear	0.5	-413.98	8	843.96	848.92	857.06
Linear + Quadratic	0.5	-414.36	9	846.71	853.14	861.45
Quadratic (Without blue sheep)	1	-419.41	6	850.82	853.53	860.64
Quadratic (Without blue sheep)	0.5	-418.32	7	850.63	854.36	862.09
Quadratic	0.5	-417.09	8	850.17	855.14	863.27
Linear	1	-417.51	8	851.02	855.98	864.12
Quadratic (Without blue sheep)	1.5	-420.75	6	853.49	856.20	863.32

Quadratic	2	-420.90	6	853.81	856.52	863.63
Quadratic	1.5	-419.64	7	853.28	857.01	864.74
Quadratic	1	-418.33	8	852.66	857.63	865.76

3.5.3 Musk deer

The global population of Musk deer is on high risk due to the illegal poaching and habitat degradation throughout its distribution range (Homes 2004, Timmins and Duckworth 2015). In the Himalayan Region all the four species of Musk deer i.e. the Himalayan musk deer *Moschus leucogaster*, Kashmir musk deer *Moschus cupreus* Alpine musk deer *Moschus chrysogaster* and Black musk deer *Moschus fuscus*, are facing the threat of warming in their respective habitat (Solomon, 2007; Dimri and Dash, 2012; Dimri et al., 2018).

3.5.3.1 Methodology

A total of 229 occurrence records of musk deer were collated from India, Nepal and Bhutan Himalaya and were further reduced to 112 locations for modeling procedure. This was done to minimize the spatial autocorrelation by retaining one occurrence point per 1 x 1 km grid cell. This data was collected from three main sources (1) our primary data collection based on the ongoing long-term monitoring of wild flora and fauna under the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) Project from 2015-2020 (2) data from our previous projects, as a part of Wildlife Institute of India’s (www.wii.gov.in) research and wildlife management programs in IHR (Sathyakumar and Prasad 1991, Sathyakumar 1994, Sathyakumar 1999, Sathyakumar and Malik 2006, Bhattacharya et al. 2007, Sathyakumar et al. 2011) and (3) published literature. For modeling the potential distribution of musk deer, a data set containing 11 predictor variables (eight bioclimatic and three topographic) were compiled. We chose to consider the biologically meaningful variables which accord for species’ ecological requirements, underpinned by expert-based opinions, which is often useful (Porfirio et al 2014, Brandt et al. 2017). Thereby, we included extreme or limiting environmental factors that can influence the distribution of HMD in Himalaya, viz. maximum temperature of the warmest month (BIO 5), minimum temperature of the coldest month (BIO 6), mean temperature of the wettest quarter (BIO 8), mean temperature of warmest quarter (BIO 10), mean temperature of coldest quarter (BIO 11), precipitation of driest quarter (BIO 17) precipitation of warmest quarter (BIO 18) and precipitation of coldest quarter (BIO 19). The three topographic variables we used were elevation, range elevation, ruggedness and range slope. The bioclimatic variables were extracted from the Worldclim Climate Database, Version 1 (http://www.worldclim.org/), (Hijmans et al., 2005) by using the R package ‘dismo’ (Hijmans et al., 2011).

A total of five modeling algorithms were used including (i) generalized linear models (GLM), with polynomial terms using a step-wise procedure to select the most significant variables based on the Akaike information criterion (AIC), (ii) generalized additive models (GAM), with automatically selected smooth splines and a nonparametric extension of GLM, bagging and boosting approaches viz. (iii) classification tree analysis (CTA), (iv) random forests (RF) and (v) multiple adaptive regression splines (MARS). We followed the modeling workflow of BIOMOD (BIOdiversity MODelling) version 2 framework programmed in R software (Thuiller et al., 2016). To evaluate the accuracy of the models a repeated data splitting procedure (cross-validation) was applied by randomly splitting the data (occurrence data combined with each pseudo-absence dataset) into 75% of the data (training set) for calibration and evaluated on the remaining 25% (validation set). In combination, a total of 60 models were built (5 niche-based algorithm × 6 cross-validations × 2 pseudo- absences samplings). The evaluation of modeling algorithm was based on (A) Receiver operator characteristic (ROC) (=AUC, Hanley and McNeil, 1982) which is a threshold-independent model evaluation indicator and (B) True Skill Statistic (TSS, Allouche et al., 2006) which is the sum of sensitivity and specificity minus 1. To predict for the proximal future distribution for Musk deer two carbon emission scenarios (Representative Concentration Pathways, RCPs), the optimistic (2.6) and pessimistic (8.5). The bioclimatic variables for the future time period were obtained from the Intergovernmental Panel on Climate Change model, 5th Assessment Report (IPCC–AR5) (http://ccafs-climate.org). A total of four General Circulation Models (GCMs) originated from the phase 5 of the Coupled Model Intercomparison Project (CMIP5) were obtained from (i) BCC CSM1-1, Beijing Climate Center, China Meteorological Administration, China, (ii) CCSM4, National Center for Atmospheric Research (NCAR), USA, (iii) HadGEM2-AO, Met Office Hadley Centre, UK, and (iv) MIROC5, Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, Japan Agency for Marine-Earth Science and Technology, Japan. The different RCPs and GCMs were used to project a range of possible future scenarios and to better understand the uncertainties (Thuiller et al., 2019). The choice of selecting the GCMs was based on the lowest values of relative error in the models (≤0.2) (Sillmann et al., 2013). The topographic variables were considered temporally consistent for the future modeling process.

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3.5.3.2 Potential distribution and range shifts

Binary consensus habitat suitability prediction maps were created for the current and future time period in ascii file format. The range shifts were calculated by the number of pixels occupied by the binary (presence and absence) current and future habitat suitability predictions. The range shift at different elevational ranges was calculated based on the elevation data derived from Shuttle Radar Topography Mission (http://srtm.usgs.gov/) at approximately one-kilometer resolution. The data analysis and maps were created using R version 3.5.2 (R Core Team, 2016) and ArcGIS 10.2 (ArcGIS, 2013).

3.5.3.3 Protection Coverage

We assessed the protection coverage currently available for the musk deer by assessing the percentage of its potential distribution proffered legal protection under the Protected Areas (PAs) boundaries. The individual protection coverage (IPC %) of each PA was calculated by estimating the geographical area under the predicted suitable habitat (>0.9) and dividing it by its total geographical area under the PA boundary. This was done by superimposing the boundary shapefiles obtained from the World Database on Protected Areas (WDPA: IUCN & UNEP-WCMC, 2013). We then calculated the overall protection coverage (OPC%) provided by all the PAs by quantifying the proportion of suitable grids within the protected area boundary as compared to its range size currently occupied in the study region (Zhang et al. 2015). The consensual binary (presence/absence) map based on the ROC threshold was used for calculations.

3.5.3.4 Importance of environmental variables

The variable importance scores across five SDMs ranged between 0-0.803. However, the mean of variable importance by different SDMs ranged from 0.035-0.515 of which the variable related to temperature extremities performed better. BIO11 (Mean Temperature of Coldest Quarter) appears to be highly decisive in modeling the musk deer distribution across Himalaya, followed by BIO10 (mean temperature of the warmest quarter) and BIO 6 (min temperature of the coldest month). The moderately important variables were BIO5 (max temperature of the warmest month) and BIO19 (precipitation of coldest quarter). Among the topographic variables, only the elevation came out as an influential predictor.

The response plot of models with highest individual performances (RF, MARS and GLM) based on AUC > 0.90 were considered important to infer more explicit linkages between HMD and environmental suitability. For the most influential predictor BIO11 (mean temperature of the coldest quarter), the response plot of RF showed a clear optimum which was further partially reflected in the trends of MARS and GLM. The higher occurrence probability of musk deer in the coldest quarter was shown within a mean temperature range between -6 to 2°C. Whereas, in the warmest quarter (BIO10), higher occurrence probability was recorded at a mean temperature between 15 to 16°C. In the coldest month, (BIO6) higher occurrence probability was recorded at a minimum temperature of -10 °C. On the other hand in the warmest month (BIO5), the musk deer were predicted to be highly distributed at around 20°C. The precipitation of the coldest quarter (BIO19) showed higher occurrence probability at around 200mm in all the best performing SDMs. In the case of elevation, the response plot of RF, MARS and GLM showed similar trends, and the presence probability was recorded always higher at 3000m.

3.5.3.5 Potential habitat suitability

The consensus suitability models predicted that the suitable conditions for the HMD across the western, central and eastern Himalaya comprised a total area of 108898 km^2. However, the continuous area of habitat suitability was more evident in western parts of the Himalaya (Fig. 21). The areas of high suitability (>0.9) include high elevation ranges of the west and northwestern Himalaya in Uttarakhand, Himachal and Kashmir regions of India. In Nepal, the habitat suitability was centered towards northern areas of west, central and east Nepal. A continuous extensive suitable habitat patch was again concentrated in the northeastern limits of Sikkim (India), Bhutan and Arunachal Pradesh (India).

3.5.3.6 Future distribution and range shift

We predict the HMD to experience habitat loss at its lagging edges throughout its current distributional range, the gain however, would largely be centered in the western and eastern parts of Himalaya for the year 2050 under two RCPs (Fig 22). Our consensus modeling framework suggests that the musk deer would lose 13.35–23.89% of its current habitat considering all the RCPs and GCMs used in this study.

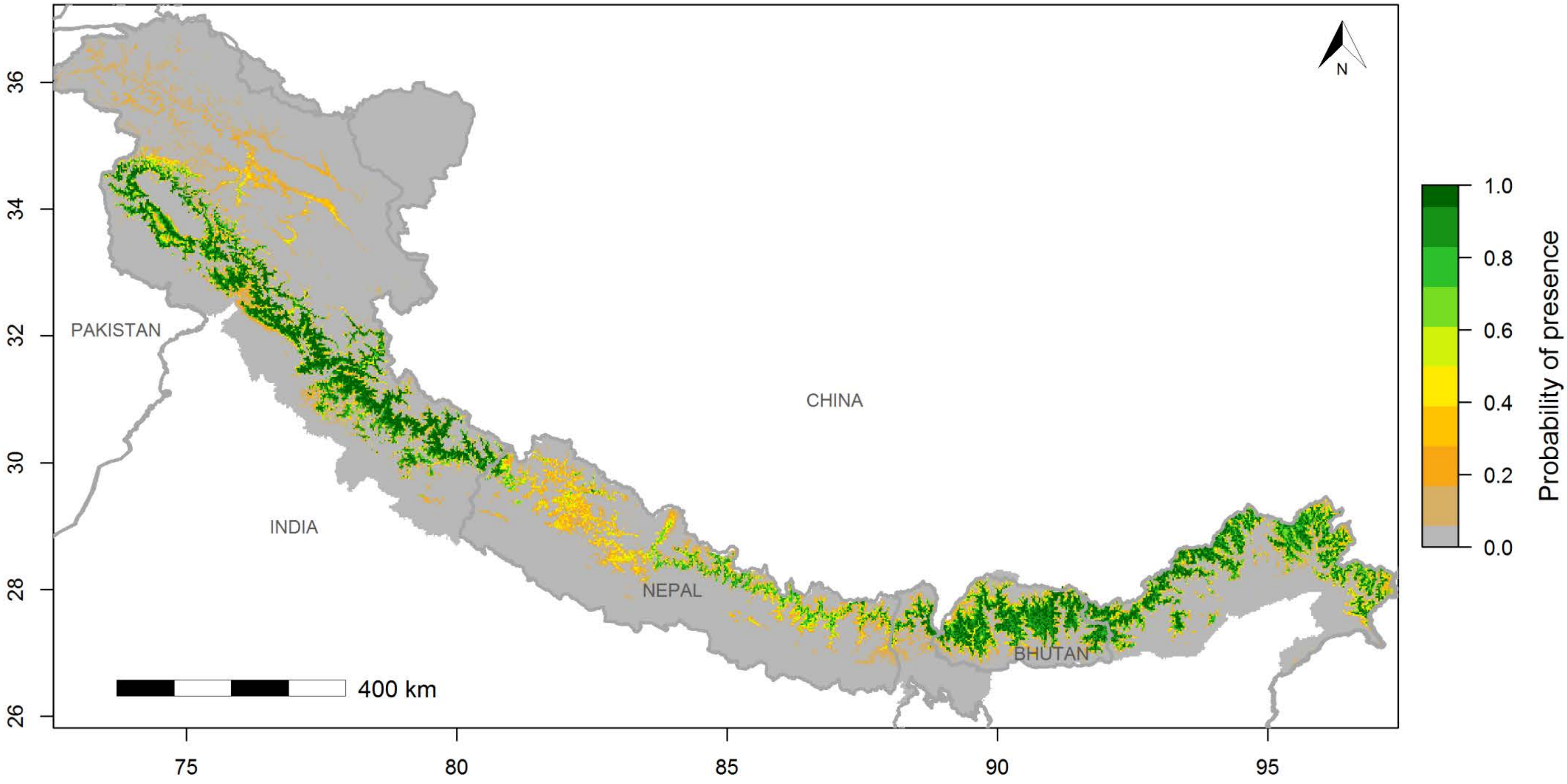

Fig. 21 Consensual current habitat suitability prediction of musk deer based on committee averaging of different modeling algorithms used in this study. Suitability values equal to 1 correspond to ideal environmental conditions and values equal to 0 correspond to suboptimum environmental conditions.

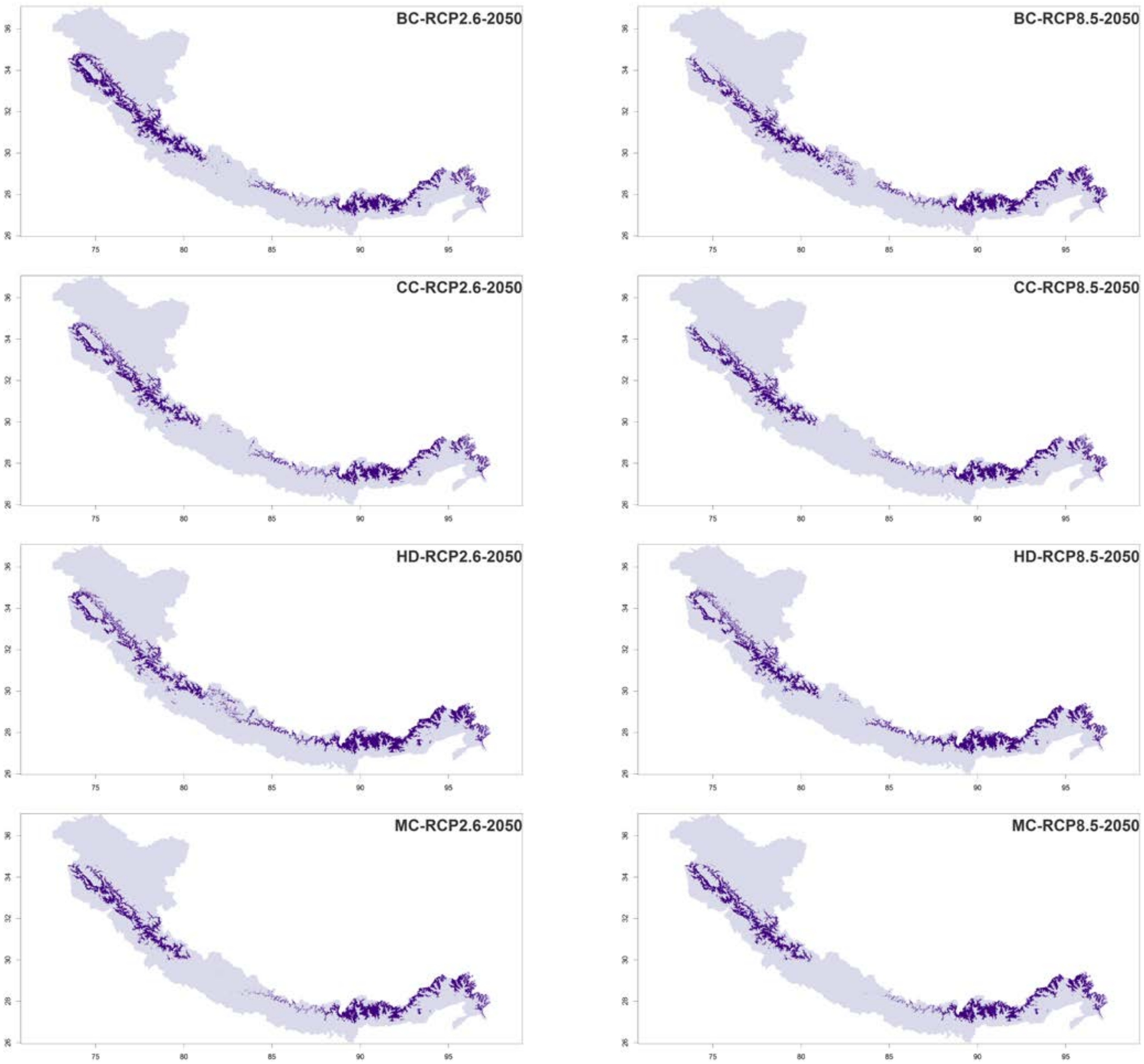

Fig. 22. Binary potential distribution of HMD under future climate based on the ensemble of five SDMs (CTA, GAM, GLM, MARS and RF). The left panel of the figure represent RCP 2.6 and the right panel represent RCP 8.5 for the year 2050. The GCMs included were, BC: BCC CSM1-1, CC: CCSM4, HD: HadGEM2-AO and MC: MIROC5

The average value of four different GCMs i.e. BCC CSM1-1, CCSM4, HadGEM2-AO, and MIROC5 suggested an overall loss of 18.07% of the habitat under RCP 2.6 and 21.03% of the habitat under RCP 8.5. Except for RCP 2.6 of HadGEM2-AO, the amount of predicted loss was always higher than the amount of gained habitat in both the RCP scenarios (Fig. 22). The net species range change was estimated to be -7.70% (RCP 2.6) as compared to -10.06% for RCP 8.5. If full dispersal scenario is considered the average distributional range of musk deer would be 100519.75 km^2 under RCP 2.6 and 97941.75 km^2 under RCP 8.5.

In general, we predict the musk deer to move towards the higher elevations though the loss would be more at elevations below 3000m considering the intensity of emission scenarios in 2050 (Fig. 23,24). Under the most extreme scenario (RCP 8.5) a considerable loss of 11% of its suitable habitat is predicted at elevations <3000m. The species was predicted to have stable habitat between 3000-4000m under both RCP 2.6 and 8.5 with the slightest change, however, depending upon the intensity of emission scenario the species may find suitable habitat at higher elevations (4000-4500m) in the year 2050.

3.5.3.7 PAs as optimal future refugia

Though we predict that the species would move towards the higher elevation for a certain extent as a consequence of climate change, however the future refugia would not be available throughout its current potential range in the Himalaya. We assume that our predicted future refugia within the PA network would serve as the greatest opportunity for the species to migrate and survive. Considering only the extreme emission scenario (RCP 8.5) we identified two major geographical zones with an extensive PA network which could serve as optimal potential refugia for the musk deer in the year 2050. This include (a) 15 PA networks in Western Himalaya (Fig. 23) : (i) Gangotri NP, (i) Kedarnath WLS, (ii) Nanda Devi NP, (iii) Valley of Flowers NP, (iv) Govind Pashu Vihar WLS and (v) NP, (vi) Rakchham-Chitkul WLS, (vii) Pin Valley NP, (viii) Great Himalayan NP, (ix) Rupi Bhaba WLS, (x) Sainj WLS, (xi) Tirthn WLS, (xii) Asrang WLS, (xiii) Daranghati WLS and (xiv) Kanavar WLS and (b) Seven PA networks in East Nepal (Fig. 24): Sikkim and Bhutan: (i) Bumdeling WLS, (ii) Wangchuck Centennial Park, (iii) Jigme Dorji NP, (iv) Biological Corridor (v) Torsa Strict Nature Reserve, (vi) Jigme Signye Wangchuck NP, (vii) Kangchendzonga NP and Kanchenjunga CA.

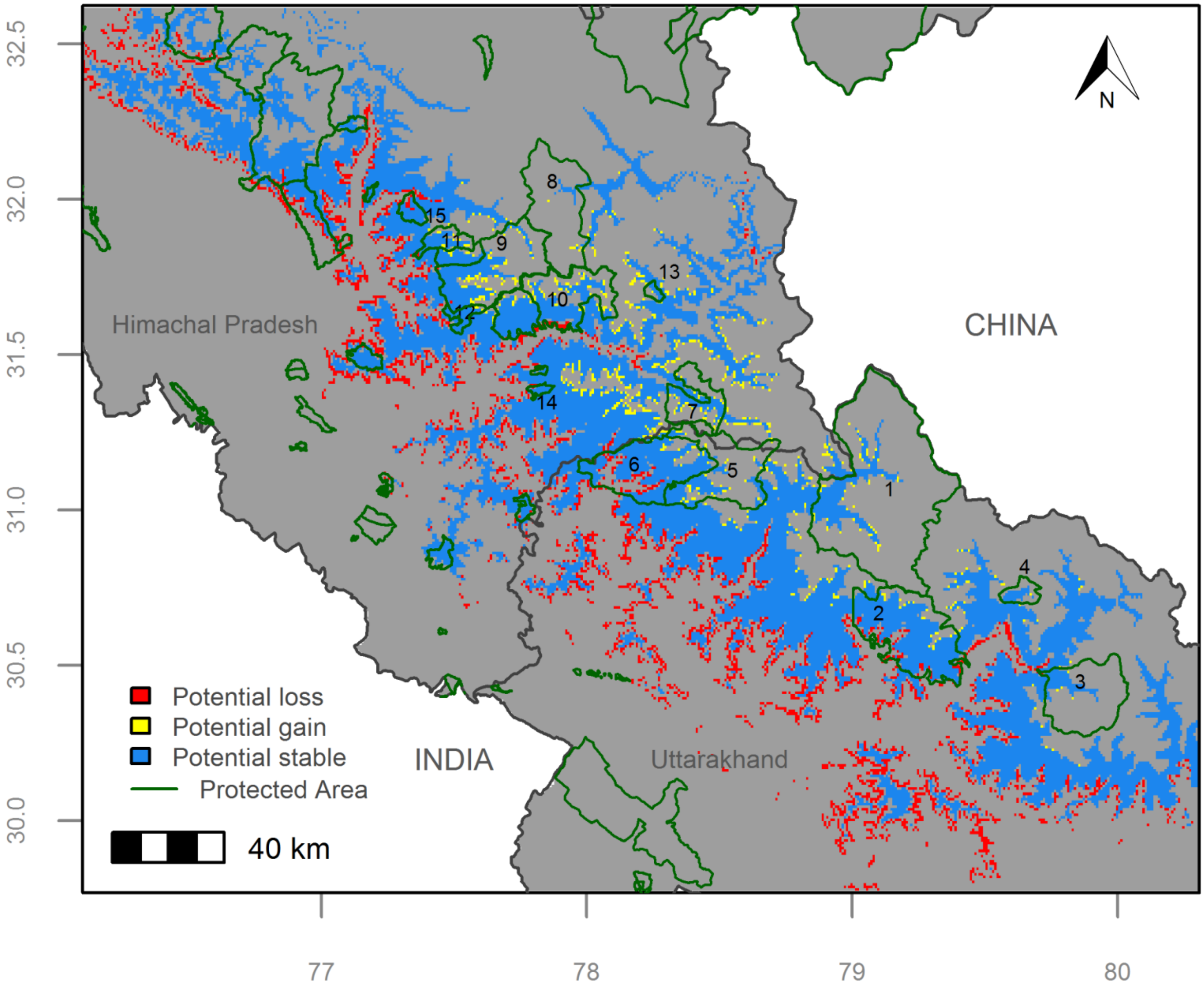

Fig. 23. PA networks identified as optimal future refugia for HMD in the year 2050 under RCP 8.5 in the western Himalaya. These include 15 PA networks: (1) Gangotri NP, (2) Kedarnath WLS, (3) Nanda Devi NP, (4) Valley of Flowers NP, (5) Govind Pashu Vihar WLS and (6) NP, (7) Rakchham-Chitkul WLS, (8) Pin Valley NP, (9) Great Himalayan NP, (10) Rupi Bhaba WLS, (11) Sainj WLS, (12) Tirthn WLS, (13) Asrang WLS, (14) Daranghati WLS and (15) Kanavar WLS

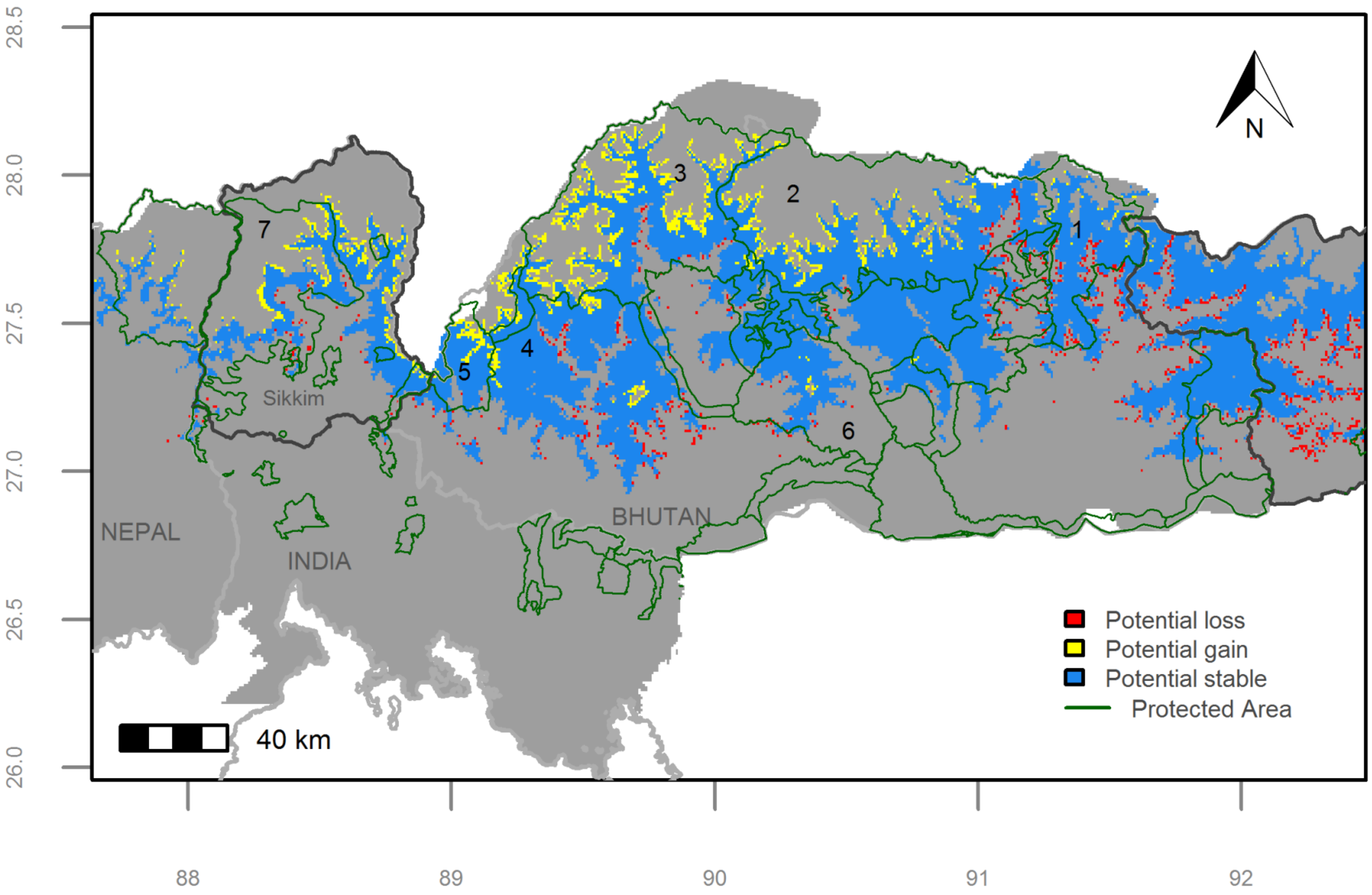

Fig. 24. PA networks identified as optimal future refugia for HMD in the year 2050 under RCP 8.5 in the eastern Himalaya. These include eight PA networks: (1) Bumdeling WLS, (2) Wangchuck Centennial Park, (3) Jigme Dorji NP, (4) Biological Corridor (5) Torsa Strict Nature Reserve, (6) Jigme Signye Wangchuck NP, (7) Kangchendzonga NP and Kanchenjunga CA.

3.5.3.8 Conclusion

Our ensemble model suggested a wide current geographic distribution of HMD, mostly in the western followed by eastern and central parts of Himalaya, predicted to be progressively reduced specifically from the lower altitudes in its entire range, considering the intensity of emission scenarios in the future. Our current suitability map however, does not concur with the expert-based range map of IUCN, which restricts the westernmost limit of this species up to Bhutan Himalaya (Timmins & Duckworth, 2015). We rather predict the current range of this species to be extending from north-western to north-eastern Himalaya, including Arunachal Pradesh, its presence beyond Bhutan further underpinned by our own records strictly based on camera-trap based data. Environmental predictors related to temperature and precipitation variability followed by elevation were influential for the current distribution of HMD, this is not surprising when the species under investigation is highly reliant on cold temperature and mountainous vegetation which is largely governed by precipitation patterns and terrain. Our results thus further highlight the role of climate variability for the precise assessment of species niche characteristics (Zimmermann et al. 2009, Franklin et al. 2013, Morán-Ordóñez et al. 2018). Concurrently, both temperature and precipitation have been considered good predictors in previous studies for modeling the distribution of HMD as well as its cogenrs in the Himalayan climate (Khadka and James, 2017, Khadka et al. 2017, Lamsal et al. 2018, Jiang et al 2020, Singh et al. 2020).

3.6 Impacts on Herpetofauna

3.6.1 Introduction

The taxa most vulnerable to any climatically imposed reductions in suitable habitat are likely to be those that have: (1) highly specialized habitat requirements, (2) ‘slow’ life histories (delayed maturation, low reproductive rate), thereby reducing their ability to recover from population reductions, (3) low dispersal rates, making it difficult to colonize suitable areas outside the existing range, and (4) are already under pressure from other anthropogenic processes (Hughes, 2003; Meynecke, 2004; Arau´ jo et al., 2006). One taxon that meets all of these criteria is the Himalayan Pit Viper (*Gloydius himalayanus*). Himalayan Pit Viper is distributed from Northern Pakistan, India (Jammu and Kashmir, Himachal Pradesh and Uttarakhand) and Nepal. Records from Sikkim and Khasi Hill needs verification. Globally distributed in Northern India, Bhutan, Nepal and Pakistan; China and possibly Afghanistan. This species is commonly found between 1500 to 3000m elevation range. This species was captured from 4876m from Dharmsala Glacier in Himachal Pradesh. This is the highest elevation record for any snake species. Himalayan Pit Viper is high altitude specialist species. It prefers dry coniferous forest. It also inhabits alpine grassland with dispersed bush vegetation and near the riparian vegetation. Sometimes in walls and boundaries of the cultivated area. This viper hideout under boulders, fallen wooden logs and leaves and in crevices in the walls of the agricultural fields. The snake is found basking on open areas with nearby vegetation and rocks, and in sunny places on grassy mountainsides. It feeds primarily on mice and skinks and other small sized pray (Vasudevan & Sondhi 2010). In disposition, it is quiet and timid, not attempting to bite when handled. The snake is viviparous and give birth to 5 to 7 young at a time (Gloyd & Conant 1990).

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3.6.2 Vulnerability to climate change

Climate change can influence range shift and change in activity pattern in snakes (Rugiero et al.2013). If the warmer habitat becomes drier then it will lead to decrease the snake activity and behavioral changes related to dehydration and impacts on prey population (Huang et al. 2013). Upslope movement of the lowland species could affect the species response due to climate change. Climate related change in human land use pattern may lead to conflict situation and increase persecution of this species. Negatively impacted from the phenomena called climate cooling and may have deleterious effect on population of this species. At the same time, they are less vagile species with limited dispersal ability which makes them vulnerable to impact of climate change. In this study, we modelled the bioclimatic envelope of this endangered snake species under current climatic conditions to identify climatic factors that may limit the species' current distribution. We also predicted the climatic envelope for the species under the 2050 and 2070, low and high climate change scenarios.

3.6.3 Methods

3.6.3.1 Study Area

The study area consists of ecoregions of Himalayan belt (Olson et al., 2001) (Fig 22). The Himalayan System, extending over 2400 km nearly east-west and consisting of complex topographical features, naturally presents a wide variety of climate and soils and consequently supports a remarkable assemblage of vegetation types (Mani 2012). At the northwestern limit, the mountain reaches a latitude as far north as 35 0 50' N, which is an area of very scanty rainfall compared to the south-eastern region lying at 27 0 N, where the outer ranges receive the full force of the monsoon rains (Mani 2012).

3.6.3.2 Species occurrence data

We conducted visual encounter survey (time constrained) at 91 plots along the elevation gradient from 500m to 4000m using Handheld GPS Garmin etrex 30 (Heyer et al, 2014) in Uttarakhand for species diversity data. We also collected occurrence data from literature survey. 66 location of Himalayan Pit Viper is recorded from field survey and literature records out of which 3 location were removed after filtering clustered location using ENM tool. Remaining 63 presence location of Himalyan Pit Viper were used to predict distribution change (Fig. 25).

3.6.3.3 Climatic Variables

The current and future climatic layers were downloaded from the WorldClim website (WorldClim, 2005). WorldClim is a set of global climate layers with spatial resolution of 30 arc-seconds, generated using thin-plate smoothing spline interpolation of weather station data for the period 1950 to 2000 (Hijmans et al., 2005). To determine the potential future distribution of the species under different climate scenarios, we used datasets of future climate using the RCPs namely, RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 were used, both available for near future (2050s) and distant future (2070s) climate projections. For current scenario we have used WorldClim 1.4 scenario and for future scenario (near future 2050 and distant future 2070) we have used ensembled layer of three different models (HadGEM2-ES,CCSM4 and MIROC-ESM-CHEM).

3.6.3.4 Species Distribution modeling (SDM)

We used maximum entropy (MaxEnt 3.4.1) species distribution modeling (SDM; Phillips and Dudík, 2008) to map the current and predicted future distribution of Himalayan Pit Viper in the study area. MaxEnt is a widely used tool for modeling species distributions using presence data of species and various environmental parameters (Kramer-Schadt et al., 2013). 63 presence records used for analysis and 20 % presence point were used as a test data. 10000 points used to determine the Maxent distribution (background points). MaxEnt uses Area under the receiver-operator curve (AUC) as a threshold, to predictive accuracy of the model (Merow et al., 2013). The generated output from MaxEnt estimates the habitat suitability (which is representative of a climatic niche) for species that generally varies from 0 (lowest) to 1 (highest) (Kumar et al., 2014). Maximum test sensitivity plus specificity logistic threshold is used to delineate the suitable habitat (Norris. 2014).

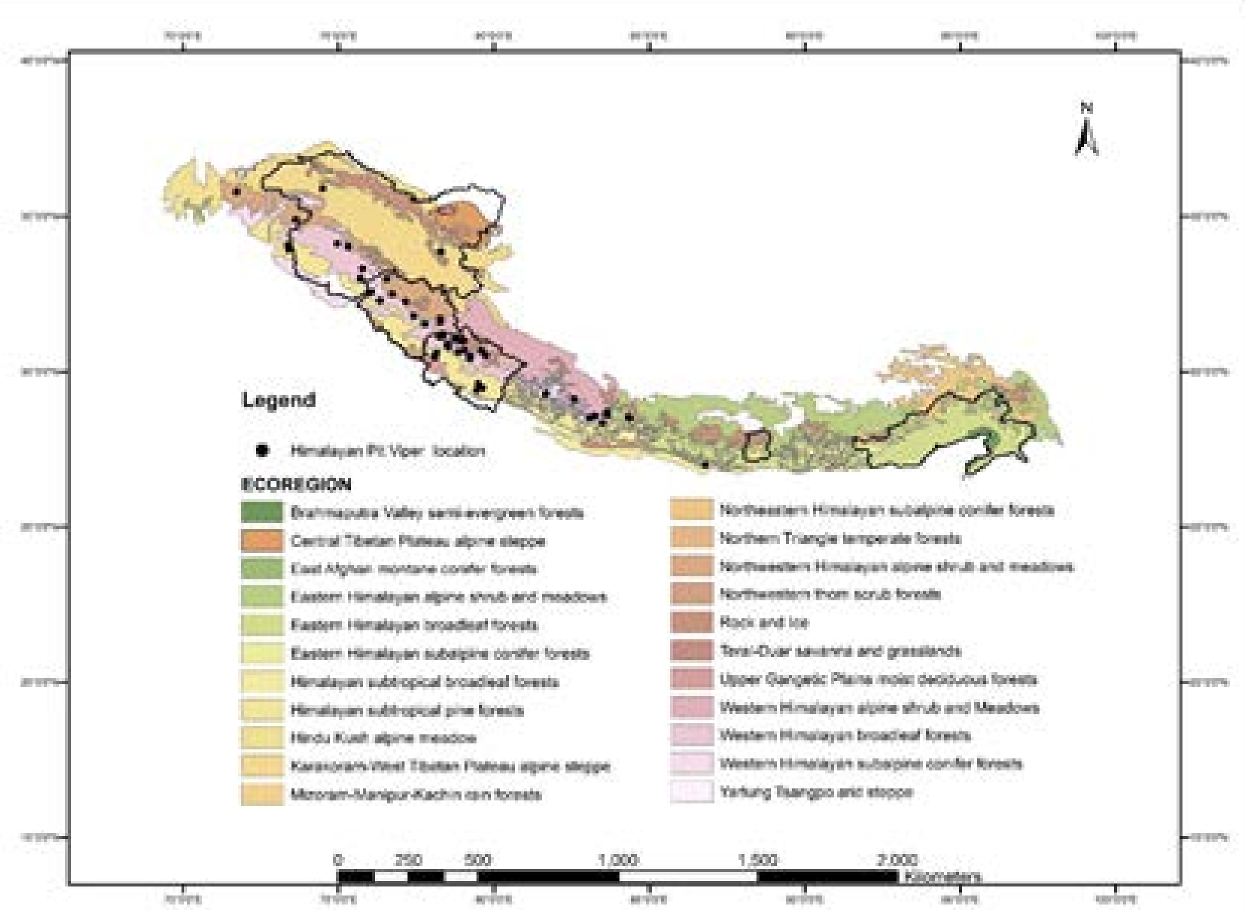

Fig. 25. Ecoregion of Himalayan region and presence location of Himalayan Pit Viper.

3.6.4 Results

In the current scenario the distribution of Himalayan pit viper occupies 45059694.11km2 in the Himalayan region (Fig. 26). This species is largely distributed in Western Himalaya. This region of Himalaya is drier than eastern parts of Himalaya which receives good amount of rainfall. As suggested by MaxEnt output the most important variable with maximum contribution to species distribution is bio17 (Driest quarter of the month) 57.8%, then followed by other important variables such as bio10(Mean temperature of warmest quarter) 14.9%, bio8(Mean Temperature of wettest quarter) 11.7%, bio7 (Temperature annual range) 8.3%, bio3 (Isothermality) 4.1% (Table 7, Fig. 27). Himalayan pit viper is closely associated with Agkistrodon genus which is evolved in colder and drier climate. Therefore, driest quarter of warmest month is contributing maximum to the distribution of Himalayan pit viper. Also, there is no other viper species in western Himalaya than Himalayan pit viper and the higher elevation niche remains empty for Himalayan pit viper to occupy.

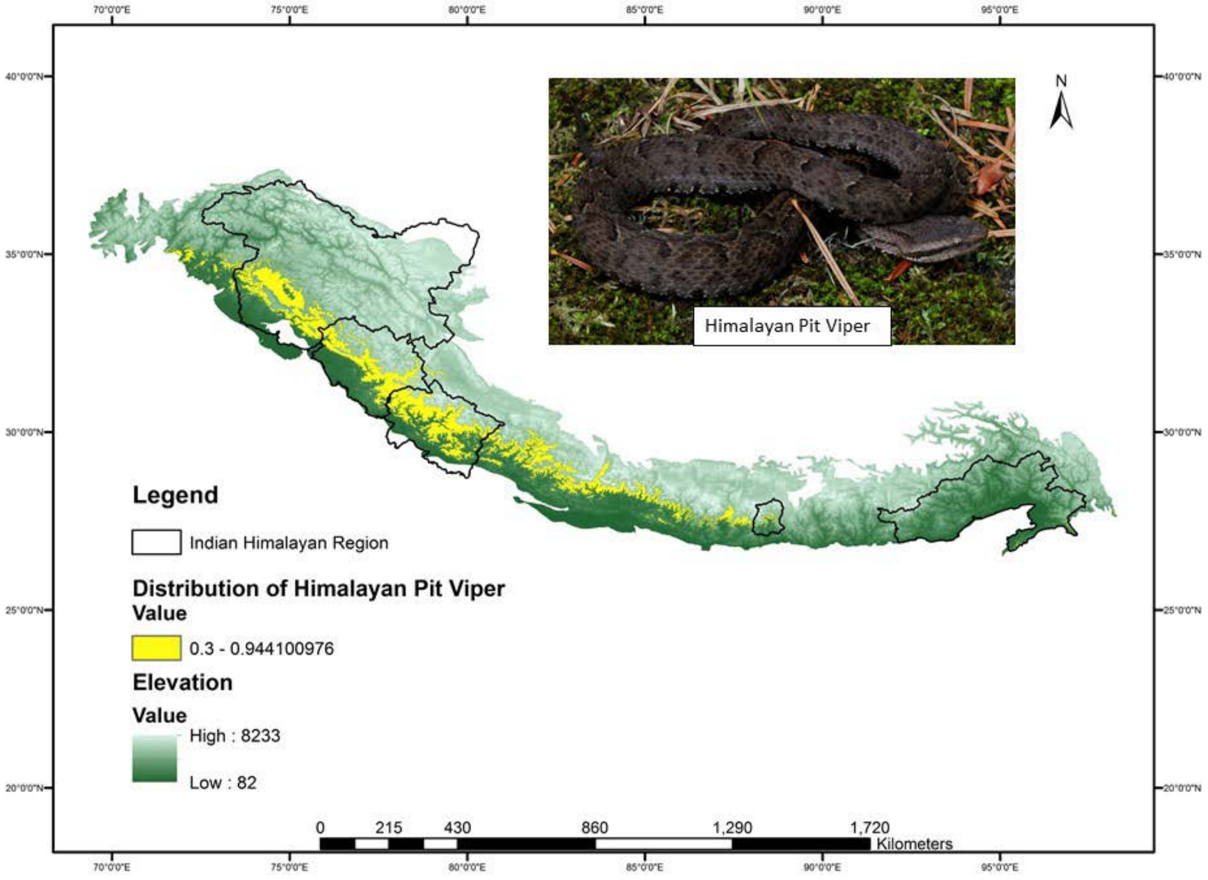

Fig. 26. Predicted distribution of range of Himalayan Pit Viper for current scenario.

However, the Mountain Pit Viper (*Ovophis monticola*) is occupying similar niche in higher elevation of eastern region of Himalaya. The competition from other pit viper species could also be the limiting factor in distribution of Himalayan pit viper in Eastern Himalaya. In most of the distant and near future scenario there is an increase in the species range. This increase in range is mostly observed in lower elevation zone (Fig. 28, Fig. 29).

The distribution of viper species is patchy as they have smaller home range. Like many of the reptiles that only inhabit a small portion of area with potentially suitable climates (Araujo and Pearson 2005; Araujo et al., 2006). However, this does not necessarily mean that the species will not be able to track future changes in climate. In case of other widely distributed snake species

H. bungaroides phylogenetic analysis has suggested two genetically divergent clades that corresponds to two distinct geographic region and may respond in a different way to climate change (Summer et al., 2009). Therefore, it is important to understand the phylogenetics within the population of *G. himalayanus* to identify different phylogenetic clades in its geographic range. As these clades are evolved in response to various adaptation strategies. We acknowledge that predictions based on the broad scale climatic variables have limited power, particularly when the analysis is based only on known sites of occurrence (Elith et al., 2006) and caution must be used when interpreting the output. Within the predicted climate envelope, there will be local scale factors that will further limit the distribution of species under future climates, primarily the presence of basking habitat or important prey species, which were not considered in this study. Similarly, wildfire is thought to play an important role in maintaining habitats for the species (Webb et al., 2005); however, the model cannot consider the changes in the wildfire that may occur under the predicted climate change scenarios.

Ectothermic tetrapod distribution is directly linked with global climate warming as well as climate cooling. As in the distant future scenario it has been observed that distribution of Himalayan Pit Viper shows to reach lower elevation limit across its ranges in Himalaya. As it is known lower limits of Himalaya is much more populated by other reptilian species than upper limits. It can be presumed that changes in the distribution may lead to competition of the species with the other viper species of lower elevation. With low elevation dwelling species such as Himalayan white lipped pit viper which is known to be distributed up to 2000m in western Himalaya. Such overlap may lift to intense competition with resources and may have ecological consequences on the its survival and population build up. Areas of higher elevation within the current range will be most important for persistence of this species because they will remain relatively moist and cool even under climate change and will match the current climate envelope. Conservation efforts should focus on areas where suitable climate space may persist under climate warming scenarios. Long-term monitoring programs should be established both in these areas and where populations are predicted to become extirpated, so that we can accurately determine changes in the distribution of this species throughout its range.

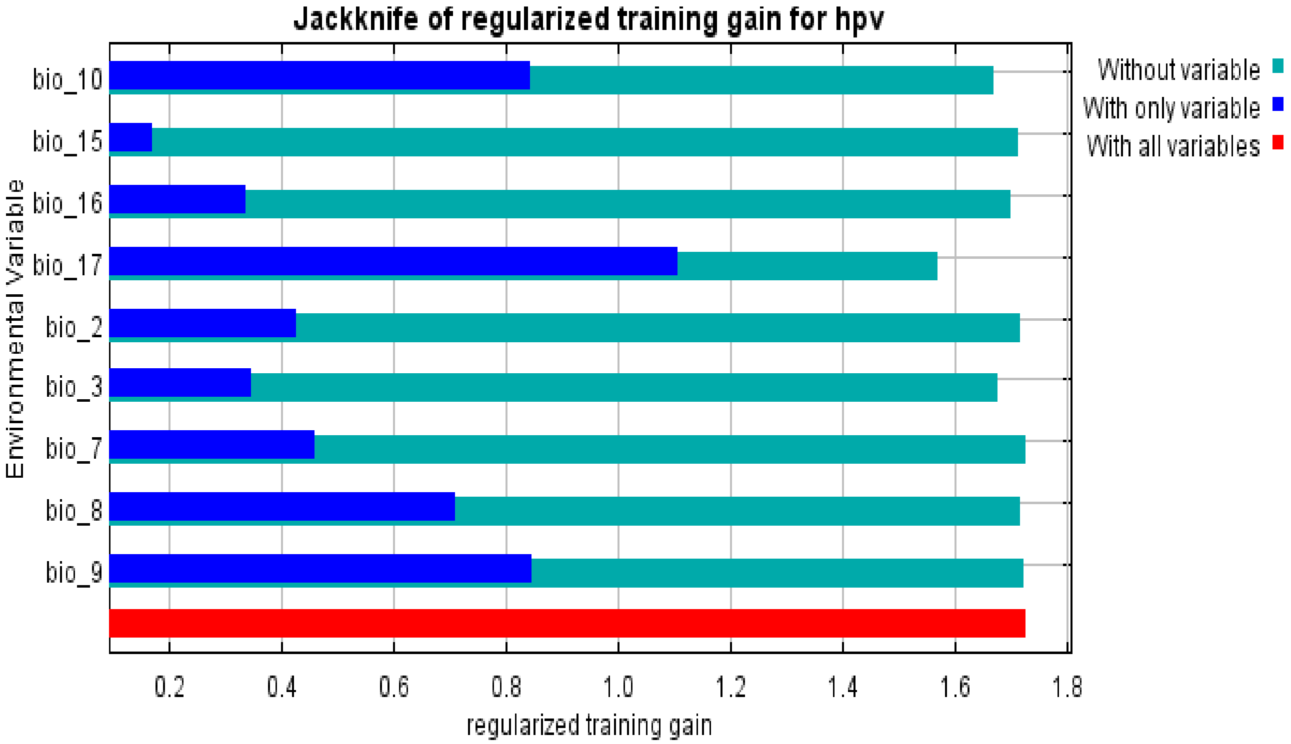

Fig. 27. Results of Jackknife test of variable importance. The environmental variable with the highest gain when used in isolation is bio_17(Precipitation of Driest Quarter).

Table 7 - Best model selected based on AUC score and variables contribution to species model. Here H=Hinge,LQP= Linear , Quadratic and Product, LQPH= Linear , Quadratic, Product, and Hinge. Bio 17 = Precipitation of Driest Quarter.

Scenario	**Model**	**AUC_Score**	**Variable**	**Variable contribution**
Present 1.4	H	0.924	Bio_17	57.8
2050_2.6	LQPH	0.946	Bio_17	48.9
2050_4.5	H	0.931	Bio_17	54.6
2050_6.0	H	0.927	Bio_17	54.7
2050_8.0	H	0.941	Bio_17	49.3
2070_2.6	H	0.929	Bio_17	56.8
2070_4.5	LQP	0.923	Bio_17	51.5
2070_6.0	LQP	0.92	Bio_17	51.1
2070_8.0	LQP	0.943	Bio_17	53.9

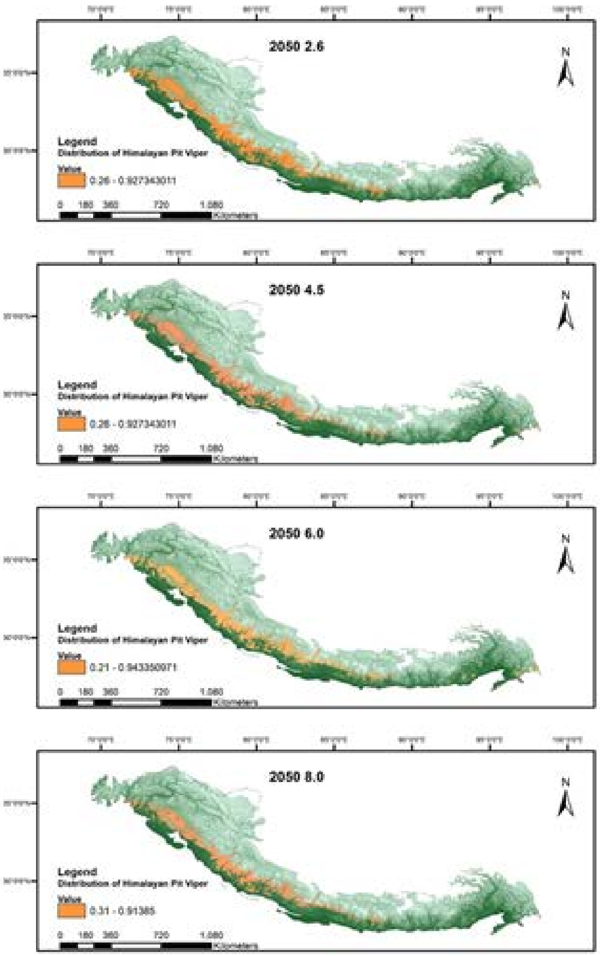

Fig. 28. Predicted distribution of range of Himalayan Pit Viper for near future scenario.

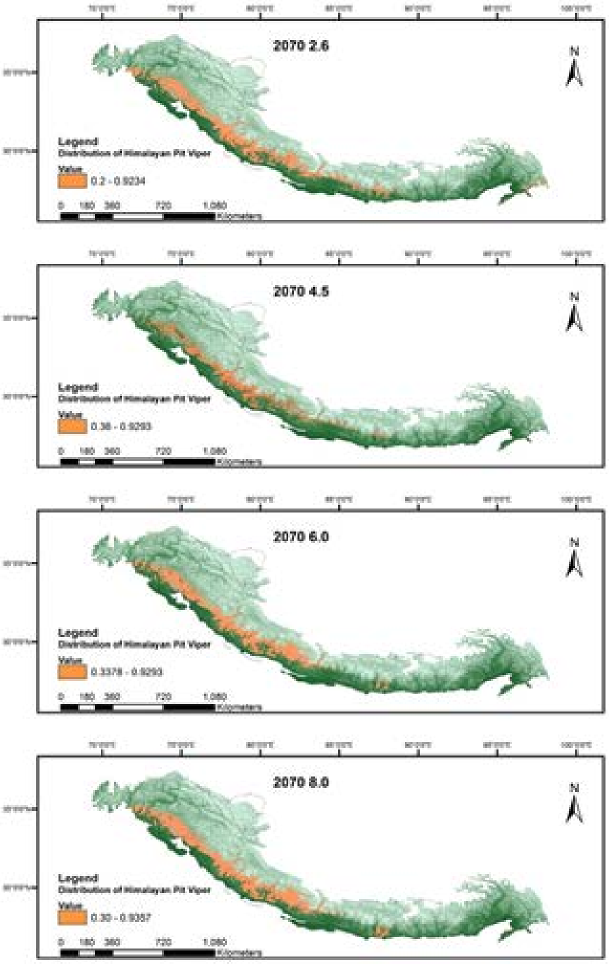

Fig 29. Predicted distribution of range of Himalayan Pit Viper for distant future scenario

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Chapter 4
Impacts on Freshwater Environments

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4.1 Introduction

Freshwaters are among the most vulnerable ecosystems on the globe and are also highly susceptible to the ongoing climate alternations (Sala et al., 2000; Jenkins, 2003; Dudgeon 2011). The biodiversity of these ecosystems are continuously declining because these are highly exposed to numerous anthropogenic stressors such as exotic species, landuse change and fragmentation of river networks (Dudgeon et al., 2006; Nel et al., 2009; Döll and Zhang, 2010). The global warming is further predicted to accelerate the freshwater biodiversity loss to this century if the ongoing anthropogenic alterations are continued at its current pace (Thomas et al., 2004; Xenopoulos et al., 2005; Lawler et al., 2009). The temperature has been predicted to increase as a consequence of climate change which would alter the precipitation and natural hydrological patterns, and thus alter the natural distribution and fundamental niche of many of the freshwater organism (Schindler, 2001; Woodward et al., 2010, Wenger et al., 2011). As per

IPCC 2002, the precipitation was predicted to be increase in both summer and winters in high altitude regions. In addition, reduction in summer flow followed by earlier snowmelt, increased evapotranspiration along with drastic reduction in stream discharge would affect natural hydrological regime (Poff et al. 2002). The consequences of climate change have been projected to be severe especially in drier areas where 75% of local fish diversity may be forced to extinction to the end of this century (Xenopoulos et al., 2005).

Himalaya, the highest mountain chain on the globe is predicted to be warming at a rate much higher than global average rate of 0.4 °C (Solomon, 2007; Dimri et al., 2018). Three major rivers *viz* Indus, Ganga and Brahmaputra drain the Himalayan region and stand significantly important to the livelihoods of many, and often bear the brunt of overexploitation through rampant damming and illegal fishing activities. (Everard et al., 2019). The natural flow regime and spatio-temporal connectivity in the downstream areas particularly in the Ganges and Indus basin have been predicted to be disturbed as a consequence of climate change (Immerzeel et al., 2010). Furthermore, these rivers are also subjected to extreme events such as intense rainfall and flash floods besides a multitude of anthropogenic stressors like pollution, channel modification. Therefore, given the consideration of various threats posed by aquatic ecosystems of Himalaya, it is important to develop effective monitoring tools followed by rigorous sampling in high altitude rivers and streams for planning relevant conservation and mitigation measures to save them from the potential loss in future environments.

4.2 Climate vulnerability to freshwater species

With regard to various levels of temperature preferences, the freshwater organism can be divided into warm, cool and cold-water types and thus are also has an unique distribution along an elevation gradient. Freshwater organisms like fish, amphibians, mussels and aquatic macroinvertebrates are classified as ectotherms and therefore temperature plays a major role in regulating their life history attributes such as growth, development, reproduction and mortality. Studies indicate that temperature thresholds are also cueing the spawning migration in fishes which has been linked to the photoperiodism affecting gonadal maturation in fishes (Baras and Philippart, 1999; Santos et al., 2007). The changes in water temperature and other hydrologic characteristics associated with climate change are expected to have profound effects on their abundance and distribution (Comte & Grenouillet, 2013; Conti et al., 2015). There are empirical evidences of range contraction and expansion specifically in freshwater fishes have been recorded based on long term distributional records (Hickling et al., 2006; Hari et al., 2006; Babaluk et al., 2000; Milner et al., 2011). In past years, several studies have also came up describing the potential impact of climate change on freshwater organisms worldwide (Sharma & Jackson, 2008; Buisson & Grenouillet, 2009; Ruesch et al. 2012; Furniss et al., 2013; Isaak et al., 2015; 2016; Troia & Giam, 2019). Though in India, studies are still rare to understand the potential impact of climate change on freshwater organism (Sarkar et al., 2017).

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In view of climate change, the Himalaya can be considered as key landscape for conservation of unique cold water fish diversity which is already under severe threat due to numerous anthropogenic stressors. The current anthropogenic threats and their consequences may likely to be complicated in future by global climate change which may pose significant extinction of fish fauna. Freshwater fish diversity in the Himalaya is structured by diverse geomorphic conditions thermal regimes and rapid water current. Owing to their distinctive adaptation to cool and coldwater conditions and a restricted dispersal ability to track their thermal environmental niche (Comte and Grenouillet, 2013; Isaak et al., 2016), it is important to assess the potential climate change impact on these organisms to prevent them from future extinction.

4.3 Selection of focal / indicator species

For the present study we selected two prime cold water fish species of Himalaya, the snow trout (*Schizothorax richardsonii*) and a non-native brown trout (*Salmo trutta fario*). The snow trout belongs to the rhithron zone (faster and more turbulent flowing speeds) of the Himalaya characterized by a mean monthly temperature of 17.3°C, high concentrations of dissolved oxygen (10.01 mg l^{-1}). This species has declined substantially compared to its historical distribution because of dam development, illegal fishing activities and also competitive pressures of the exotic fishes. The species is distributed all along the five Himalayan states (i.e. Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh) and dependent on pristine cold waters of the Himalayan river basin. In view of climate change this migratory fish is expected to face several threats because its life history, growth, migration and reproduction is highly dependent on temperature and precipitation patterns. On the other hand the non-native brown trout is a generalist predator and a native of Europe have been introduced in over 24 nations worldwide (Elliott, 1989). Their introduction in India happened in 1899 and has been thriving with the native fish populations since then (Sehgal, 1999, Peter, 1999). Brown trout and Rainbow trout (*Oncorhynchus mykiss*) were both introduced in India during the British reign for sport purposes. They were attempted to be introduced simultaneously in north (Kashmir) and south (Nilgiris) by transplantation of eyed-ova and were spread to several Himalayan states. Many reviews worldwide have mentioned references to brown trout as being detrimental to native fish species (Gerig et al., 2017; Muhlfeld et al., 2017). Infamously, occupying a rank in the world’s worst 100 invasive species, it is a global invader. In the same vein, it has, since its introduction, proliferated considerably throughout the Himalaya. High establishment rates of this invader act as prime caveats for the endemic snow trout exacerbated by their coalescing elevational limits and rhithron zone preferences.

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The native snow trout were considered under severe threat due to the ongoing habitat alterations and is en route to future extinction due to climate change as well as invasion pressures from the non-native brown trout. As such, assessing the way invasive-exotics and natives would respond to changing climate in climatically vulnerable Himalaya is of utmost importance. The present study thus aimed to (a) assess the life history life-history responses of the native snow trout by investigating two sympatric (snow trout co-occurring with brown trout) and allopatric (snow trout in absence of brown trout) populations (b) predicting future range shifts and climate responses of snow trout by using multi-projection ensemble and (c) we also identified potential spatial overlaps with brown trout in current and future scenarios.

4.4 Local scale biological and ecological characterization

Life-history traits like fecundity, egg diameter, size and age at maturity show major variation across the biotic and abiotic stressors (Stearns, 1992), thus highly idiosyncratic to the environmental setup a species is placed in. Given such tremendous role of life history in governing a species' ability to tackle threats, its understanding can have major conservation implications for the native fishes under anthropogenic, climate and invasion pressures. Various management decisions have been made globally based on the life history responses of the threatened native species (Goldstein et al., 2018). Regardless, the studies discussing invasion threats on Himalayan fishes are more or less anecdotal (Gupta and Everard, 2019; Gupta et al., 2020) lacking empirical evidences on the native fish species' responses to invasion. Robust scientific analysis and trait-based research on the invasion effects on the Himalayan native fish fauna is thus strongly warranted for effective restoration and conservation measures. Many facets of the brown trout invasion in Himalaya are uncertain. That, whether the brown trout invasion has actually altered the native population, or that the presumptions are rather derogatory, is yet not verified. Regardless, the brown trout habitat preferences hint its range to be strongly coalescing with that of the Himalayan snow trout. The current elusive state of knowledge on the trait-based responses of snow trout co-occurring with the brown trout in Himalaya, impede the understanding on the invasion potential of the brown trout and the resilience of the native snow trout to cope-up with these invasions.

4.4.1 Study area and Fish sampling

Sympatric and allopatric associations of snow trout with introduced brown trout were investigated in Tirthan and Asiganga rivers in the west and north-western Himalaya, India. Fish sampling was conducted across the year in Tirthan (2017 and 2018) and Asiganga (2018). Owing to its long stretch, which could only be accessed through trekking along the river bed, a two-year sampling in Tirthan was necessitated. Sampling was conducted at an interval of 500 m for the higher-order streams (4th and higher) while a 200 m interval was chosen for the lower order streams (3rd and lower) to ensure an equivalent representation as they often had a length of less than 500m. This extensive survey resulted in a total of 109 sampling points in River Tirthan and 22 in River Asiganga. Owing to inaccessibility of most of the sampling area due to heavy snowfall in peak winter months, we further selected 22 accessible sampling sites in Tirthan and 15 in Asiganga, representative of the upper, lower and middle stretch for monthly sampling. Cast nets of 10 and 30 mm mesh sizes were used for sampling. The catch per unit effort (CPUE) was deduced by dividing the catch of each sampling site by number of hours fished. All of the snow trout and brown trout captured were measured for total length (to the nearest mm) and weight (to the nearest g) in both the rivers.

4.4.2 Assessment of fish life history traits

Weight-Length Relationship (WLR) for all the populations were deduced using the length and weight data of fishes following Clark (1928). Relative condition factor (Kn_i ; Le Cren, 1951) was used to investigate the condition of the individual fishes. Kn_i was deduced by the deviation of an individual from the average weight for the population at a given length using the equation:

$$Kn_i = \frac{W_i}{\widehat{W}_i}$$

Where, $\widehat{W}_i$ is the recorded weight of the i$^{\mathrm{th}}$ fish and $\widehat{W}_i$ is the predicted mean weight calculated by anti-logging the predicted log weights of the fitted regression. Reproductive investment in the form of gonado-somatic Index (GSI) was calculated as a quotient of gonadal weight by the total body weight. A percentage conversion of the quotient was then used as the GSI value denoted by Ig (%) as:

$$Ig\% = \frac{Gonadal\ Weight}{Body\ Weight} \times 100$$

Length at maturity of fishes were determined by visual observations of the gonads classifying them from I to VI (Fontana, 1969). A logistic regression approach was used to model the length at which 50% of the population matures. The maturity stages were binomial transformed classifying I–II as immature, III–V as mature and VI as spent

4.4.3 Weight-length relationships (WLR)

A total of 602 fishes were used for the WLRs including a total of 240 snow trout from Asiganga (allopatry) and 133 from Tirthan (sympatry). While Asiganga showed complete absence of brown trout a total of 229 brown trout were captured from the Tirthan basin. The average estimated CPUE for the snow trout in Asiganga was 1.75±1.90 kg h^{-1} (0.22–6.14 kg h^{-1}) while that for Tirthan was distinctly lower at 0.48±0.30 kg h^{-1} (0.14–1.03 kg h^{-1}). For brown trout, the estimated CPUE was 0.86±0.45 kg h^{-1} (0.14–2.36 kg h^{-1}) in the Tirthan River. All the populations sampled showed a female biased sex ratio (57.5 % for allopatric and 59.4 % for sympatric female snow trout). Total length ranged from 113–360 mm in allopatric and 60–359 mm in sympatric snow trout. Brown trout showed a similar length range of 145–350.2 mm. The study observed two distinct growth stanzas for the sympatric snow trout population , with the smaller-stanza (n=19) individuals having a significantly different WLR (r^2=0.981, 95% CI of b = 2.756 to 3.116, ANOVA F-test statistic = 1187.9; p< 2.2e-16) than the larger-stanza (n=114) individuals (r2=0.946, 95% CI of b = 2.455 to 2.684, ANOVA F-test statistic = 1968.5; p< 2.2e-16) with an inflexion point at about 120 mm (Fig 1). This was quite different from the allopatric population, which showed a single growth stanza. Despite the similar sampling effort for both the populations, smaller-stanza in the catch of sympatric snow trout, might have resulted from greater percentage of small individuals.

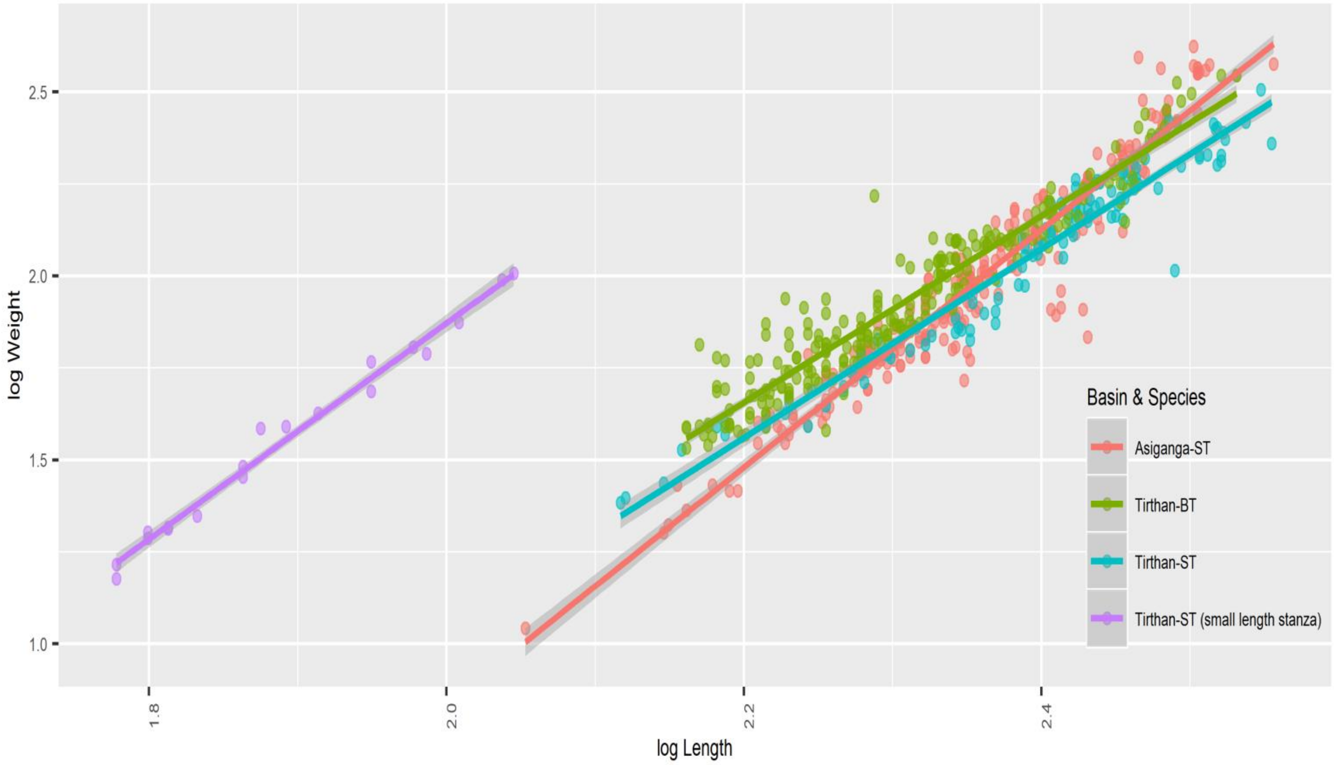

Fig. 1 Log-log plot showing the weight length relationships (WLRs) for snow trout in allopatry (Asiganga-ST) and sympatry (Tirthan-ST) with the brown trout (Tirthan-BT). A distinct small length stanza (Tirthan-ST (small length stanza)) in the sympatric snow trout is discernible with a near allometric b (2.936) than the larger stanza which showed negative allometry (b=2.569).

4.4.4 Condition factor

In the case of condition factor (Kn), the Welch's t-test failed to find evidence for any difference in Kn at an alpha of 0.05 (Welch's t-test statistic=-1.321, p=0.189) between the sympatric (mean Kn=1.015) and allopatric populations (mean Kn=1.061) of snow trout. The brown trout in Tirthan (mean Kn=1.013) also showed no difference in Kn with its sympatric snow trout population (Welch's t-test statistic=-0.134, p=0. 893). While there were no differences in Kn observed inter and intra-specifically, a temporal pattern in variation were distinct (Fig. 2). A distinct variability was found in the Kn trends across the months for the allopatric snow trout (Kruskal-Wallis rank sum test p value <0.001), with highest differences evident in the months preceding (Holm-adjusted p value<0.05 (November–August)) and following (Holm–adjusted p values: <0.001 (November–January); <0.05, (November–February) the completion of spawning in November. On the contrary, no significant temporal trend in Kn was observed for the snow trout in sympatry with the brown trout (one-way ANOVA; p =0.512).

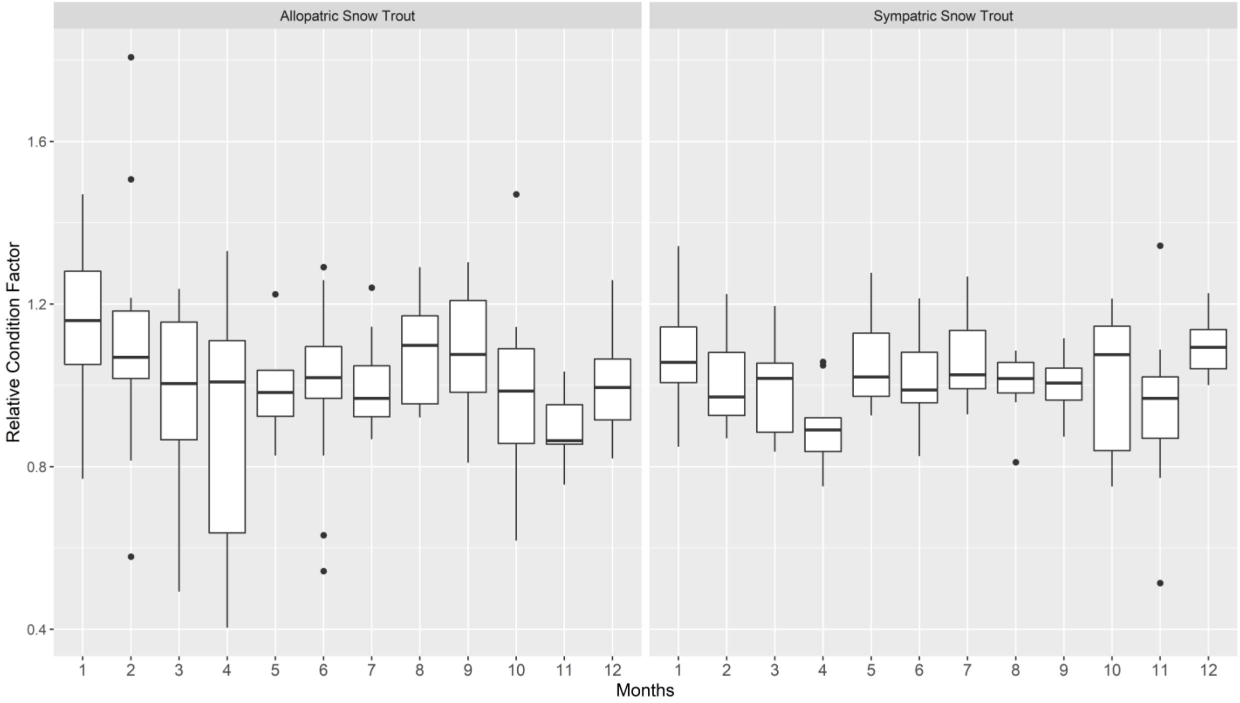

Fig. 2 Annual variation in Le Cren's relative condition factor for the allopatric and sympatric snow trout, where the months from January to December are represented as 1 to 12. Horizontal lines in the boxes represent the mean values; whiskers represent the standard deviation; the black dots represent the outliers.

4.4.5 Gonado-somatic Index

A substantial increase in GSI of snow trout was documented when the species is transitioned from stage III to V in sympatry with the Brown trout (Fig. 3 a). The brown trout spawners had a lower GSI (2.46±0.79) than that of the snow trout. The absolute fecundity estimates for the spawning (V) stage were higher for the sympatric (5492±1291.08, max=8124) than the allopatric (3089±1708.541, max=6143) snow trout (Fig. 3 b).

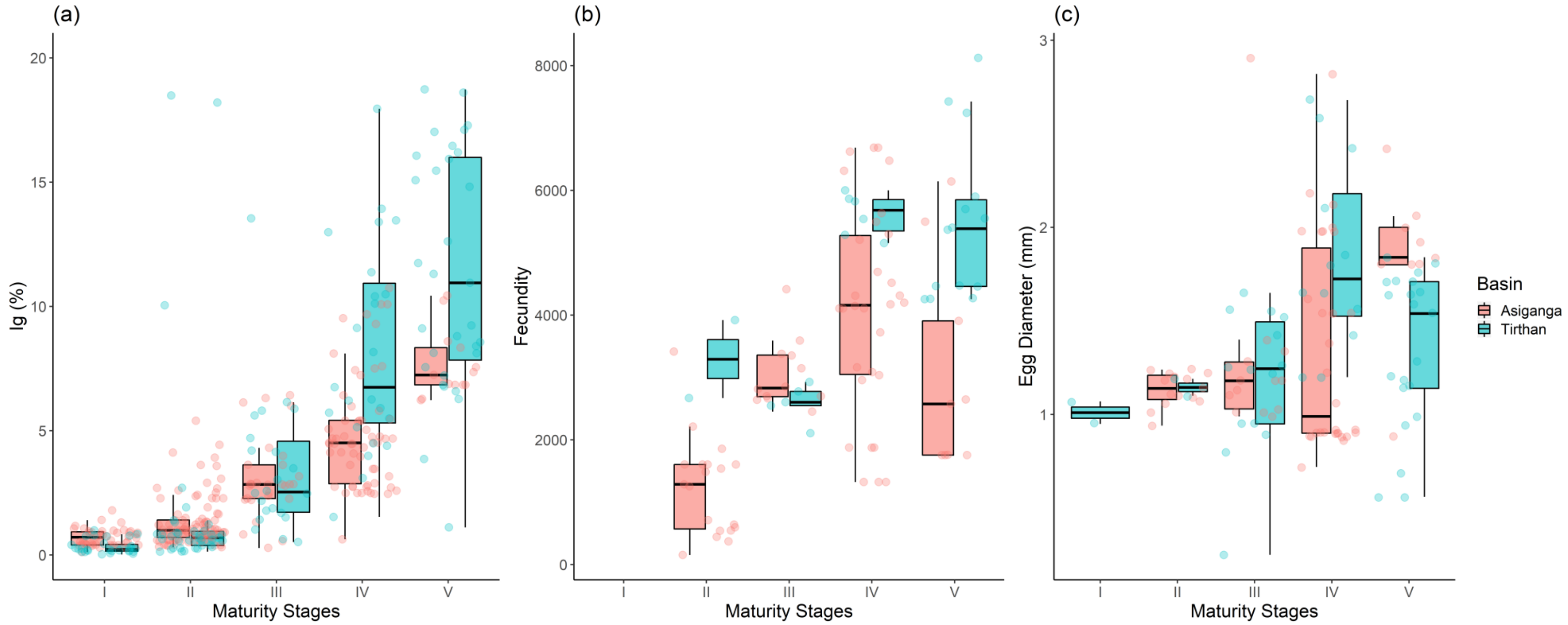

Fig. 3 Box whiskers parallelly jittered to visualise the maturity stages (I-V) of the allopatric (River Asiganga) and sympatric (River Tirthan) snow trout in relation to (a) gonadosomatic index (Ig (%)): differs significantly between the two snow trout populations (ANOVA type III SS; p=0.0003) with the fecund fishes (stage V) in the sympatrics showing higher Ig (11.95±5.21) than that of the allopatrics (7.67±1.37), (b) absolute fecundity: higher at stage IV and V for the sympatrics (5492±1291.08) than the allopatrics (3089±1708.54). (c) egg diameter: transition from stage IV to V shows a plummet in the sympatrics (1.843±0.504 to 1.347±0.417) unlike the allopatrics which show an increase (1.339±0.558 to 1.836±0.409).

4.4.6 Egg diameter

The mean egg diameter dropped from stage IV to V in the sympatric population (1.843±0.504 to 1.347±0.417), unlike the allopatric population which showed a significant increase in egg diameter as they enter the spawning stage (1.339±0.558 to 1.836±0.409) (Fig. 3 c). The brown trout spawning females had a lower absolute number of eggs (1030.3±443) with an egg diameter nearly double (3.221±0.723) that of the snow trout. Fully fecund fishes (stage V) started to appear at as low as 102 mm total length in the sympatric snow trout unlike a length of 224 mm for the allopatric snow trout (Fig. 4).

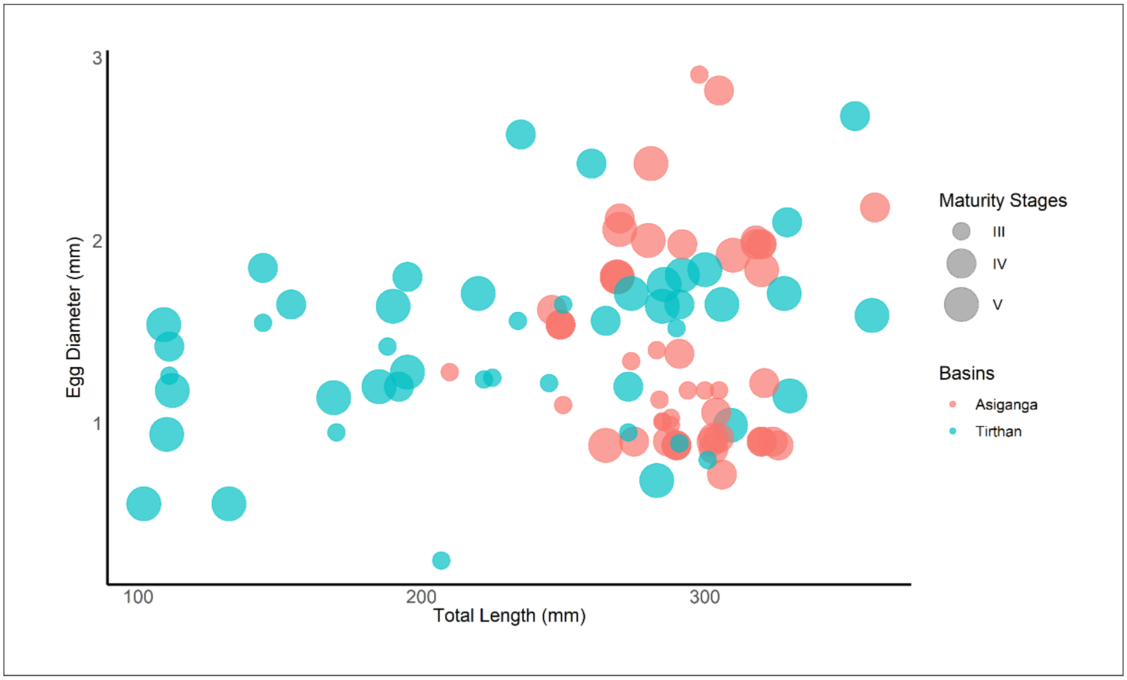

Fig. 4 Bubble plot of the egg diameter as a function of the total length for the sympatric (River Tirthan) and allopatric (River Asiganga) snow trout.

4.4.7 Length at first maturity

The Bayesian length ogives for the snow trout predicted 50% of the allopatric snow trout population in Asiganga to mature at the length of 248.9 mm with the model best fit at parameters A=-5.63 and B=0.02. (Fig. 5, 6, 7).

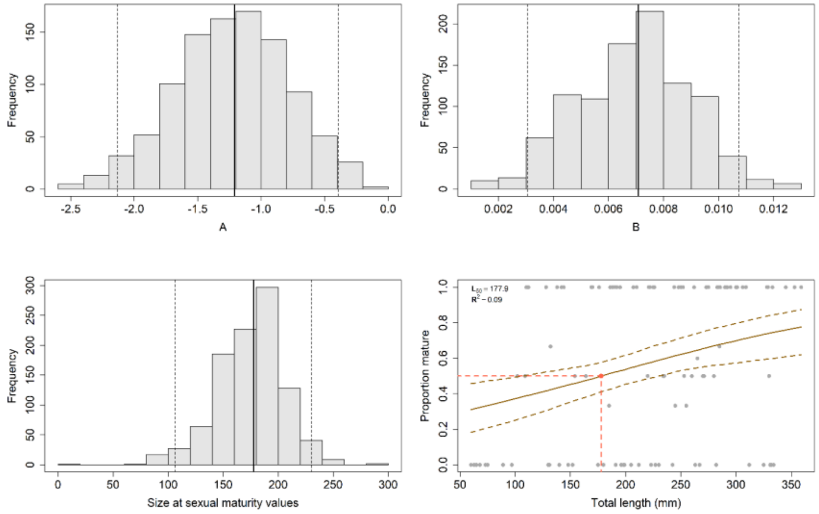

Fig. 5 The Bayesian regression parameters and ogives for the sympatric snow trout. The upper left and right facets represent the frequency histograms for parameter A and B. The lower right facet represents the length at first maturity (L50)

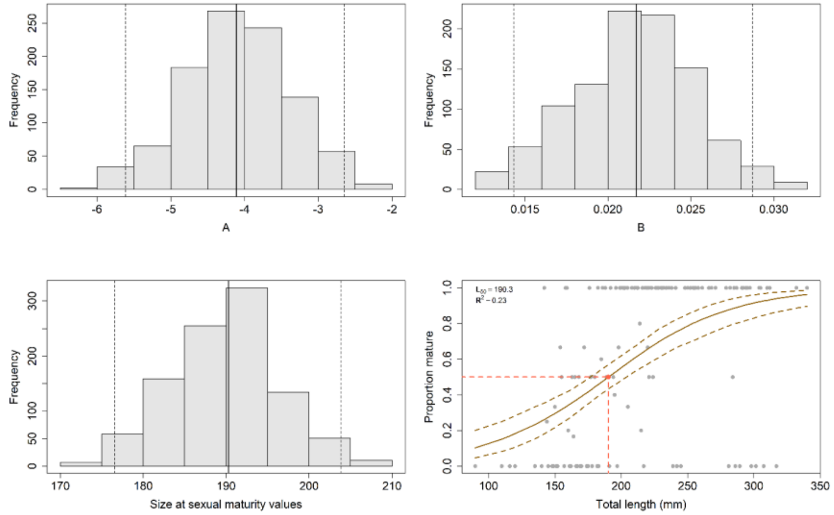

Fig. 6 The Bayesian regression parameters and ogives for the brown trout. The lower right facet represents the length at first maturity ogives (L50)

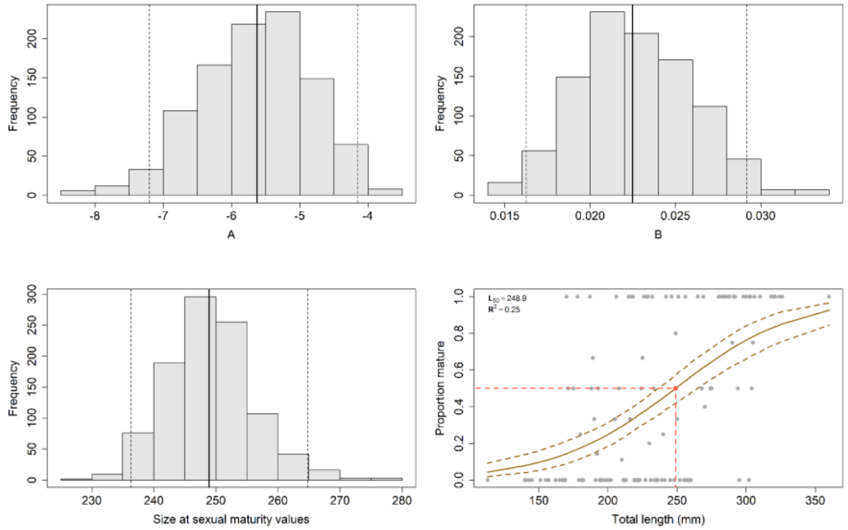

Fig. 7 The Bayesian regression parameters for the allopatric snow trout

4.5 Modeling approach and selection of climatic and bioclimatic variables

Determining the potential distribution of target species in the current and future climatic conditions is feasible through the Species Distribution Modeling (SDMs) under various Global Circulation Models (GCMs) and Representative Concentration Pathways (RCPs). In view of climate change the snow trout is expected to face several threats because its life history, growth, migration and reproduction is highly dependent on temperature and precipitation patterns. Therefore, changes in temperature and subsequent hydrological imbalance due to climate change are expected to have substantial effects on their survival in near future. We used SDMs based on the ensemble modeling approach to predict the future potential distribution of snow trout in the current climatic and future climatic environment. We also assessed the potential spatial overlap with the brown trout distribution in current and future time periods.

4.5.1 Collection of occurrence records

Occurrence records of snow trout and brown trout were collected from three main sources (1) our previous field sampling (Rajvanshi et al., 2012; Sarkar et al., 2012) (2) Global Biodiversity Information Facility (GBIF; http://www.gbif.org/), literature containing present and historical information (3) data from our current field sampling recorded from 2015 to 2020 under National Mission for Sustaining Himalayan Ecosystem (NMSHE) project.

4.5.2 Collection of predictor variables

For modeling the potential distribution of coldwater species like snow trout, a data set containing 25 predictor variables (19 bioclimatic, two topographic, and four hydro-geomorphic) were compiled. The bioclimatic variables were extracted from the Worldclim Climate Database, Version 1 (http://www.worldclim.org/), (Hijmans et al., 2005). These climatic variables are the monthly mean interpolation of the records collected over 50-year time period (1950–2000). The present analysis was based on (30 arc-seconds (approximately 1 km at the equator)) resolution on the core Himalayan scale.

4.5.3 Niche models

The habitat suitability models for snow trout in the IHR were predicted using BIOMOD version 2 framework programmed in R software (Thuiller et al., 2016). Six niche-based modeling methods were used including (i) generalized linear models (GLM), with polynomial terms using a step-wise procedure to select the most significant variables based on the Akaike information criterion (AIC), (ii) generalized additive models (GAM), with automatically selected smooth splines and a nonparametric extension of GLM, bagging and boosting approaches viz (iii) classification tree analysis (CTA), (iv) random forests (RF), (v) multiple adaptive regression splines (MARS) and (vi) maximum entropy (MaxEnt).

4.5.6 Future predictions

We modeled the future potential distribution of snow trout and brown trout based on three carbon emission scenarios (RCPs): optimistic (2.6), moderate optimistic (4.5) and pessimistic (8.5). The bioclimatic variables for the future environments under the aforementioned RCPs were obtained from the Intergovernmental Panel on Climate Change model, 5th Assessment Report (IPCC–AR5) (http://ccafs-climate.org) for the two time periods: 2050s (average of 2040–2069) and 2070 (average of 2070–2099). A total of five General Circulation Models (GCMs) from the phase 5 of the Coupled Model Intercomparison Project (CMIP5) were obtained from (i) BCC CSM1-1, Beijing Climate Center, China Meteorological Administration, China, (ii) CCSM4, National Center for Atmospheric Research (NCAR), USA, (iii) HadGEM2-AO, Met Office Hadley Centre, UK, (iv) MIROC5, Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, Japan Agency for Marine-Earth Science and Technology, Japan and (v) MRI-CGCM3, Meteorological Research Institute, Japan. The different RCPs and GCMs were used to project a range of possible future scenarios and to better understand the uncertainties (Thuiller et al., 2019). The topographic and hydrogeomorphic variables were considered consistent temporally for the future modeling process.

4.5.7 Model Performance and variable importance

The AUC (ROC) and TSS scores of six different niche-based algorithms cumulatively calculated from the different cross-validation runs and pseudo-absences sampling were represented with a mean and standard deviation. All the models used ranged between the AUC values of 0.804 and 0.916 while the TSS vales ranged between 0.576 and 0.773. RF on average, turned out to be the most effective in the predictive ability followed by MARS, GLM, GAM, MaxEnt and CTA based on their AUC and TSS score. The final consensus model based on committee averaging procedure by defining weights among 72 model projections resulted in an AUC of 0.99. The sensitivity and specificity of the consensus model were 94.64 and 94.26 respectively. The variable importance scores among 13 environmental variables ranged between 0.044-0.289 of which, the flow accumulation FLA being the most influential. The minimum temperature of coldest month TCM (0.261) and mean temperature of wettest quarter TWC (0.212) resulted as the next most influential environmental variables followed by moderately important predictors viz, precipitation seasonality PES (0.186) and altitude ALT (0.185). The variable importance scores were coherent across all niche-based algorithms used in the study.

4.6 Potential habitat suitability and climate change impact

The final consensus model based on committee averaging procedure revealed majority of suitable habitats western Himalayan rivers of which the main channel and tributaries of upper Ganga, Yamuna, Beas and Satluj river basins provide an extensive suitable habitat (Fig. 8). The mid elevational ranges of Indus basin tributaries like Jhelum, Chenab, Ravi are found to be climatically suitable for snow trout. The main channel and large tributaries of major rivers like Karnali, Gandaki, Koshi in the central Himalaya offer favourable conditions for the snow trout. Towards the eastern Himalaya, the distribution of snow trout was limited to certain stretches of the rivers and its tributaries. The present habitat suitability modeling revealed a broad potential distribution with its current range size of 54252 cells distributed throughout the central, western and eastern Himalayan drainages.

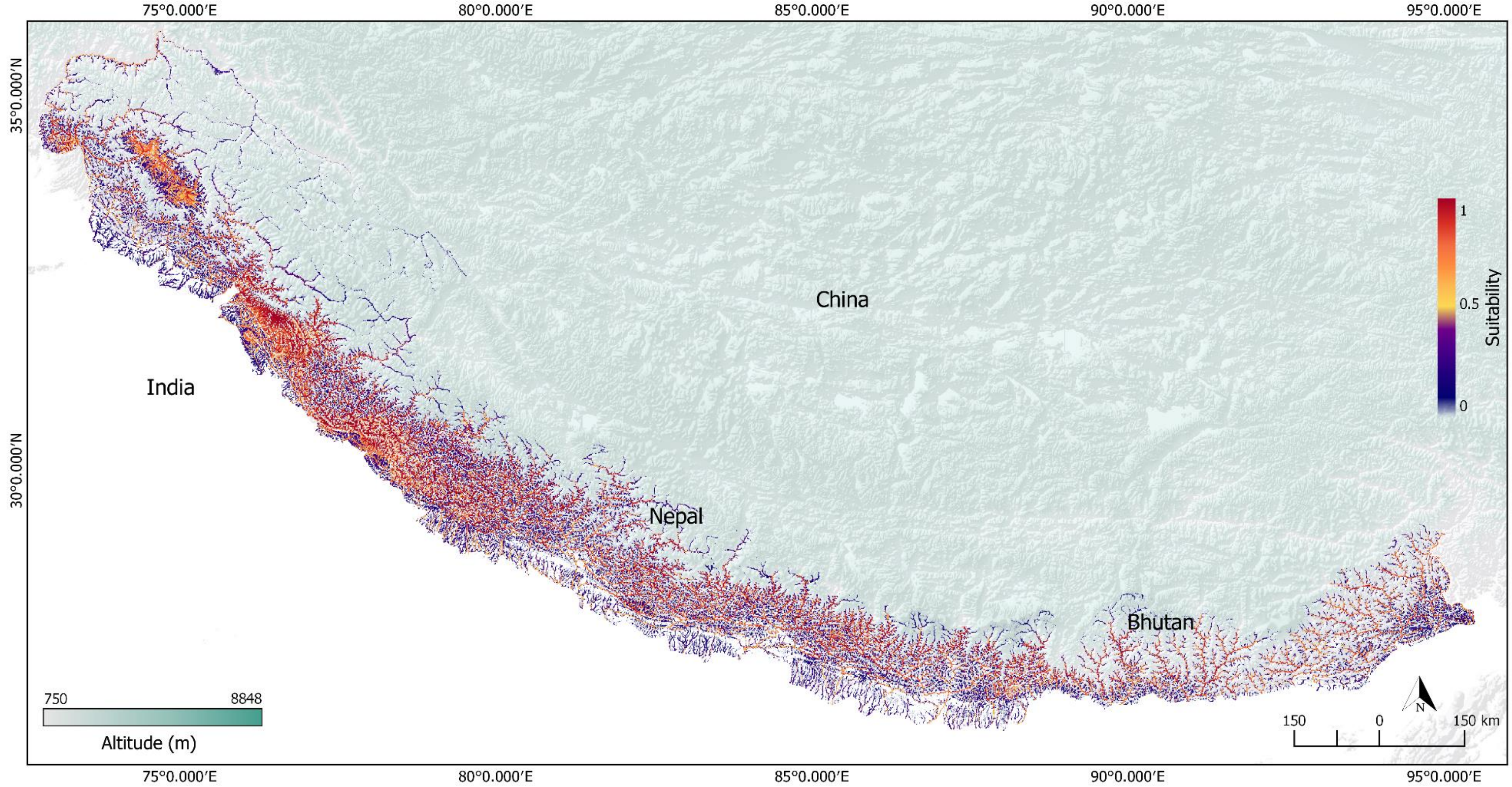

Fig. 8 Consensual current habitat suitability prediction based on committee averaging of different modeling algorithms used in this study. Suitability values equal to 1 correspond to ideal environmental conditions and values equal to 0 correspond to suboptimum environmental conditions for the snow trout.

Our results on the future predictions in terms of range shifts, generated from the consensus model across five GCMs in different time periods (2050 and 2070) under three RCPs revealed a considerable collapse of climatically suitable habitat as a consequence of climate change. The major habitat loss was predicted at relatively low to mid-elevation ranges throughout the Himalayan drainages of which eastern Himalaya showed dramatic shrinkage in snow trout habitats in the future environments as compared to western and central Himalaya (Fig 9, 10, 11). The percentage of predicted loss in the two time periods (2050 and 2070) was always higher than the percentage of gained habitat in all the RCPs (Table 1). Considering the low emission scenario, the net loss was estimated to be 7.41% by 2050 and 9.46% by 2070, while in the extreme emission scenario the net loss could reach up to 16.29% by 2050 and 26.56% by 2070. We identified that the high altitude streams and a considerable area in eastern Himalayan drainages would create conflict in future environments as they serve as future refugia for both native snow trout and non-native brown trout (Fig 12). In addition, assuming the full dispersal scenario, the current massive network of dams across the Himalayan rivers would further create a strong deterrent for the species to colonize the potential refugia at higher altitudes.

Table 1. Summary of the predicted gain, loss and species range change of the snow trout habitat under three representative concentration pathway (RCP) scenarios for the years 2050 and 2070. Values before the parentheses indicate the average range shifts and values in parentheses indicate the minimum and maximum values of five different general circulation models (GCMs).

Time frame	**Scenarios**	**Predicted gain (%)**	**Predicted loss (%)**	**Net species range change (%)**
2050	RCP2.6	16.10 (3.42-33.63)	23.51 (14.11-33.97)	−7.41 (−26.34-19.52)
	RCP4.5	12.70 (2.01-17.14)	29.41 (23.26-52.53)	−16.70 (−50.53-−6.34)
	RCP8.5	16.62 (7.40-28.66)	32.90 (22.78-43.12)	−16.29 (−35.72-5.88)
2070	RCP2.6	14.50 (1.88-22.45)	23.96 (18.73-39.85)	−9.46 (−37.98-2.99)
	RCP4.5	15.64 (2.78-36.66)	33.90 (22.24-56.41)	−19.26 (−53.63-14.42)
	RCP8.5	19.13 (6.38-28.92)	45.69 (37.32-62.58)	−26.56 (−56.20-−12.88)

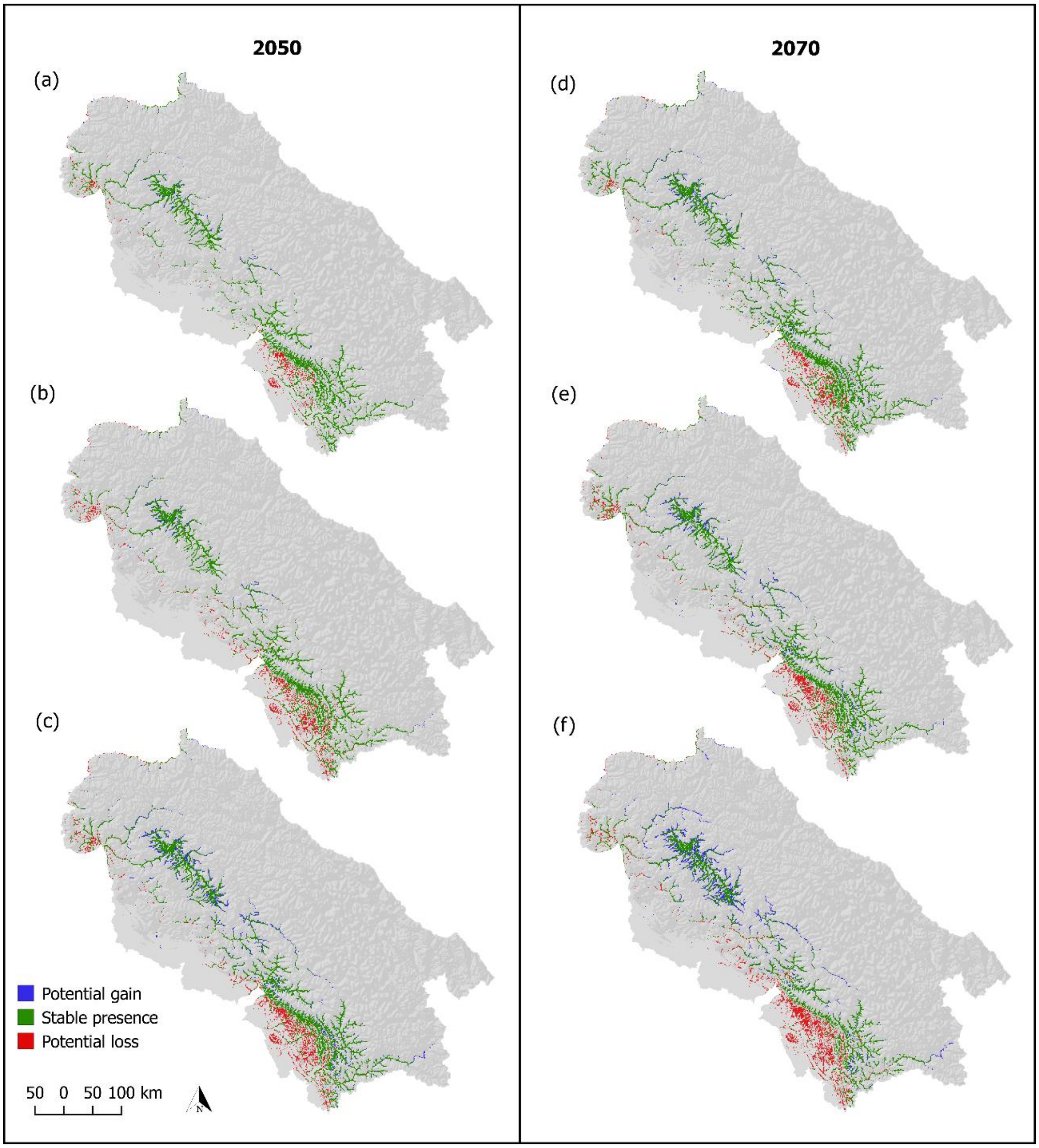

Fig. 9 Predicted range shifts of the snow trout under future climate change in the catchments of Indus in the western Himalaya based on the ensemble of five general circulation models (GCMs), RCPs 2.6 (a) 4.5 (b) and 8.5 (c) for the year 2050; and RCPs 2.6 (d) 4.5 (e) and 8.5 (f) for the year 2070. Though losses are expected to be more as compared to gain, the future refugia can be seen in the upper portions of the basin.

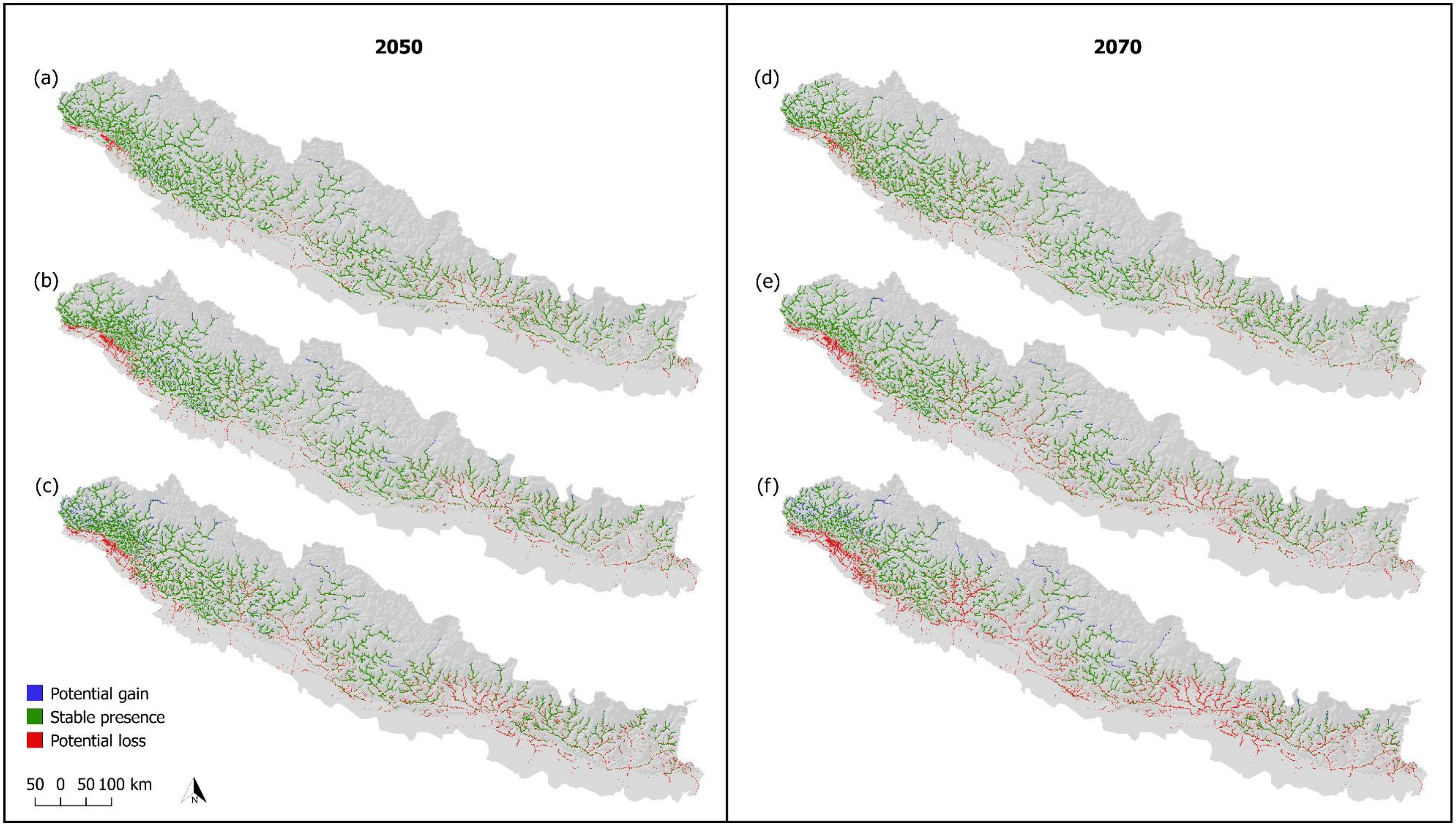

Fig. 10 Predicted range shifts of the snow trout under future climate change in the catchments of Ganges in the central Himalaya based on the ensemble of five general circulation models (GCMs), RCPs 2.6 (a) 4.5 (b) and 8.5 (c) for the year 2050; and RCPs 2.6 (d) 4.5 (e) and 8.5 (f) for the year 2070. Though losses are expected to be more as compared to gain, the future refugia can be seen in the upper portions of the basin. Proceeding the highest loss in Brahmaputra, second highest loss is predicted in the Ganges basin during the 2070s

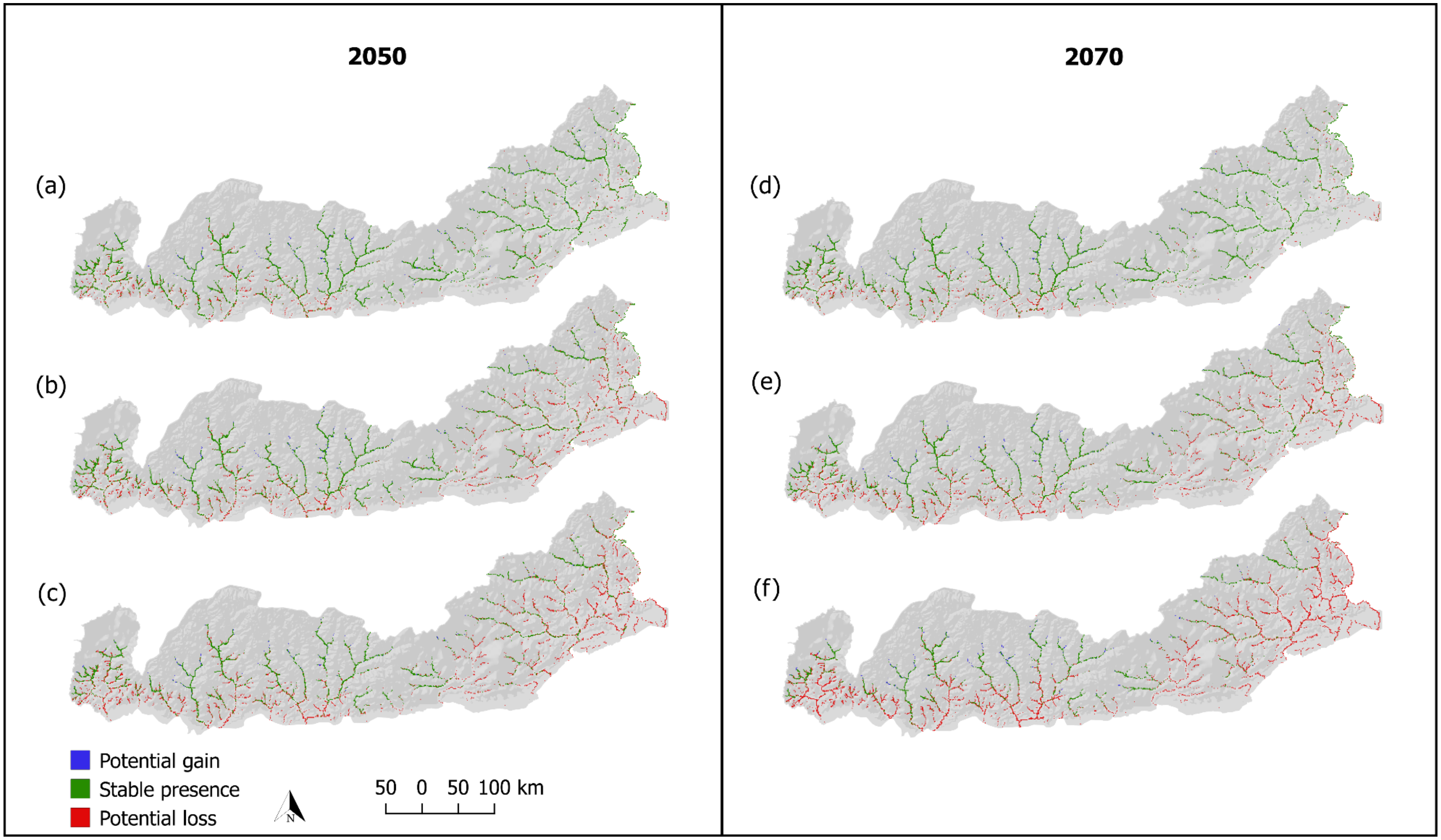

Fig. 11 Predicted range shifts of the snow trout under future climate change in the catchments of Brahmaputra in the eastern Himalaya based on the ensemble of five general circulation models (GCMs), RCPs 2.6 (a) 4.5 (b) and 8.5 (c) for the year 2050; and RCPs 2.6 (d) 4.5 (e) and 8.5 (f) for the year 2070. While all the basins are predicted with an overall loss in habitat, Brahmaputra in the eastern Himalaya specifically shows the maximum potential loss followed by the central (Ganges) and western (Indus) Himalayan drainages.

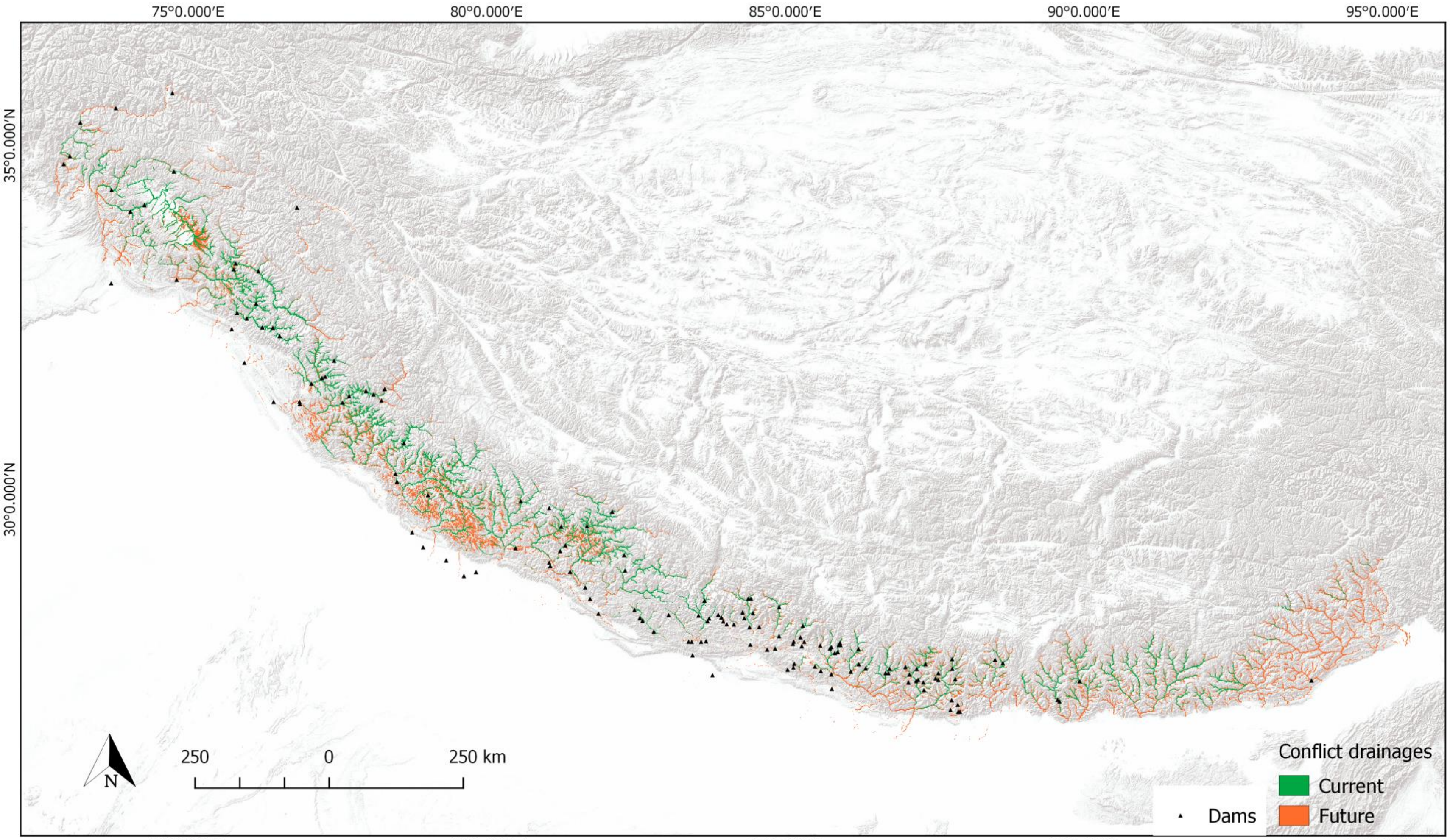

Fig. 12. Spatial overlap of native snow trout and nonnative brown trout populations in the Himalayan drainages. The future prediction to represent the conflict drainages was based on RCP 8.5 for the year 2050.

4.7 Conclusion / Summary

1. The study demonstrated that the sympatric snow trout adapted to a ‘fast’ life history with maturation at a smaller length, greater fecundity and smaller egg diameter to cope up with brown trout invasion.

2. Investment in a reproductive-somatic trade off was evident with a disrupted size structure and reduced abundance vis-à-vis the allopatric population. Although, the fast life history adaptations of snow trout might increase their competitive ability with invasive brown trout, yet trading off the somatic fitness in the process, seemingly acts as a deterrent to longevity.

3. The study reveals that the snow trout seems to forcibly invest in reproductive efficiency, thereby reducing its somatic fitness, as a plausible effort to cope up with the brown trout invasion pressures.

4. Idiosyncratic investigations are warranted for the sympatric snow trout in other Himalayan rivers to understand the envelope of responses, which snow trout can exhibit to such invasions. Cessation of brown trout stocking in Tirthan is a prudent recommendation, barring which, brown trout might most likely suppress the native snow trout population to a probable local extinction in the near future.

5. In view of climate change the results provide a foremost basis to understand several possible ways in which the biological parameters of both the populations can be changed in future environments. The study also provides a starting point to collect long term data on such interactions and life history attributes to develop more robust models based on mechanistic approaches.

6. A wide-ranging mid-elevation river network is predicted to be currently suitable for the snow trout in Himalaya, however a significant part of its current distributional range would be lost over time. Our results highlight that snow trout would expand their range

upwards into the high-altitude streams with a concurrent predominant range contraction in most of their lagging edges, ultimately creating a high-altitude squeeze.

7. The net habitat loss under three RCP scenarios (RCPs 2.6, 4.5 and 8.5) was estimated to range from 7.41% to 16.29% for the year 2050 which would further increase in the year 2070 ranging from 9.46% to 26.56%. These results provide a strategic information on prioritizing climate-adaptive actions to target the currently suitable habitats and future refugia identified.

8. The consensus predictions also reveal that the high-altitude tributaries of Jhelum, Chenab, Satluj, Beas and the upper Ganges basin would potentially contribute as snow trout refugia in the future environments. However, the range expansion strongly depends on the provisioning of suitable dendritic connectivity as well as the species' potential to move to favourable environments.

9. Assuming the full dispersal scenario, the current massive network of dams across the Himalayan rivers would probably act as a barrier for the species to colonize the potential refugia at higher altitudes.

10. The higher altitude cold water regions in majority of the Himalayan rivers are furthermore dominated by introduced brown trout which might pose further competition and with habitat loss, might synergistically entail a escalated threat to the endemic snow trout population in the Himalayan rivers.

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Chapter 5

Impacts on Soil Micro Flora, Fauna and their Habitats

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5.1 Introduction

5.1.1 Soil micro flora

Soil microflora, comprising bacteria, archaea, viruses, protists and fungi, play an important role in bio-geochemical processes such as nutrient cycling, soil organic matter decomposition, nitrogen mineralization and soil chemistry (Prosser, 2007). They help in maintaining the soil health, plant growth and ecosystem functioning (Hill et al., 2000). They are most diverse compared to other organisms. Hence scientific information on their community composition and abundance are vital for understanding the functions of all ecosystems. Investigation of soil microflora diversity in extreme environments has gained major attention globally due to their unique functional properties (Madigan, 2000) for understanding ecosystem function response to global changes.

Global climate change is one of the emerging challenges faced by the modern science and society. One of the major drivers of climate change is significant increase in greenhouse gases, particularly carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and nitric oxide (NO). A significant amount (~25%) of natural CO_2 emission occurs from soil through microbial decomposition of dead organic matter, a process known as soil respiration (Schlesinger et al., 2000; Raich et al., 2002). With about 2000 Petagram (1 Pg = 10^{15} grams) of stored organic carbon, soil is the largest sink for terrestrial organic carbon and have the potential to influence atmospheric CO_2 concentration (Smith, 2004; IPCC, 2007). Since microbial communities live in intimate relationship with their surrounding environment, small changes in environmental and climatic factors have substantial influence on soil microbial respiration affecting atmospheric CO_2 level (Bardgett et al., 2008; Singh et al., 2010). Bacterial communities are the most abundant microorganisms in the soil and majorly affect soil heterotrophic respiration by responding quickly to changes in soil environment such as temperature, moisture and CO_2 concentration (Singh et al., 2010). Their short reproductive cycle, fast metabolic adaptability and specific environmental requirements make them important indicators of climate change effects (Singh et al., 2010). Though the soil bacterial communities are known to be highly sensitive to climate change, there is limited scientific information on the soil processes they regulate.

In recent years, there has been a spurt on climate change research globally and attempts have been made to understand the environmental drivers of soil microbial diversity, composition and their potential role as indicators of ecosystem response. A number of environmental factors such as soil temperature, moisture, pH, nutrient availability and annual average number of frost days have been identified to shape local microbial communities in different mountain ecosystems of the world such as Colorado Rockies (North America), mountain ranges of Alberta (Canada), Tibetan Plateau (Asia), the European Alps (Europe) and the Gorbeia Natural Park (Europe) (Lipson et al., 2004; Guan et al., 2013; Lanzen et al., 2016; Yashiro et al., 2016). Long-term monitoring of impacts of climate change indicates shifts in microbial community composition and/or physiological processes towards equilibrium to existing climatic conditions (Wang et al., 2017; Yergeau et al., 2012). Despite significant numbers of studies addressing these issues in various mountain ecosystems of the world, data from the Indian subcontinent are completely lacking.

Recognized as one of the global biodiversity hotspots and well known for its geo-hydrological, cultural and aesthetic values the Himalayan region harbors diverse ecosystems, which are extremely sensitive to climate change (Yang et al., 2007; Longbottom et al., 2014). This region harbors a gradient of environments and ecosystems ranging from extremely low carbon stock such as morainic soils to carbon-rich peatlands and humid forests, which play a significant role in global carbon cycle. Climate change impacts especially on high altitude ecosystems and its biota are of critical concern as they have a higher footprint at local as well as regional scales. In the coming decades the Himalayan region is expected to face regular fluctuations in precipitation and temperature, resulting in destabilization of soil organic matters (Longbottom et al., 2014), impacting terrestrial CO_2 emission (Falloon et al., 2007). Although some efforts have been made to estimate carbon stocks in this region (Bhattacharya et al., 2008; Longbottom et al., 2014), information on impacts of climate change on soil microbial communities are completely lacking. Community compositions of soil microbes play essential role in regulating their functions and hence it is important to know compositional changes in response to variations in their surroundings environment. To address the knowledge gaps, this study was initiated for the first time to investigate soil bacterial community along environmental gradients especially covering different alpine habitats in the Western Himalaya. The objectives of this study were (a) to assess the variation in microclimatic factors and soil environmental variables across different alpine habitats, (b) to explore the patterns in soil bacterial community diversity, composition and function, (c) to understand the role of environmental variables in shaping the bacterial communities and (d) to assess the impacts of experimental warming on these communities. This study provides in depth insights into micro-climatic and edaphic factors that play significant role in shaping soil bacterial community composition and function in Western Himalaya. The data generated in this study forms the baseline for future comparisons and identification of alpine habitats that are potentially vulnerable to changing climatic conditions. The results will further assist in long term monitoring and characterization of the effects of climate change on soil microbial community composition facilitating understanding of feedbacks to carbon cycle.

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Bhagirathi River valley towards Gomukh glacier inside Gangotri National Park (GNP), Western Himalaya

5.1.2 Soil micro fauna

Rise in soil temperature due to global warming may increase nutrient availability and cause indirect changes by increasing nutrient mineralization of soil organic matter and altering soil microbial biomass consequently changes the vegetation cover and plant species composition (Graglia et al, 1997), which will alter litter quality and the net primary productivity ultimately affecting the soil microflora and fauna. High altitude soil fauna composition is dominated by free-living soil nematodes and microarthropods (Sohlenius et al, 1997; Heal, 1997). Interestingly, Nematode community has been suggested as a potential instrument for assessing soil conditions and biomonitoring system (Bongers, 1989) as they respond rapidly to disturbance and enrichment (Korthals et. al. 1996; Tenuta & Ferris, 2004) increasing microbial activity leads to change in microbial feeders in a community. In soil, nematodes have direct contact with their microenvironment indicating the community structure and occupy key positions in soil food webs (Neher, 2001). Various indices can depict the environmental disturbance using nematode genera, life strategy, or trophic structure (Bongers, 1990; Freckman and Ettema, 1993). In the cold ecosystem like in our study area, there is a lack of earthworms which are known as 'ecosystem engineers', and nematode forms the dominating underground taxa and acts as a valuable tool for assessment of climate change impact in the soil ecosystem.

The present study aimed to create baseline data of soil nematode community structure including diversity for long term monitoring and to determine the sensitivity of soil nematodes in two sites in the subalpine and alpine region (*Deodar, Pinus, Betula* dominated subalpine and very less dwarf shrub-dominated alpine sites) to environmental change by altering temperature by the installation of Open top experiment setup. High altitude terrestrial ecosystems are stressed by extreme climatic conditions and strongly nutrient-limited due to direct and indirect effects of snow cover and low temperature in the alpine and subalpine region. Hence minor change may lead to change in community structure of various free-living nematodes which is sensitive to change which will be useful for evaluating the impact of climate change in Indian Himalayan system which may alter predator-prey interactions and will have significant effects on the soil food web, nutrient cycling, microbial biomass in the soil. Therefore, Nematode community structures were assessed and the use of nematode biodiversity to indicate climate change in IHR is discussed using OTC Experimental setup.

5.1.3 Methods

5.1.3.1 Soil micro flora: sample collection and analysis

We conducted this study in the upper catchment of Bhagirathi River towards Gomukh glacier inside Gangotri National Park (GNP), Uttarakhand, India (Fig. 1), the largest national park in Uttarakhand (~ 2390 sq. km). It is located between 79° 49' to 79° 25' E and 30° 43' to 31° 28' N and covers two biogeographic zones of India namely Trans-Himalaya and Western Himalaya (Pusalkar and Singh, 2012; Kumar et al., 2018). We used a combination of soil sampling along elevation gradient (3000–4000 m) and experimental warming approach at selected alpine sites in GNP to determine impacts of changing environmental variables on soil bacterial communities. For experimental warming we installed Open Top Chambers (OTCs) in alpine habitats near Bhojwasa at 4000 m to artificially increase soil temperature by 1–1.5°C. We monitored resulting changes in environmental variables, such as, microclimatic conditions and soil edaphic factors along with bacterial community composition and functions.

We collected a total of 96 soil samples using standard protocol from experimental warming plots and along elevation gradient. The major vegetation types along the elevation are subalpine birch-rhododendron forests, alpine scrub, alpine herbaceous meadows and morainic slope. Temperature data were generated from data loggers installed at different elevations along the sampling gradient. In the laboratory we analyzed field collected soil samples for key parameters, viz., soil moisture, pH, soil organic carbon (SOC), dissolved organic carbon (DOC), total nitrogen (TN) and carbon to nitrogen ratio (C:N). To assess soil microbial community activities we estimated activities of two organic carbon degrading microbial enzymes, namely β-glucosidase and per-oxidase, using standard protocol. Further, we used next-generation sequencing technique to analyze 16S rRNA bacterial marker gene from soil extracted DNA. Sequences generated helped us to identify bacterial community diversity, abundance and composition. In depth analysis was conducted to understand the relationship between environmental variables and bacterial community composition and function.

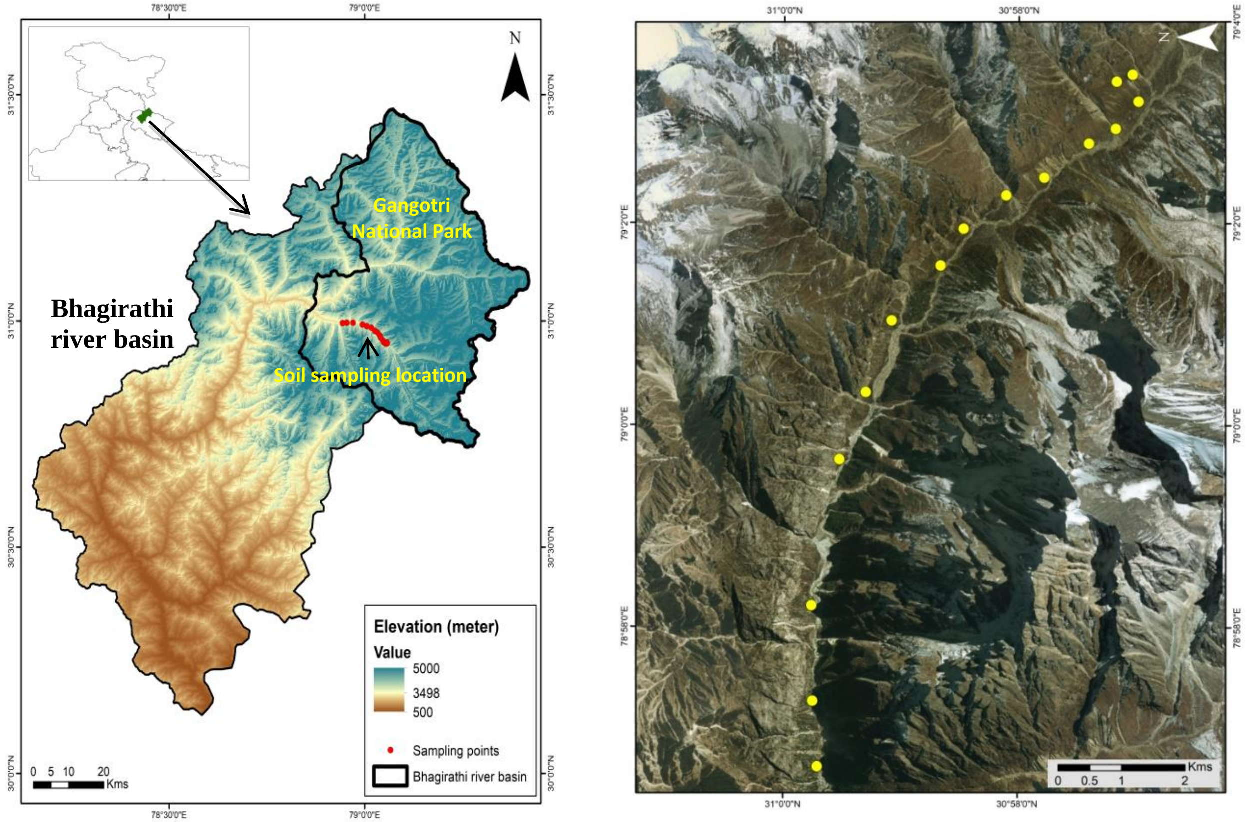

Fig. 1 Map showing location of (a) Bhagirathi basin in Western Himalaya and (b) Soil sampling locations

5.1.3.2 Soil micro fauna: sample collection and analysis

We selected the Nelang valley & Gangotri valley of Gangotri National Park as our study area for soil sample collection (Fig. 2). Gangotri National Park (GNP),30°50’N,78°45’ E -31°12’ N, 79°02’ E) was established in the year 1989, has a wide altitudinal range (from 1200m – 6000m) and lies at upper catchment of Bhagirathi basin. This Park comes under Biographical zone 2A of Western Himalaya. Gangotri valley of GNP represents the high altitude areas of western IHR. The unique mountain ecosystem of GNP plays host to a large number of animals, plants, and herbs. The study area comprises of different vegetation types along the elevation gradient. The highest elevation is covered by ice and bare rocks, alpine steppes, meadows, Alpine scrubs(*Caragana*, *Artemisia*, etc) at a higher elevation (>3800m), stunted tree line (3500-to-3800m), vegetation comprised of Himalayan Birch (*Betula utilis*), subalpine mixed conifer forests with West Himalayan Fir (*Abies pindrow*), Deodar (*Cedrus deodara*) and Blue Pine (*Pinus wallichiana*) being the dominant species. The natural vegetation is largely dominated by the Deodar (*Cedrus deodara*) at a lower elevation, Himalayan Pine (Pinus wallichiana), and Bhojpatra (*Betula utilis*) from middle elevation gradient to the tree-line. An intensive study was conducted in Bhagirathi basin I comprising of different vegetation types in the subalpine, and alpine region along the elevational gradient (3000m- 5000m). No prior study exists on the soil nematode community in the study area (Fig. 3).

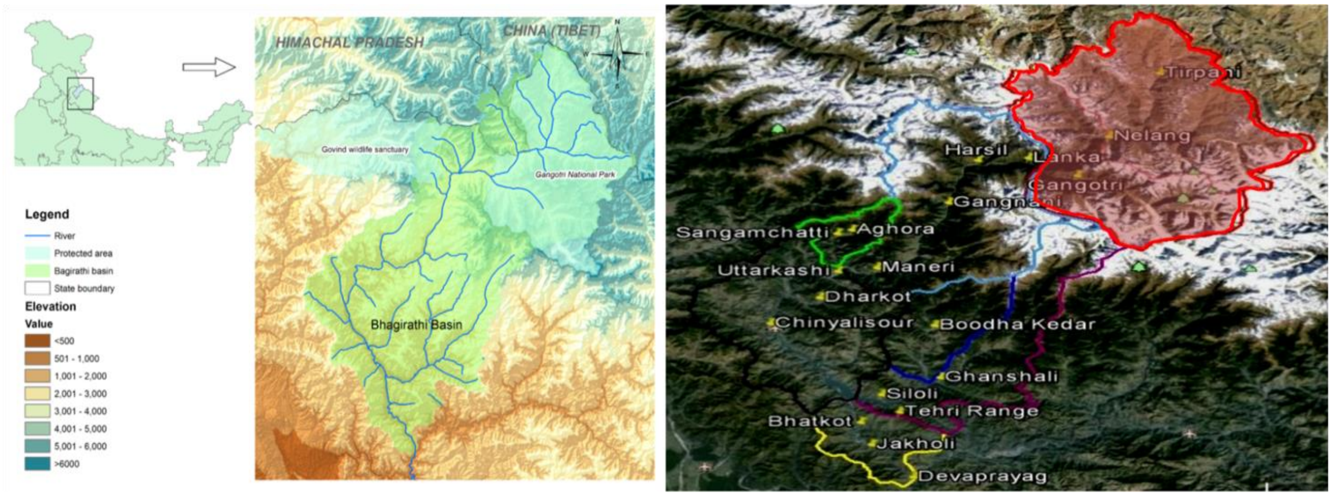

Fig. 2 Study area - Bhagirathi sub-basin I (Highlighted in red)

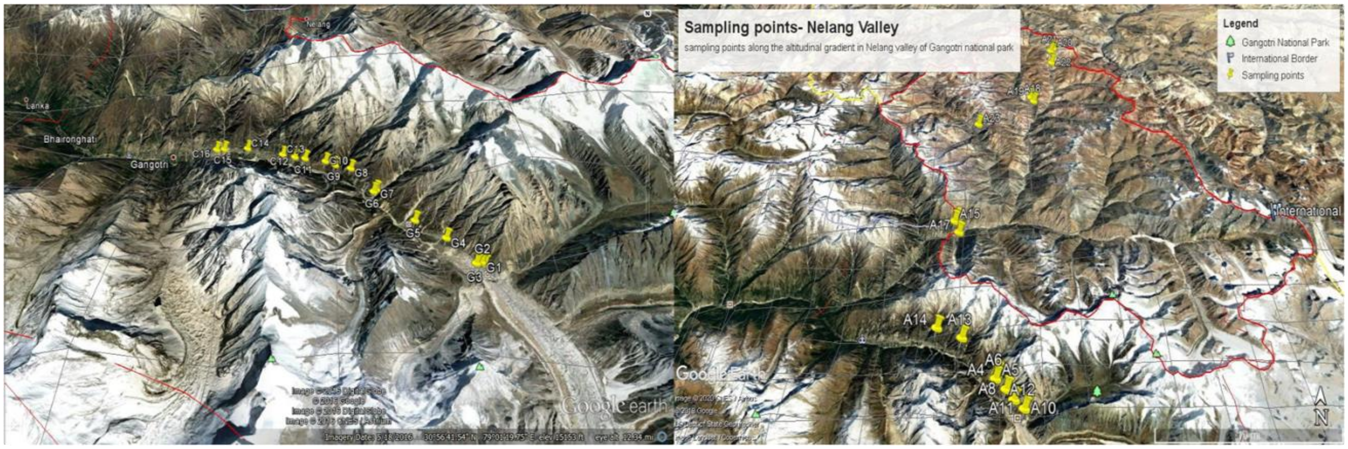

Fig. 3 Sampling sites in Gangotri and Nelang Valley magnified on satellite imagery

The soil has been sampled along the elevation gradient across different vegetation ranging from 3000-5000 m (Gangotri valley and Nelang Valley) (Fig. 3). At a sampling site, beneath the host plant, leaf litter (if present) as well as the upper layer of soil was removed. Soil samples were collected at 10-20 cm depth using soil auger of diameter 3 cm (Rizvi, 2008). Random sites were selected at every 100 m elevational gradient. Five to six sampling points were taken to get maximum diversity which constituted one composite sample. Sampling was also performed in the same manner across the different vegetation types (Subalpine-*Deodar, Pinus, Betula*, Alpine Scrub -*Artemisia, Caragana*, Mixed shrubs). These were packed in an airtight polythene bag and transferred to lab for analysis. During May 2017 and 2018, 24 soil cores were collected from experimental plots (6 Treatment Plots + 6 Control Plots x 3 Sites (with replicates) x 2 years = 24 total samples) (Fig. 4). Cores were taken 10 cm deep using soil auger of diameter 3 cm and shovel in case of rocky soil from the center of the plot to minimize any edge effects. Samples were transferred to the lab in airtight bags. Soil nematodes were extracted from 100 g samples by using cobs sieving and decantation technique Nematodes were identified up to the genus level by BX53 DIC /BF Olympus research microscope with an attached DP27 digital camera. Nematode genera were allotted to trophic groups and colonizer- persister groups and ecological indices were calculated. Nematodes were identified according to Yeates et al. (1993). All nematodes extracted from soil samples were identified and counted.

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Fig. 4 Installation of Open Top Chamber

Nematodes were extracted using decantation and sieving (Cobb, 1918) method. Nematodes were collected after 24 hours, heat-killed, and fixed with a Formalin-acetic acid fixative (FAA) solution. Specimens were identified to the genus level using an inverted microscope at 100 X magnification Nematode genera will be allotted to trophic groups (Yeates et al., 1993) and colonizer-persister groups based (Bongers, 1990). Simultaneously, analysis of soil was done for various parameters. Different parameters such as soil reaction (pH), soil moisture, organic carbon, available nitrogen, potassium, and phosphorus, and soil texture were analyzed in the laboratory by using standard protocols. Soil pH was determined in 1: 2.5 soil: water ratio using the pH meter with glass electrodes (Jackson, 1973); electrical conductivity (µSc m-1) was determined by the method of Jackson (1973). The organic carbon in the soil was estimated by methods suggested by Walkley and Black (1934); total N content by alkaline potassium permanganate (Kjeldahl, 1883); NaHCO3 extractable P (Olsen et al., 1954) by spectrophotometer, ammonium acetate extractable K (Hanway and Heidel, 1952) by flame photometer.

After sample processing the following community and diversity related indices were calculated: Frequency N: Frequency of nematode genus, i.e. the number of samples in which the genus was present. Absolute frequency (AF): (Frequency of the genus) /total number of samples counted X 100. Mean density (D): Number of nematode specimens of the genus counted in Samples / total number of the samples collected. Relative density (RD) %: Mean density of the genus /Sum of the mean density of all nematode genera X 100.

Apart from that the Shannon's diversity was calculated with a formula $H' = -\Sigma$ pi ln pi. Maturity indices were calculated based on c-p values assigned to different genera of soil nematodes, where c-p value 1-5 represents r-strategy colonizers to K-strategy persister; MI -Free-living nematodes with cp1-5 (Bongers, 1990); MI25 Free-living nematodes with cp 2-5 (Bongers et al., 1995; Neher and Campbell, 1994). PPI- Plant-parasitic nematodes (Bongers, 1990); Nematode Channel Ratio calculated as NCR = B/B+F. Enrichment index calculated as EI = (e/e+b) x100. Structure index calculated as (SI) = (s/s+b) x100 and Channel ratio was calculated (CI) to understand the dynamics of soil food web.

5.2 Micro-flora and fauna: assemblage, diversity and distribution

5.2.1 Bacterial diversity and community composition

For taxonomic composition of the soil bacteria we analyzed soil samples (n = 80) collected along a elevation gradient from 3000-4000m at every 100m increase inside Gangotri National Park (GNP) covering different seasons. The major habitat types along the gradient are subalpine forest (3000-3500m), alpine scrub (3500-3900m), alpine meadow (3900-4000m) and moraine (4000m). Through next generation sequencing we generated a total of 3,575,315 sequences of 16S rDNA bacterial marker gene after quality check. These sequences were classified into different operational taxonomic units (OTUs) based on 97% sequence similarity level for bacterial species identification. On average 46819±11962 sequence reads per sample were analyzed. The sequences were grouped at all taxonomic levels starting from phylum to genus. Of the identified OTUs, we could classify 97.1% into 33 phyla, 87.1% to 101 classes, 84% to 252 orders, 80% to 423 families, 75.4% to 956 genera and 1.2% to 20945 species (Table 1). Twelve bacterial phyla with relative abundance >1 % were found to be abundant along the gradient. The dominant phyla were *Proteobacteria* (37.2%), *Actinobacteria* (24.5%), *Firmicutes* (9.9%), *Acidobacteri*a (5.22%), *Bacteroidetes* (4.47%), *Planctomycetes* (4.1%), *Patescibacteria* (3.3%), *Verrucomicrobia* (3.25%), *Gemmatimonadetes* (2.4%), *Dependentiae* (1.1%), *Chlamydiae* (1.38%) and *Chloroflexi* (1.87%) accounting for 98.69% of the total bacterial sequence reads identified (Fig. 5). Ten bacterial taxa identified at genus level with relative abundance > 1 % were found to be abundant along the gradient. Of these, 17% genera belong to the phylum *Proteobacteria*, 23% to *Actinobacteria*, 2.9% to *Firmicutes*, 1.7% to *Verrucomicrobia* (Fig. 6)

Table 1. Taxonomic composition of bacteria in Gangotri National Park

Taxonomic level	Total OTU	% Taxonomic classification
Phylum	33	97.1
Class	101	87.1
Order	252	84
Class	423	80
Genus	956	75.4
Species	20954	1.2

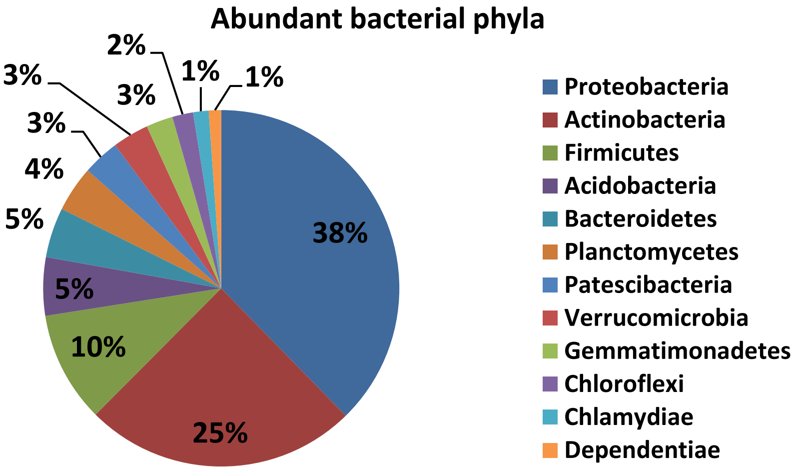


Fig. 5 Relative abundance of bacterial abundant phyla along elevation gradient in GNP

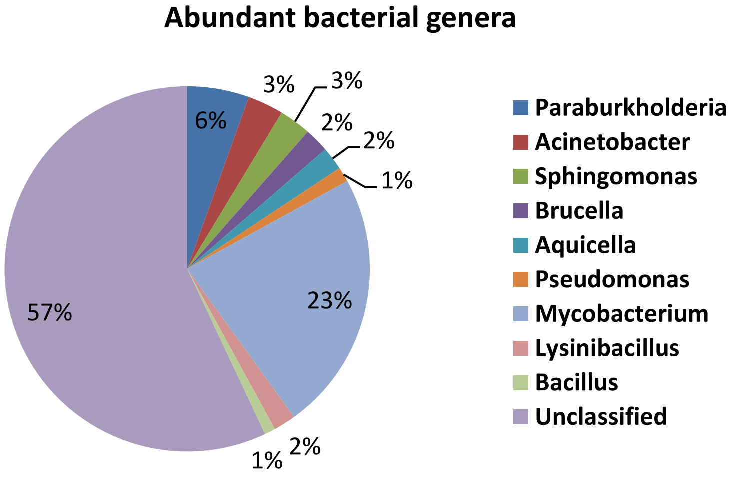


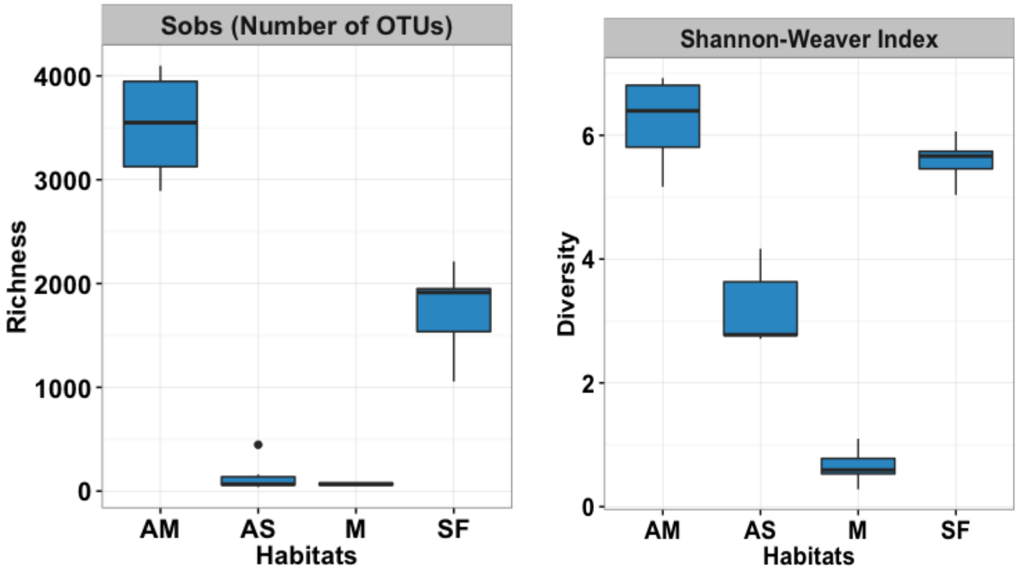
Fig. 6 Relative abundance of bacterial genera along elevation gradient in GNP

5.2.2 Bacterial indicators taxa for different habitats

We have identified indicator taxa at genus level using indicator species analysis for subalpine forests and alpine meadow, which would be important for long term monitoring purposes. The list of indicator taxa is provided in Table 2.

5.2.3 Bacterial richness and α-diversity along elevation gradient

We estimated bacterial richness i.e. number of observed OTUs by Sobs and α-diversity by Shannon–Weaver index. Richness and α-diversity varied between habitats along the gradient. Richness and diversity ranged from 69.12±11.35 to 3522±568 and 0.65±0.2 to 6.22±0.8 from morainic soil (4000 m) to alpine meadow (3900-4000m) respectively (Fig. 7a and 7b). We found significant difference in richness and diversity between morainic soil, alpine meadow and subalpine forest (3100-3500m) (Kruskal-Wallis 1 way ANOVA, P = 0.01) (Fig. 7a and 7b). Similarly, bacterial richness and diversity was significantly different between sparsely vegetated alpine scrub (3600-3900m), alpine meadow and subalpine forest (Kruskal-Wallis 1 way ANOVA, P = 0.03) (Fig.s 7a and 7b).



(a) (b)

Fig. 7. Bacterial richness and diversity of different habitats along elevation gradient. Abbreviations: M = Morainic soil, AM= Alpine meadow, AS = Alpine scrub, SF = Subalpine Forest. Sobs = Observed richness, Shannon-Weaver = α-diversity index.

5.2.4 Bacterial β-diversity and distribution along elevation gradient

To calculate bacterial β-diversity and compare community composition between habitats, we performed Hellinger transformation of relative abundances of OTU at genus level and calculated Bray-Curtis dissimilarity matrices. To visually assess whether habitats with dissimilar vegetation harbored different microbial communities we conducted principal-coordinate analysis (PCoA) on Bray-Curtis dissimilarity matrix. Principal-coordinate analysis (PCoA) showed that there is no clear difference in community composition between the habitats apart from the moraine, which harbors significantly different composition (Fig. 8). When the OTUs were grouped at phylum level, the relative abundance of *Proteobacteria* was highest in alpine scrub (64%) and lowest in morainic soil (6.74%), whereas *Actinobacteria* dominated morainic soil (90.1%) and was relatively less in other habitats [alpine meadow (25.6%), subalpine forest (18.24%) and alpine scrub (14.76%)] (Fig. 9). While alpine meadow had the highest relative abundance of *Firmicutes* (24.4%), *Planctomycetes* (8.64%) and *Chloroflexi* (3.27%), subalpine forest had *Bacteroidetes* (6.03%) as the highest, otherwise relative abundance of *Acidobacteri*a, *Patescibacteria, Verrucomicrobi, Chlamydiae* and *Dependentiae* were equal in alpine meadow and subalpine forest (Fig. 9). *Proteobacteria* is categorized as copiotrophic bacteria, which live in nutrient-rich environments capable of rapidly using available resource but cannot tolerate low nutrient habitats. Therefore bacteria belonging to this phylum are more abundant in nutrient rich habitats along the elevation. *Actinobacteria* live particularly in soil with low moisture and organic carbon content by virtue of their hyphal growth and hence have been found in greater abundance in morainic soil. *Acidobacteria* is absent in morainic soil and other abundant phyla such as *Bacteroidetes, Verrucomicrobia, Patescibacteria, Gemmatimonadetes, Planctomycetes, Chlamydiae* present in habitats with vegetation growth are relatively low in abundance in morainic soil (Fig. 9). The phylum *Chloroflexi* is more abundant in alpine herbaceous meadow and subalpine forest habitats.

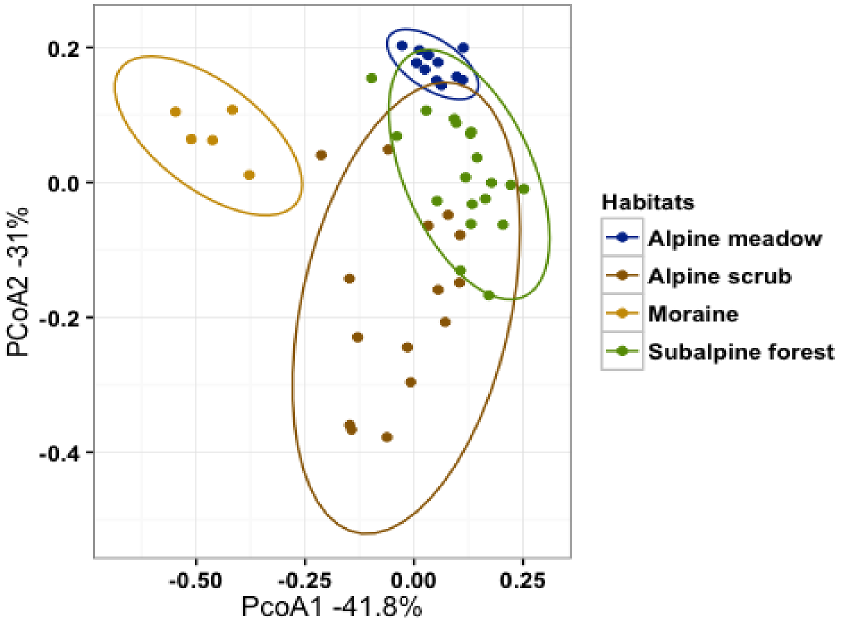


Fig. 8 Principal coordinate analysis (PCoA) based on Bray-Curtis dissimilarity matrices of OTU abundance at genus level for different habitats along elevation

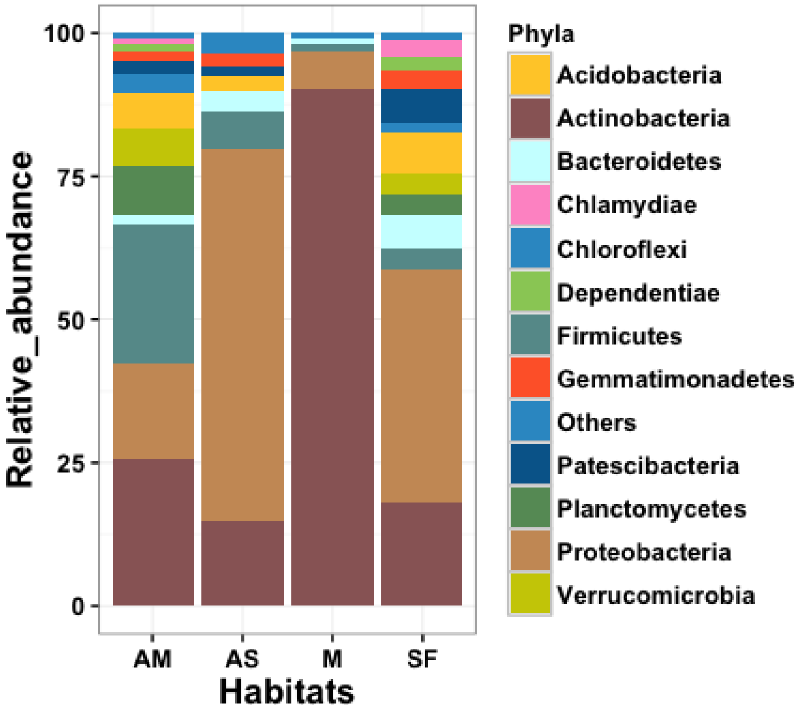


Fig. 9 Relative abundance of dominant bacterial phyla in different habitats along elevation gradient. Abbreviations: M = Morainic soil, AM= Alpine meadow, AS = Alpine scrub, SF = Subalpine Forest.

Table 2. Indicator species in (a) alpine meadow and (b) subalpine forest

(a) Alpine meadow indicator genus

	Taxonomy						
S	**Phylum**	**Class**	**Order**	**Family**	**Genus**	**In**	**p.**
1	Proteobact	Alphaproteoba	Acetobacteral	Acetobacterac	Acidicaldus	1	0.
2	Proteobact	Gammaproteo	Betaproteoba	Burkholderiac	Pelomonas	1	0.
3	Proteobact	Deltaproteoba	Myxococcale	Phaselicystida	Phaselicystis	1	0.
4	Firmicutes	Bacilli	Bacillales	Planococcacea	Chungangia	0.9	0.
5	Firmicutes	Bacilli	Bacillales	Planococcacea	Domibacillus	0.9	0.
6	Planctomy	Planctomyceta	Gemmatales	Gemmataceae	Fimbriiglobus	0.9	0.
7	Armatimo	Chthonomona	Chthonomona	Chthonomona	Chthonomonas	0.9	0.

(b) Subalpine forest indicator genus

	Taxonomy						
S	**Phylum**	**Class**	**Order**	**Family**	**Genus**	**In**	**p.val**
1	Proteobact	Alphaproteob	Caulobactera	Caulobacterac	Caulobacter	0.9	0.001
2	Proteobact	Alphaproteob	Rickettsiales	SM2D12	SM2D12_ge	0.9	0.001
3	Bacteroide	Bacteroidia	Sphingobacte	Sphingobacter	Mucilaginibacter	0.9	0.001
4	FBP	FBP_cl	FBP_or	FBP_fa	FBP_ge	0.9	0.001
5	Bacteroide	Bacteroidia	Chitinophaga	Chitinophagac	Cnuella	0.9	0.001

5.2.5 Lichen species richness along elevation gradient

More than 1500 samples of lichens were collected from Bhagirathi basin, Uttarakhand. A total of 291 species were identified including micro and macrolichens from various habitat types with respect to different elevation zones and vegetation types. These species belong to 87 genera and 33 families occur on various substrata in subtropical, montane, subalpine and alpine regions of the basin. Parmeliaceae was the largest family with 87 species recorded in the study area followed by Physiaceae (34), Lecanoraceae (27), Cladoniaceae (20), Collemataceae (13) and Ramalinaceae (11) (Fig. 10).

The majority of Parmeliaceae species have a foliose, fruticose, or subfruticose growth form and grows abundantly in the soil, bark or as epiphytes. Maximum diversity of the species was recorded in the montane and subalpine forests. An interesting species such as, *Menegazzia terebrata*, which is the only known species under the genus *Menegazzia* in Northern hemisphere was also recorded during the study. Representation of soil-dwelling lichens like genus *Cladonia* also reflect good habitat conditions in the study area. Some of the ecologically important species, *Usnea longissima*, *U. orientalis* which are important fodder for the Himalayan musk deer during the lean season were also recorded from the area. Many species are still to be identified, which may lead to increase in the tally of the recorded species during the study.

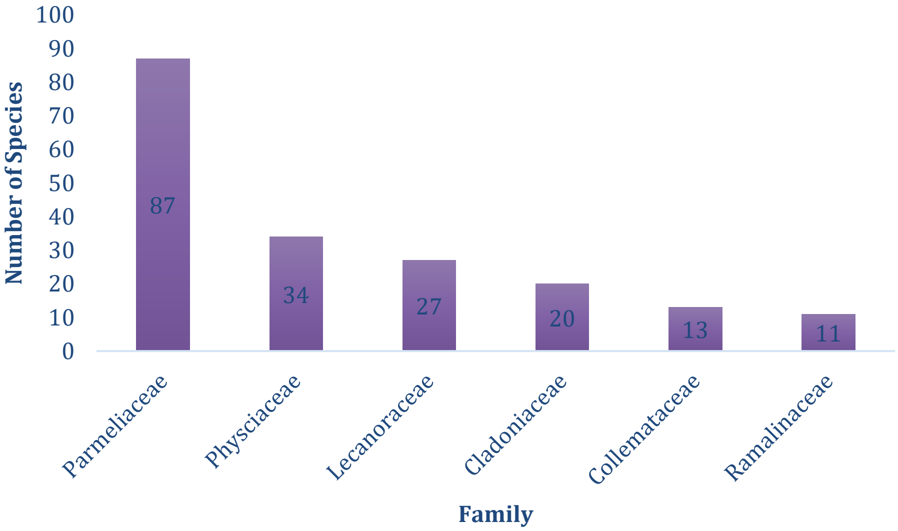


Fig. 10 Dominant lichen families recorded in the study area

5.2.6 Patterns of species Richness

The species richness was maximum in elevation zones between 2000-2500 m and 3500-4000 m asl (Fig. 11). This zone has some of the undisturbed and dominant oak forests in the study area especially on way to Dayara from Raithal and Barsu, on the way to Gomukh glacier from Gangotri temple and in the Bhilangana valley which supports the luxurious growth of the lichen with high species richness. Other studies also suggested a peak of high species richness in mid-elevation zones for major families of lichen in the Himalayan region (Baniya et al. 2014). Areas below 1500 m asl have low species richness due to comparatively low canopy cover and anthropogenic pressure of lopping and grazing. Elevation zone of 1000-1500 m asl in the valley has most of the hill settlements as this zone supports a large number of agricultural practices by local people. This condition leads to more pressure on forest resources. As compared to this, high elevation zones 3500-4000 m asl have more protected area (PA) status and have low grazing and resource collections which might be suitable for the high lichen growth and richness.

Fig. 11 Patterns of lichen species richness along the elevation gradient in the study area

5.2.6 Soil-inhabiting nematode diversity and community composition

Fifty-seven genera belong to 30 families and eight orders from Gangotri valley and Thirty-four genera belongs to 20 families and eight orders from Nelang valley were recorded. *Aporcelaimus* and *Discolaimus* were the most dominant genera and also among the predators with the highest frequency of occurrence 88.24% and RD 4.71; 6.41% respectively, followed by *Plectus* and *Wilsonema* (frequency of occurrence 82.35%). *Cryptonchus*, *Tylocephalus*, and *Alirhabditis* found to be rare with a frequency of occurrence 5.88% and RD 0.03%. Whereas, among the predators, Mylonchulus recorded as a rare genus (N=1 and AF=5.88%).

Plectus and *Wilsonema* were the most dominant genera among the bacterivorous with the highest frequency of occurrence 82.35 % and RD 6.07; 6.87% respectively, while *Cryptonchus* was the rarest with a frequency of occurrence 5.88% and RD 0.03%. Among plant parasite, *Dorylaimellus* was the most dominant genus (N=11, AF= 64.7%) while *Pratylenchus*, *Merlinius*, and *Coslenchus* were the least common (N=3, AF=17%). The most frequent genus among fungivores was *Aphelencoides* (N=12, AF=70%) and least was *Tylenchus* (N=8). *Moshajia* was the most dominant genus in omnivores (N=14, AF= 82%) whereas *Campydora* was least frequent N=3. In Nelang valley, *Stegelletina* was the most dominant genera and also among the predators with the highest frequency of occurrence 100% and RD 4.89. Various genera dominate among the bacterivorous with the high frequency of occurrence, while *Amphidelus* and *Cephalobus* were the least with the frequency of occurrence 20% and RD 0.5% and 0.28% respectively (Table 3).

Bacterial feeders dominate in the study area, followed by predators, omnivores, and plant-parasites in abundance. Bacterivores (44%) represented the highest genetic diversity, followed by predators (19%), plant parasites (18%), omnivores (12%), and fungivores (7%). Based on individual abundance, bacterivores represented the highest abundance (49%), followed by predators 15%, omnivores 14 %, plant parasite 13%, and fungivores 9% in Gangotri valley while in high elevational one Nelang valley, Bacterivores (55%) represented the highest genetic diversity, followed by fungivores (15%), predators (12%), plant parasites (12%), and omnivores (6%) (Fig. 12).

Table 3 Population structure of soil-inhabiting nematodes in Gangotri Valley and Nelang Valley

Genera	Gangotri Valley		Nelang Valley	
	AF%	**RD%**	**AF%**	**RD%**
Bacteriovors				
Acrobeles	76.47	5.55	95	6.79
Acrobeloides	70.59	3.64	95	6.79
Alirhabditis	5.88	0.03	x	x
Cephalobus	35.29	0.83	20	0.28
Cervidellus	17.65	1.04	95	10.85
Chiloplacus	64.71	1.91	95	4.95
Cryptonchus	5.88	0.03	x	x
Eucephalobus	17.65	0.31	65	1.78
Pseudacrobeles	52.94	0.83	55	2.11
Stegelletina	41.18	1.08	100	4.89
Plectus	82.35	6.07	95	4.06
Anaplectus	29.41	0.45	x	x
Ceratoplectus	52.94	1.94	75	1.95
Cylindrolaimus	70.59	3.61	x	x
Prismatolaimus	64.71	10.86	60	1.5
Rhabdolaimus	35.29	0.59	75	2.95
Wilsonema	82.35	6.87	50	1.33
Teratocephalus	47.06	1.77	75	2.89
Mesorhabditis	29.41	0.45	25	0.56
Monhystera	29.41	0.38	x	x
Nothacrobeles	35.29	0.56	75	0.83
Panagrolaimus	17.65	0.21	75	2.39
Protorhabditis	5.88	0.03	x	x
Rogerus	23.53	0.49	x	x

Tylocephalus	5.88	0.03	x	x
Amphidelus	x	x	20	0.5
Fungivore				
Aphelencus	52.94	1.67	45	1.45
Aphelencoides	70.59	3.3	90	3.73
Tylenchus	47.06	2.43	x	x
Tylencholaimus	64.71	0.62	x	x
Axonchium	52.94	0.66	x	x
Ditylenchus	x	x	70	2.67
Paraphelenchus	x	x	70	3.73
Filenchus	x	x	55	2.34
Plant Parasites				
Basiria	35.29	0.97	x	x
Coslenchus	17.65	1.25	25	1.22
Helicotylenchus	52.94	1.39	20	2.73
Hemicycliophora	52.94	1.77	10	0.56
Hoplolaimus	58.82	1.8	x	x
Merlinius	17.65	0.73	x	x
Paratylenchus	23.53	1.01	x	x
Pratylenchus	17.65	0.69	x	x
Tylenchorynchus	58.82	1.67	70	2.17
Dorylaimellus	64.71	1.42	x	x
Omnivore				
Campydora	17.65	0.28	x	x
Eudorylaimus	76.47	5.66	90	5.34
Moshajia	82.35	2.71	x	x
Oriverutus	17.65	0.42	x	x
Thornenema	76.47	1.42	x	x
Dorylaimoides	58.82	2.29	x	x

Dorylaimus	52.94	1.53	x	x
Mesodorylaimus	x	x	40	5.06
Predators				
Actinolaimus	82.35	2.01	55	1.78
Aporcelaimellus	82.35	3.05	x	x
Aporcelaimus	88.24	2.78	x	x
Clarkus	23.53	0.38	x	x
Coomansus	17.65	0.28	55	1.33
Discolaimus	88.24	3.78	x	x
Discolaimoides	64.71	1.7	90	4.56
Mylonchulus	5.88	0.07	x	x
Prionchulus	23.53	0.21	75	3.95
Tripyla	35.29	0.49	x	x

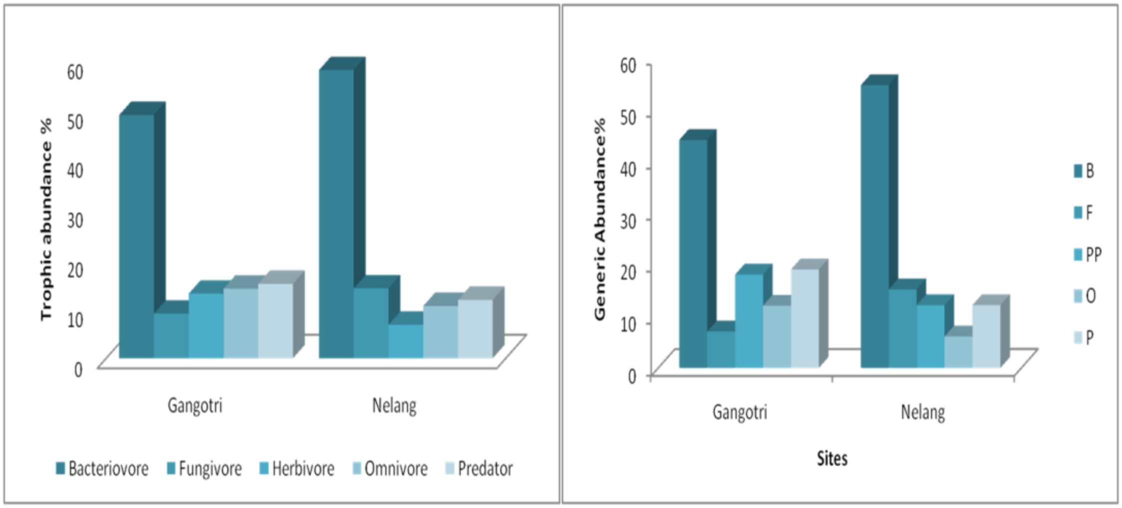


Fig. 12 Trophic Abundance and Generic abundance in Gangotri and Nelang Valley

Among the 57 genera, Dorylaimida (30%) represented the most abundant order (Fig. 13), followed by Araeolaimida (21%), Rhabditida (17%), Tylenchida (13%), Monhysterida (11%

each), Aphelenchida (5%), Enoplida (2%), Mononchida in Gangotri while in Nelang valley, Rhabditida(42%) represents the most abundant order followed by Dorylaimida (16.7%) and Monhysterida (1.5%) as least abundant order. Dorylaimida found to be the most abundant group indicating the fewer disturbances in the Gangotri valley. The result is in agreement with the findings of other studies on soil nematode community structure in forest areas (Johnson et al., 1972; Thomas, 1978; Sohlenius and Wesilewska, 1984; Neher et al., 2005).

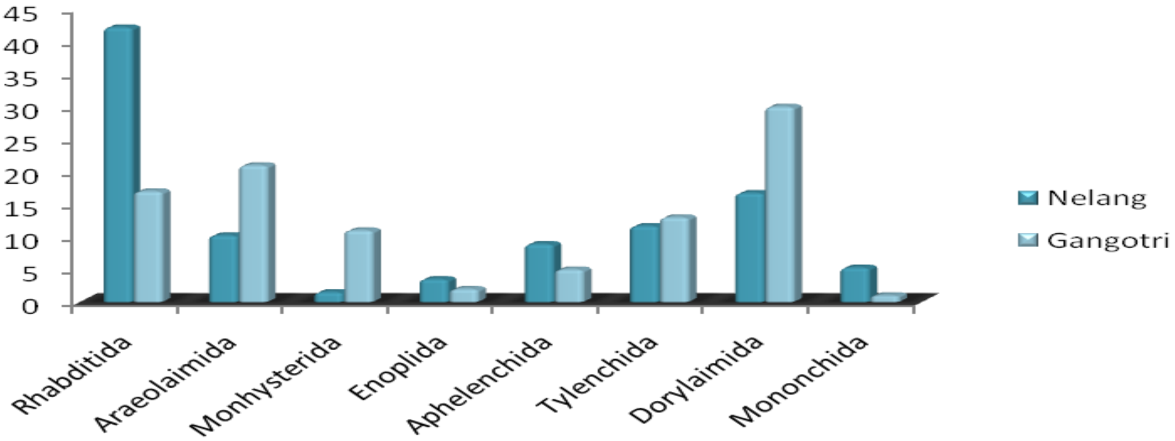


Fig. 13 Ordinal diversity (Abundance) in Gangotri and Nelang Valley.

The soil in the park was sandy loam and vary from (5.57 -8.0) along the elevation gradient. However, Soil Organic Carbon (SOC) increases in the middle elevation at 3500-3600 m and further decreases along the elevational gradient. The mid-elevation mixed subalpine forest harbors dense vegetation cover of *Betula utilis* and *Pinus wallichiana*. The soil was dark in comparison with the color patterns of samples collected from higher elevations. The correlation analysis indicated that the soil of this area was also rich in nutrients such as Nitrogen and Phosphorous. The mean soil Nitrogen, Phosphorus, and Potassium contents calculated as 0.311±0.01%, 0.697±0.1%, and 0.142±0.09 %respectively. The value of NPK first increased and then decreased along the elevation, but the changes were not statistically significant (Kruskal Wallis test, $p>0.05$ for all cases (Table 4).

Table 4 Correlation coefficients and their significance in 0.05 level (2-tailed) among various soil physicochemical parameters

	N	**P**	**K**	**pH**	**EC**	**SM**	**SOC**	**Sand**	**Clay**	**Silt**
N	1	0.029	0.627	0.026	0.881	0.082	0	0.108	0.293	0.187
P	**0.685***	1	0.651	0.498	0.365	0.162	0.006	0.726	0.803	0.651
K	0.176	0.164	1	0.7	0.96	0.328	0.467	0.405	0.855	0.214
pH	**0.693***	0.243	-0.14	1	0.275	0.354	0.08	0.3	0.318	0.59
EC	-0.055	-0.321	-0.018	0.383	1	0.347	0.556	0.405	0.328	0.446
SM	0.576	0.479	0.345	0.328	-0.333	1	0.038	0.009	0.002	0.098
SOC	**0.964****	**0.794****	0.261	0.578	-0.212	**0.661***	1	0.138	0.276	0.229
Sand	-0.539	-0.127	-0.297	-0.365	0.297	**-0.770****	-0.503	1	0.002	0.006
Clay	0.37	0.091	0.067	0.353	-0.345	**0.842****	0.382	**-0.842****	1	0.187
Silt	0.455	0.164	0.43	0.195	-0.273	0.552	0.418	**-0.794****	0.455	1

5.3 Experimental warming set up: Open Top Chambers (OTCs)

5.3.1 Response of soil bacteria to experimental warming

5.3.1.1 Variation in air and soil temperature under experimental warming:

Annual mean air and soil temperature was found to be 2.49°C and 5.43°C respectively at our experimental site. The OTCs successfully increased mean annual soil and air temperature by 1.5°C and 1.7°C respectively in comparison to control plots during the studied period.

5.3.1.2 Variation in plant growth, soil properties and enzyme activities under experimental warming:

After 2 years of warming we found significantly higher cover and abundance of plants inside all OTCs during both spring and summer (growing phase) (Fig. 14). On the contrary experimental warming had different impacts on the soil properties. Inside OTCs soil moisture content and pH showed decreasing trend during both seasons (Fig.s 15a and 15b). Soil organic carbon (SOC), total nitrogen (TN), and C/N ratio did not show any significant variation (Fig. 15c, 15e and 15f). However, dissolved organic carbon (DOC) significantly increased inside OTCs during summer (Mann–Whitney U-test, $p = 0.01$) (Fig. 15d). In addition, we found some effects of warming on activities of microbial extracellular enzymes, such as β-glucosidase and per-oxidase, known for degrading labile and recalcitrant organic material respectively. Activity of both enzymes showed increasing trend inside OTCs in comparison to control plots (Fig. 16a and 16b). Activity of per-oxidase increased by 18.8% during summer and β-glucosidase by 13.7% during spring. However we found no change in microbial biomass carbon (MBC) (Fig. 16c)

5.3.1.3 Variation in soil bacterial community α and β diversity due to experimental warming:

We used 16S rRNA marker gene sequences to determine bacterial community richness (Sobs) and α-diversity (Shannon-Weaver diversity) based on the number of operational taxonomic units (OTUs) identified at 97% sequence similarity. We also studied changes in bacterial community composition at both phylum and genus levels. The warming experiment did not lead to any significant change in bacterial richness and diversity (Mann–Whitney U-test, $p = 0.345$) (Fig. 17). At genus level we observed no significant change in bacterial community composition (Multi Response Permutation procedure, A = -0.04488, $p = 0.8886$). However after two years of warming during summer, relative abundance of some bacterial taxa showed significant change. The relative abundance of phyla *Acidobacteria* significantly (Mann–Whitney U-test, $p = 0.029$) decreased by 38.75 % inside OTCs than control plot (Fig. 18a). In addition we found significant changes in the relative abundance of some rare bacterial genus. We observed significant increase in relative abundances of some rare genera *Pseudorhodoplanes* and *Elsterales_unclassified* belonging to the phylum *Proteobacteria*, and genus *Edaphobacter* belonging to phylum *Acidobacteria* (Fig. 18b). On the other hand, some rare bacterial genus such as *Pseudoxanthomonas*, R7C24_ge and *Mesorhizobium* belonging to *Proteobacteria*, *Subgroup_6_unclassified* and *Blastocatellia_(Subgroup_4)_unclassified* belonging to

Acidobacteria, *Anaerolineaceae_unclassified* belonging to *Chloroflexi*, *Candidatus_Peribacteria* belonging to *Patescibacteria* and *Fimbriimonadaceae_unclassified* belonging to *Armatimonadetes* showed significant decrease in abundance (Fig. 18b).

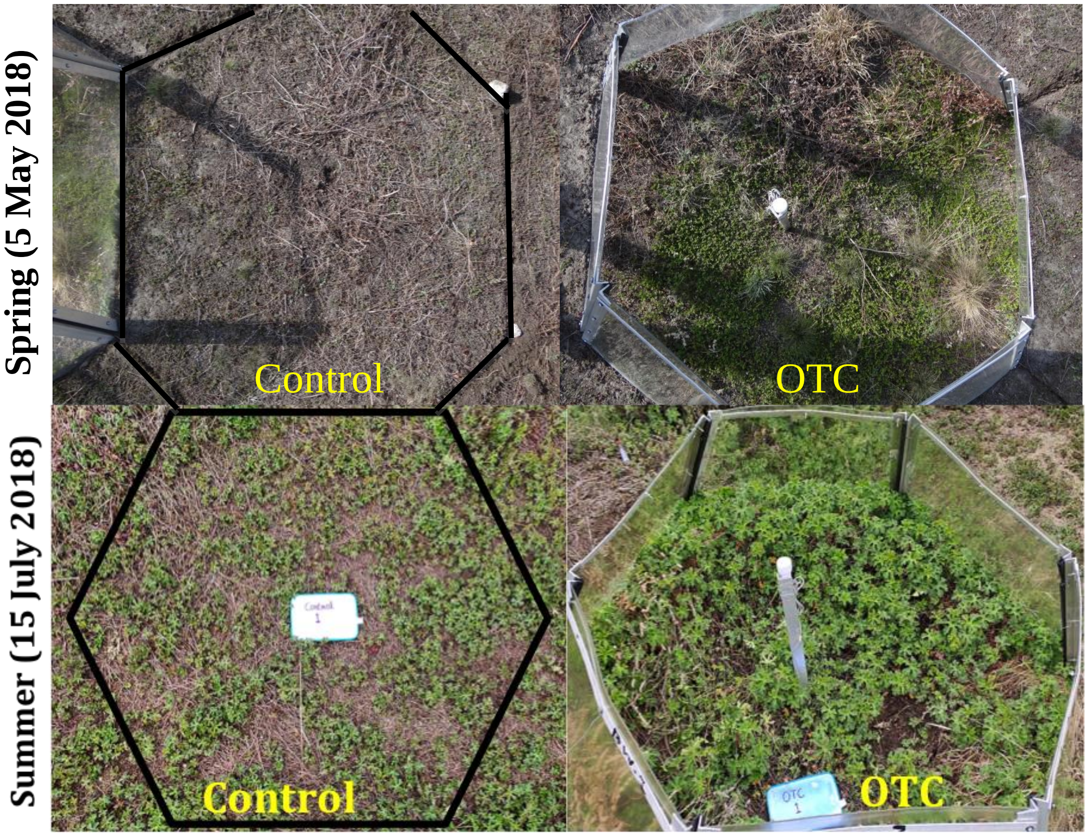
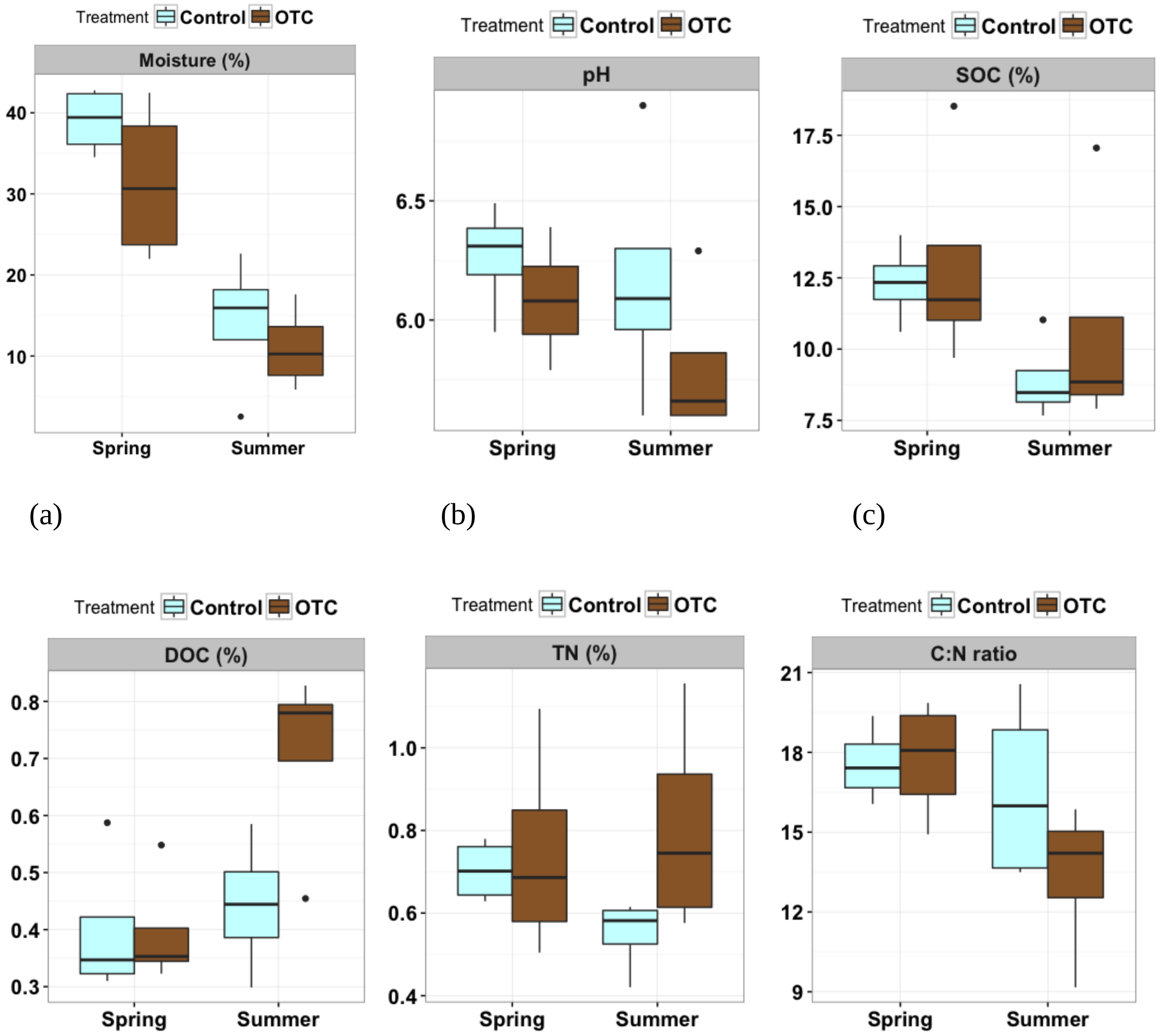


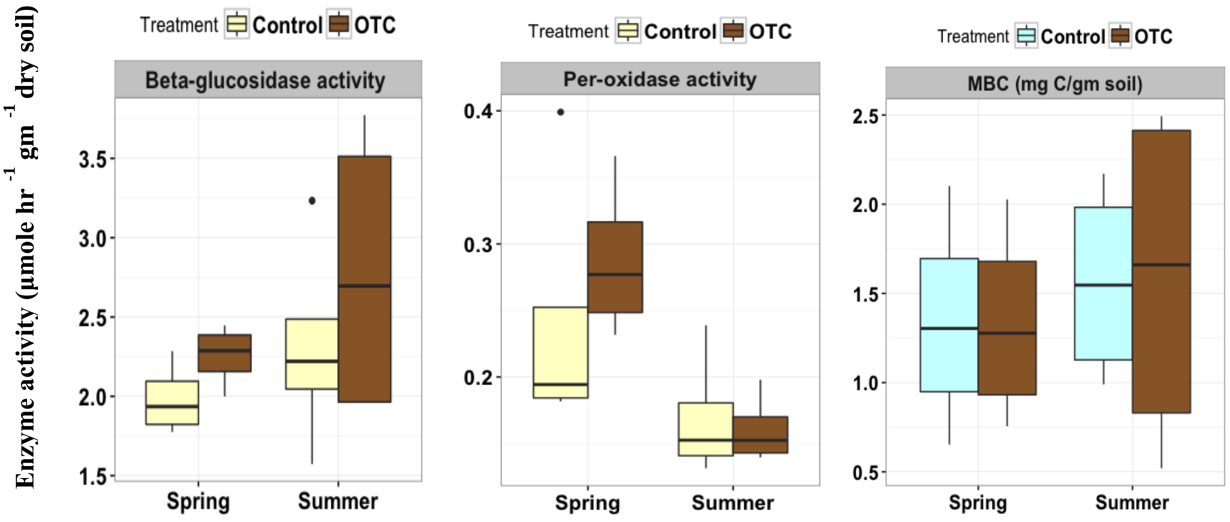
Fig. 14 Changes in vegetation growth after two years warming during spring (May 2018) and summer (July 2018). Abbreviations: OTC = Open top chambers; Control = Control plot.



(a) (b) (c)

(d) (e) (f)

Fig. 15. Variation in soil properties after two years warming during spring (May 2018) and summer (July 2018). Soil property abbreviation: SOC (soil organic carbon); DOC (dissolved organic carbon); TN (total nitrogen); C:N (Carbon to Nitrogen ratio). SOC, DOC and TN are expressed as percentage per gram of soil.



(a) (b) (c)

Fig. 16. Variation in microbial enzyme activites of β-glucosidase and per-oxidase after two years warming during spring (May 2018) and summer (July 2018). Abbreviations: OTC = Open top chambers. Control = Control plot, MBC = Microbial biomass carbon.

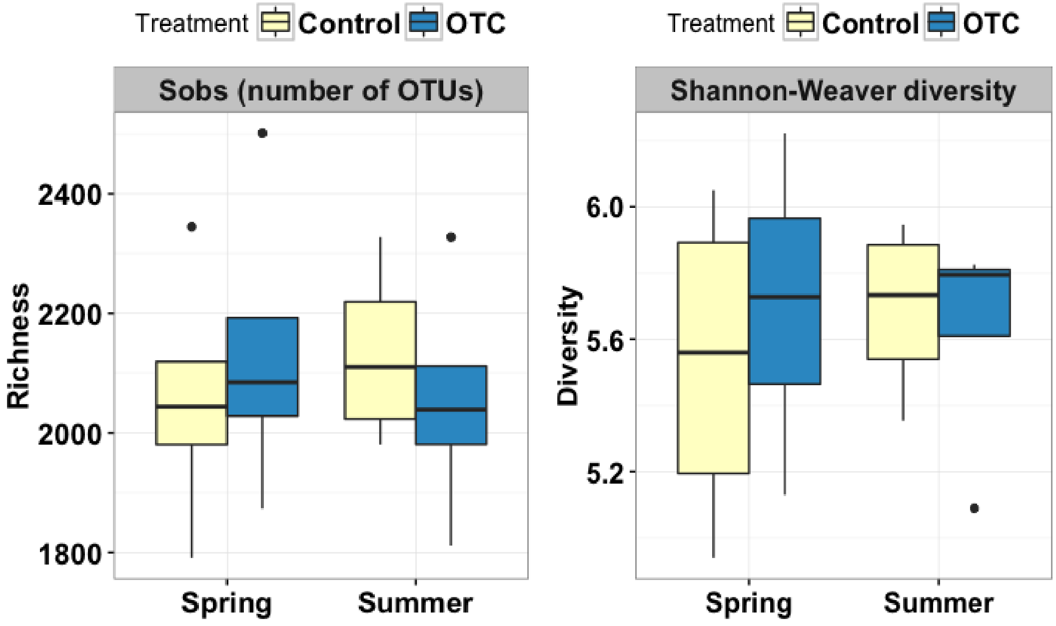
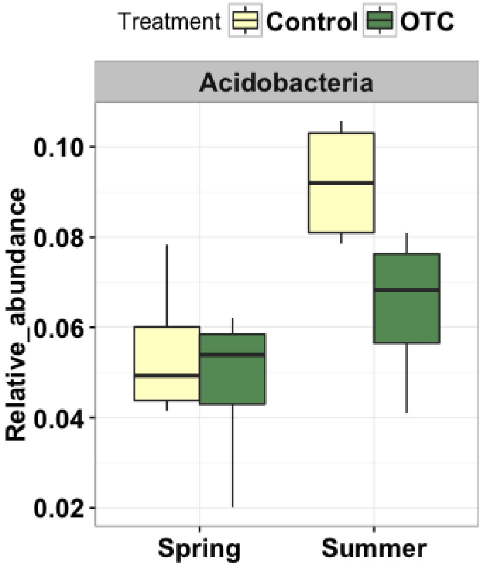
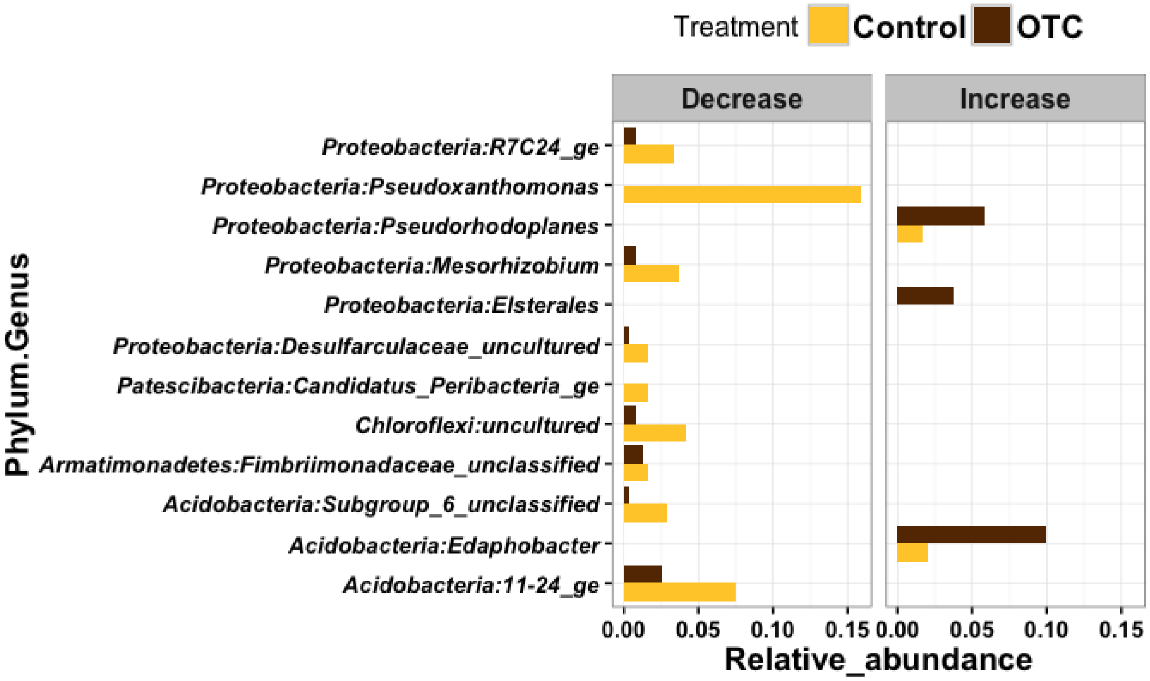


Fig. 17. Variation in bacterial community richness and diversity after two years warming during spring (May 2018) and summer (July 2018). Abbreviations: OTC = Open top chambers, Control = Control plot, Sobs = Bacterial richness.



(a)



(b)

Fig. 18. Changes in relative abundance of (a) bacterial phyla after two years warming during spring (May 2018) and summer (July 2018) and (b) genera after two years warming during summer (July 2018). Abbreviations: OTC = Open top chambers, Control = Control plot.

5.3.1.4 Discussion

Two years of experimental warming using OTCs showed no significant change in bacterial community richness, diversity and composition. This implies that bacterial community at high altitude alpine habitats in IHR is compositionally stable under changing environment and might not experience any loss in diversity under short-term temperature rise scenarios. Some recent studies have reported similar observations from alpine meadow in northwestern Sichuan, China (Zi et al., 2018) and Sub-Artic peatland in Sweden (Weedon et al., 2017). However, the experimental warming led to changes in relative abundance of some bacterial phyla and genus.

We observed a significant decrease in relative abundance of bacterial phyla *Acidobacteria* known to prefer soil with low nutrient availability (Fierer et al., 2007; Orwin et al., 2018). This indicates that short term warming inside OTCs might have increased nutrient availability and affected abundance of bacterial species. This possible increase in nutrient availability might have lead to increase in relative abundances of some rare bacterial genus belonging to *Proteobacteria*, such as *Pseudorhodoplanes* and *Elsterales unclassified,* known for their fast growth preferably in nutrient rich habitats (Fierer et al., 2007; Orwin et al., 2018). Given that *Proteobacteria* are capable of degrading available labile carbon and has high growth rate (Fierer et al., 2007; Orwin et al., 2018), decomposition of soil organic carbon might increase under short term warming. Some rare bacterial genus such as *Pseudoxantho monas*, R7C24_ge, *Mesorhizobium, Blastocatellia_(Subgroup_4)_unclassified,Anaerolineaceae_unclassified, Candidatus_Peribacteria and Fimbriimonadaceae_unclassified,* showed significant decrease in relative abundance and understanding their functional role is critical. The bacterial genera, which have undergone changes in relative abundance due to warming, might serve as good indicators of climate warming in high altitude alpine habitats. In addition we observed increasing trend in the activity of organic carbon degrading enzyme activities and dissolved organic carbon content suggesting that short term warming might lead to functional modification of the bacterial communities with significant impact on soil carbon cycle.

5.3.2 Response of soil nematode community to experimental warming

Six hexagonal OTCs, each chamber was built with high-quality multilayered polycarbonate sheets (4 mm thickness) with high solar transmittance (transmits ~ 92% of visible light, reflect 4% of incoming radiation and pass on ~ 85% of incoming energy). Each site provided with a minimum of two replicates. Chambers installed in the spring of the year 2016. Open top chambers (OTCs) are innovative and cost-effective devices for investigating the effects of altered climatic factors such as temperature, humidity on growth dynamics, and yield response of plants and soil microbial community activity. These chambers are hexagonal in shape and opened on the top. The opened design ensures that the system has airflow and receives the same amount of precipitation during rainfall. A plot is left untreated adjacent to each OTC within two meters having the same area and similar vegetation and serves as a natural control. Due to the thick snow cover, strong winds, and low temperatures during winter in the Himalayan alpine region, experiments can only be conducted during the growing season, which lasts on average from May till mid of November. Weather stations (HOBO U23 Pro v2 Temp and HOBO U23 Pro v2 2X external temperature data logger) are installed in the OTC and the adjacent outside control, at a height of 15 cm above the ground surface for recording air temperature every hour. Soil temperature and moisture are also measured at 5 cm depth. Samples were collected every year from chambers and adjacent control plots at each site. Following the same procedure as mentioned above after sample collection.

There is difference in temperature between experimental and control plots but has no significant effect of on means of daily temperature variability. Comparison of means of soil and air temperature inside OTC and control plot depicted significant difference in case of maximum air and soil temperature in both Chirbasa and Bhojbasa (p-value <0.01). However, though the minimum and average soil and air temperature were slightly (~1 degree C) higher inside OTC than control plot for both places, the differences were not statistically significant except for minimum air temperature (p-value<0.5) for both years (Fig. 19). Nematode community structure was studied in treatment and control plots to understand the effect of change in temperature on soil mesofaunal group. High altitude terrestrial ecosystems are stressed by extreme climatic conditions and strongly nutrient-limited due to direct and indirect effects of snow cover and low temperature in the alpine and subalpine region. Hence minor change may lead to change in community structure of various free-living nematode which is sensitive to change which will be useful for evaluating the impact of climate change in Indian Himalayan system. Dissimilarity tests based on the Bray-Curtis distance showed that nematode communities from the treatment plot were significantly different from the control plots when assessed at the generic level (PERMANOVA p=0.011*) (Fig. 20). But no inter-annual difference in the community

(PERMANOVA p=0.179) with a significant decrease in the relative abundance of predaceous genera *Tripyla*, *Discolaimus* and an increase in *Rhabdolaimus* and *Pseudacrobeles and Acrobeloides* for the treatment plot (Table 5)

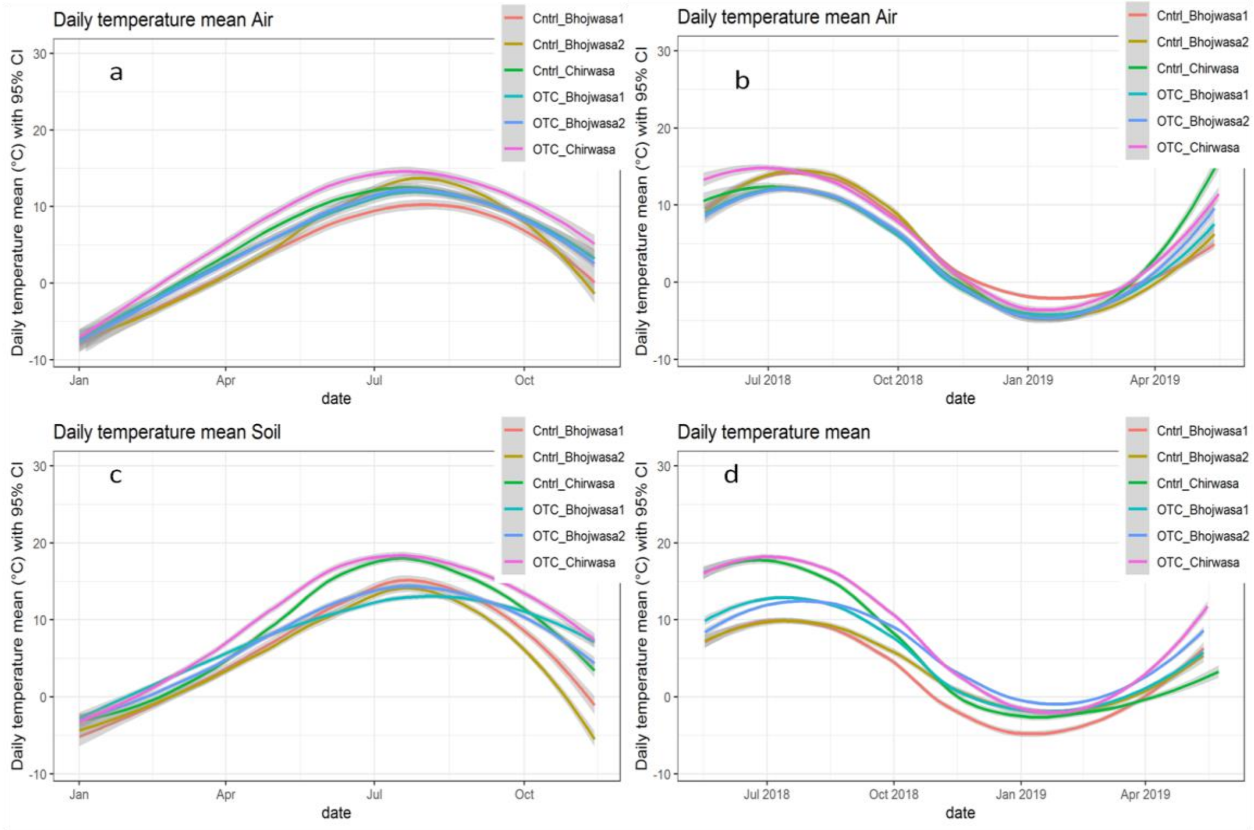


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Fig. 19 a-c Daily mean temperature of air and soil (Jan-Nov, 2017); b-d Daily temperature mean of air and soil (May 2018-April 2019)

Table 5 Average density of nematode taxa in control and OTC plots (values marked with asterisk are significantly different (p<0.05)

Genera	Control	OTC	Genera	Control	OTC
Acrobeles	3.58±0.62	2.35±1.11	*Axonchium*	3.66±0.53	2.3±0.54
Acrobeloides	4±0.71	5.55±1.11*	*Tylenchus*	3.62±0.94	3.2±1.19

Cervidellus	2.66±0.18	2.7±0.57	*Hoplolaimus*	5.91±1.97	2.9±0.47
Chiloplacus	6.37±2.89	3.05±0.59	*Tylenchorynchus*	6.54±2.10	3.95±0.69
Eucephalobus	4.87±1.32	4.9±0.63	*Pratylenchus*	4.41±1.86	1.45±0.40
Pseudacrobeles	2.29±0.20	3.2±0.48**	*Helicotylenchus*	7.29±3.32	2.15±1.06
Stegelletina	1.41±0.55	2.3±0.60	*Aporcelaimellus*	3.08±1.14	1.55±0.83
Plectus	3.45±0.51	1.5±0.67	*Eudorylaimus*	8.16±1.05	4.9±1.87
Anaplectus	0.83±0.39	1±0.54	*Oriverutus*	3.33±1.51	2.25±0.83
Ceratoplectus	1.41±0.46	1.7±0.64	*Discolaimus*	9.79±3.21	1.55±0.55**
Cylindrolaimus	2.41±0.18	1.15±0.55	*Discolaimoides*	3.12±0.90	1.75±1.04
Prismatolaimus	1.41±0.41	1.7±0.61	*Dorylaimellus*	5.66±1.03	4.7±0.72
Rhabdolaimus	4.62±0.95	8.5±1.54*	*Tripyla*	3.5±1.14	1.75±0.85*
Wilsonema	1.79±0.68	2.45±0.95	*Mononchus*	1.08±0.27	1.25±0.37
Teratocephalus	0.12±0.13	0.5±0.32	*Clarkus*	1.95±0.41	1.6±0.81
Aphelencus	1.87±0.40	1.6±0.28	*Prionchulus*	2.08±0.61	1.55±0.42
Aphelencoides	1.70±0.33	1.95±0.49	*Mylonchulus*	1.5±0.66	1.45±0.60

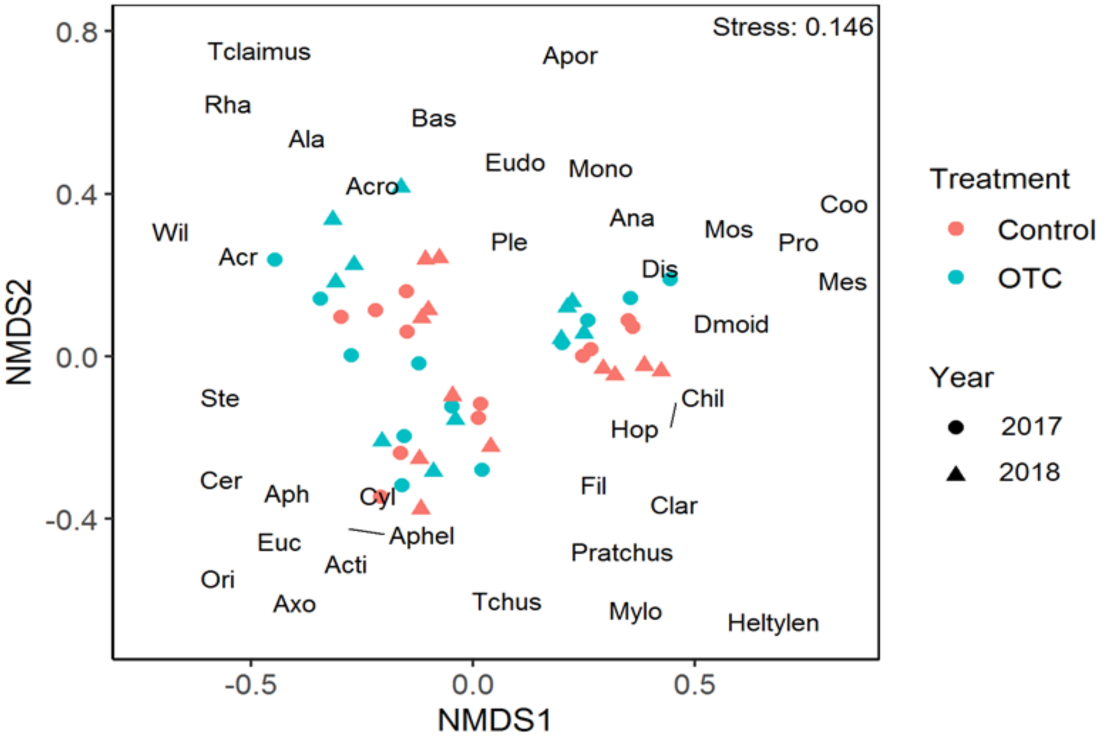


Fig. 20 NMDS ordination (Bray-Curtis dissimilarity) of nematode communities based on relative abundances of nematode genera. Each point reflects the community found in an individual sample (n=12 per treatment x 2 years). Points that are close together have more similar communities than points that are far apart.

To identify nematode food web properties the enrichment index (EI) and structural index (SI) were calculated (Fig. 21). These are the extension to the maturity index (Ferris et al. 2001). Enrichment and structural index guild plot showed a control plot was more enriched but less structured than the control plot based on their response to disturbance and enrichment (Fig. 22). It can be concluded that an increase in temperature increased the disturbance level inside the OTC. The OTC plots have a comparatively greater abundance of nematodes but the nematode community was less diverse and mature (lower MI in OTC) compared to the control plots but was not statistically significant.

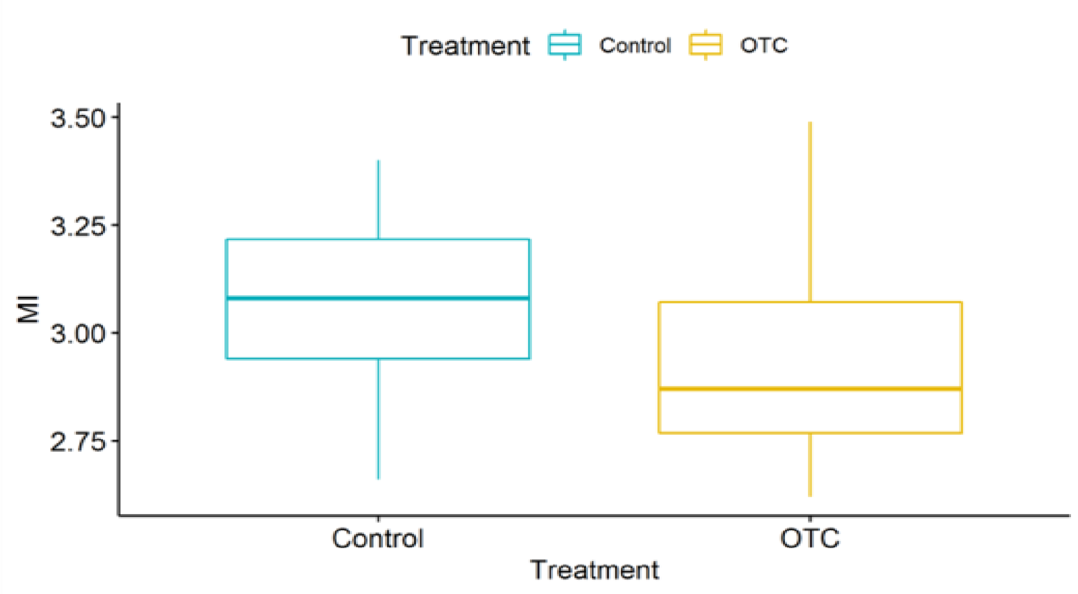


Fig. 21 Maturity index across Open top chamber and Control plot

There was a significant effect of treatment on total nematode abundance, MI by year. Overall, Genera richness, Shannon Index was greater in Control plots but was not statistically significant while MI and total nematode abundance were significantly greater in control plots (p-value=0.005, 0.030 respectively) (Table 6). Structural Index was significantly greater in OTC plots (p-value=0.002) SI indicates an increase in trophic linkages which corresponds to disturbance level (physical or chemical). Plant-parasitic nematode abundance was greater in the OTC plots than the control plots. In terms of the trophic group, Bacteriovores increased in OTC plots which may be due to the increase in microbial activities in treatment plot, and Predators and omnivores significantly decreased in Open top chambers (p-value=0.001, 0.04).

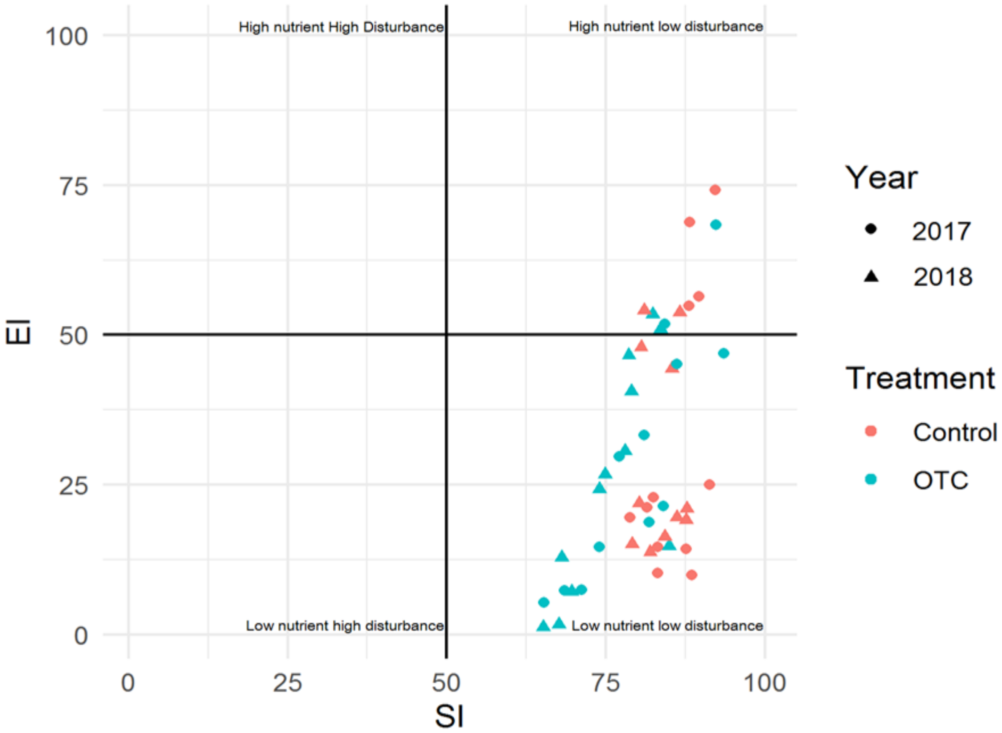


Fig. 22 Structure-Enrichment plot by treatment and year. Quadrants are labeled after Ferris et al. (2001). Colors show treatment: Control plots are red and OTC plots are blue. Shapes show year: circles are 2017 and triangles are 2018.

Table 6 Mean Value ±SD of various nematode community Parameter for control plot and OTC Plots

Indices	Control	OTC
Maturity Index(MI)	3.06±2.91	2.91±0.21
Nematode Channel Ratio(NCR)	0.76±0.11	0.78±0.10
Plant parasite Index(PPI)	0.38±0.28	0.28±0.11
Shannon diversity(H')	3.16±0.11	3.1±0.15
Enrichment Index(EI)	30.71±20.88	27.58±19.1
Structural Index(SI)	84.19±5.68	77.67±8.04

Soil and the air temperature was nearly ~1 °C higher inside OTC in comparison with the control plot outside for almost throughout the year in 2017 except in August- September in Bhojwasa. Thick vegetation cover inside OTC may be one of the explanations of this. The temperature difference was nearly ~1.9 °C higher inside OTC from may 2018-may 2019, but the soil moisture was different across the treatment and control plot, suggesting that warming has indirect effect on nematode diversity by affecting soil moisture in treatment plot. As a result, warming-induced soil moisture could be the the major reason for differences in nematode responses between OTC and Control and for the decrease in soil nematodes trophic groups except for bacterial feeders and Plant parasites in OTC plots in the present study (Table 7). Results showed that an increase in plant parasite nematodes may be due to the decrease in the number of predaceous nematodes as they consume the plant parasite nematodes.

Table 7 Mean Value ±SD of soil nematode trophic groups in control plot and OTC Plots

Trophic group	Control	OTC
BF	47.3±17.0	48±19.3
FF	14.9±6.90	11.7±5.88
PP	12.6±8.15	25.9±19.5
O	21±8.28	16.7±12.0
PR	30.7±12.8	19.3±11.4

5.3.1 Trends along elevation gradients

5.3.2.1 Micro flora

Air temperature was measured by HOBO data loggers (HOBO U23 pro v2, Onset Computer Corporation, MA, USA) deployed along the gradient at 200 m elevation interval from 3100 m to 4000m. Temperature data was recorded at every one-hour interval during the entire study period. Mean annual air temperature decreased along the gradient and ranged from 8.15 to 1.4°C and correlated significantly (Pearson's, $p = 0.001$) with elevation (Fig. 23). To check the relationship between air and soil temperature in the study sites, we also installed two data loggers to measure soil temperature at 3565 m (subalpine forest) and 4020 m (alpine meadow), respectively, for three-year period. Analysis of three years of air and soil temperatures at these two sites showed that there is a strong positive correlation (Pearson's, $p = 0.001$) between daily mean air temperature and soil temperatures at 5 cm depth (Fig. 24). Soil moisture content (SMC), pH, mean temperature previous 30 days of sampling (MT_30days) ranged from 1.88%-17.57%, 4.91-6.65 and 1.35°C-7.19°C respectively (Table 8). High values of SMC were found in alpine meadow and subalpine forest and were significantly higher than alpine scrub and glacial landform (Table 8). In all sites with vegetation pH was generally acidic and was found to be significantly lower in alpine meadow than glacial landform (Table 5). Soil organic carbon (SOC) and total nitrogen (TN) showed contrasting trend. SOC (ranging from 0.13%-5.1%) was found to be highest at lower elevation, i.e, in subalpine forests and TN (ranging from 0.022%-0.42%) was highest at higher elevation, i.e, in alpine meadow (Table 5). C:N ratio in all habitats was found to be below 20:1 and was significantly lower in glacial landform than all habitats with vegetation (Table 8). The soil properties did not show any significant correlation with elevation.

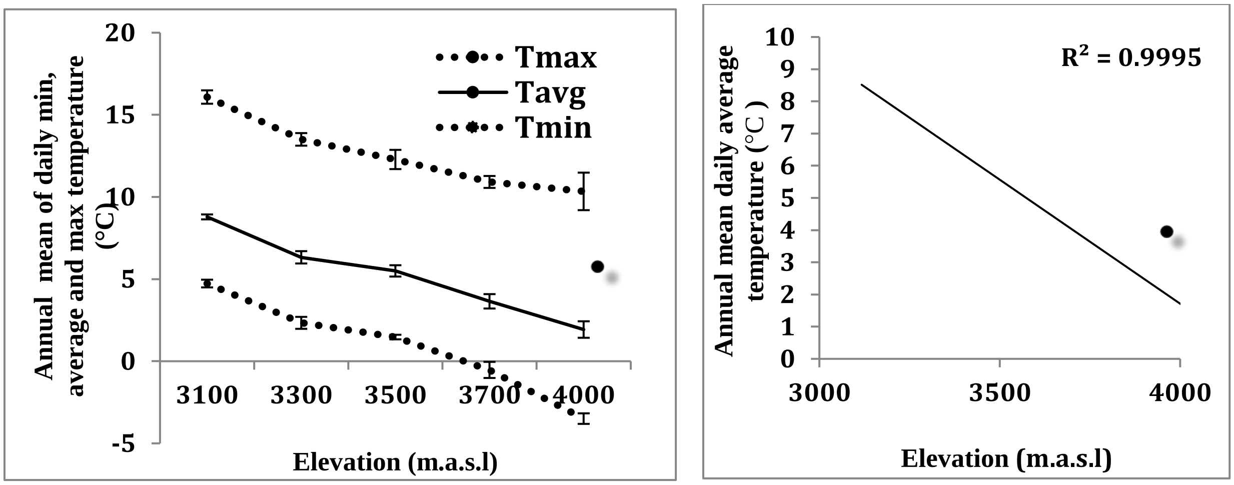


Fig. 23 Annual mean of daily average, minimum and maximum temperature for the years 2016 -2019

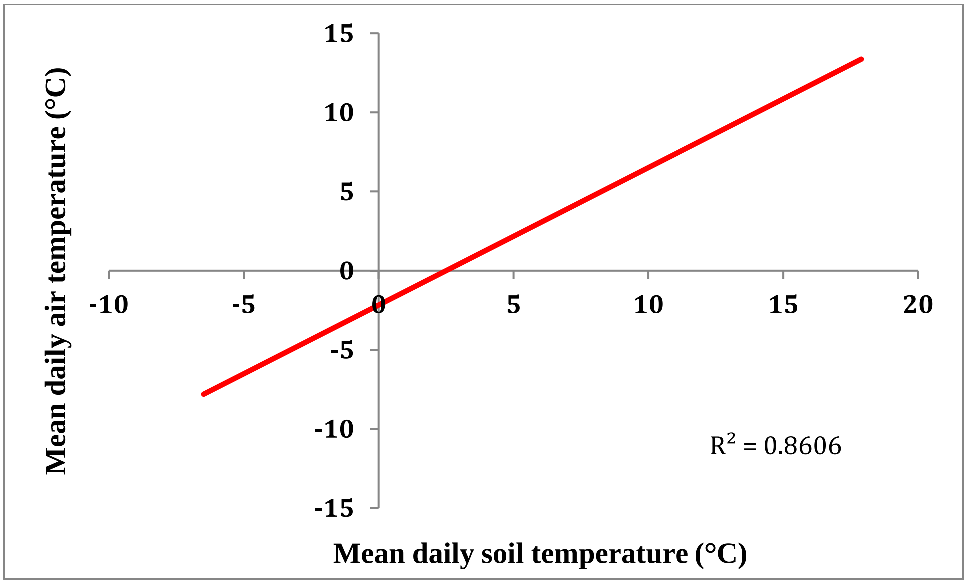


Fig. 24 Identified correlation between soil and air temperature along the elevation for the years 2016-2019

Table 8. Detail of environmental variables of different habitats, glacial landform (GL), alpine meadow (AM), alpine shrubs (AS) and subalpine forest (SF), along elevation gradient

Habitats	**Soil moisture content (SMC) (%)**	**pH**	**MT_30days**	**Soil organic carbon (SOC) (%)**	**Total nitrogen (TN) (%)**	**C:N**
Gl	6.35±3.47	6.65±0.85	1.35±0.59	0.13±0.15	0.022±0.02	4.63±3.08
AM	17.57±8.59	4.91±0.5	1.49±0.19	4.37±0.88	0.42±0.06	10.43±1.53
AS	1.88±1.27	5.81±0.6	4.51±0.73	2.53±1.28	0.22±0.09	10.91±1.54
SF	9.94±6.87	5.58±0.65	7.19±1.43	5.1±2.55	0.35±0.16	14.21±2.37

5.3.2.2 Influence of temperature and physicochemical properties on bacterial richness and α-diversity along elevation gradient:

We estimated bacterial observed richness and α-diversity by Sobs and Shannon–Weaver diversity indices respectively. Spearman's correlation analysis did not show any relation between bacterial richness and diversity with elevation and temperature but showed significant correlation with soil properties. Soil moisture content (SMC), soil organic carbon (SOC), total nitrogen (TN) and C:N ratio correlated positively with observed richness (Sobs) and Shannon–Weaver diversity (Fig. 25a-h). Stepwise multiple regression modeling indicated that observed richness (Sobs) could be predicted by soil organic carbon alone where as Shannon diversity by soil organic carbon and C/N ratio (Table 9).

5.3.2.3 Influence of temperature and edaphic on soil bacterial community composition:

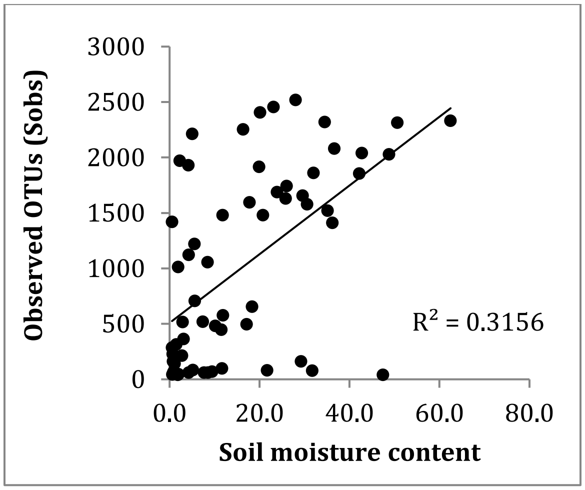
To visualize any difference in bacterial community composition of different habitats along the elevation, we performed principal-coordinate analysis (PCoA) based on bray-Curtis dissimilarity matrix. We found community composition in morainic soil is different from the others habitats. Canonical redundancy analysis indicated that variation in bacterial community composition among the different habitats could be significantly explained by soil organic carbon (SOC) and C/N ratio (Fig. 26). These two variables together explained 17 % of the bacterial community variation [ANOVA, $F_{(2,43)} = 4.39$, $p = 0.001$]. Neither elevation nor temperature showed any significant contribution in explaining community dissimilarity. We further examined influence of edaphic factors on the relative abundance (>1%) of major bacterial taxa. Univariate regression analysis showed that the phylum *Proteobacteria* is positively associated and *Actinobacteria* is negatively associated with C/N (Fig. 27). Relative abundance of the bacterial taxa *Saccharimonadales* (phylum *Patescibacteria*) has been found to be positively associated with soil moisture (Fig. 27).

Table 9. Significance of stepwise multiple regression model for bacterial richness and diversity index

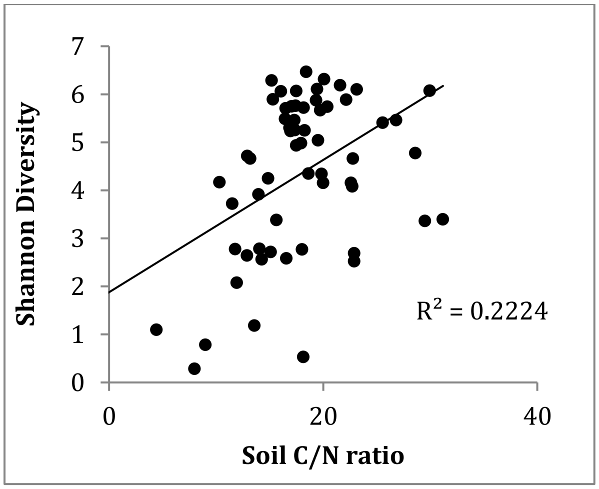
Response variable	**Adjusted r^2 (%)**	**Predictor variable**	**Coefficients**	***F* value**	***P* value**
Observed OUT (Sobs)	40.6	Organic carbon	0.645	42.67	<0.001
Shannon Diversity	31.4	Organic carbon	0.392	14.975	<0.001

5.3.2.4 Discussion

Earlier studies on soil bacterial richness and diversity across elevation gradient showed increasing (Singh et al., 2013), decreasing (Bryant et al., 2008; Zhang et al., 2015), higher or lower diversity in mid-elevation (Fox, 2013; Singh et al., 2014) patterns. Compared to these studies we did not find any clear trend in our study, potentially indicating that factors other than changing climatic condition along the elevation are involved in shaping the bacterial community in high altitude habitats. Our analysis based on 80 soil samples collected from different subalpine and alpine habitats along 1000 m elevation gradient in Gangotri National Park indicate that edaphic factors strongly influence soil bacterial richness, diversity and community composition instead of temperature. As opposed to temperature, we found soil organic carbon (SOC) and C/N ratio to play major role in shaping bacterial richness, diversity and composition. In addition, relative abundance of two of the most abundant bacterial phyla, *Proteobacteria* and *Actinobacteria*, having important role in soil organic carbon decomposition is strongly associated with soil C: N ratio. Similar influence of soil organic carbon and C: N on bacterial communities have been reported from Changbai Mountain tundra (Shen et al., 2015). Taken together, our result indicate that C: N ratio and soil organic carbon are the major environmental factors affecting the bacterial richness, diversity and community composition in high altitude habitats of western Himalaya.



(a)



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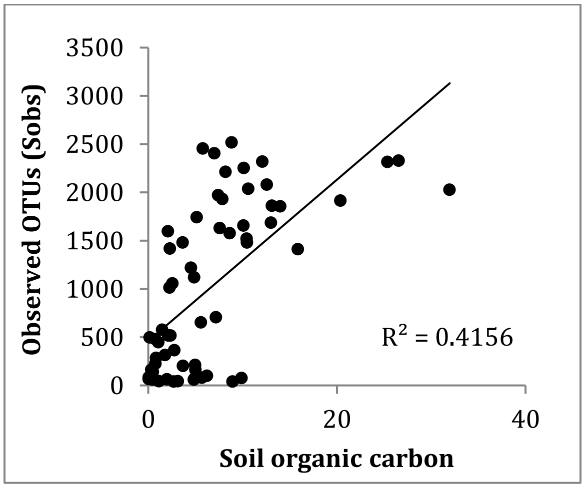

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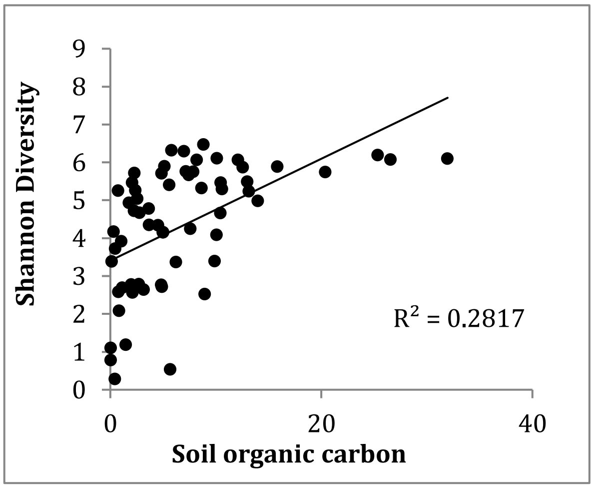

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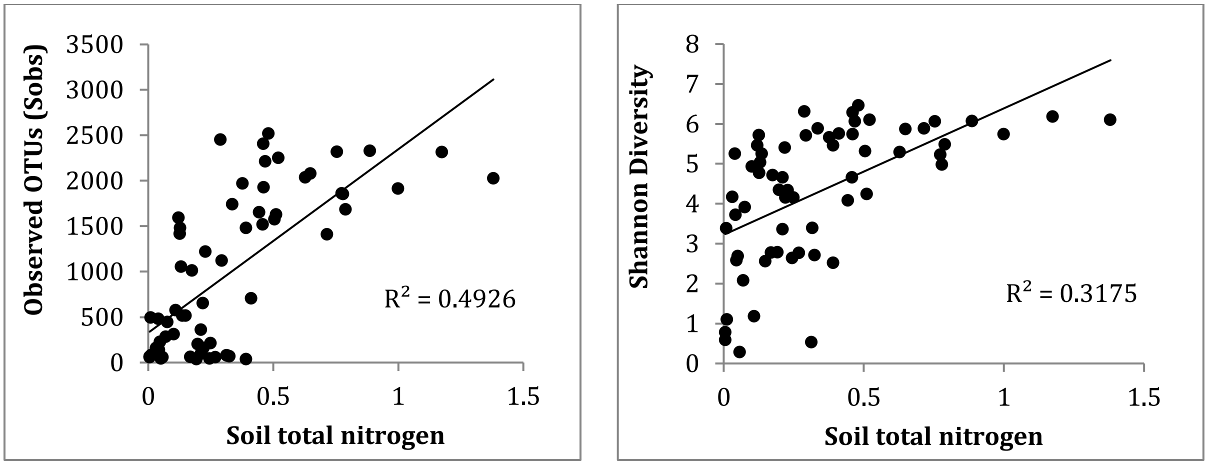


(c) (f)

Fig. 25. Observed numbers of OTUs (a-c), and Shannon Diversity Index values (d-f) as function of soil moisture content, organic carbon, total nitrogen and C/N ratio. The fitted lines are from univariate regression analyses.

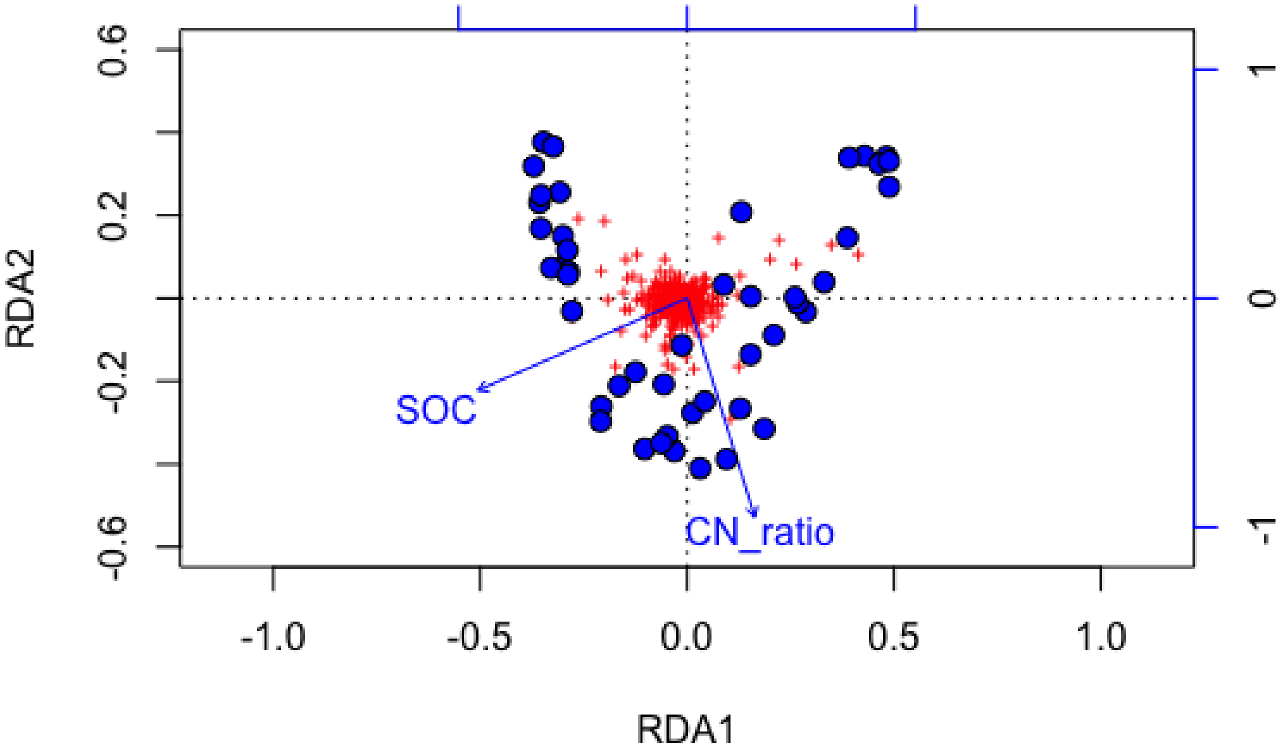
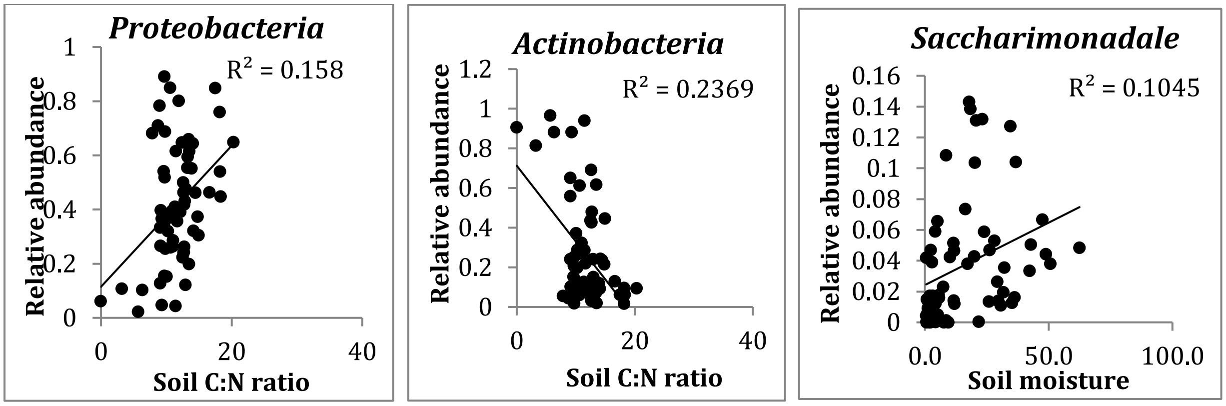


Fig. 26. Canonical redundancy analysis showing relations between sites and edaphic factors.



(a) (b) (c)

Fig. 27. The relative abundances of bacterial taxa as functions of (a–b) soil C:N ratio and (c) soil moisture. The fitted lines are from univariate regression analyses.

5.3.3.1 Micro fauna

Both abiotic factors (soil properties) and biotic factors (trophic links, relationships with plant diversity) were studied to understand the underground ecological parameters driving the pattern in nematode abundance and diversity in high altitude region of GNP.

Spearman correlation analysis showed the different trophic group reacts with the climatic gradient. mainly Soil moisture, Soil total organic carbon, and nitrogen, where organic carbon and nitrogen showed significant correlation with bacterial feeders and total nematode composition whereas elevation showed a significant negative correlation with plant parasite and total nematode composition and soil moisture were positively related with the various trophic group what was not significant except with omnivores and the total nematode composition (Table 10).

Table 10 Spearman correlation coefficients between the variables in Gangotri National Park. Asterisks indicate significant correlation at probability levels of 0.05(*), 0.01(**) and 0.0001 (***).

	Elevation	*N*	*SM*	*OC*	*B*	*F*	*PP*	*O*	*PR*	*Total Nem*
Elevation	1.000						0.02*			0.004**
N	-0.75	1.00			0.009**					0.003**
SM	-0.57	0.52	1.00					0.04*		0.01*
OC	-0.76	0.87	0.65	1.00	0.002**					0.003*
B	-0.34	0.61	0.41	0.69	1.00					
F	-0.39	0.28	0.35	0.38	0.03	1.00				
PP	-0.54	0.29	0.26	0.36	-0.15	0.87	1.00			
O	-0.42	0.30	0.49	0.23	-0.12	0.63	0.72	1.00		
PR	-0.42	0.43	0.40	0.30	-0.23	0.58	0.62	0.76	1.00	
Total Nem	-0.65	0.66	0.60	0.67	0.31	0.81	0.78	0.80	0.76	1.00

The principal component analysis (Fig. 28) explains 43.8% of the variation. The first axis explains 27.8 % and 16% defined by the second axis for Gangotri valley. The study showed that the plots with higher nitrogen, organic carbon, and soil moisture are associated with higher faunal diversity of bacterial and fungal feeders and also with the occurrence of genera, *Nothacrobeles*, *Axonchium*, *Dorylaimus*, and *Pseudacrobeles*. Omnivores and predators were highly contributing feeders. The analysis also highlighted that the majority of genera showed a negative relation with elevation, while phosphorus and potassium were the least contributing factors in the study area. The correlation analysis among the different soil parameters showed that SOC has significant positive correlations with nitrogen (r=0.964), phosphorous (r=0.794), and soil moisture (r=0.661).

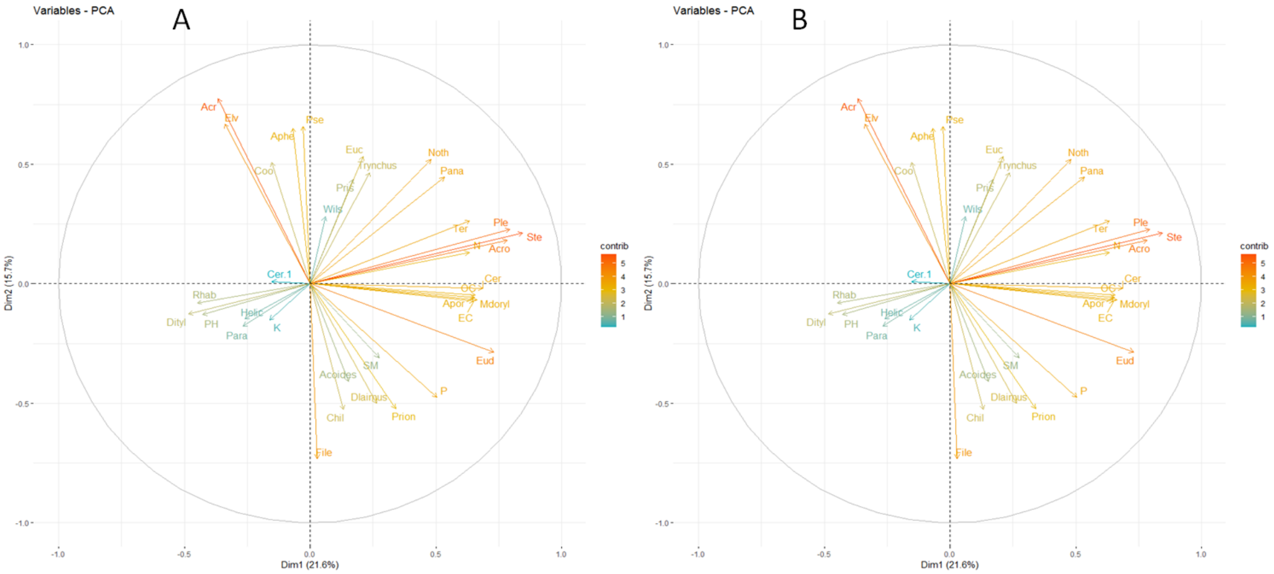


Fig. 28 Principal Component Analysis on soil parameters and nematode data of Gangotri (A) and Nelang Valley (B). Environmental variables and nematode genera are marked by arrows.

In the case of Nelang valley, the principal component analysis explains 37.3 % of the variation. The first axis explains 21.6 % and 15.7% defined by the second axis for Nelang valley. Omnivores and predators were highly contributing feeders. The analysis also highlighted that the majority of genera showed a negative relation with elevation except for the Acrobeles at an elevation range of 4000-5000m. Bacterivors showed a positive relation with Organic carbon and nitrogen. *Helicotylenhus, Ditylenchus, and Paratylenchus* were associated with pH and Potassium levels in Nelang valley (Fig. 28). Soils samples collected from high altitudes (>3500m) has significantly less SOC and soil nutrients except from 3700 to 3800m in gangotri valley. This may be explained as the impact of long term human influence in the forms of camping and altering the natural habitat. As an example, famous trekking destination and pilgrimage site of Bhojbasa is situated in this range. Soil moisture and soil organic carbon decreases along the elevation, it may be due to harsh weather conditions at higher altitude where no vegetation can survive. The high affinity between soil physicochemical characteristics and abundance of nematode in different ecosystem has been used as criteria to assess soil health and to understand the dynamics of food webs. This study may further help in climate change study in current scenario of global warming.

Pairwise comparison of the similarity of soil nematode structure in different vegetation types from Analysis of Similarity showed a significant difference in different vegetation type except for Subalpine (Deodar) with Subalpine (*Betula, Pinus*) and Alpine scrub (*Caragana*) with Alpine scrub (Mixed shrubs) (Table 11). The analysis showed the most difference in generic composition occurred between Subalpine-*Pinus* & Alpine Scrub- *Artemisia* (R=0.455, P=0.001) which may be due to the different climatic gradients along elevation. Dissimilarity tests based on the Bray-Curtis distance showed that nematode communities showed significant difference across vegetation type where alpine caragana is very much similar in terms of generic level (Fig. 29). It could be due to almost similar climatic variables across the vegetation type of alpine caragana and alpine scrubs (mixed shrubs). As this is a first observation from the study area, more detailed study is required to conclude on this result.

Table 11 Pair wise comparison of similarity of soil nematode structure in different vegetation types from Analysis of Similarity)

Vegetation Type	SAD	SAP	SAB	ASA	ASC	ASMS
SAD		0.1	0.378	0.414	0.684	0.936
SAP	0.747		0.144	0.455	0.453	0.98
SAB	0.020	0.180		0.653	0.765	0.765
ASA	0.018	1.00e-04	0.0043		0.310	0.248
ASC	9.0e-04	0.028	0.001	0.011		0.082
ASMS	0.008	0.008	0.002	0.0405	0.190	

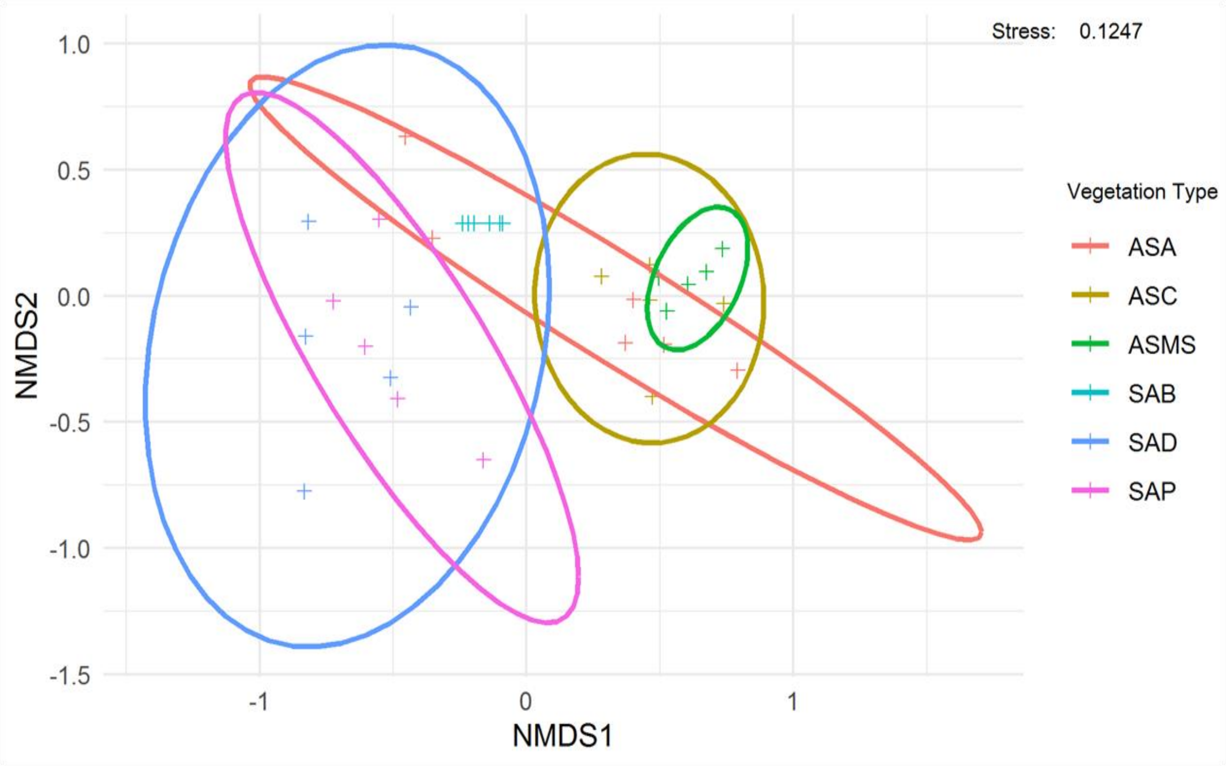


Fig. 29 NMDS ordination (Bray-Curtis dissimilarity) of nematode communities based on relative abundances of nematode genera across different vegetation types. Each point reflects the community found in a vegetation type. Points that are close together have more similar communities than points that are far apart. Colors show Vegetation Type.SAP: Sub alpine (Deodar); SAD: Subalpine(Pinus); SAB: Sub alpine(Betula); ASA: Alpine Scrub(Artemmisia); ASC: AlpineScrub(Caragana); ASMS: Alpine Scrub(Mixed shrubs)

At altitudinal gradient, pairwise comparison showed that the least significant difference was between 3000-3500 and 4000-4500m (R=0.355, P = .0106) and no difference at elevation 4000-5000 (Table 12). The community structure of soil-inhabiting nematodes varies with altitude, vegetation. Dissimilarity tests based on the Bray-Curtis distance showed that nematode along the elevation gradient were significantly different when assessed at a generic level (PERMANOVA p=0.001*) (Fig. 30) and showing the similarity at elevational range from 4000-5000 m at a generic level.

Table 12 Pair wise comparison of similarity of soil nematode structure along elevational gradient from Analysis of Similarity)

Elevation	3000-3500m	3500-4000m	4000-4500m	4500-5000m
3000-3500m		0.29	0.22	0.56
3500-4000m	8.00e-04		0.35	0.61
4000-4500m	0.0106	2.00e-04		0.12
4500-5000m	1.00e-04	1.00e-04	0.06	

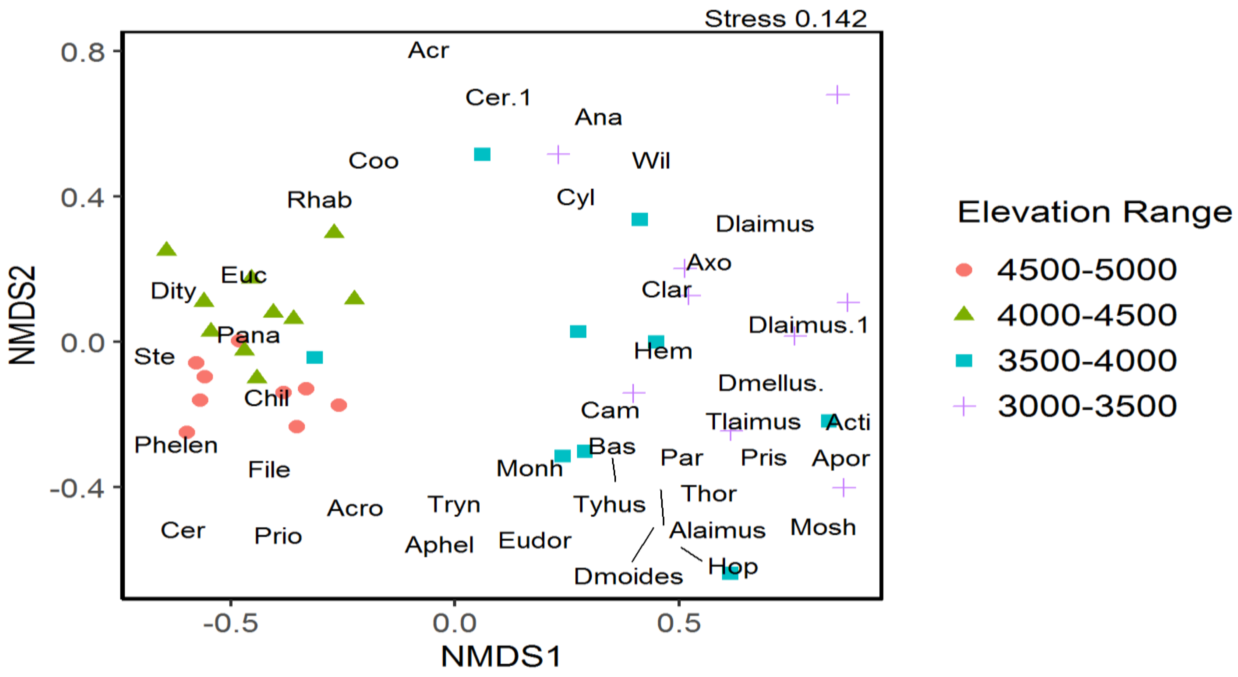


Fig. 30 NMDS ordination (Bray-Curtis dissimilarity) of nematode communities based on relative abundances of nematode genera along elevation gradient

High nematode diversity and Maturity Index (MI=2.9) indicated the soil of GNP is structured and mature and less disturbed. Comparatively low nematode diversity and Maturity Index (MI=2.7) indicated the soil of Nelang valley is less stressed but less mature than Gangotri valley. Low value of nematode channel ratio showed that both the valley follows bacterial decomposition pathway in soil ecosystem. Soil inhibiting nematode diversity is high than the high elevation Nelang valley which may be due to difference in vegetation type and harsh environment.

Table 13 Correlation coefficients and their significance in 0.05 level (2-tailed) among various soil physicochemical parameters

Indices	Nelang Valley	Gangotri Valley
MI	2.7±0.20	2.9±0.76
NCR	0.79±0.08	0.86±0.14
PPI	0.28±0.23	0.36±0.26
EI	29.69±2.66	40.1±4.25
SI	70.41±2.22	79.6±2.42
H'	2.79±0.17	3.1±0.30

The enrichment index (EI) and structural index (SI) –two maturity index extensions were also calculated according to access nematode food web properties. The EI and SI are based on nematode functional guild according to the responses to disturbance and enrichment. The EI and the SI were plotted (Fig. 31), where along the x-axis SI indicates an increase in trophic linkages which corresponds to disturbance level (physical or chemical) and Y axis shows increased presence of opportunistic groups (EI) which corresponds to availability of resources (Ferris et al., 2001). EI values were significantly greater in Gangotri valley while there was no significant difference in SI values between two valleys (Table 13). On the structure-enrichment plot, Gangotri valley was comparatively more enriched and structured than the Nelang valley.

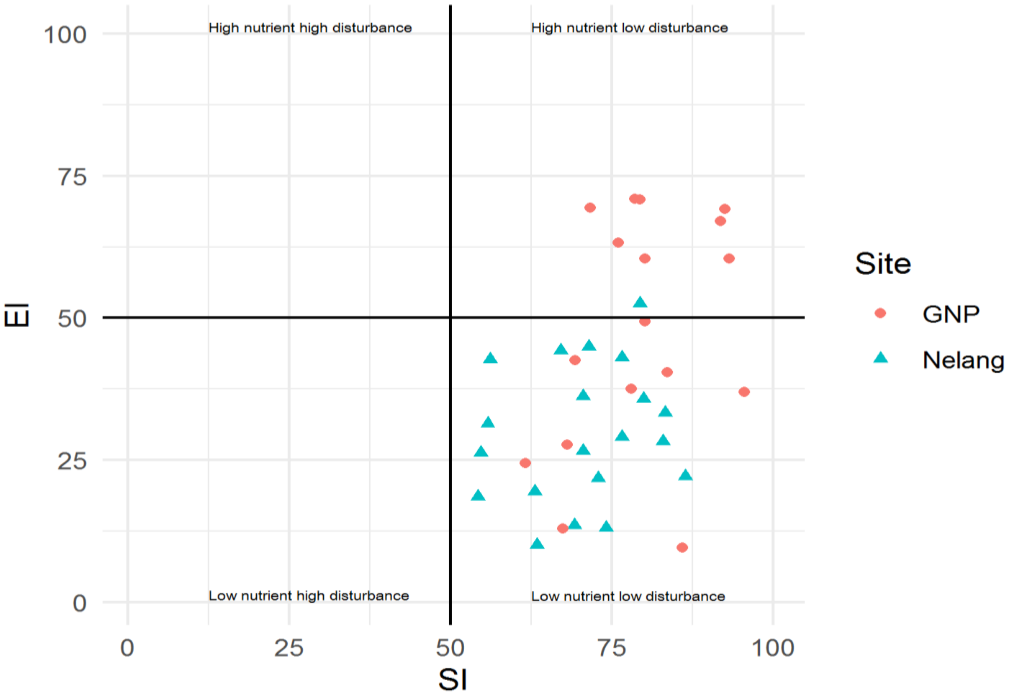


Fig. 31 Structure -Enrichment plot by Sites along Elevation Gradient. Quadrants are labeled after Ferris et al. (2001). Colors show sites: Gangotri valley is red and Nelang is blue.

5.4 Long term monitoring requirements

Experimental warming plots established in alpine habitats inside Gangotri National Park have effectively simulated climate-warming phenomenon by artificially increasing mean annual soil temperature by 1.5°C. Long term monitoring of these plots are necessary to confirm the trends observed so far. It is important to establish similar experimental plots in alpine habitats in eastern Himalaya in order to develop future predictive models for microbial feedback to climate warming. In addition to the study conducted on response of soil bacterial community composition and function to experimental warming, it necessary to also monitor soil respiration. This would facilitate establishing direct link between soil microbial community function and CO_2 emission from soil. In relation to this, long term monitoring of both plant and microbial (bacteria and fungi) community diversity and composition change is required for in depth understanding of the factors responsible for altered CO_2 emission dynamics from soil. The experimental sites in the remote locations require continuous monitoring for understanding warming impacts on the ecosystem. Currently, due to lack of permanent base stations near our experimental sites continuous monitoring could not be conducted. A base station with power back up would be essential for continue long term monitoring of the experimental sites.

Earlier there was a lack of comparable data (Baseline data basically) on climate change studies on soil micro level in the region, therefore, Baseline data on soil mesofauna diversity along the elevation gradient in the high altitude of western IHR (3000 m -5000 m) has been generated and OTC has been installed and data has been collected (from OTC and Control sites) for 3 years which is under analysis in I phase of our project. However systematic long term monitoring is required to understand the climate change effect and to overcome the doubts to maintain resilience and sustaining the IHR soil ecosystem and its services provided by soil micro faunal communities. But there is a considerable gap in our knowledge of the soil faunal community in central and eastern high altitude regions of the Indian Himalayan region which play an important role in various crucial soil ecological processes and western and eastern IHR varies in different aspects. Therefore in next phase, our objective will be to carry out research on soil mesofaunal community in central Himalaya region and to continue long term monitoring of OTC experimental studies in central and western Himalaya to understand the comparable differences if any in diversity and community structure for ambient soil health status and temperature effects on soil health based on Maturity indices of soil nematode feeders at various trophic levels for maintaining resilience and sustaining the IHR soil ecosystem and its services provided by soil microfaunal communities.

5.5 Conclusion / Summary

This study in Gangotri National Park, Western Himalaya is the first to provide detailed information on the influence of microclimate and edaphic factors on soil bacterial community diversity, composition and function along an environmental gradient of 1000 m. The fine-scale environmental gradient studied displayed highly diverse bacterial communities among different habitats. The study reveals that sub-alpine forests and alpine meadows harbor extremely rich microbial communities and short duration climatic warming may not affect their composition. Further it was also found that soil organic carbon and C/N ratio showed significant effect in shaping bacterial richness, α-diversity and compositional dissimilarity, indicating a close relationship between soil carbon and nitrogen content with bacterial community. However, these communities do exhibit differential response to warming in terms of their activities.

The experimental warming study at high altitude alpine habitats confirmed that merely increasing temperature will not have significant impact on bacterial community richness, diversity and composition indicating their resistance and stability under changing climatic conditions in short term. In contrast, increasing temperature affected relative abundance of some specific bacterial taxa and activities of organic carbon degrading enzymes, implying functional modification of microbial communities due to warming. Short term experimental warming for two years resulted in an increase of 1.5 to 1.7°C in temperature. Long term monitoring at established experimental sites is required to confirm the trends. Further investigation is necessary to establish the use of specific bacterial taxa and microbial activity as successful indicators of potential impacts of climate warming.

Our results provide baseline data, which will be useful for long-term monitoring of soil bacterial community composition and function for understanding feedbacks to carbon cycle under predicted temperature rise scenarios. The findings of the study underline the need for replicating the experimental studies at multiple sites covering eastern and western Himalaya to understand the ecosystem responses. This would help in developing models for predicting the relative sensitivities of soil microbial functional groups, their biomass carbon and soil respiration to global warming.

Baseline data on soil nematode diversity of high altitude region has been generated through this study. As high altitude regions are more sensitive to even minor changes, which may affect the soil-inhabiting nematodes assemblage, the results can be utilized to understand and compare the soil health status in long term monitoring studies in the high altitude forest of Indian Himalayan Region. The analysis is based on 4680 specimens (individuals) of nematodes. Eight Orders, 30 families, 57 genera are recorded from Gangotri valley. Eight Orders, 20 families, 34 genera's from Nelang valley. All the genera and species recorded refer as 1st record from the region as it is the pioneer study in the region. Enrichment and structural guild shows Gangotri soil is more nutrient-enriched and structured than the Nelang valley. Pairwise comparison of the similarity of soil nematode structure in different vegetation types from Analysis of Similarity) showed a significant difference in different vegetation types except for Subalpine (*Deodar*) with Subalpine (*Betula*, *Pinus*) and Alpine scrub (*Caragana*) with Alpine scrub (Mixed shrubs).

The community structure of soil-inhabiting nematodes varies with altitude, vegetation in Gangotri National Park. The high affinity between soil physicochemical characteristics and abundance of nematode in a different ecosystem can be used as criteria to assess soil health and to understand the dynamics of food webs. Omnivores and predators were highly contributing feeders. The analysis also highlighted that the majority of genera showed a negative relation with elevation except for the *Acrobeles*, *Coomansus*, and *pseudoacrobeles* at an elevation range of 4000-5000m. Soil and the air temperature was nearly ~1 °C higher inside OTC in comparison with the control plot outside for almost throughout the year in 2017 except in August- September in Bhojwasa. Thick vegetation cover inside OTC may be one of the explanations of this. The temperature difference was nearly ~1.9 °C higher inside OTC from may 2018-may 2019, but the soil moisture was different across the treatment and control plot, suggesting that warming has indirect effect on nematode diversity by affecting soil moisture in treatment plot. As a result, warming-induced soil moisture could be the the major reason for differences in nematode responses between OTC and Control and for the decrease in soil nematodes trophic groups except for bacterial feeders and Plant parasites in OTC plots in the present study.

Bacterial feeder and Plant parasite nematode abundance is higher in OTC but was not significant. *Acrobeloides* & *Rhabdolaimus* are the only bacterial feeder whose density is significantly increased by the elevated condition of OTC. Overall, Genera richness, Shannon Index was greater in Control plots but was not statistically significant while MI and total nematode abundance were significantly greater in control plots (p-value=0.005, 0.030 respectively. Structural Index was significantly greater in OTC plots (p-value=0.002) SI indicates an increase in trophic linkages which corresponds to disturbance level (physical or chemical). Plant-parasitic nematode abundance was greater in the OTC plots than the control plots. In terms of the trophic group, Bacteriovores increased in OTC plots which may be due to the increase in microbial activities in treatment plot, and Predators and omnivores significantly decreased in Open top chambers (p-value=0.001, 0.04). A decrease in maturity index for the OTC plot indicated that disturbance level increased in chambers which are different from the control plots based on trophic relationship.

The enrichment index (EI) and structural index (SI) were calculated which are extensions to the maturity index (Ferris et al. 2001). Enrichment and structural index guild plot showed the control plot was more enriched but less structured than the treatment plot based on their response to disturbance and enrichment to identify nematode food web properties between the plots. Open top chamber experiment requires long term monitoring with modification and installing of various analytical apparatus to change the parameters which are expected to alter with climate change to understand the soil nutrient dynamics and ecosystem.

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Chapter 6

Assessment of adaptive capacity and socioeconomic vulnerability

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6.1 Introduction

Climate change is unambiguous and a real threat being experienced globally. Climate change effects are predicted to increase intensity and frequency of extreme weather events, alter precipitation patterns affecting incidence and severity of droughts, and increase temperature (Seneviratne et al. 2012; Dai 2011; Min et al. 2011; Zwiers et al. 2011; Coumou and Rahmstorf 2012; IPCC 2014). The varied effect of recent climate change and extreme weather events around the world causing uneven impacts on the populations even within a small geographic area. South East Asia, and South Asia which harbours a large number of poor people depending on marginalized resources has experienced consistent and frequent extreme weather events and climatic variations in the past decades (Dev 2011). India has also witnessed flooding and high intensity rainfall during the last two decades (Rajesh et al 2014, Magrath et al 2007, Goswami et al 2006) and an increase in extreme precipitation has also been predicted for future (Kumar 2013). The Indian Himalayan Region due to its fragility and high sensitivity to minor climatic variance is prone to climatic shock on its socioeconomy. The rugged terrain, lack of infrastructural development, arduous bio-physical environment increases the concerns about the rising threats to the population belonging to the marginalized areas of IHR. The gap of knowledge on how these stresses will affect the villages and household level economy and how intense the effect will be, create a critical situation, where at present, policy level intervention can't be implemented efficiently. Together with the development of the scientific understanding of the nature of and physical exposure to climate change, there is a critical need to investigate the social vulnerability and capacity of populations to prepare for short-term and long-term adjustment to these future changes at different scales (Lemmen and Warren, 2004).

By definition "vulnerability is a multi-layered and multidimensional social space defined by the determinate political, economic and institutional capabilities of people in a specific place at a specific time" (Watts and Bohle 1993). On the contrary resilience was depicted as the capacity of a socio-ecological system to absorb external stress imposed upon it by reorganizing and evolving into more desirable units to improve the sustainability of the system and preparing it better for future impact (Nelson et al 2007, Folke 2006). It can be measured by assessing the different assets or capitals available for the system to cope with the hazards of climate change. However, not all the people depending on marginalised resources can be accounted as vulnerable. It depends on the exposure risk to shocks or crisis and lack of adaptive capacities to cope with the unprecedented stress or limited recovery from the crisis and shock (Lundberg and Wuermli 2012, Sen 1999). There are concerns on the ever-increasing threats to the current livelihood and daily consumption patterns of households and individuals earning their livelihood from the stressful sectors. Critical gaps exist with regard to the methodological and evidence based downscaled assessment of the impacts at the village and household level vulnerability (Fao 2008a). These constraints limit the understanding of the channels through which the climate related hazards will affect the vulnerable households and thus reduces the ability to design and implement the effective policy measures for adaptation (Karfakis, et al 2011b). The vulnerability or resilience of an individual or a household is determined by the stress response of the available resources and most significantly the ability of the households or individuals to avail the resources (Sen

1999, Sen 1981, Adger 1999, Hewitt 1997, Ribot et al 1996, Watts and Bohle 1993). Vulnerability to climate change on the basis of socio-economic condition and livelihood was assessed by several authors throughout the world using different indices. Following the pioneering work by Adger (1999), several analytical techniques and indices were developed, such as the Social vulnerability analysis [Armas and Garvis 2016, Rajesh et al 2014, Dunning and Durden 2013, Tapshell et al 2010, Schmidtlein et al 2008, Rygel et al 2006, Vincent 2004, Cutter et al 2003), Climate vulnerability Index (Pandey and Jha 2012, Smit and Pilifosova 2001), Livelihood vulnerability index (Ligesse et al 2016, Can et al 2013, Hahn et al 2009), Economic Vulnerability Index (Carilolle 2011), Multidimensional Livelihood Vulnerability index (MLVI) (Gerlitz et al 2017), Livelihood Effectiveness Index (Urothody and Larsen 2010), Hazard and place model (HoP) and Disaster resilience and Place model (DROP) (Cutter and Finch 2008) and climate vulnerability and adaptive capacity analysis (Reed et al 2013, Adger 2003, Car 2008, Kelly and Adger 2000).

Climate change vulnerability analysis majorly have two component the innate resilience of the society or household and the shock or stress imparted from the climate change (Niles and Salermo 2018, Adger 2004, Bohle et al 1994). The major objective of the study is to establish an indicator-based approach to assess the adaptive capacity and vulnerability of selected households and villages, that can be replicated in a larger spatial scale for identifying climate sensitive areas for effective adaptation and mitigation planning for better sustainability. Indicators for vulnerability assessment was selected on the basis of sustainable livelihood framework and IPCC 2014 guideline from both climate shock and adaptive capacity components. Both Secondary information from census data of India and primary household and village level survey data on selected indicators were used to assess the adaptive capacity and vulnerability of villages in the IHR.

6.2 Metrics for assessment

6.2.1 Study area

Indian Himalayan region has an opulent and wide diversity of natural resources. However, this biological and natural richness is offset by geological fragility and geographical isolation. The upshots of this mountain-specific biophysical condition of fragility and isolation are poor physical and economic infrastructure; poor access to markets, technologies, and information;

poor institutional services; and limited economic opportunities (Fang and Leduc, 2010). Consequently, most people here are marginalized and are among the poorest in the region living on a subsistence level. According to a report by the International Centre for Integrated Mountain Development (ICIMOD), 31% of the population of the Hindukush Himalaya live below the poverty line (Hunzai et al., 2011).

Poverty in the region generally manifests in low income, ill health, poor access to health facilities, malnutrition, poor education, low skills, high dependence on the natural environment, high insecurity (due to political disturbances which are often violent, the insecurity is also due to the topography and physiology of the region that is prone of numerous natural hazards and risks, physical vulnerability, drudgery, and limited capability and capacity for enterprise (Karki et al., 2011). The study was carried out in three river basins namely Bhagirathi Basin of the state of Uttarakhand, Beas Basin of Himachal Pradesh, and Teesta Basin of Sikkim. Uttarakhand and Himachal Pradesh are the two states situated in the western Himalayas prevailing hilly terrain and both are within the biogeographic zones of Himalayas and Trans Himalayas (Rodgers et al 2000).

The climate and ecography vary greatly along with the elevation and slope. Uttarkashi and Tehri Garhwal Districts are situated in the Garhwal region of the state of Uttarakhand and traversed by the tributaries of the mighty river Ganga. The population density of Uttarkashi and Tehri Garhwal was 41 and 148/km^2 respectively with the decadal growth rate of 11.75% and 2.35% respectively (District Census 2011, http;//www.census2011.co.in/district.php). Tehri Garhwal is one of the most highlighted districts of the state of Uttarakhand because of the Tehri dam, the highest dam in India, and more than 1 million people of 110 villages were relocated due to the establishment of the dam (Prashant 2004, Joshi 2006). As a consequence, the livelihood and agricultural practices of the villagers were affected a lot (Panwar and Upreti 2015). In the Beas basin, the study was carried out in and around the Great Himalayan National Park and Conservation Area (GHNPCA) of Kullu district. The area is traversed by Tirthan, Parbati, and Sainj river, the tributaries of Beas river, and formed three distinct valleys. Great Himalayan National Park is a world heritage site designated by UNESCO for its Outstanding Universal value of natural resources and heritage. The population density of Kullu district was 79 people/ km^2, with a decadal growth of 14.65% (District Census 2011, http;//www.census2011.co.in/district.php). The economy of the local people of both the study area depends on agriculture and horticulture.

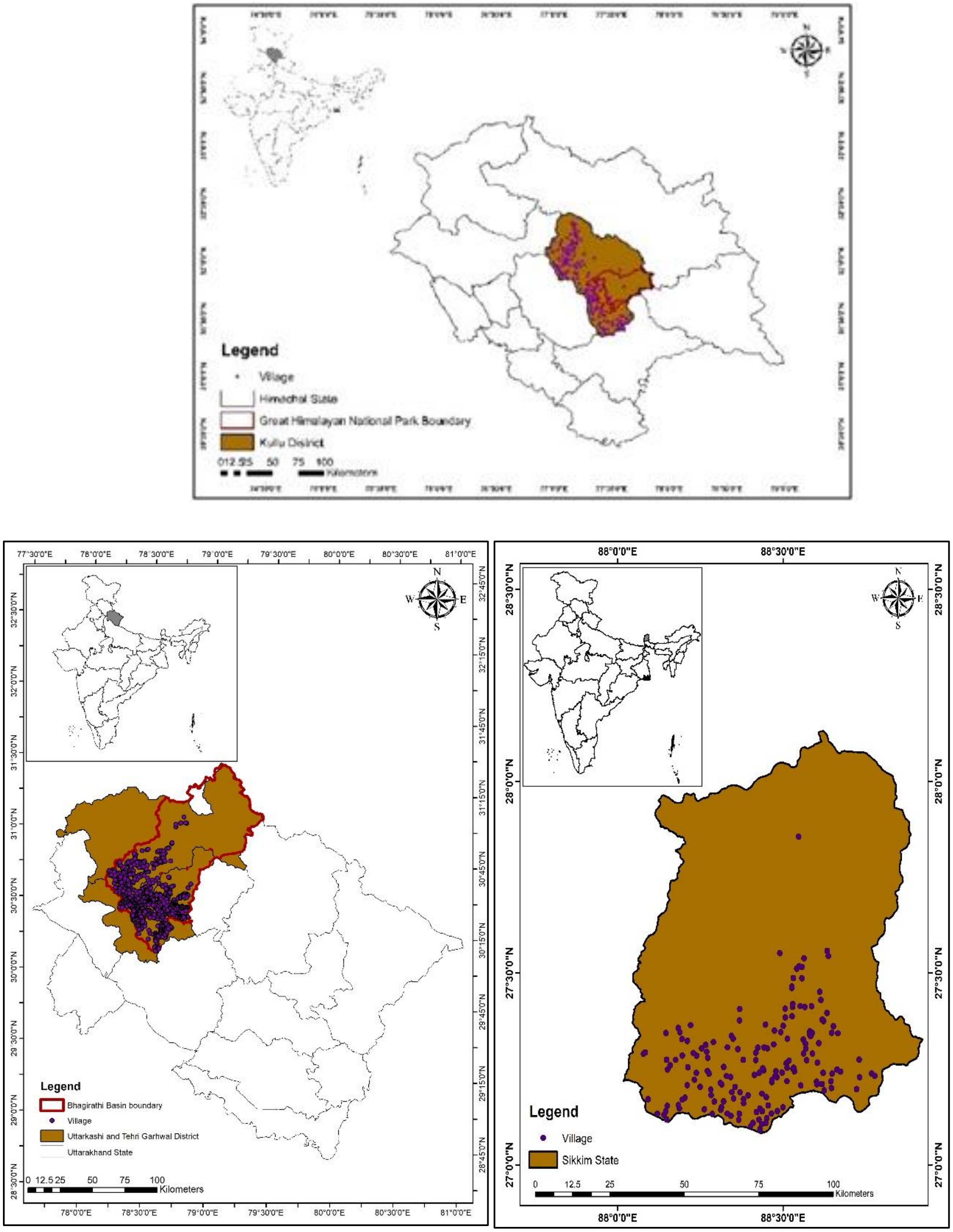

Fig. 1 Study area in Beas basin in Himachal Pradesh (1a) Bhagirathi basin in Uttarakhand (1b) and Teesta basin in Sikkim (1c).

Teesta basin, the third study area is in the Eastern Indian Himalayan state of Sikkim. Teesta is the major river in the state with its tributaries like Rangpo and Rangeet which traverse through the state. The study was done in the East, South, and West district of the state with a population density of 295, 196, and 117 people/ km^2, respectively, and the decadal growth rate of 14.79%, 11.57%, and 10.58% respectively. Sikkim is having a forest cover of 47.69%, and 35% of the total geographical area of the state is under Khangchendzonga National Park (O'Neil 2017). The economy and livelihood of the state depend largely on agriculture and tourism (Chakraborty 2014, Chakraborty and Chakma 2016, Gupta et al 2019). The location of the study area within the two districts and the villages was given in Figure 1a (Beas Basin), 1b (Bhagirathi Basin), 1c (Teesta Basin).

6.2.2 Methodology

Census of India 2011 data set available in the census India website (http://www.censusindia.gov.in) based on the country wise census carried out in 2011 was used as a baseline data to select villages in the study area. Information's like the number of households and population, presence of basic amenities like medical, education, road connectivity, market, post office, and banking facilities were collected for individual villages for all the three study areas. To examine the access to various resources by the villager's remoteness index of each village was calculated following Dasgupta and Badola (2020). The weighted score of presence, absence, and distance from the motorable road, hospital, health center, primary and secondary school, market, police station, post office, bank, the nearest town, and tourist spots were used for calculating the value of remoteness index. The information of villages in different block and districts were validated in Google earth Pro software and information on the altitude of the village was extracted from it. 826 villages out of 1096 villages were identified from the demarcated study area within Uttarkashi and Tehri Garhwal districts of Bhagirathi basin. Similarly, 322 of the 452 villages from all the districts of Sikkim and 217 villages of 326 villages of Kullu district of the study area near Great Himalayan National Park were identified and information on altitude was extracted for each village. A Twostep cluster analysis of the villages was done using SPSS software based on altitude, geographical area, population, and remoteness index of the villages. From each cluster, villages were selected for getting information on climate sensitivity indicators like dependency on agriculture, disaster proneness, and presence of wildlife conflict. For each parameter, scores were given on a three-point scale (3,2,1) based on high, medium, and low/nil. A total of 102 villages were surveyed for Bhagirathi Basin and 145 villages were surveyed in Sikkim to get information on the climate sensitivity indicators. Villages in the study area in and around the Great Himalayan National Park village-level survey was not done. A second level cluster analysis was done with this information to again group the villages in different subclusters (Dasgupta 2020). Villages were selected from these different clusters randomly for the household level survey. In the study area near Great Himalayan National Park, the second clustering of villages was not done and villages were selected randomly based on altitude, population, and distance gradient from the National Park area.

A household survey questionnaire was designed to characterize the socioeconomy of the respondents, based on the household economy approach (Lawrence 2007). Indicators or assets were selected under natural, physical, human, and financial capital. The details of the indicators selected under different capital assets were given in the Table 1.

Table 1 – Details of the Indicators selected under different capital assets -

		Village level	Data source	Data used for
No.	Capital	Indicator		
1	Physical	Altitude	Google Earth	Ranked
2	Physical	Disaster risk	Village Survey	Ranked
3	Physical	Agricultural dependency	Village Survey	Ranked
4	Physical	Remoteness	Village Survey	Ranked
5	Physical	Wildlife Interaction	Village Survey	Ranked
6	Physical	Water accessibility	Village Survey	Ranked
7	Physical	Total geographic area	Census 2011	Ranked
		Household level		
1	Human	Education	Household level	Ranked
2	Financial	Occupation	Household level	Ranked
3	Human	Total members earn	Household level	Number
4	Human	Number of dependent persons	Household level	Number
5	Natural	Agricultural area	Household level	Ranked
6	Financial	Variety of Pulses	Household level	Number
7	Financial	Production of pulses	Household level	Ranked
8	Financial	Variety of Cereals	Household level	Number
9	Financial	Production of Cereals	Household level	Ranked
10	Financial	Variety of fruits and vegetables	Household level	Number
11	Financial	Production of Fruits and	Household level	Ranked
12	Financial	House status (Kaccha/Concreate)	Household level	Ranked
13	Physical	Electricity	Household level	Presence/absence

14	Physical	Running water	Household level	Presence/absence
15	Physical	LPG connection	Household level	Presence/absence
16	Physical	Fuel wood	Household level	Presence/absence
17	Physical	Kerosine	Household level	Presence/absence
18	Natural	Fodder variety	Household level	Number
19	Natural	Fodder extraction	Household level	Ranked
20	Natural	Fuelwood extraction	Household level	Number
21	Human	Total family member	Household level	number

The households were selected through stratified random sampling based on the social and economic status of the household in the village. The household to be surveyed was decided on the number of total households in the village along with the variation of the information given by the respondents. In each household the interview was conducted with the concern of the family members and irrespective of gender and age respondents willing to give information was interviewed through a semi-structured questionnaire with both close and open-ended informative questions. The household-level questionnaire survey was completed in 646 households in the Bhagirathi basin, 454 in the Beas basin, and 246 in Teesta Basin. The collected information was entered in the excel sheet and sorted accordingly. The values of some of the indicators where the variance is very high like agricultural production of cereals and pulses were ranked (details are given in Table 1). The non-numeric information like occupation class and education of the respondents were also ranked from highest to lowest classes.

The indicator values representing each household were transformed using the maximum-minimum transformation process (equation 1).

$$index_{s_d} = \frac{s_d - s_{\min}}{s_{\max} - s_{\min}} \quad \text{Equation 1}$$

The indicator scores were then summed up to get the scores of capital assets and scores of capital assets added up to get the scores of the adaptive capacity of the household. K means clustering algorithm was used to group the households in different clusters from highly vulnerable to highly resilient using R software (R version 4.0.0 (2020-04-24)). The score of adaptive capacity and four different capital assets viz, natural capital, physical capital, financial capital, and human capital was used for the clustering. The number of clusters that can better group different households was decided using the elbowed method inbuilt in the clustering algorithm that uses the ratio of within and between the sum of squares of groups created during the process of clustering (Figure 2a). The average value of all the indicators at the household level was used to calculate the adaptive capacity of the village level. Villages were also grouped through K means clustering algorithm based on the adaptive capacity score and cumulative scores of the indicators as different capital assets. Exposure to natural disasters, agricultural dependency, and exposure to wildlife conflict were taken as indicators for the sensitivity of villages to climatic stress. The agriculture sector is stressed by changing temperature and precipitation regime (Fishman 2016, Knox et al 2012), and each degree centigrade of temperature rise is expected to reduce 4.9% of the production (Chalinor et al 2014). Climate change also affects the movement and home range of wild animals, resulting in conflict in forest fringe villages. The change in mean annual temperature and precipitation from 2001 to 2018 was taken as the indicator for climate shock. The data was downloaded from Past climate data of the WorldClim database (Flik et al 2017) and average maximum temperature, average minimum temperature, and average annual precipitation was calculated for the years 2001 and 2018 using ArcGIS ….. The data for each village was extracted using GPS points of the villages through ArcGIS……..The sensitivity and climate shock scores were standardized using equation 1. The standardized value of sensitivity and climate shock scores of each village were deducted from the adaptive capacity score to get the present vulnerability score of each village. Villages were grouped again using the same clustering algorithm used earlier and designated to highly resilient to highly vulnerable classes. Five different clusters were formed according to the cluster number suggested by the elbowed method (Figure 2b). To assess the future climate shock on the villages ‘middle of the road’ carbon emission scenario (representative concentration pathway) RCP 4.5 was used. The bioclimatic variable 1 (Bio1, annual mean temperature) and Bioclimatic variable 12 (Bio12, annual precipitation) were obtained from the 5th Assessment report of the Intergovernmental Panel on Climate Change model (IPCC-AR5). Bio 1 and Bio12 layers of HadGEM2-AO, (met office Hadley center, UK), general circulation models originated from phase 5 of the Coupled Model Intercomparison Project (CMIP5) was obtained. The data for each village was extracted similarly using ArcGIS….. The change in annual average temperature and annual precipitation from present and future was calculated for each village and the value was standardized using equation 1. The standardized value was deducted from the present vulnerability score of each village to get the future vulnerability score of the villages.

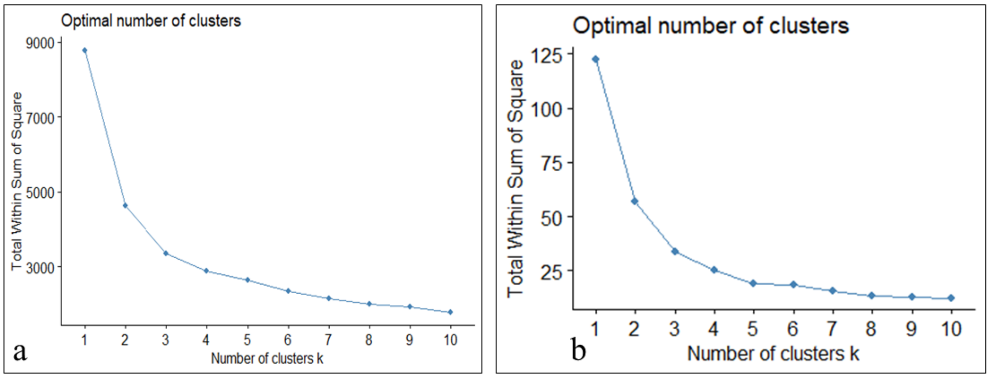

Fig. 2 Optimum number of the cluster for "kmeans" clustering (a) household level and (b) village level

6.3 Results

6.3.1 Demography

As the number of interviews to be done depends on the total household of the villages the number of respondents from each village varies from a minimum of 6 (in Kyal Baghi village of Bhagirathi Basin) to a maximum of 47 (in Ladari village of the Bhagirathi basin). Among 1346 respondents 547 respondents were female and 799 were male accounts for 40.64% and 59.36% respectively (The details are given in supplementary table 1). Female respondents were lowest in Sarchi village of Beas Basin (7.14%), whereas highest in Kannon village of Beas basin (80%). No female respondents were ready to give an interview in Nijhaan and Thatibir village of Beas Basin. The overall ratio of females to the male respondent was 82.17%, which means 82 female respondents to every 100 male respondents were interviewed. As in the Indian Himalayan region, most of the household and agricultural workload is mostly shared by the women folks of the villages considerable representation of women respondents were kept during the household level survey. Agriculture is the major occupation of the respondents (47.18%) followed by daily wagers and government jobs (6.61% and 6.09% respectively) (Figure 3). Around 14% of the respondents were housewives. The agricultural dependency of the respondents was highest in the Beas basin (77%) followed by Teesta and Bhagirathi basin (34.55% and 31.42%). Village wise occupation class was given in supplementary Figure 3.

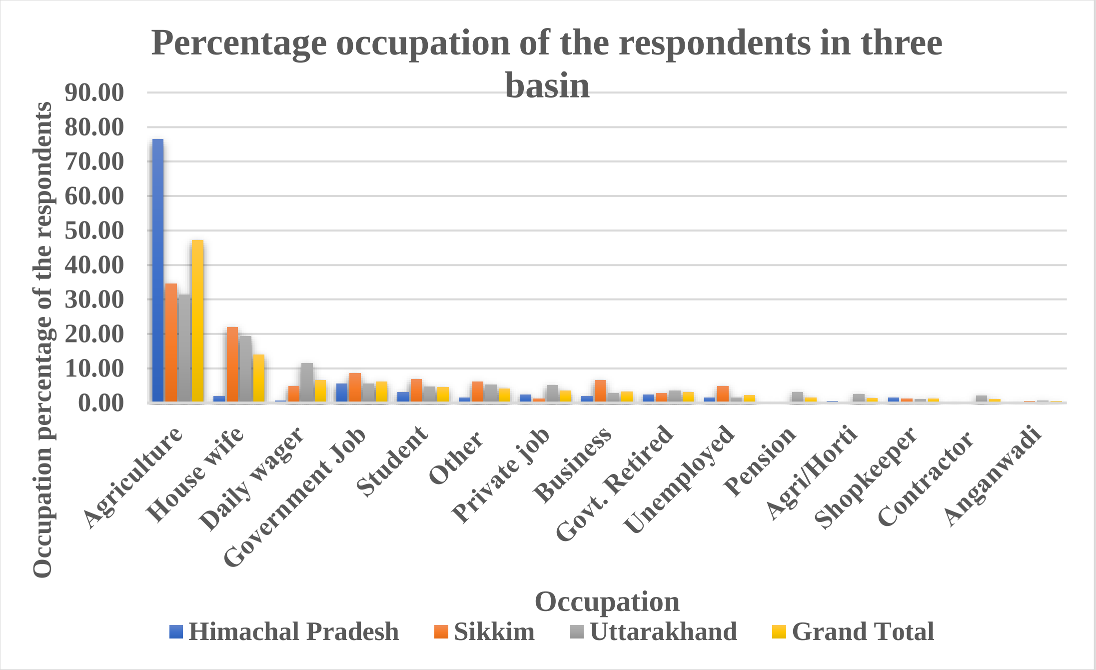

Figure 3 – Overall occupation of the respondents in the three-study area

6.3.2 Household adaptive capacity

The household adaptive capacity scores range from 4.55 to 16.32. The higher the score the resilient of the household increases. The 'kmeans' clustering algorithm grouped the households in five different groups from Highly vulnerable to highly resilient. Cluster 1 is having 351 households designated as vulnerable households as per the adaptive capacity score. Cluster two to cluster five are having 173, 225, 285, and 312 households respectively and designated as highly resilient, highly vulnerable, resilient, and moderate respectively. The range of household adaptive capacity scores in each cluster and the centroid is given in Table 2.

Table 2 Household adaptive scores and designation of different clusters

Household	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Lowest score	7.29	12.03	4.55	9.77	9.52
Highest score	10.32	16.32	9.22	11.37	10.78
Centroid	9.24	13.42	7.40	11.37	10.78
Designation	vulnerable	highly	highly	resilient	moderate

The range of capital asset scores and household adaptive capacity of each cluster was given in Figure 4. More than 50% of the households of Ladari, Girgaon, Gujetha, and Phadamchen villages were classified as highly vulnerable. There were 8 villages of Bhagirathi basin, two of Teesta basin, and 15 villages of Beas basin where less than 5% of households were highly vulnerable. In Barsali, Kyalbaghi, Hee, Chether, and Raila villages more than 50% of the surveyed households were vulnerable. Barsu, Bayana, Pata, and Purali villages of Bhagirathi basin, Bul village of Teesta basin, and Dhaugi, Jauri, Lapah, and Manara villages of Beas basin don't have any households grouped as vulnerable. Barsu and Pata villages of Bhagirathi basin and Dhaugi village of Beas basin was having highly more than 50% of the resilient household of the total household surveyed in those villages. Among all the villages surveyed over the three basins, 29 villages which include 8 villages from Bhagirathi basin, 12 and 9 villages each from Teesta and Beas basin don't have any household that is grouped in highly resilient classes. Similarly, 23 villages which include three, thirteen, and seven villages from Bhagirathi, Teesta, and Beas basin respectively don't have any resilient households. More than 50% of the surveyed households were resilient in Kumrada, Indragaon, Sitakot, and Lapah villages.

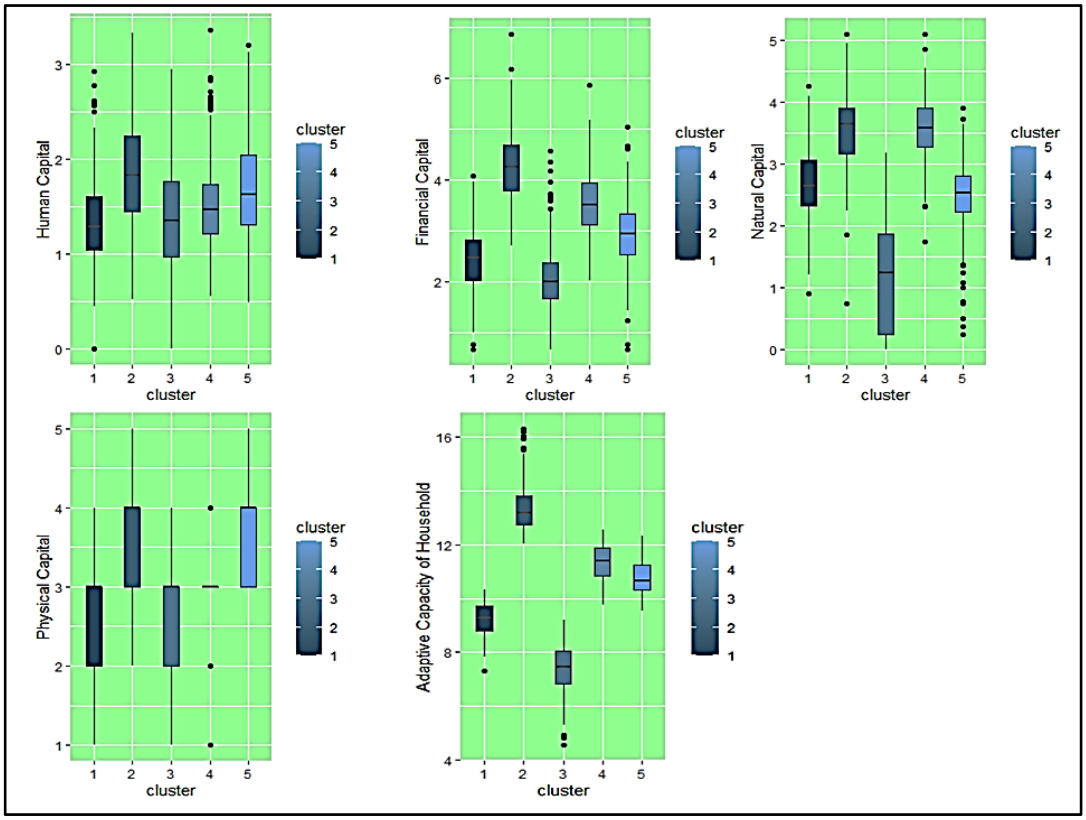

Figure 4 – the range of different capital assets and household adaptive capacity in different clusters.

6.3.2 Village adaptive capacity

Average household adaptive capacity for each village was calculated and added to the standardized value of altitude, remoteness index of the village, total geographic area, and total household of the village to get the village adaptive capacity. Village adaptive capacity score and the standardized values of altitude, remoteness index of the village, total geographic area, and the total household of the village were used to cluster villages in five groups of highly vulnerable to highly resilient villages. The range of values of different variables in each cluster was given in Figure 5. Out of 77 villages surveyed, 7 villages fall under the highly resilient group, 20 villages under the resilient category, 31 under the moderate category, and 15 and 4 villages were in the vulnerable and highly vulnerable category respectively. There were 4 villages in the Bhagirathi basin and 3 in the Beas basin falls under the highly resilient category, whereas none of the villages of the Teesta basin was in this category. None of the villages of the Beas basin falls under the highly vulnerable category, whereas 3 and 1 villages of Bhagirathi and Teesta basin come under the highly vulnerable category respectively. The list of villages in different categories was given in Table 3. The adaptive capacity of the villages of the Beas basin was significantly higher than that of Bhagirathi and Teesta basin (Kruskal Wallis Chi-squared =10.5782, p-value =0.01, P-value of Post hoc Dunn test for Beas and Teesta basin was 0.0048 and that of between Beas and Bhagirathi basin was 0.0139. There was no significant difference in the remoteness index value, total no of households, geographical area, and altitude between the villages of three basins (Figure 6). There was a significant difference in the financial capital between the villages of the Teesta and Bhagirathi basin (Kruskal Wallis chi-square =11.0895, df = 2, p-value = 0, the value of post hoc dunn test between Teesta and Bhagirathi basin was 0.0013.). A significant difference in Human capital was found between the villages of the Teesta and Beas basin (P-value of post hoc Dunn test or Kruskal Wallis rank-sum test was .0086 between Teesta and Beas basin. The difference in natural capital score is also significant between villages of Teesta basin and Beas basin and that of between the Teesta basin and Bhagirathi basin (P-value of Post hoc Dunn test of Kruskal Wallis rank-sum test was 0.000 for both the cases). Similarly, the difference in the physical capital score is significant between the villages of the Beas basin and Bhagirathi basin and that of the Teesta basin and Bhagirathi basin (P-value of post hoc Dunn test of Kruskal Wallis rank-sum test was 0.0004 and 0.000 respectively).

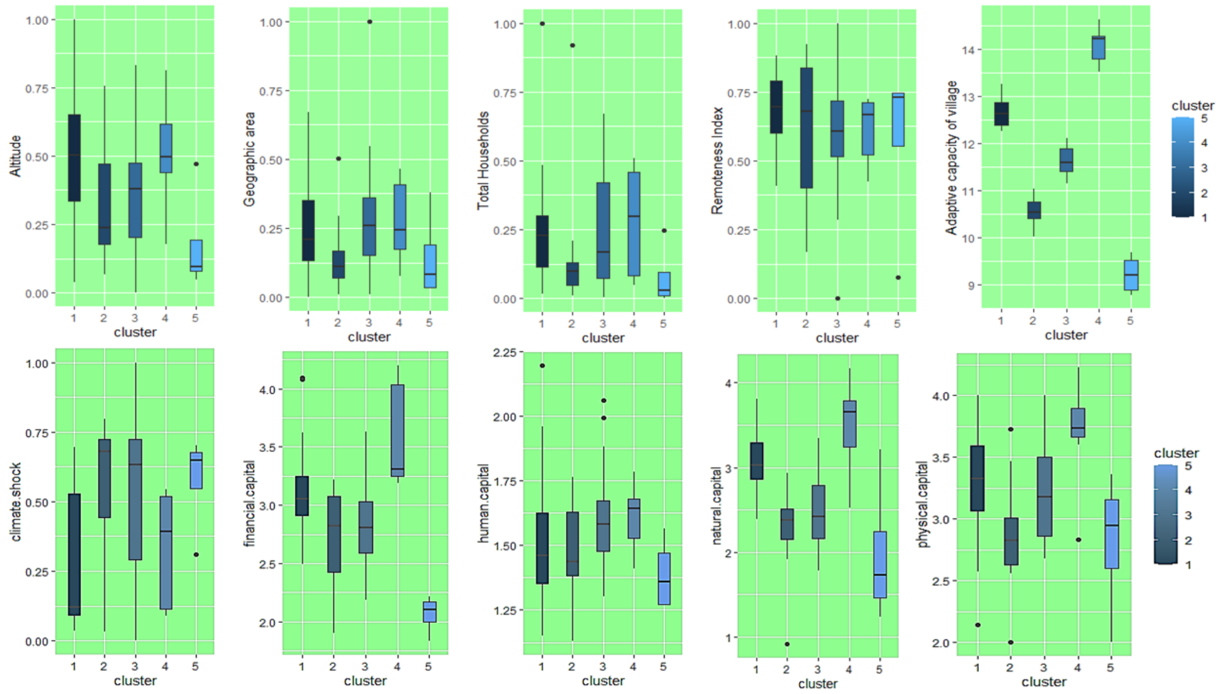

Figure 5 – The range of different capital assets and other variables used for clustering villages.

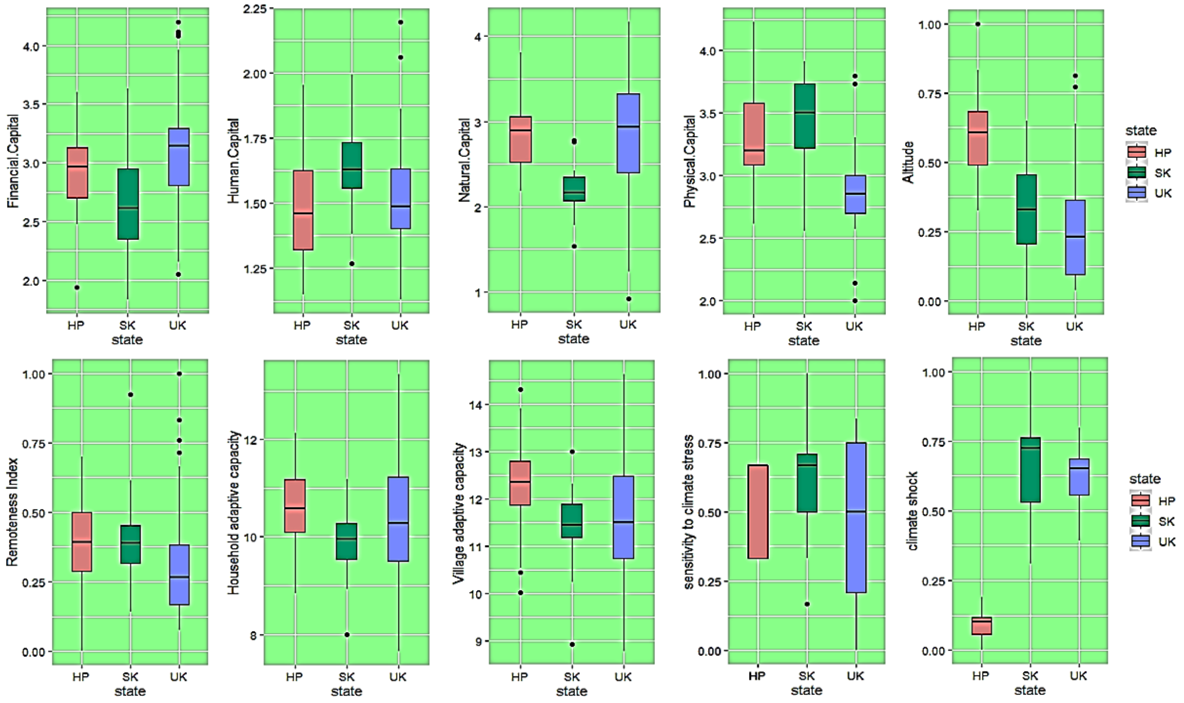

Fig. 6 The range of scores of different capital assets and other variables in three study sites

6.3.3 Present Vulnerability

The present vulnerability score was deduced by deducting the standardized value of sensitivity to climate change and climate shock for each village from the village adaptive capacity. The new cluster formed based on the vulnerability score changed the status of 58 villages from lower to higher vulnerability classes. The vulnerability status of 21 out of the 30 villages changed in the Bhagirathi basin and for Beas and Teesta basin, vulnerability status changed for 17 and 19 villages respectively. The status of 5 villages changed from highly resilient to resilient, 14 villages from resilient to moderate, 19 villages from moderate to vulnerable, 13 villages from vulnerable to highly vulnerable, and 1, 2, and 3 villages from highly resilient to moderate, resilient to vulnerable and moderate to highly vulnerable respectively. The list of villages with changed vulnerability status is given in table …. Climate shock is significantly high in the Teesta and Bhagirathi basin compared to the Beas basin and the difference is statistically significant ($P<0.05$, Kruskal Wallis Chi-Squared test and post hoc Dunn test). Although there is no significant difference in sensitivity to climate shock between the three basins when compared using the Kruskal Wallis Chi-squared test (P>0,05).

Table 3 Village wise adaptive capacity, present vulnerability, and future vulnerability status in three study sites

State	village	Adaptive capacity	Present Vulnerability	Future Vulnerability
Uttarakhand	Baijkot	resilience	moderate	moderate
Uttarakhand	Barsu	highly resilience	resilience	resilience
Uttarakhand	Bayana	highly resilience	moderate	moderate
Uttarakhand	Bhatwari	resilience	resilience	moderate
Uttarakhand	Gajoli	moderate	vulnerable	vulnerable
Uttarakhand	Garat	moderate	moderate	vulnerable
Uttarakhand	Hadiyari	moderate	vulnerable	vulnerable
Uttarakhand	Hitanu	resilience	vulnerable	vulnerable
Uttarakhand	Ladari	vulnerable	highly vulnerable	highly vulnerable
Uttarakhand	Pata	highly resilience	resilience	resilience

Uttarakhand	Purali	highly resilience	resilience	moderate
Uttarakhand	Kumrada	resilience	moderate	vulnerable
Uttarakhand	Dharali	moderate	vulnerable	vulnerable
Uttarakhand	Indragaon	resilience	moderate	vulnerable
Uttarakhand	Barsali	vulnerable	vulnerable	highly vulnerable
Uttarakhand	Sitakot	moderate	moderate	vulnerable
Uttarakhand	Chamiyala	moderate	vulnerable	vulnerable
Uttarakhand	Srikot	moderate	moderate	vulnerable
Uttarakhand	Pakh	moderate	vulnerable	highly vulnerable
Uttarakhand	Koti	moderate	vulnerable	highly vulnerable
Uttarakhand	Kyalbagi	highly vulnerable	highly vulnerable	highly vulnerable
Uttarakhand	PataT	vulnerable	highly vulnerable	highly vulnerable
Uttarakhand	Khand	vulnerable	highly vulnerable	highly vulnerable
Uttarakhand	Dharwal	vulnerable	highly vulnerable	highly vulnerable
Uttarakhand	Ramgarh	vulnerable	vulnerable	highly vulnerable
Uttarakhand	Pipola	vulnerable	highly vulnerable	highly vulnerable
Uttarakhand	Girgaon	highly vulnerable	highly vulnerable	highly vulnerable
Uttarakhand	Gujetha	highly vulnerable	highly vulnerable	highly vulnerable
Uttarakhand	Pabela	vulnerable	highly vulnerable	highly vulnerable
Uttarakhand	Musangaon	vulnerable	highly vulnerable	highly vulnerable
Sikkim	Aifaltar	moderate	vulnerable	vulnerable
Sikkim	Rongong	resilience	moderate	moderate
Sikkim	Ray	moderate	vulnerable	highly vulnerable
Sikkim	Heepatal	vulnerable	highly vulnerable	highly vulnerable
Sikkim	Radukhando	moderate	vulnerable	highly vulnerable
Sikkim	Bhegha	moderate	vulnerable	vulnerable
Sikkim	Zoom	moderate	vulnerable	vulnerable

Sikkim	Bul	moderate	vulnerable	highly vulnerable
Sikkim	Samdong	resilience	vulnerable	vulnerable
Sikkim	Bhusuk	vulnerable	highly vulnerable	highly vulnerable
Sikkim	Parbing	moderate	vulnerable	vulnerable
Sikkim	Hee	moderate	highly vulnerable	highly vulnerable
Sikkim	Phadamchen	highly vulnerable	highly vulnerable	highly vulnerable
Sikkim	Phachekhani	vulnerable	highly vulnerable	highly vulnerable
Sikkim	Tikjeck	moderate	vulnerable	vulnerable
Sikkim	Lingdok	moderate	vulnerable	vulnerable
Sikkim	Lungzik	moderate	vulnerable	highly vulnerable
Sikkim	Kartok	moderate	vulnerable	vulnerable
Sikkim	Ben	moderate	highly vulnerable	highly vulnerable
Sikkim	Kau	moderate	highly vulnerable	highly vulnerable
Himachal Pradesh	Balagarh	moderate	moderate	moderate
Himachal Pradesh	Bhallan	moderate	moderate	vulnerable
Himachal Pradesh	Chakurtha	resilience	resilience	resilience
Himachal Pradesh	Chether	vulnerable	highly vulnerable	highly vulnerable
Himachal Pradesh	Chipnni	resilience	resilience	moderate
Himachal Pradesh	Deotha	moderate	vulnerable	vulnerable
Himachal Pradesh	Dhaugi	highly resilience	highly resilience	highly resilience
Himachal Pradesh	Jauri	resilience	resilience	resilience
Himachal Pradesh	Jungla	moderate	moderate	moderate
Himachal Pradesh	Kalwari	resilience	moderate	moderate
Himachal Pradesh	Kanon	resilience	moderate	moderate
Himachal Pradesh	Lapah	resilience	moderate	moderate
Himachal Pradesh	Mail	vulnerable	highly vulnerable	highly vulnerable
Himachal Pradesh	Manara	resilience	moderate	moderate
Himachal Pradesh	Manyaar	moderate	vulnerable	vulnerable
Himachal Pradesh	Manyashi	resilience	moderate	moderate

Himachal Pradesh	Mazhaan	vulnerable	highly vulnerable	highly vulnerable
Himachal Pradesh	Nijhaan	moderate	moderate	vulnerable
Himachal Pradesh	Palaach	highly resilience	resilience	resilience
Himachal Pradesh	Raila	resilience	moderate	moderate
Himachal Pradesh	Ratwah	resilience	moderate	moderate
Himachal Pradesh	Rote1	moderate	moderate	moderate
Himachal Pradesh	Sarchi	highly resilience	resilience	resilience
Himachal Pradesh	Shangarh	resilience	moderate	moderate
Himachal Pradesh	Shapnil	moderate	moderate	vulnerable
Himachal Pradesh	Thatibir	resilience	moderate	moderate
Himachal Pradesh	Tindar	resilience	moderate	moderate

6.3.4 Future climate shock

The standardized value of the difference in the future and present annual mean temperature and precipitation deducted from the present vulnerability score to get the future vulnerability score of each village. The vulnerability status of 11 villages of Uttarakhand, 4 villages of Teesta basin, and 4 villages of Beas basin changed from a higher to lower resilient group. The resilient status of Bhatwary and Kumrada village of Bhagirathi basin and Chippni village of Beas basin changed to moderate. The status of Garat, Kumrada, Indragaon, Sitakot, and Srikot village of Bhagirathi basin and Bhallan, Nijhaan, and Shapnil village of Beas basin changed from moderate to vulnerable. The status of Barsali, Pakh, Koti, and Ramgath village of Bhagirathi basin and Ray, Radukhando, Bul, and Lungzik village of Teesta basin changed from vulnerable to highly vulnerable. The adaptive capacity, present vulnerability, and Future vulnerability of all the villages of three study sites were presented in Figure 7 (a-c, d-f, and g-i for adaptive capacity, present vulnerability, and Future Vulnerability in the Beas, Bhagirathi, and Teesta basin respectively).

6.4 Discussion

Climate change as a real threat has resulted in a paradigm shift in the present research by trying to understand what is the experience and expected outcome of the events to anticipate where it will impact and who will be impacted (Macgregor 2010, Pachauri et al 2014, Goodrich et al 2019). Vulnerabilities resulting from the climatic stressors are manifestations of interlinkages of different contextual conditions and socio-economic drivers (Goodrich et al 2019). In the fragile landscape of the Indian Himalayan region, many aspects of the exposure, sensitivity, and resilience are context-specific and people's dependency on nature and ecosystem services, which are also prone to climate impacts had created a complex condition for the livelihood and sustainability of the people (Xu et al 2019). In the low population density areas, like the present study area the livelihoods of the people engaged in agriculture, horticulture, and fisheries depend directly on the environment, and changing climate threaten their source of income and also the safety nets for their sustainability (Berks 2007, Watts et al 2015, Rodriguez et al 2016). People in these areas also may have less access to medical care and disaster-response resources than people in higher-population-density areas (Morrow, 1999). In areas with lower population densities, diminishing resources are associated with developmental activities and with limited social-service delivery (Lobao, Adua, & Hooks, 2014). Vulnerability study must understand and assess how climate change will affect the natural ecosystem along with the adaptive capacity of the local community to deal with these scenarios (Adger et al 2004, Bohle et al 1994, Fussel and Klein 2006, Rodriguez et al 2016). In the present study indicator-based assessment of different capital assets was done to get a cumulative index of adaptive capacity for households as well as villages. There are important benefits of index-based assessment mentioned in the literature (Albizual et al 2019, Gilberto 2006). The index-based assessment contributes to the operationalization of the vulnerability concept, accounting for the interplay between climate stressors, adaptive capacity, and climate sensitivity mechanism (Lin and Polsky 2015) that can be used to assess both the impacts and coping capacity to the stressors to prepare anticipatory policy for increasing resilience of the community (Eakin and Bojórquez-Tapia 2008; Hahn et al. 2009; Lin and Polsky 2015). The index-based approach thus grounded on the assessment of climate stress, sensitivity, and resilience of the community and reveals the need for context-specific policy development (O'Brien et al 2004, Jhan et al 2020).

Indicator-based studied on vulnerability and adaptive capacity have shown the importance of different indicators in developing the index (Reference). In the present study, it was evident that almost all the indicators were significantly affecting the capital assets score and the adaptive capacity scores of the villages. Village adaptive capacity of different study sites varies as the scores of the different indicators for households as well as villages vary among themselves. The capital asset values also differ within and between the different study basins. Both household and village adaptive capacity was low in households and villages surveyed in the Bhagirathi basin and Teesta Basin. Although sensitivity to climate shock remains the same, future climate shock also high in the villages surveyed in Bhagirathi and Teesta Basin, compared to the Beas basin of Himachal Pradesh. As a result, vulnerability score was high in the villages of Bhagirathi and Teesta Basin in comparison to the villages surveyed in the Beas basin. Although the low adaptive capacity of the villages of Teesta Basin may be attributed by the low agricultural income due to the conversion to organic agriculture in recent time, in near future the income generation is expected to be high as the benefit of the good policy initiatives by the local government will increase the potential of good agricultural production. In the case of households and villages of the Beas basin, the dependency of cash crops may decrease the adaptive capacity in the future if the production of cash crops decreases as an effect of climate change. So close monitoring and involvement of the stakeholders is needed for assisting farmers' decision and financial stability of the climate-dependent sectors.

The Region of the Great Mountains is socio-economically vulnerable to climate change. Poverty, rural populations, and dependency on agriculture and other climate-sensitive sectors to support the economy enhance the vulnerability of the region. In the present study, a framework was established to assess the household and village adaptive capacity and vulnerability to climate stress using both primary and secondary data in the Indian Himalayan region. Indicators were selected under different capital and household and village adaptive capacity was calculated based on the cumulative score of the capital assets and the physiognomy of the villages. Changes in precipitation and temperature and future climate change scenarios highlight the importance to implement measures to protect the most vulnerable population, promoting crops that adapt better to the predicted climate conditions. The present and future vulnerability identify the villages where immediate mitigation and adaptation strategies to be formulated. There is a scope to follow the methodology to evaluate a larger number of villages and areas to generate large scale strategic knowledge in the region for better implementation planning of developmental and climate change mitigation and adaptation strategies. Local, regional, and state climate analyses must be emphasized to climate impacts and mitigation strategies where communities must develop and implement adaptation plans. Local governments and regional planning agencies should conduct detailed studies to understand better the potential impacts of climate change. Also, local planning processes need to involve the most vulnerable communities when developing appropriate mitigation and adaptation strategies.

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Chapter 7

Decision Support Systems (DSS) for Indicator Species: A Case Study

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7.1 Introduction

World-wide, climate change mediated response of species are visible in changes in phenology, migration, changes in behaviour or activity patterns apart from earlier onset of spring and lengthening of growing seasons. From a management perspective, a much needed scientific investigations are required on climate change variability on species and their habitats. The high susceptibility of several wild flora and fauna in the IHR demands certain steps based on scientific information for adaptation processes as well as to plan suitable actions to cope up the challenges in future environments. The current level of scientific knowledge is scarce to meet the present and future challenges of climate change induced threats to terrestrial biodiversity and ecosystem services in IHR. Furthermore, the climate-driven warming in IHR is expected to affect the current distribution of wild species which would be resulting range shifts over a period of time. A broad scale continuous monitoring is thus required to produce a decision support system for managers to develop appropriate measures for addressing climate change vulnerabilities in IHR.

The NMSHE task force IV (2015-2020) has been successful in developing baseline data, species distribution models underpinning the distributional patterns in the current time frame, which are in line with the ground-truthed data. In addition, long-term monitoring plots and automated temperature and precipitation data loggers for continuous data collection have been deduced across three basins in IHR (*viz.* Beas in north-west, Bhagirathi in the west and Teesta in the east). As seasons cue the species regenerative success, phenological patterns governing life history characteristics have also been deduced for varied taxa. To better facilitate the study outputs in terms of spatial visualization and enhanced data storage capabilities a separate data visualization and download portal has been developed as a part of NMSHE. This portal will provide easy access of information for decision-makers and stakeholders for assessing and identifying vulnerabilities and build resilience to climate change. On this portal, users can explore climate, physical and socioeconomic datasets and map them to visualize the vulnerability of a specific region; and share their inputs with adaptation professionals around the world. The NMSHE through its various training programs and workshops within the institute and also in forest departments of states like Sikkim and Uttarakhand, citizen science documentation such as Wildlife Watch Series (I-V), contributed towards awareness in understating the climate change impact on key wildlife species in the IHR.

7.2 Concept and practice of wildlife watch

The selection of species for ‘Wildlife Watch’ was based on evaluation and scoring of criteria such as (a) the status (endangered/threatened) based on IUCN and Indian Wildlife (Protection) Act, (b) functional role (apex predator/ key stone species), (c) values (charismatic, cultural, umbrella/flagship species), (d) detectability in the wild, and (e) sensitivity to climate change or climate variability. Using the aforementioned criteria, selected key species representing mammals, birds, herpetofauna, fishes, invertebrates and flora was described.

Wildlife Watch Series (I-V) for awareness in understating the climate change impact on key wildlife species in the IHR.

For every species, several characteristic features were described such as taxonomic status, local/vernacular names, their physical attributes, elevation range, habitats they inhabit, some key field identification features, the probable distribution map of the species in the IHR, species photographs, and illustrations of tracks/signs which will come handy for the user. The key references used for compiling the information for the species were presented at the end of the user guide. This user guide can be used by all stakeholders, both amateur as well as trained. For an amateur, creating awareness and reporting of presence only based on visual encounters and signs as part of wildlife monitoring are envisaged. Most of the local community members, pilgrims, tourists, and school/University students would fall in this category. For trained biologists, managers, frontline staff of Forest/Wildlife Departments, field staff of the defence and para-military forces, trained Nature Club members, would fall in the second category from which we envisage reporting more information as per data format provided at the end of this user guide. In order to facilitate easy reporting back to WII, we have provided a mobile number for SMS or phone call and a web link as well. Any additional information could be provided in remarks and sent to WII. All the information with source are being stored in a database at WII for future monitoring.

7.3 Ecotones: a determinant of the tolerance limits and DSS

Sensitivities to climate change can be best observed in organisms that respond to changing environment evidently. Stream macroinvertebrates are potential candidates to measure slightest of changes in the water quality and have thus been used worldwide in rapid water quality assessments as indicators of river heath (Anderson et al., 2017). They have strict temperature tolerance limits idiosyncratic to each taxon due to narrow hydrological and thermal niches (Verberk et al., 2013; Giersch et al., 2016; Lencioni, 2018). In the same vein, they can be chosen as model organisms for climate change studies whereby their community-level compositional shifts in response to climatic drivers can result in distinct ecotones (McArthur & Sanderson, 1999; Kakouei, 2018). Changes in environmental conditions lead to changes in ecotones, eventually leading to range shifts of taxa on either ends of the ecotone (Wasson et al., 2013; Li et al., 2019). The ecotones are thus indicative of high turnovers in the community composition along the altitudinal gradients, which in turn act as climatic gradient surrogates, owing to a high correlation with temperature (Bässler et al., 2010).

The ecotones are areas where taxa of narrow tolerance limits to the environmental changes, occupy the opposite ends, depending on the kind of correlation with the environmental covariate in consideration. Changes in the environmental conditions lead to changes in the ecotones, eventually leading to range shifts of the taxa on either ends of the ecotone. The Climate Sensitive Zones (CSZs) concept is a utilization of the ecotonal effects where change points in the community composition are tracked owing to a high turnover along altitudinal gradients These zones in turn act as climatic gradient surrogates, owing to a high correlation with temperature. The concept of ecotones in the terrestrial systems has been effectively utilized for climate studies, although deducing CSZs along a dynamic system like the rivers has only once been utilized (Shah et al. 2015).

7.4 Measuring climate sensitivities in freshwater environments

Freshwater macroinvertebrates are potential candidates to measure slightest of changes in the water quality and have thus been used worldwide in rapid water quality assessments as indicators of river heath. They have strict temperature tolerance limits idiosyncratic to each taxon due to narrow hydrological and thermal niches. In the same vein, they were chosen as model organisms for climate change in this study whereby their community turnovers have been utilized in delineating distinct bands which depict zones most sensitive to climate change. Beas Basin in Himachal Pradesh and Bhagirathi Basin in Uttarakhand were sampled for this study (Fig. 1).

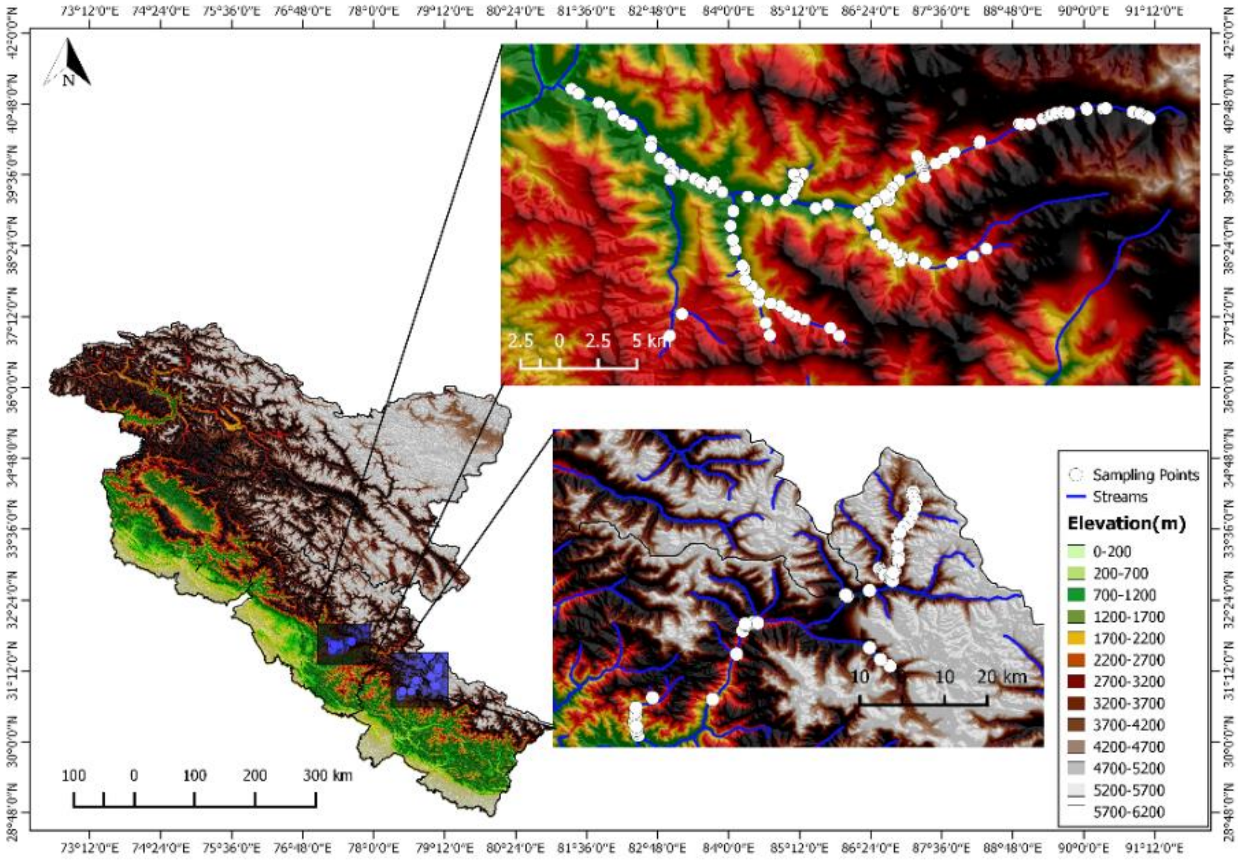


Fig. 1 Study area sampled for delineating vulnerable areas in rivers

7.4.1 Sampling and collection

Sampling was carried out from the June 2016 to June 2018 across the catchment of River Tirthan and Bhagirathi. The studied streams constituted an elevational range of 900-4800 m asl (Fig. 2), most which could only be traversed by trekking along the stream beds.

Upper Stretch (4000-5000masl) Middle-upper Stretch (3000-4000masl)

Middle-lower Stretch (2000-3000masl) Lower Stretch (1000-2000masl)

Fig. 2. Representative panel showing study streams representing different attitudinal zones of your streams from different altitudinal zones in River Tirthan (Beas basin).

An extensive sampling design (Conquest & Ralph, 1998) was followed with a downstream to upstream approach starting at the confluence and moving onto the origin. The entire catchment was rigorously covered for stringent community turnover identification. For the higher order streams (4th and higher) sampling was conducted at every 500 m asl. However, in case of the lower order streams (3rd and lower), an interval of 200 m asl was chosen to ensure equivalent representation of lower order tributaries which often covered a stream length of less than 500m. A total of 108 sampling points was covered, of which 95 points showed presence of macroinvertebrates, while 13 points characterised majorly by turbulently flowing cascades were documented with no macroinvertebrates. Within each sampling point, 19 environmental parameters were recorded including (1) Topographical: altitude (2) Geomorphological: total channel width (bank to bank) and wetted channel width measured on site, distance from source, distance from confluence and stream length calculated by manual digitisations on the google earth (3) Hydrological: water depth and flow (measured with the FP111- global water flow probe) (4) Physical and chemical: pH, alkalinity (ppm), water temperature (°C), total dissolved solids (ppm) and dissolved oxygen (mg/L) measured using YSI pro multiparameter water monitoring kit (5) Substrate composition (proportion of bedrocks, boulders, cobbles, gravels and sand) and (6) Bioclimatic: bio 1 (annual mean temperature) and bio 12 (annual precipitation) were extracted to points at 1x1 km resolution using QGIS. The layers were downloaded from the WorldClim data set (Hijmans et al., 2005).

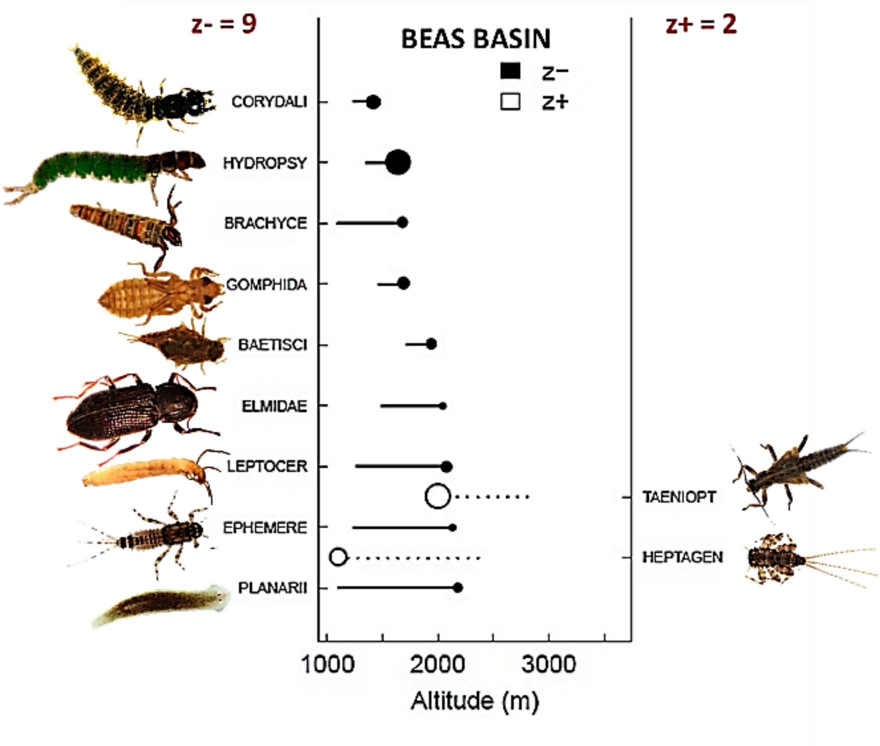
The macroinvertebrate fauna was sampled using a nylon D frame dip net (30 cm diameter, 55 cm depth and 500 μm mesh size). We used combined approaches of Castella et al. (2001) and Moong (2007) in which collections were made by kick sampling 10 × 0.1 m^2 replicates in 10% intervals of a 100 m long reach by disturbing the substrate for 30 s per replicate. Waterfalls were sampled by scouring the rock surfaces by hand, allowing the current to carry insects into the net. Along stream margins and in ponds, vegetation was swept with the D-net. The mineral and organic materials along with the macroinvertebrates collected were transferred to a white tray after each replicate sampling. After all the replicates were sampled, the macroinvertebrates were hand-picked directly from the tray using forceps and hand-held magnifying lens to avoid further sorting in the laboratory. Samples were added into labelled vials and preserved with 95% ethanol, with the best estimations that organic debris, remaining water and body fluids bring the concentration to 70% (Hauer & Lamberti, 2007). Identifications of macroinvertebrates were done in laboratory following specific keys (Pinder & Ohtaka, 2004; Birmingham et al., 2005; Subramanian & Sivaramakrishnan, 2007; Webb & McCafferty, 2008; Bouchard, 2009; Haney et al., 2013). Identifications were made to the lowest possible levels. Nevertheless, all the individuals could not be identified to a common taxonomic rank owing to lack of uniform keys for the region as well as high numbers of young instars difficult to identify. As such, family-level identifications were chosen for statistical tests, to avoid heterogenous analysis that could have incurred by inclusion of lower ranks. Furthermore, regardless of a difference in number of sampling sites as well as variable identification levels, inter-basin comparisons over broad spatial scales can be best made with family level identifications of macroinvertebrates (Warwick, 1988, 1993; Bournaud et al., 1996; Arscott et al., 2006).

7.4.2 Data analysis

The analysis was initiated after the removal taxa occurring in less than 5 % of the sampling sites. This was done to avoid the potential operator bias resulting from the stochastic occurrences (Arscott et al. 2006). No transformations were used on the macroinvertebrate community data as it contained numbers ≥ 0 and only discrete counts (O’Hara & Kotze, 2010). Further, the GLM removes the prerequisite of transforming count data (Maindonald & Braun, 2007). Also, TITAN being robust on untransformed density data, transformations were not performed (Baker et al., 2015).

7.5 Identifying Climate Sensitive Zones (CSZ)

Latitudinal gradients can act as methodological setups to infer climate change effects on the ecosystem, much effectively than the experimental warming or observational methods (de Frenne et al. 2013). The ongoing study is revealing interesting trends with respect to latitudinal governance on climate sensitivity. Macroinvertebrates sampled from Beas (n=2204) and Bhagirathi Basins (n=1541) revealed a total of 59 and 39 families respectively. Comparing the study in the north-west Himalaya (Beas basin) with that of north Himalaya (Bhagirathi Basin), this study also aimed at understanding what role latitude plays in governing the community turnovers. For a targeted approach on the latitude, we tried to nullify the altitudinal intertwining by keeping the elevational range of the study in both the basins. This way the variation in the CSZs of both the areas can clearly be explained on the basis of latitude. PCA followed by CART model revealed altitude to be the final predictor variable ($p<0.01$). TITAN revealed a total of 4 (z-=3, z+=1) indicator families for Bhagirathi and 11 (z-=9, z+=2) for Beas (Fig. 3).



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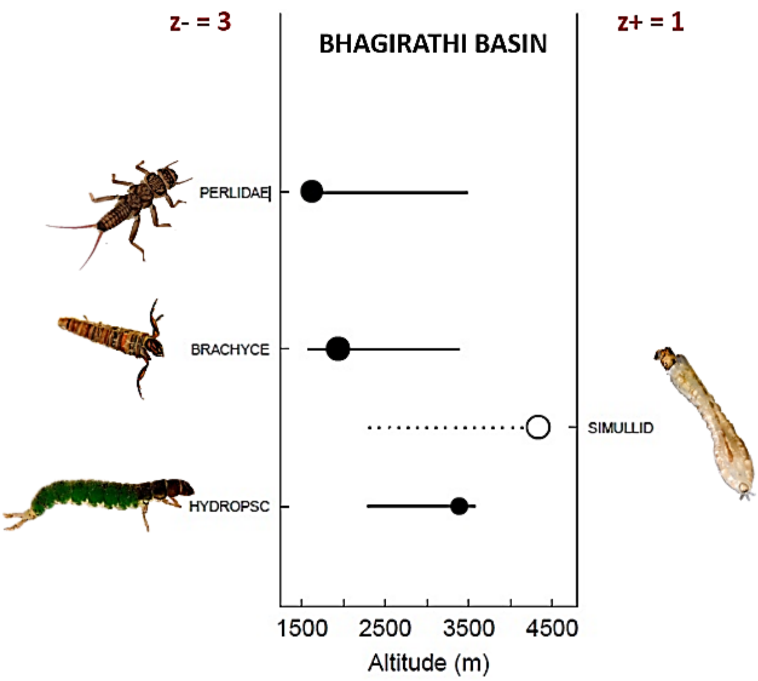
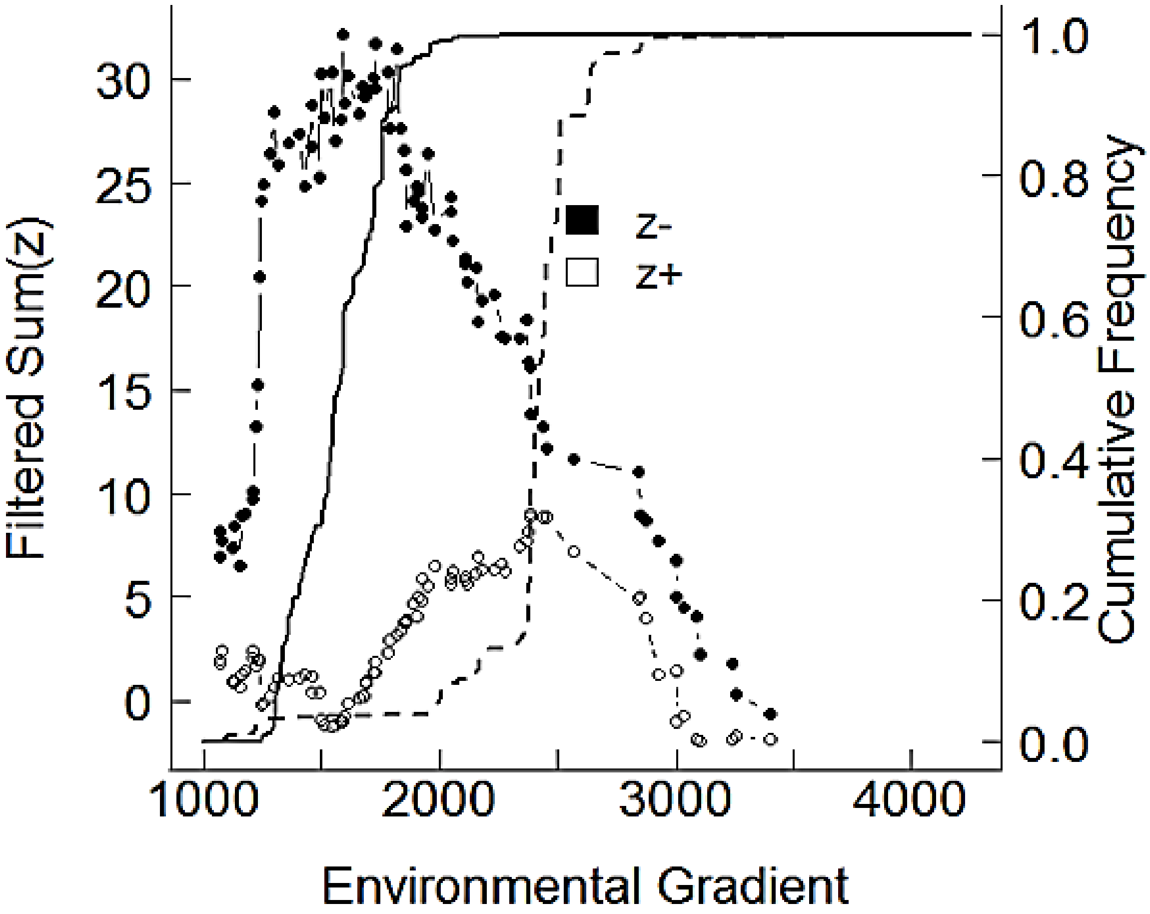


(b)

Fig. 3 TITAN 2 analysis showing Change point and 95 % confidence limits of significant indicator species for (a) Beas (n=11) and (b) Bhagirathi (n=4) Basins

A higher elevation of the CSZ in Bhagirathi Basin is in concordance with studies conducted on terrestrial and avifauna apart from the flora, where the ecotone drops in elevation as the latitude rises from equator to the pole. Although studies have been conducted over broad latitudinal scales worldwide, but comparisons of the CSZ have never been done for rivers. The present study is thus the first ever record to test if latitude governs climate sensitivities in the lotic natural systems. Community change score values derived from TITAN delineated CSZ from 1593 to 2383 masl and 2318 to 4328 masl for Beas and Bhagirathi Basins respectively (Figs. 4 and 5).



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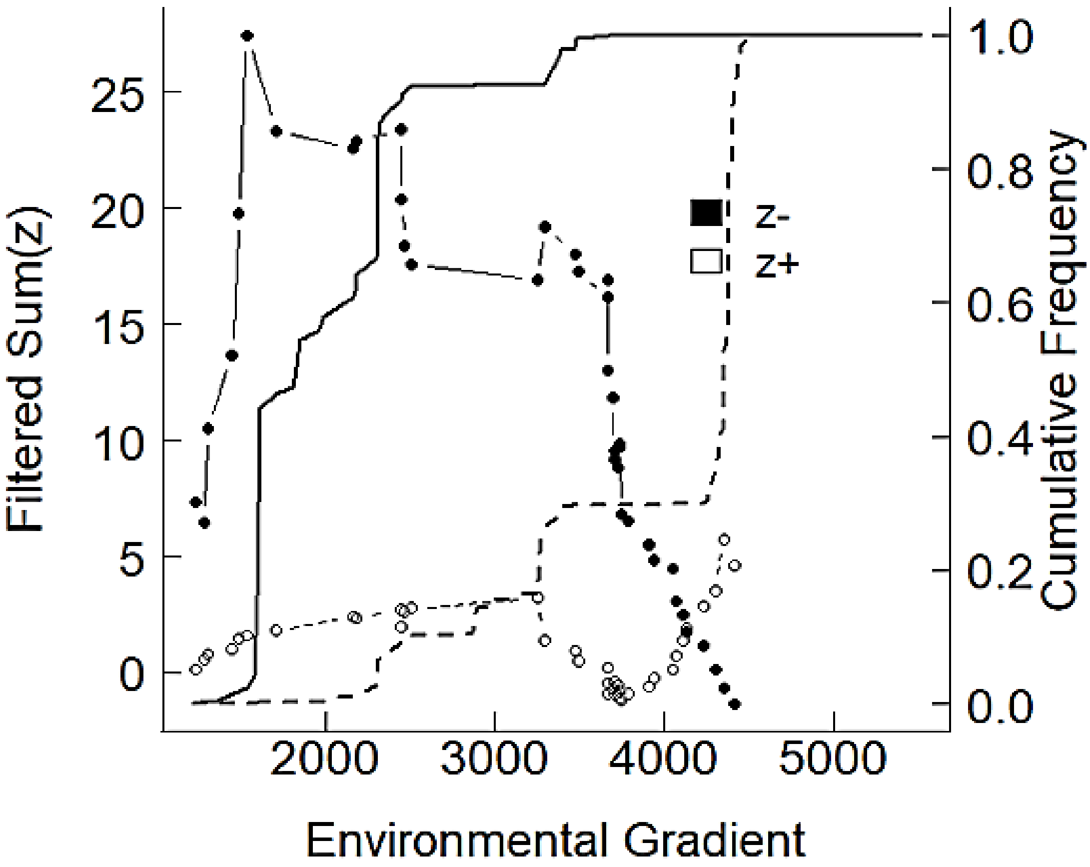
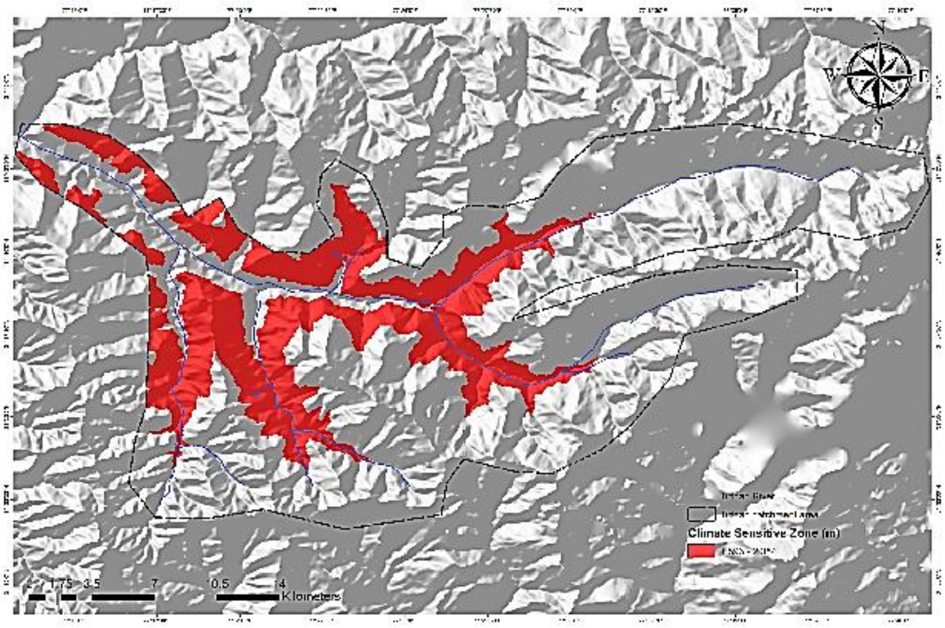
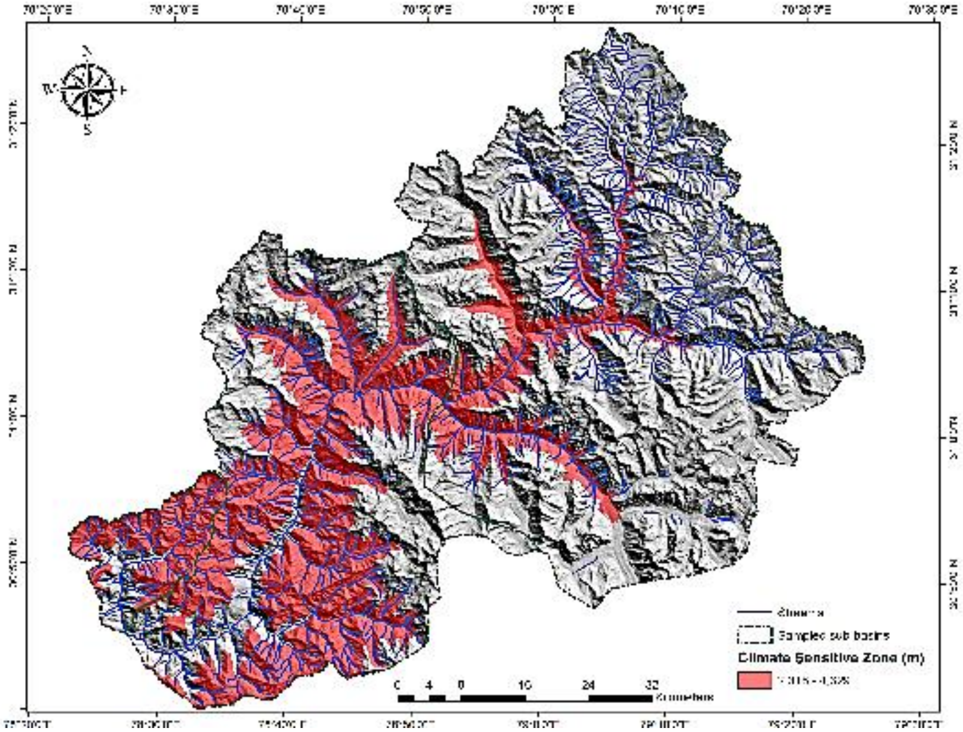


(b)

Fig. 4 TITAN 2 analysis showing filtered sum of indicator taxa (z) across the gradient for (a) Beas (turnover band: 1593-2383masl) and (b) Bhagirathi (turnover band: 2318-4328masl) Basins



(a)



(b)

Fig. 5 CSZs delineated through TITAN 2 highlighted within the basin boundaries of (a) Beas (turnover band: 1593-2383masl) and (b) Bhagirathi (turnover band: 2318-4328masl)

7.6 Conclusion / Summary

1. Through our study, we delimit specific elevational ranges along rivers for long-term monitoring of climate change responses. Our comparisons of riverine ecotones in two western Himalayan rivers opens up a platform to understand the macroecology of community turnovers in riverine ecosystems.
2. Climate change would shift the distributional range of macroinvertebrates and their altitudinal thresholds in river networks on the western Himalaya. The study provides a platform for further build-up of ecological evidences on these trends targeting other higher altitude streams and rivers of Himalaya.
3. The streams in the western Himalaya showed a noticeable gradual decline in annual mean temperature across the altitude, rendering the upper altitudes cold and rather narrow in terms of available thermal niche, thus limiting the ecotone at a lower elevation in our study.
4. Long mountain chains have been documented to show ecotones at higher elevations in their middle regions in comparison to the regions at their edges (Körner, 1999). This can be attributed to a range of geographical and atmospheric factors such as the wind speed, direction and humidity apart from exposure to the sun which might be affecting the ecotonal placements.
5. The heuristic approach we follow to trace climate-driven responses in unaltered riverscapes through our study, offers to detect early climate change signals by identifying sensitive indicator taxa as well as zones for long term monitoring. This can also be considered as a cost-effective approach for low-income countries wherein citizens and forest staff can contribute in data generation and monitoring.

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Chapter 8

Spatial Ecology for Climate Change Impact Assessment

8.1 Background

In recent decades, changes in climate have caused impacts on natural as well as human systems on all continents and across the oceans. Evidence of climate-change impacts is strongest and most comprehensive for natural systems. In many regions, changing precipitation patterns or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality. Glaciers continue to shrink almost worldwide due to climate change, affecting runoff and water resources downstream. Climate change is causing permafrost warming and thawing in high latitude regions and in high-elevation regions. Many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change. While only a few recent species extinctions have been attributed as yet to climate change, natural global climate change at rates slower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years. Consequently, the structure and functions of the ecosystems as well as human well-being are affected by this rapid biodiversity loss and species extinction which is a major environmental issue.

Spatial ecology focuses on the study and modeling of the role(s) of space on ecological processes that in turn affects ecological patterns (Fig. 1). The natural world has become increasingly fragmented due to human activities; anthropogenic landscape change has had a ripple-effect impact on wildlife populations, which are now more likely to be small, restricted in distribution, and increasingly isolated from one another. Due to the rapid advances in computer technology more advanced methods of statistical data analysis have come into use. Spatial ecology modeling uses components of remote sensing and geographical information systems (GIS). The repeated use of remotely sensed imagery and geographic information systems in a particular area has led to increased analysis and identification of spatial patterns over time and have also increased the ability to determine how human activities have impacted animal habitat and climate change. Spatial ecology deals with the ultimate distributional or spatial unit occupied by a species. The response of an organism or a species to the environment is particular to a specific scale and may respond differently at a larger or smaller scale. Most often, ecological patterns are a result of multiple ecological processes, which often operate at more than one spatial scale. In spatial ecology, scale refers to the spatial extent of ecological processes and the spatial interpretation of the data. Through the use of such spatial statistical methods such as geo-statistics and principal coordinate analysis of neighbor matrices (PCNM), one can identify spatial relationships between organisms and environmental variables at multiple scales.

Source: www.zafiri.com

Fig. 1 Spatial ecology for moderating habitat fragmentation through corridors

With more recent growth in spatial models, the availability of spatial data, computing capacity, and ongoing large-scale environmental change, spatial ecology has become an integral part of the entire field of ecology and conservation. The practical use of spatial ecology concepts is essential to understanding the consequences of fragmentation and habitat loss for wildlife. Understanding the response of a species to a spatial structure provides useful information regarding biodiversity conservation and habitat restoration.

8.2 Rationale

In a tropical country such as India the land resources are excessively burdened by the high human population with only 0.25 ha/person on a per capita basis (Meiyappan et al., 2017; Census of India, 2011). Forests and agriculture are the two major land use categories which provide livelihood to almost half of the population. However, the increasing population and technological advancements has created a heavy demand for resources leading to tremendous destruction and degradation of the environment. Climate change causes additional stress on the ecosystems that are already burdened with high levels of human interferences. Therefore, it is critical to understand the spatial and temporal patterns of the landscape and identify the primary driving forces operating at multiple scales, towards offering further scientific knowledge and policy inputs to deal with the future climate change and management of sensitive landscapes.

Mountain ecosystems are particularly vulnerable as they are ecologically fragile and under conflicting interests between economic development and environmental conservation. The Himalayan region is one of the most dynamic and diverse mountain systems of the world with complex terrain and topography reaching more than 8000 m. The fragile landscapes of the Himalayan region are highly susceptible to natural hazards, leading to ongoing concern about current and future climate change impacts in the region (Cruz et al., 2007). The network of protected areas which protect the unique wealth of flora and fauna in the Indian Himalayan region is subject to changes in structure and composition due to climate change. Therefore, climate change is a matter of great concern in this region

8.3 The Indian Himalayan Region (IHR)

The study has been implemented across the Indian Himalayan Region (IHR). The Indian Himalayan region is the section of the Himalaya within India that covers the entire northern part of the country spanning five major states within it viz. Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh and the hill regions of West Bengal (Fig. 2). It extends between latitudes 26°20' and 35°40’ North, and between longitudes 74°50’ and 95°40’ East. The region is responsible for providing water to a large part of the Indian sub- continent and contains varied flora and fauna. The total area covered is about 5 lakh km^2 and forms the northern boundary of the country.

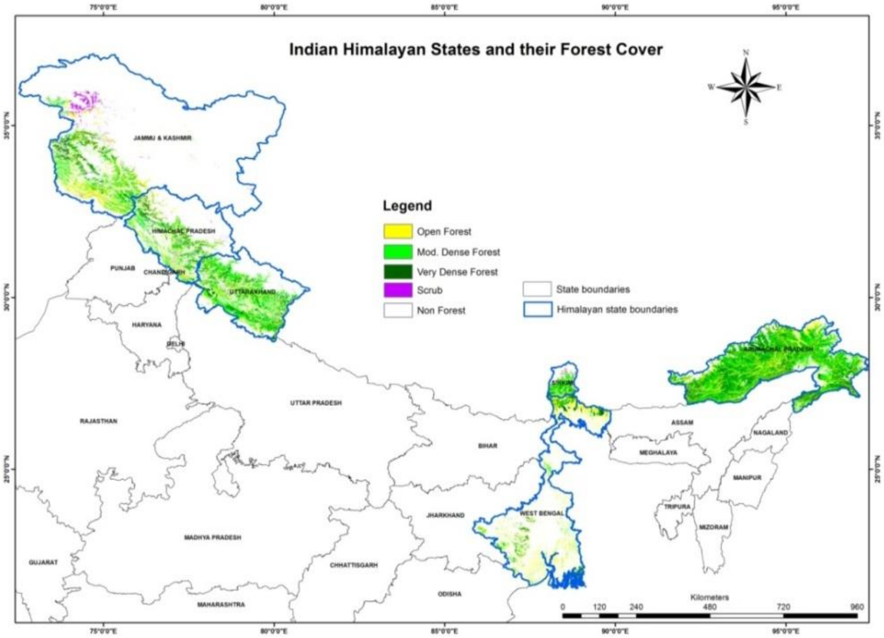


Fig. 2 Map showing the Indian Himalayan states with their forest cover

Physiographically, the IHR extends from the foothills of south (Siwaliks) up to Tibetan plateau on the north (Trans-Himalaya) comprising about 95 districts of the country. The region occupies the strategic position of entire northern boundary (North-West to North-East) of the nation and touches almost all the international borders (7 countries) with India. It contributes about 16.2% of India's total geographical area, and most of the area is covered by snow-clad peaks, glaciers of higher Himalaya, dense forest cover of mid-Himalaya. The IHR is characterized by a diverse array of ecosystems and corresponding floral and faunal assemblages. It has a wide altitudinal range from <100 m to over 8000 m above sea level. Most of the areas above 5500 m above sea level are under perpetual snow. The state of West Bengal has only the northern parts covered by Himalayas therefore only the northern districts of Darjeeling and Jalpaiguri have been considered for the study. The major Himalayan states are described below:

1. Jammu & Kashmir is situated between 32^{o}17' and 37^{o}5' N latitudes and 72^{o}40' and 80^{o}30' E longitudes in the extreme northern part of India. It is surrounded by China in the north, Tibet on the east, Himachal Pradesh on the south and Pakistan on the west. The state has a number of lakes, rivers, rivulets and glacial regions. Indus, Chenab and Sutlej (Jhelum) are the major rivers. Climatic variations in the state are extreme ranging from tropical in Jammu plains to semi-arctic cold in Ladakh.

2. Himachal Pradesh is located between the latitudes $30^{o}23'$ – $33^{o}13'$ N and longitudes $75^{o}43'$ - $79^{o}4'$ E. The state is bounded by Uttarakhand on the southeast, Tibet on the east, Punjab on the west and southwest, Haryana on south and Jammu & Kashmir on the north. The elevation ranges between 460 meters to 6,600 meters above mean sea level. Chenab (Chandrabhaga), Ravi (Iravati), Sutlej (Shatadru), Beas (Vipasa) and Yamuna (Jamuna) are the major rivers. The northern part of this state has almost cool climate throughout the year. There is heavy snowfall in the winters. The southern part has plain like conditions.
3. Uttarakhand is located between $28^{o}43'$ – $31^{o}27'$ N latitudes and $77^{o}34'$ – $81^{o}02'$ E longitudes is bound by Himachal Pradesh in the north-west, Nepal in the east, China (Tibet) in the north and Uttar Pradesh in the south. Starting from the foot hills in the south, the state extends upto the snow-clad peaks of the Himadri making the Indo-Tibetan boundary. The elevation ranges from 200m to more than 8,000m above mean sea level. The climate of the state is quite harsh with below freezing point temperature in many of the subdivisions of the state. Ganga, Yamuna, Saraju, Kali are the important rivers. The other details are listed in the Table 1.
4. Sikkim is located in the eastern Himalaya between $88^{o}3'$ - $88^{o}57'$ E longitude and $27^{o}03'$ – $28^{o}07'$ N latitude. The state is bound by Tibet on north, Nepal on west, Bhutan on east and West Bengal on south. India's highest mountain peak Kangchendzonga (8,579 m), which is world's third highest peak, rises from this state. The state extends to about 115 km from north to south and 65 km from west to east. Most of the areas of the state are snow covered throughout the year. The state is a treasure house of flowering plants due to its unique geographical position, varied topography and high annual rainfall. Teesta is the main river of the state with other rivers like Lahen, Lachung, Rangit and Rangpo. The climate of this state varies with the altitudes and the upper region is extremely cold, but the southern part is humid.
5. Hill districts of West Bengal is situated just below the state of Sikkim and lies between $26^{o}24'$ and $27^{o}12'$ N latitudes and $88^{o}01'$ and $89^{o}51'$E longitudes. Both Darjeeling and Jalpaiguri districts are the northernmost district of the state of West Bengal in eastern India and are part of foothills of the Himalayas. The elevation ranges from 100m to 2,042m above mean sea level. Some of notable rivers of this region are Mechi, Balason, Rammam, Rangeet, Teesta, and Jaldhaka.

6. Situated in the extreme north-west of India, Arunachal Pradesh lies between 26°28'and 29°30' N latitudes and 91°30' and 97°30' E longitudes. Brahmaputra, Kameng, Subansiri, Siang, Lohit and Tirap are the important rivers. The elevation ranges from 150m to 7,090m above mean sea level. The state is situated in the Eastern Himalaya and is the richest bio-geographical province of the entire Indian Himalayan zone. The province has been identified as one of the world's 18 biodiversity hotspots.

Table 1 Description of the major Indian Himalayan states

Himalayan State	**Area (km2)**	**Total Population**	**Forest Cover (%)**	**No. of National Parks**	**No. of Sanctuaries**	**No. of Conservation Reserves**
Jammu & Kashmir	2,22,236	1,25,41,302	10.34	3	13	-
Himachal Pradesh	55,673	68,64,602	26.40	3	32	-
Uttarakhand	53,483	1,00,86,292	45.32	6	7	3
Sikkim	7,096	6,10,577	47.31	1	7	-
Hill districts of West Bengal	8,929	57,19,669	34.09	3	9	-
Arunachal Pradesh	83,743	13,83,727	80.30	2	11	-

Chapter 9

Development of Spatial and Inter-Operable Database

9.1 Introduction

Global climate change, habitat loss, human appropriation of natural resources and the spread of pathogenic, exotic and domestic plants and animals are major challenges for humanity because these processes alter the functioning of ecosystems and their ability to provide human society with the goods and services (Cardinale et al., 2012; Naeem et al., 2012). Biodiversity is declining rapidly, with global and local extinctions and widespread population declines. These declines are driven by many factors, including land use change, climate change and population growth. In recent years, there is an explosion in the availability of biodiversity data describing the distribution, function, and evolutionary history of life on earth. Integrating these heterogeneous data remains a challenge due to large variations in observational scales, collection purposes, and terminologies (König et al., 2019).

Biodiversity conservation is integrally spatial; within it we use spatial thinking to define priority areas and divide land cover into categories, track land use and habitat use, and locate and monitor species. As increasing pressures are placed on land use, it is vital for decision making to be spatially well-informed and integrated. But the stakeholders often fail to collaborate and share spatial data. Adding to decision making difficulties, the vital datasets are frequently of poor accuracy, are not interoperable or are out of date (Chandler et al., 2016). Such issues can lead to conflicts between and within natural resource users and environmental protection initiatives, which often results in ineffective natural resource management and environmental degradation. Access to consistent spatial data has a range of benefits for conservation decision making, as well as profound implications for the quality of environment and development planning. It can reveal trends between different landscape relationships; it allows for spatially informed decision making; and it allows for land use trade-offs to be managed more effectively. For decision making on biodiversity conservation to be effective and well informed, these underpinning data needs to adhere to the following key principles: (i) Accuracy: Data needs to be high quality and trustworthy; (ii) Transparency: To be transparent, all data should include supporting information on how and when it was collected; (iii) Openness: Data should be free to access and use; (iv) Interoperability: Data should be able to be easily shared and exchanged between users and software. Environmental organisations responsible for decision making can be empowered by open, accurate, and exchangeable spatial data. These principles listed above also can create geospatial data that are useful and accessible to all stakeholders.

9.2 Implications of database interoperability

Biodiversity supports the health of ecosystems and the services they provide to society. Yet biodiversity is rapidly declining globally, despite commitments by governments to reduce the rate of loss (Butchart et al., 2010). Monitoring is an essential part of biodiversity conservation, allowing governments and civil society to identify problems, develop solutions, and assess effectiveness of actions. Spatial data has emerged as vital requirement for monitoring the status of environmental parameters relevant to biodiversity conservation (Pettorelli et al., 2014). Tackling a global challenge like biodiversity loss requires the assembly of global information products across multiple spatial and temporal scales. Satellite remote sensing along with other spatial data are extremely useful at generating consistent observation records of key drivers of biodiversity change (i.e. land cover and land use dynamics and climate variables) from a local to global scale (Hansen and Loveland, 2012).

The data interoperability refers to the functionality of information systems to exchange data and to enable sharing of information. Many geographical databases have been developed for different programs and applications, but data acquisition and data sharing are still a big problem because no interoperability exists among these different databases. Several large-scale databases have been set up at institutional level to deal with changing land use and climate patterns, forest decline, ecosystem services, etc. Although initiatives have been taken to identify and develop where and how these systems could communicate with each other and exchange information, each of these systems has been created for a specific purpose. In keeping with the main data protection principles, interoperability cannot give rise to the access or use of any data via another information system or give access to more data than is needed.

The data interoperability and sharing will aide in (i) data continuity; (ii) data affordability and (iii) data access. Data continuity refers to the need to preserve and improve existing long-term archives of spatial data. Habitat loss and degradation, species invasions and changing climatic conditions are among the most significant threats to biodiversity globally (Millennium Ecosystem Assessment, 2005). These threats can impact biodiversity at a range of spatial and temporal scales, requiring global data collection and long timeseries of data acquisitions to understand trends and develop robust predictions about their future impacts on biological diversity. Data affordability matters as it has a large impact on its use and the resulting benefits (Mathae and Uhlir, 2012). If too expensive, spatial data will not be used as extensively as originally intended. Conservation is chronically underfunded (McCarthy et al., 2012) and governments and civil society will only use these data for implementing conservation policies and monitoring their progress if they can afford them. Data access, broadly describes the ability of users to discover, retrieve, and manipulate data and extract useful information from spatial data for monitoring of biodiversity.

9.3 Methodological framework

A geodatabase is a collection of geographic datasets of various types held in a common file system folder, a Microsoft Access database, or a multiuser relational DBMS (such as Oracle, Microsoft SQL Server, PostgreSQL, Informix, or IBM DB2). Geodatabases can be of any sizes, have varying numbers of users and can scale from small, single-user databases built on files up to larger workgroup, department, and enterprise geodatabases accessed by many users. The geodatabase storage model is based on a series of relational databases and a database management system (DBMS). Simple tables and well-defined attribute types are used to store the schema, rule, base, and spatial attribute data for each geographic dataset. This approach provides a formal model for storing and working with spatial data. The geodatabase is a storage used to hold a collection of datasets. There are different types (Fig. 1):

File geodatabases — A file geodatabase is stored as multiple files in a folder. Each dataset is contained in a single file. By default, files upto 1TB can be saved, but can be extended to 4 or 256 TB using keyword configuration. File geodatabases support the full information model of the geodatabase, which comprises network datasets, terrain datasets, relationship classes, etc. File geodatabases can have more than one editor at the same time provided they are editing in different feature datasets, stand-alone feature classes, or tables. The file geodatabase is ideal for GIS projects, personal use, and in small organizations. It has strong performance and scales well to hold extremely large data volumes without requiring the use of a DBMS. Plus, it is portable across operating systems. Users can employ multiple file geodatabases for their data collections and access these simultaneously for their GIS work.

Enterprise geodatabases — Also known as multiuser geodatabases, are virtually unlimited in size and can support unlimited numbers of users. They are stored in a relational database such as Oracle, Microsoft SQL Server, IBM DB2, PostgreSQL, or SAP HANA. Enterprise geodatabase provides a large, multiuser geodatabase that can be edited and used simultaneously by many users. It also provides the ability to manage a shared, multiuser geodatabase as well as support for a number of critical version-based GIS workflows.

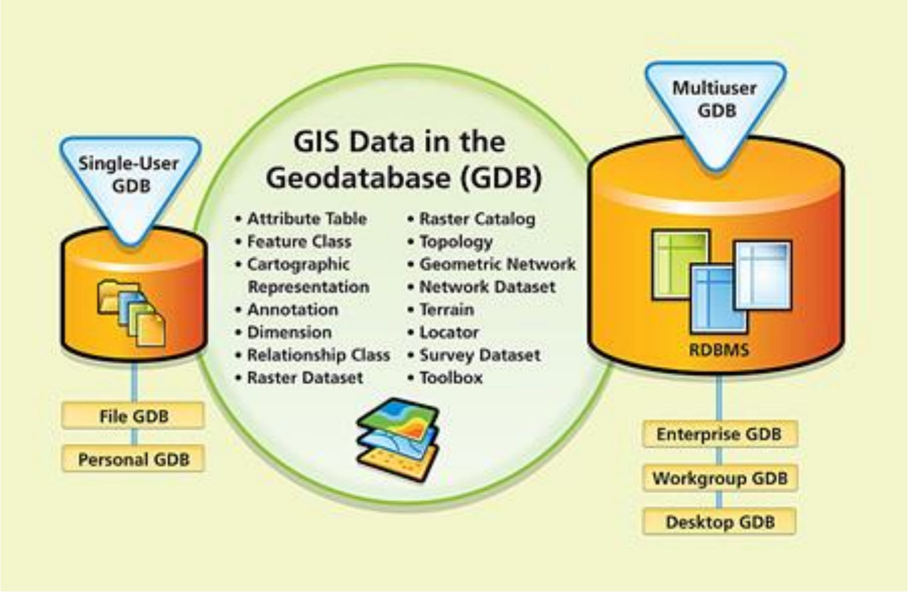


Fig. 1. Spatial Geodatabase

At present the spatial data layers are stored as a File Geodatabase for sharing within the Wildlife Institute's NMSHE team but will be upgraded to Enterprise Geodatabase for sharing data between other task forces and other institutes.

9.4 Database profile

A total of 37 data layers including land use land cover, forest cover, drainage, road network, nightlight data, etc. (Table 2) were created and categorized under 7 Thematic Heads

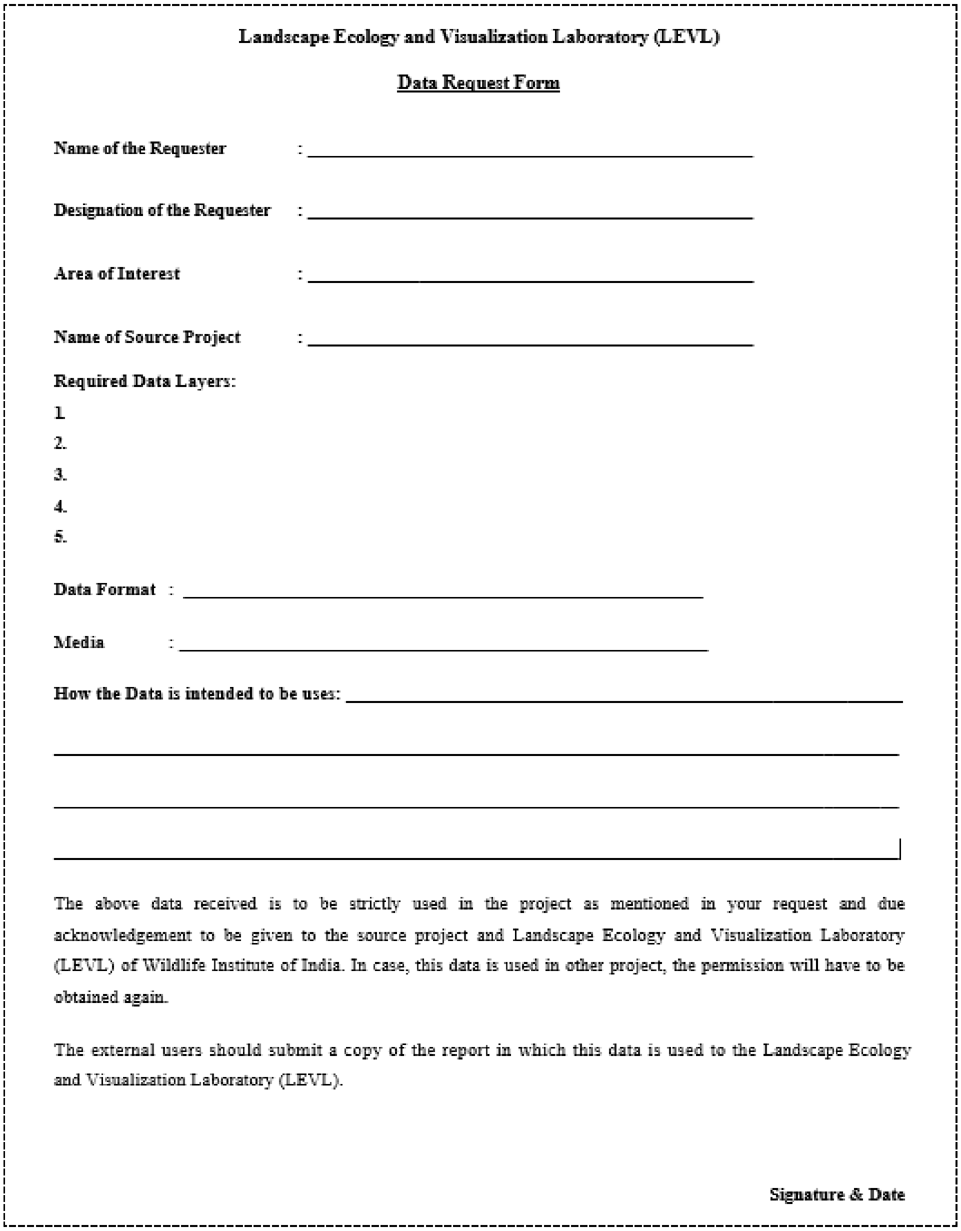
(Topography, Climate, Ecological. Hydrological, Anthropogenic, Administrative and Field Data). Spatial Ecology team of Wildlife Institute of India Task Force is very much engaged to expand the spatial database and to improve the use of spatial data between all the Task Forces of NMSHE.

Table 2 Metadata of Spatial Layers at Landscape Ecology and Visualization Laboratory

Sl. No	Name of the Layer	Coverage	Layer	Spatial Res.	Acquired Date	Date of Download	Source
1	National Boundary	India	Vector	-	-	Apr 16	SOI
2	State Boundary	India	Vector	-	-	Apr 16	SOI
3	Districts Boundary	India	Vector	-	-	Apr 16	SOI
4	Taluk Boundary	India	Vector	-	-	Apr 16	SOI
5	Village Boundary	Uttarakhand	Vector	-	-	Apr 16	SOI
6	Protected Area	India	Vector	-	-	Apr 15	WII
7	Biogeographic Zone	India	Vector	-	-	Apr 15	WII
8	Forest Division	Uttarakhand	Vector	-	-	Nov 15	State Forest
9	Protected Areas	IHR	Vector	-	-	Oct 15	ICIMOD
10	Boundary	IHR	Vector	-	-	Oct 15	ICIMOD
11	FAO Soil Types	IHR	Vector	-	-	Oct 15	ICIMOD
12	Elevation	IHR	Vector	-	-	Oct 15	ICIMOD
13	Road Network	India	Vector	-	-	Apr 15	SOI / WII
14	Major Cities Location	India	Vector	-	-	Apr 15	SOI / WII
15	River	India	Vector	-	-	Apr 15	Hydro SHEDS
16	Drainage	Ganga	Vector	-	-	Aug 15	NIH
17	Basin Boundary	Ganga	Vector	-	-	Aug 15	NIH

18	Basin Boundary	IHR	Vector	-	-	Oct 15	ICIMOD
19	Forest Cover	India	Raster	100m	2014	Apr 15	FSI / WII
20	MODIS NDVI	Asia	Raster	250m	2000, 2005,	Nov 15	Earth Explorer
21	NBSS Soil - Ganga	Ganga	Raster	1Km	2004	Aug 15	NIH
22	Globeland30	India	Raster	30m	2000, 2010	Aug 17	Global Land
23	Climate Change	Global	Raster	300m	2015	June 2016	ESA
24	MODIS-GLC LULC	Global	Raster	500m	2010	June 2016	USGS-LCI
25	GLC-Share LULC	Global	Raster	1Km	2014	June 2016	GLCN
26	Aster - DEM	India	Raster	30m	2011	Apr 15	ASTER / WII
27	SRTM - DEM	India	Raster	90m	2000	Apr 15	SRTM / WII
28	Human Foot Print	Global	Raster	1 km	2009	Apr 16	NASA-SEDAC
29	Nightlight	Global	Raster	1 km	2013	Apr 16	NOAA
30	Worldclim Temp (Future	Global	Raster	900 m	2040-2080	Oct 15	Worldclim
31	Worldclim Preci (Future	Global	Raster	900 m	2040-2081	Oct 15	Worldclim
32	Worldclim Bioclim	Global	Raster	900 m	2040-2082	Oct 15	Worldclim
33	Worldclim (Historical)	Global	Raster	900 m	1950-2000	Oct 15	Worldclim
34	IMD Temperature	India	Grid	110 km	1951-2013	Nov 15	IMD
35	IMD Precipitation	India	Grid	25 km	1951-2014	Nov 15	IMD
36	Primary Census	India	Excel		2011	Nov 15	Census of India
37	Housing and Slum data	Uttarakhand	Excel		2011	Nov 15	Census of India

To study and preserve biodiversity, resource managers need access to long-term spatial data about the environmental conditions in their study area. The effectiveness of a geodatabase lies in the ease of accessibility for users to access the data in the database. Landscape Ecology and Visualization Laboratory (LEVL), established as a part of NMSHE Programme has setup a Spatial Database System that acts as a central data repository for different thematic areas in the Indian Himalayan Region (IHR) and provides easy access to these data both within and outside the Wildlife Institute of India. All of the published datasets are available for sharing after simple registration and acceptance of the data use agreement (Fig. 2).



Landscape Ecology and Visualization Laboratory (LEVL)

Data Request Form

Name of the Requester : ____________________

Designation of the Requester : ____________________

Area of Interest : ____________________

Name of Source Project : ____________________

Required Data Layers:

1.
2.
3.
4.
5.

Data Format : ____________________

Media : ____________________

How the Data is intended to be uses: ____________________

The above data received is to be strictly used in the project as mentioned in your request and due acknowledgement to be given to the source project and Landscape Ecology and Visualization Laboratory (LEVL) of Wildlife Institute of India. In case, this data is used in other project, the permission will have to be obtained again.

The external users should submit a copy of the report in which this data is used to the Landscape Ecology and Visualization Laboratory (LEVL).

Signature & Date

Fig. 2 Data Request Form

The data sharing is restricted only within the Wildlife Institute of India at present but will be available for larger stakeholders through web portal once the Enterprise Geodatabase is set up.

9.5 Potential for Policy intervention and Decision Making

The coming years bring a range of goals, targets and challenges for environmental decision making. The Sustainable Development Goals (SDGs), launched in September 2015, require major environment and development action to be taken. The Convention on Biological Diversity Aichi Targets, is the main global mechanism to protect biological diversity, come to an end in 2020. As a result, most countries have set environmental targets for 2020-2025. For these targets to be effective, countries need to be equipped with the right information. The next decade will therefore be vital for the effective and transparent collection of environmental, developmental and biodiversity conservation data to support the decision making.

Alongside the direct benefits for environmental stakeholders, access to transparent and accurate spatial data can better equip governments, and other stakeholders in land use and investment decision making by: (i) Strengthening the implementation of environmental policies, by empowering those responsible to identify development projects and to engage early to resolve issues; (ii) Empowering government and stakeholders to more effectively engage with decisions relating to land-use and development planning; (iii) Giving planners a vision on the level of environmental diligence required before embarking on the developmental projects (Schmitt et al., 2016). The collected spatial data and projects give conservation agencies and stakeholders the ability to find more sustainable solutions. Development agencies are often significantly non-transparent in providing data on where, when, and how much activity is occurring. This leads to less effective conservation decisions and engagement with these sectors.

Spatial data complements many other traditional data systems. Most of the environmental indicators can and should be visualised spatially, especially at the sub-national scale, because it can help decision-makers visualize and understand data such as the visual overlay of multiple data sets. These can reveal relationships, patterns and trends that may not otherwise be perceived (Chandler et al., 2016). Geospatial data is valuable when used to visually track progress of environmental disturbances. Location specific information gives insight into the distribution of needs and on how to optimise development investments and biodiversity planning. Links can also be made between potentially detrimental trends and spatial features such as roads and proximity to water resources or green spaces, helping to form a complete picture from which more targeted decisions can be made.

9.6 Conclusion / Summary

To increase the use of spatial data for ecological and conservation purposes requires a commitment by all the stakeholders including researchers, managers and policy makers to promote a higher level of interdisciplinary work among these communities, creating opportunities for the advancement of all the disciplines (Pettorelli et al., 2014). Solutions may include sharing existing biodiversity data more widely via web interfaces. Landscape Ecology and Visualization Laboratory (LEVL), established as a part of NMSHE Programme has setup a Spatial Database System that acts as a central data repository for different thematic areas in the Indian Himalayan Region (IHR) and provides easy access to these data both within and outside the Wildlife Institute of India. Landscape Ecology and Visualization Laboratory initiative under National Mission for Sustaining Himalayan Ecosystem (NMSHE) programme is responsible for developing and maintaining the Spatial Database. This initiative has put in place LEVL’s Data Sharing Policy, data and metadata standards, and necessary hardware and software infrastructure.

The Data Sharing Policy facilitates data sharing between all the task forces, enabling data use beyond the original research, and has been aligned with the open and free access to scientific information and knowledge. Database in form of land use landcover, fragmentation, disturbance, bio-rich area has been generated for all the 6 Indian Himalayan States viz. Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Northern Districts of West Bengal and Arunachal Pradesh as a part of the spatial database and this information can be used for better planning, management and decision making. The spatial database has been generated for easier access, faster retrieval and data visualization of spatial data and for easier collaboration between the other taskforces.

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Chapter 10

Drivers of Landscape Change: Climatic and Anthropogenic

10.1 Introduction

Landscape change research has gained rapid attention in the last couple of decades (Hersperger et al., 2010). The highly dynamic nature of land, communities and their impact on ecology have catapulted landscape change research to the premier domains of global change studies (Burgi et al., 2004). Moreover, changes in the landscape are the major factors which have a constant impact on the biodiversity conservation efforts worldwide especially in the tropics (Xue et al., 2016). Land change science also facilitates the identification of activities and processes (anthropogenic or bio-physical) which influence the smooth operation of ecological systems (Hersperger et al., 2010). These activities most commonly referred to as the "driving forces" of landscape change (Burgi et al., 2004) or "drivers" (Wood and Handley, 2001) that operate at multiple spatial and temporal scales. A number of driving forces of both natural and anthropogenic categories have been identified; the natural driving forces mostly pertain to the terrain, climatic factors, soil and extreme natural events while the anthropogenic driving forces refer to various activities related to human such as infrastructure development, agriculture and population density, etc (Burgi et al., 2004).

Vegetation cover constitutes one of the most important attributes of a landscape. Vegetation stabilizes the ecosystem by protecting soil, maintaining biodiversity, regulating climate and hydrology of the regional environment. Any drastic change in the vegetation cover has cascading effects on the entire ecosystem structure and function and has very critical implications for global climate as well. The status of vegetation cover is measured by normalized difference vegetation index (NDVI) which parameterizes the growth status of surface vegetation. The calculation of NDVI (Eq. 1) is based on the principle that vegetation absorbs red (RED) and reflects near infra-red (NIR) wavelengths much more than other wavelengths (Tucker and Townshend, 1985). NDVI values range from -1 to +1 with positive values indicating the presence of dense vegetation cover with high productivity (Fang et al., 2004) while low negative values correspond to non-vegetated areas like water, snow and bare ground (Yin et al., 1997).

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \qquad \text{(Eq.1)}$$

NDVI is highly influenced by climate and human activities. Beginning 1980s, a lot of research has been conducted concerning the relationship of NDVI with climatic and anthropogenic factors (Ning et al., 2015). Similarly, many researchers included the impact of human activities when studying NDVI relationships with climatic factors (Gong et al., 2002; Nemani et al., 2003; Herrmann et al., 2005; Zhang et al., 2006a; Seaquist et al., 2009; Rutherford et al., 2016; Liang et al., 2018) and mentioned that both these factors are pivotal in influencing the NDVI (Xin et al., 2007; Yang et al., 2009; Dai et al., 2011; Xu et al., 2014). Some other studies argued that human factor in fact was more influential in controlling NDVI variations as opposed to climatic factors (Ma et al., 2006; Zhang et al., 2006b). Morawitz et al., 2006, indicating that anthropogenic factors were more important drivers at the watershed scale but at regional scales climate patterns were primary drivers. It was pointed out that studying NDVI values at multiple scales can be useful to detect spatial patterns and mechanisms. In the Indian context, a study by Jeyaseelan et al., 2007, analyzed the temporal NDVI over entire Indian subcontinent between the years 1982 and 2003 and concluded that the NDVI variations are not highly related with rainfall patterns and that land cover changes may be the primary drivers of the observed changes in NDVI.

10.2 Modeling approach

A spatial database of dependent and independent variables was established (Table 1). The Moderate Resolution Imaging Spectrometer (MODIS) NDVI with a foot-print of 250 m was used for the years 2000, 2005, 2010 and 2015. The night time stable data of Defence Meteorological Satellite Program (DMSP) of United States Air force with a spatial resolution of 2.8 km at full mode, and 0.56 km at fine mode was used. The Global Human Footprint Dataset Version 2, 2005 which represents the relative human influence in each terrestrial biome expressed as a percentage (Sanderson et al., 2002) was used.

Table 1 Details of datasets used in the study

Data layers	**Resolution**	**Units**	**Data type**	**Source**
Dependent Variables				
NDVI 2000, 2005, 2010 and 2015	250 m	-	Continuous	NASA-MODIS
Independent Variables				
Elevation	30 m	meters	Continuous	ASTER
Slope	30 m	Degrees	Continuous	Derived from elevation
Aspect	30 m		Categorical	Derived from elevation
Human Footprint	1 km	Percent	Continuous	WCS
Night light	1 km	Percent	Continuous	DMSP/OLS
Population Density	1 km		Continuous	Survey of India
Bioclim layers				www.wordclim.org
Mean annual temperature (Bio1)	1 km	Degree Celsius	Continuous	
Mean Diurnal Range (Bio2)	1 km	Degree Celsius	Continuous	
Isothermality(Bio3)	1 km		Continuous	
Temperature Seasonality (Bio4)	1 km	Degree Celsius	Continuous	
Maximum Temperature of Warmest month (Bio5)	1 km	Degree Celsius	Continuous	
Minimum Temperature of Coldest month(Bio6)	1 km	Degree Celsius	Continuous	
Temperature Annual Range (Bio7)	1 km	Degree Celsius	Continuous	
Mean Temperature of Wettest Quarter (Bio8)	1 km	Degree Celsius	Continuous	
Mean Temperature of Driest Quarter(Bio9)	1 km	Degree Celsius	Continuous	
Mean Temperature of Warmest Quarter(Bio10)	1 km	Degree Celsius	Continuous	
Mean Temperature of Coldest Quarter(Bio11)	1 km	Degree Celsius	Continuous	

Annual Precipitation (Bio12)	1 km	Millimetres	Continuous	
Precipitation of Wettest month (Bio13)	1 km	Millimetres	Continuous	
Precipitation of Driest month(Bio14)	1 km	Millimetres	Continuous	
Precipitation seasonality (Bio15)	1 km	Millimetres	Continuous	
Precipitation of Wettest Quarter(Bio16)	1 km	Millimetres	Continuous	
Precipitation of Driest Quarter(Bio17)	1 km	Millimetres	Continuous	
Precipitation of Warmest Quarter(Bio18)	1 km	Millimetres	Continuous	
Precipitation of Coldest Quarter(Bio19)	1 km	Millimetres	Continuous	

10.2.1 Selecting determinants of landscape pattern/vegetation cover

The framework for data collection and analytical procedure involved in the study is described below.

1. Data Preparation and Spatial Analyses: The NDVI images were rescaled to -1 to +1 range. The negative values corresponding to non-vegetated areas were removed to obtain the vegetation NDVI. The different data layers were converted to the actual values that they represent, e.g. degree Celsius for temperature, meters for elevation, etc. The bioclimatic layers pertaining to temperature were also rescaled by a scaling factor of 10. The digital elevation model (DEM) data was used to generate the slope and aspect layers. The slope and aspect layers were categorized into different classes. The data was then extracted for the study area. Scale plays a central role in determining the outcome of observations (Levin, 1992; Schneider, 1994; Peterson and Parker, 1998) and different patterns emerge at different scales of investigation. Therefore, a systematic grid sampling method was adopted to analyze the data at different spatial scales and the entire study area was divided into uniform sampling grids of 16km (n=251), 4km (n=3478) and 1km (n=53148). Each grid size represents a different level of ecological organization such as large environment correlates, medium level structural correlates and local level anthropogenic correlates respectively, although these correlates interact across scales as well. These sampling grids at multiple scales were used to derive the descriptive statistical estimates namely, mean, sum and standard deviations for each variable.

2. Selection of Bioclimatic Variables: The 19 bioclimatic layers were extracted for all the states of IHR. A principal component analysis was run in ArcGIS software for these layers to generate a covariance and correlation matrix. In normal situation, a correlation value of 0.5 is considered as threshold in variable selection. Since we had large number of highly auto-correlated variables, and that model building was aimed at with least possible variables, the threshold of 0.8 was considered for independent variable selection. Accordingly, the bivariate correlation matrix was studied and 10 bioclimatic variables were selected based on the threshold coefficient and their ecological significance.

3. Selection of candidate variables for Model Building: An initial list of 49 candidate variables (includes all the variables listed in Table 4.2.1 along with their statistics namely mean, standard deviations and sum) was prepared on the basis of background knowledge and theoretical concepts. NDVI (2015) and NDVI change (2000-2015) were selected as the target/dependent variables to be investigated with respect to the other predictor/independent variables. NDVI change was used to detect drivers of change across time (2000-2015). The NDVI change was calculated as the sum of the change between 2000-2005, 2005-2010 and 2010-2015 to get the cumulative change from 2000 to 2015. The change data was converted into binomial form for logistic modelling wherein 0 represents no change and 1 represents change (the positive and negative changes separately). The normality of the target variables was assessed with the help of data distribution histograms. Pearson correlation coefficients were estimated and plotted on a scatter plot. A total of 15 predictor variables (exhibiting a linear/roughly linear relationship with the target variable NDVI (2015)/ NDVI change) were selected for input into further model building.

4. Regression Modelling: A Generalized (GLM) Linear Model with logistic link function was used for finding the most efficacious predictors which can best explain the NDVI changes from 2000 to 2015 at each scale. The mathematical formula used is shown below in Eq. 1 & Eq. 2:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots \beta_n X_n + \varepsilon \qquad \text{(Eq. 1)}$$

$$\eta_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots\ldots \beta_n X_{ni} \qquad \text{(Eq. 2)}$$

where, Y is the dependent variable; η_i is the linear predictor; X_1, X_2, X_n are the n number of explanatory variables; β_1, β_2 and β_n are the coefficients, and ε is the random error term or the residual. The units for the coefficients match the predictor variables. In Generalized Linear Models there is a linear predictor (η_i) and two functions 1) link function which describe how the mean depends on the linear predictor and 2) variance function which describes how the variance depends on the mean. We used a logistic link function for the binomial data which maps from 0 to 1. Both positive and negative changes were modeled, however, only the drivers of negative changes have been reported.

The model building was implemented in R platform. The model was run with an initial selection of the predictor variables and then subsequent addition and removal until the best possible model was arrived at. The outputs from a GLMs included a table of variable coefficients, adjusted R^2, deviance residuals, Akaike Information Criterion (AIC) value and Fisher Scoring Iteration. The coefficient is an estimate of how much the dependent variable would change given a one-unit change in the explanatory variable. The coefficient table includes the list of explanatory variables used in the model with their coefficients, standard errors, t-values/z-values and probabilities. The GLM summary outputs such as AIC and R^2 were used to select the best model for each spatial scale.

10.3 Major determinants of landscape change

The NDVI has changed significantly during the study time period in all the IHR states. However, there were sharp declines in some areas and sharp rise in other areas with values ranging from -0.61 to 0.84. In Uttarakhand, the mean annual NDVI shows an upward trend from 0.31 in 2000 to 0.33 in 2015 with the highest mean of 0.39 in 2005. In contrast, the annual maximum NDVI depicted a decreasing trend from 0.68 in 2000 to 0.63 in 2015. In Himachal Pradesh, Arunachal Pradesh and Jammu and Kashmir, the annual maximum NDVI depicted a decrease from 0.7 in 2000 to 0.61 in 2015, while there is no overall change depicted in the annual maximum NDVI for Sikkim. Hence, all the IHR states depict a decreasing trend in the annual maximum NDVI from 2000 to 2015 except for the year 2005 where all the states display high values of annual maximum NDVI.

The analysis of the cumulative changes provided a clear picture of the trend (Fig. 1, 2 & 3). For example, in Uttarakhand the values range from -5.71 to 4.78 indicating very sharp decline in some areas. However, majority of the landscape showed an increase in NDVI especially the high altitude vegetated and forested areas as denoted by the increased NDVI values. The districts of Garhwal, Chamoli, Pithoragarh, Bageshwar and Rudraprayag showed an overall increase in vegetation cover/vigour while an overall decline was seen in Dehradun, Uttarkashi. Nainital and Haridwar districts. Dehradun district seems to be the most affected as it portrays high decline in majority of the areas and also the highest observed decline in NDVI. In Himachal Pradesh the cumulative change values range from -3.82 to 3.31. High decline was observed in Kangra, Chamba, Kullu and Una districts while increase (which was less comparatively) was observed in Mandi, Bilaspur, Solan and Shimla. The cumulative changes in landscape vegetation cover are shown in Fig. 4.3.1, 4.3.2 & 4.3.3 for all the six Himalayan states at all three spatial scales.

The magnitude of decrease is very highly evident in Jammu and Kashmir with values ranging from -7.15 to 4.01. Almost all the districts portray high decreases in NDVI especially parts of Baramula, Punch and Muzaffarabad and high increases in parts of Anantnag and Udhampur. As compared to other Himalayan states, the state of Sikkim has comparatively observed little decline in NDVI values which range from -2.84 to 4.95. The North and West districts of Sikkim show high increases in NDVI. The decrease is concentrated to few patches in the upper elevation areas of North district and eastern parts of East district. The scenario is quite surprising in Arunachal Pradesh which has cumulative change values ranging from -8.37 to 3.90 and the highest decrease observed in NDVI values. The state shows an overall increase in NDVI for most areas; however, the magnitude of decline is very high in certain districts which include Upper Siang, West Siang, Upper and Lower Subansiri. In absence of high human disturbance in these areas, such high decline in NDVI can be attributed solely to the impacts of changing climatic factors. The assessments from the driver identification would be able to provide a clearer picture for this trend. The bioclimatic variables showed a lot of redundancy as observed from the pair-wise correlation coefficient matrix. Detailed analysis of the correlation matrix led to the selection of the following ten bioclimatic variables namely Bio1, Bio2, Bio3, Bio5, Bio6, Bio 7, Bio12, Bio13, Bio14 and Bio17 for further analysis. Some variables had high values of coefficients yet, they were retained due to their biological relevance.

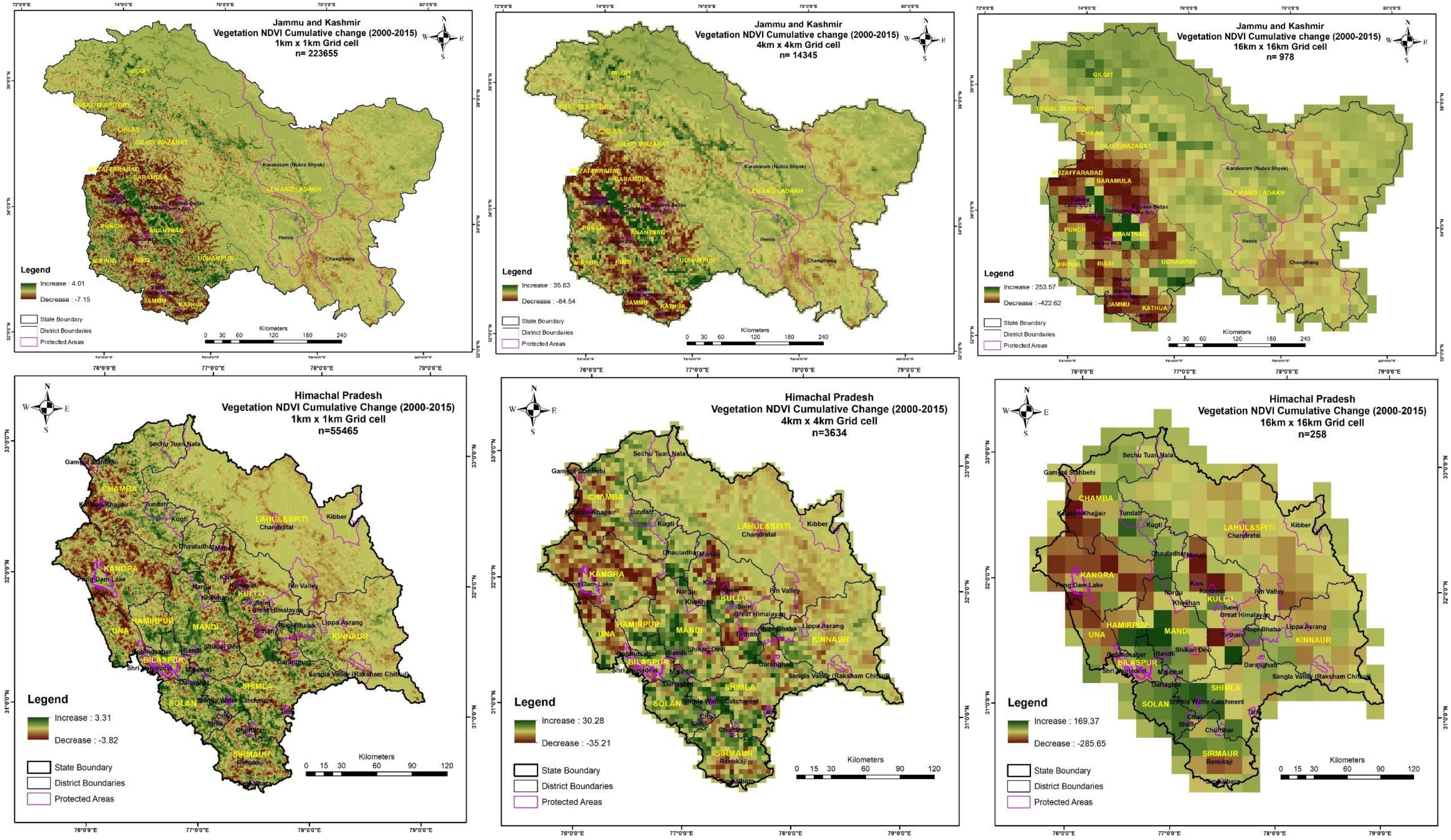

Fig. 1 Cumulative changes in NDVI for Jammu & Kashmir & Himachal Pradesh at 1 sq.km, 4 sq.km and 16 sq.km grid

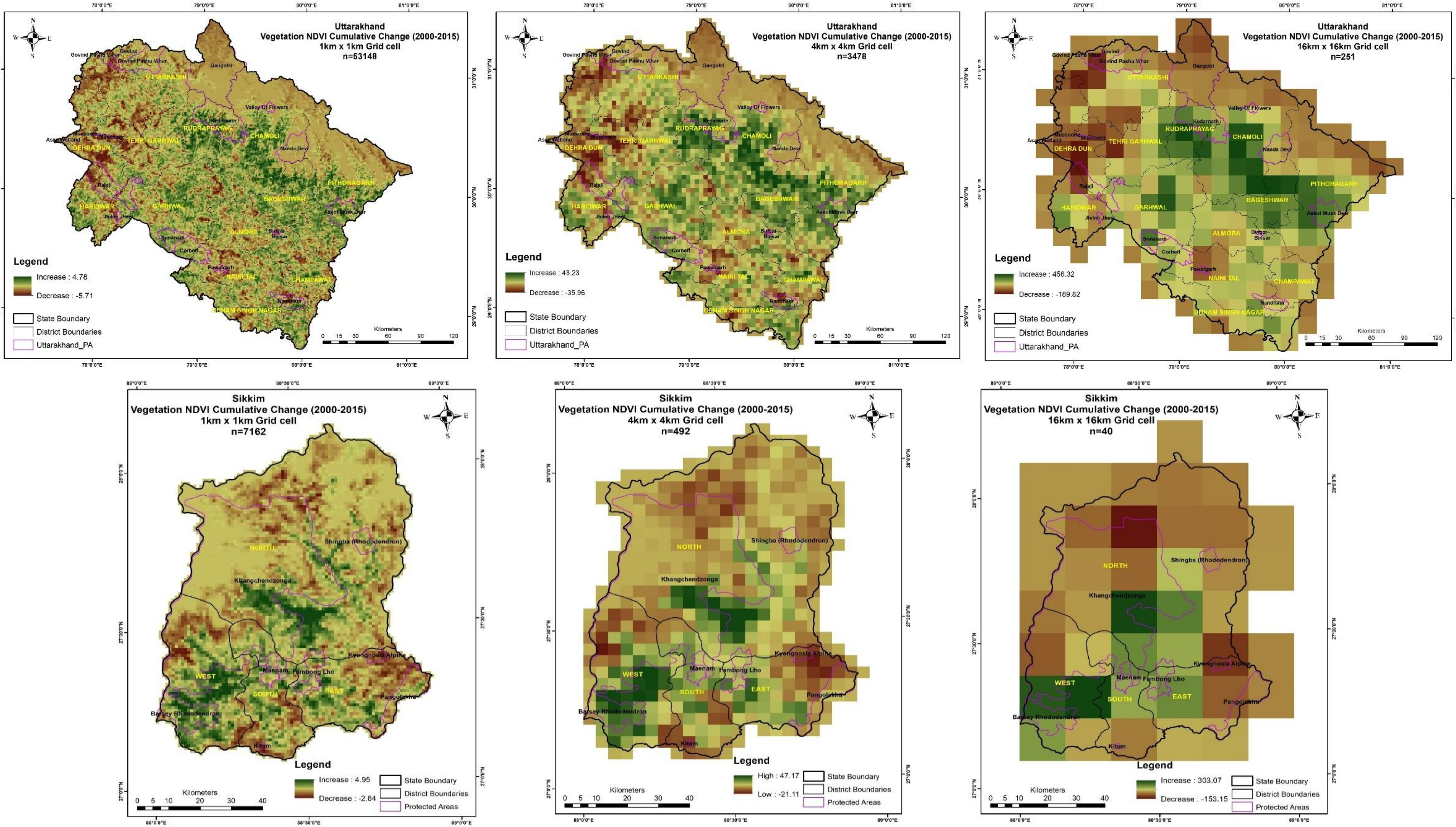

Fig. 2: Cumulative changes in NDVI for Uttarakhand & Sikkim at 1 sq.km, 4 sq.km and 16 sq.km grid

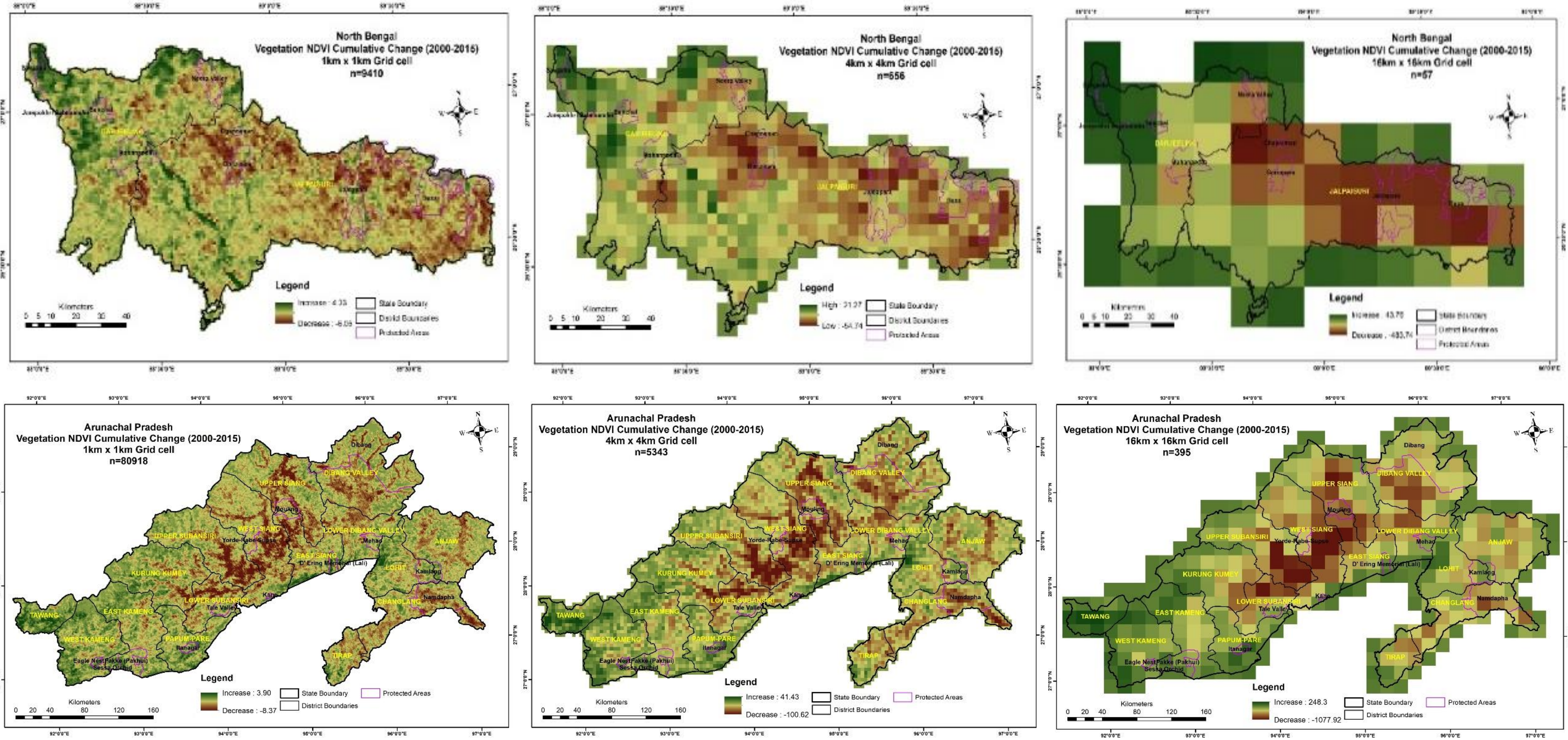

Fig. 3 Cumulative changes in NDVI for Hill Districts of West Bengal & Arunachal Pradesh at 1 sq.km, 4 sq.km and 16 sq.km grid

10.4 Drivers of Change

The results of the logistic regression for cumulative NDVI change from 2000 to 2015 using generalized linear model are presented for the state of Uttarakhand in Table 2. The results for other IHR states have been provided in Annexure -II (Table 1 - Table 5). The results were interpreted on the basis of the z-values and the level of significance (p-values). The z-value is used to test the importance of the predictor variables and higher this value in a model greater is the importance of that variable (Hosmer & Lemeshow, 1989).

Table 2 GLM outputs for NDVI change from 2000 to 2015 in Uttarakhand

	Estimate	*Std. Error*	*z value*	*Pr (>|z|)*
Grid Scale 16 km^2				
Intercept	-8.12E-01	9.26E-02	-8.768	< 2e-16 ***
Human Footprint (s)	3.17E-02	3.11E-03	**10.183**	< 2e-16 ***
Mean annual Temp(s)	-2.95E-01	3.87E-01	-0.762	0.4462
Max. Temp Warmest Month(s)	-1.08E+04	4.30E+04	-0.251	0.8021
Min. Temp Coldest Month(s)	1.08E+04	4.30E+04	0.251	0.8021
Temperature Annual range (s)	1.08E+04	4.30E+04	0.251	0.8021
Annual Precipitation(s)	-1.32E-02	2.46E-03	-5.353	8.67e-08 ***
Prec. of Wettest Month(s)	1.27E-02	5.40E-03	2.351	0.0187 *
Precipitation of Driest Month (m)	1.53E-02	1.23E-02	1.247	0.2126
Precipitation of Driest Month (s)	-3.30E-01	5.34E-02	-6.18	6.39e-10 ***
Prec. of Driest Quarter(s)	2.21E-01	2.33E-02	9.467	< 2e-16 **
Grid Scale 4 km^2				
Intercept	-0.6793493	0.2729708	-2.489	0.01282 *
Human Footprint (s)	0.0066181	0.0015895	4.164	3.13e-05 ***
Max. Temp Warmest Month(s)	0.073986	0.0121319	**6.098**	1.07e-09 ***
Annual Precipitation(std)	0.0558672	0.0195623	2.856	0.00429 **
Annual Precipitation(s)	-0.0003269	0.0003929	-0.832	0.40542
Prec. of Driest Quarter(s)	-0.006668	0.004043	-1.649	0.09909
Grid Scale 1 km^2				
Intercept	-2.13E-01	8.41E-02	-2.533	0.01132 *
Human Footprint (s)	5.65E-02	2.42E-03	23.353	< 2e-16 ***
Population (s)	-1.68E-04	8.33E-05	-2.019	0.04351 *
Min. Temp Coldest Month(s)	1.60E-01	5.36E-03	**29.755**	< 2e-16 ***
Annual Precipitation (m)	-6.27E-04	1.35E-03	-0.463	0.64309
Prec. of Wettest Month (m)	8.55E-03	3.70E-03	2.309	0.02096 *
Prec. of Wettest Month(s)	-7.62E-03	1.05E-03	-7.294	3e-13 ***

Prec. of Driest Quarter (m)	-2.07E-02	6.83E-03	-3.038	0.00238 **
Prec. of Driest Quarter(s)	5.69E-02	3.27E-03	17.436	< 2e-16 ***
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.0001$: *s=sum, std=standard deviation, m=mean.*				

Human footprint emerged to be the primary driving force behind the NDVI change at the 16 km^2 grid scale in Uttarakhand, Himachal Pradesh and Sikkim while seasonal extremes like precipitation of the driest quarter/month were important at this scale in states of Jammu & Kashmir. This indicates that at the regional scale relative human influence plays a very important role in directing the changes in NDVI. Arunachal landscape change seems to be more influenced by the changing temperature patterns for example, mean annual temperature at the 16 km^2 and 1 km^2 scale and temperature extremes at the 4 km^2 scale. Similar results were observed for the hilly districts of North Bengal. In Himachal Pradesh, human footprint was identified as the primary factor driving the decline in NDVI at all the three spatial scales.

On the other hand, at the 4 km^2 grid scale, human footprint is the primary driver in Himachal, Jammu & Kashmir and Sikkim. The results show that maximum temperature of the warmest and coldest month are the most important spatial drivers of NDVI change in Uttarakhand (Table 4.4.1), Sikkim and Arunachal Pradesh at the 4 km^2 grid scale (Annexure-II: Table 3 & Table 4). However, in North Bengal districts mean annual temperature seems to be driving the changes in NDVI.

The changes in landscape appear to be highly influenced by the seasonal extremes in temperature like minimum temperature of the coldest month at the 1km^2 grid scale. For example, as shown in Annexure-II (Table 1 - Table 5), the seasonal extremes in temperature are the primary factors governing the changes in the states of Uttarakhand, Sikkim and North Bengal. However, precipitation factor such as annual precipitation was important in Jammu & Kashmir at this scale. Human footprint was driving the NDVI changes at the 1 km^2 grid scale in the state of Himachal Pradesh only.

10.5 Conclusion /Summary

The dynamics of terrestrial vegetation are a very potent indicator of the processes and the patterns that exist between climate and the terrestrial ecosystems at multiple spatial scales. Most of the IHR states portray an overall increase in NDVI which is more pronounced in the higher altitudes than the lower areas however the elevation-dependent relation was not explored in this study. The increase in NDVI of the high-altitude areas can be attributed to the increasing temperature and changing precipitation patterns.

The mean annual temperature is an approximation of the total energy inputs to an ecosystem. Higher air temperatures beyond a certain level cause adverse impacts on the vegetation growth, reproduction and pollination (Hatfield and Prueger, 2015). However, both chronic and acute exposure to extremes of temperature might lead to a decline in the vegetation growth and development. This implies that in the events of increasing future temperatures there would be dramatic impacts on the vegetation productivity whether it be croplands or the forested habitats. The IHR landscape showed an overall increase in NDVI and the increase was more pronounced in the higher altitude. The decrease was mostly confined to the urban areas undergoing tremendous developmental activities. The results can be summed up in the following two sentences:

The entire landscape of the IHR has experienced varying levels of degradation and this degradation is driven by both human as well as natural factors. Anthropogenic factors are the primary drivers of decline in vegetation NDVI at the regional scales while the finer scales are more controlled by the seasonal extremes like heat waves and cold waves.

Spatial scale plays a vital role in identifying the driving forces that influence vegetation cover change. The results imply that landscape scale should be the cornerstone of most policy planning and decision-making processes. Since the land use planning, policies and management planning are framed at different levels of land hierarchy, it is very important to keep in mind the different processes operating at each level so as to plan and act effectively.

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Annexure-II

Table 1 GLM outputs for NDVI change from 2000 to 2015 in Himachal Pradesh

	Estimate	***Std. Error***	***z value***	***Pr(>|z|)***
Grid Scale 16 km^2				
(Intercept)	1.308e+02	5.104e+01	2.562	0.011014 *
Aspect (m)	−5.305e-01	2.375e-01	-2.233	0.026411 *
Human Footprint (s)	3.085e-02	5.251e-03	**5.876**	1.35e-08 ***
Mean Diurnal Range (std)	4.502e+01	2.254e+01	1.997	0.046907 *
Mean Diurnal Range (s)	-2.922e-02	5.661e-03	-5.162	5.02e-07 ***
Isothermality (std)	3.113e+01	1.292e+01	2.409	0.016735 *
Annual Precipitation (s)	-7.240e-04	2.348e-04	-3.083	0.002283 **
Prec. of Wettest Month (s)	1.234e-03	5.916e-04	2.087	0.037934 *
Precipitation of Driest Month (s)	2.762e-02	7.401e-03	3.732	0.000235 ***
Prec. of Driest Quarter (m)	-6.650e-01	2.604e-01	-2.553	0.011270 *
Grid Scale 4 km^2				
(Intercept)	4.493e+00	8.623e-01	5.211	1.98e-07 ***
Aspect (m)	-1.454e-02	3.462e-03	-4.198	2.76e-05 ***
Human Footprint (m)	2.933e-01	2.384e-02	**12.301**	< 2e-16 ***
Mean Diurnal Range (std)	6.884e+00	6.781e-01	10.151	< 2e-16 ***
Mean Diurnal Range (s)	-2.013e-02	2.515e-03	-8.004	1.60e-15 ***
Annual Precipitation (m)	-5.270e-03	6.574e-04	-8.016	1.46e-15 ***
Annual Precipitation (s)	-5.591e-04	9.273e-05	-6.029	1.82e-09 ***
Prec. of Wettest Month (s)	11.478e-03	2.255e-04	6.552	6.46e-11 ***
Precipitation of Driest Month (s)	2.190e-02	2.967e-03	7.381	1.93e-13 ***
Grid Scale 1 km^2				
(Intercept)	1.411e-01	2.522e-02	5.594	2.24e-08 ***
Human Footprint (m)	1.330e-02	5.283e-04	**25.173**	< 2e-16 ***
Mean Annual Temperature (s)	2.181e-01	1.066e-02	20.461	< 2e-16 ***
Max. Temp of warmest month (s)	-1.136e-01	5.455e-03	-20.819	< 2e-16 ***
Min. Temp of coldest month (s)	-1.050e-01	5.372e-03	-19.544	< 2e-16 ***
Annual Precipitation (m)	-2.568e-04	1.265e-05	-20.293	< 2e-16 ***
Annual Precipitation (s)	--4.835e-04	2.877e-05	-16.806	< 2e-16 ***
Prec. of Wettest Month(s)	1.267e-03	7.492e-05	16.910	< 2e-16 ***
Prec. of Driest Month (s)	1.164e-02	9.677e-04	12.028	< 2e-16 ***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.0001$: *s=sum, std=standard deviation, m=mean.*

Table 2 GLM outputs for NDVI change from 2000 to 2015 in Jammu and Kashmir

	Estimate	***Std. Error***	***z value***	***Pr(>|z|)***
Grid Scale 16 km^2				
(Intercept)	-5.249e+01	5.753e+00	-9.125	< 2e-16 ***
Human Footprint (m)	5.214e+00	7.634e-01	6.830	1.50e-11 ***
Human Footprint (std)	-7.991e+00	1.678e+00	-4.762	2.21e-06 ***
Max. Temp of warmest month (s)	5.010e-03	1.303e-03	3.844	0.000129 ***
Annual Precipitation (m)	-4.069e-01	8.625e-02	-4.717	2.74e-06 ***
Annual Precipitation (s)	-9.388e-04	1.452e-04	-6.467	1.58e-10 ***
Prec. of Wettest Month (m)	7.573e-01	1.852e-01	4.090	4.68e-05 ***
Precipitation of Driest Month (s)	-4.053e-02	5.005e-03	**-8.097**	1.68e-15 ***
Prec. of Driest Quarter (m)	3.045e+00	6.293e-01	4.839	1.52e-06 ***

Prec. of Driest Quarter (s)	1.281e-02	2.220e-03	5.773	1.05e-08 ***
Grid Scale 4 km^2				
(Intercept)	-3.063e+00	1.171e-01	-26.160	< 2e-16 ***
Human Footprint (m)	3.329e-01	1.385e-02	**24.035**	< 2e-16 ***
Isothermality (std)	--1.407e+00	1.278e-01	-11.008	< 2e-16 ***
Max.Temp of warmest month (std)	5.442e-01	7.018e-02	7.754	9.51e-15 ***
Annual Precipitation (m)	-4.038e-02	2.418e-03	-16.699	< 2e-16 ***
Annual Precipitation (s)	-7.834e-04	8.247e-05	-9.499	< 2e-16 ***
Prec. of Wettest Month (m)	8.396e-02	4.158e-03	20.193	< 2e-16 ***
Precipitation of Driest Month (s)	-3.326e-02	1.702e-03	-19.546	< 2e-16 ***
Prec. of Driest Quarter (m)	2.297e-01	2.096e-02	10.961	< 2e-16 ***
Prec. of Driest Quarter (s)	1.234e-02	1.029e-03	11.991	< 2e-16 ***
Grid Scale 1 km^2				
(Intercept)	-1.665e-01	3.277e-03	-50.82	<2e-16 ***
Human Footprint (m)	1.140e-02	2.845e-04	40.05	<2e-16 ***
Night Light (m)	-1.113e-02	3.419e-04	-32.56	<2e-16 ***
Max. Temp of warmest month (s)	5.936e-03	1.050e-04	56.52	<2e-16 ***
Min. Temp of coldest month (s)	2.720e-03	6.915e-05	39.34	<2e-16 ***
Annual Precipitation (m)	-4.023e-03	3.158e-05	**-127.41**	<2e-16 ***
Prec. of Wettest Month (m)	8.435e-03	9.339e-05	90.32	<2e-16 ***
Prec. of Wettest Month (s)	-1.274e-03	3.672e-05	-34.69	<2e-16 ***
Precipitation of Driest Month (s)	-2.355e-02	4.721e-04	-49.90	<2e-16 ***
Prec. of Driest Quarter (m)	2.103e-02	2.096e-04	100.37	<2e-16 ***
Prec. of Driest Quarter (s)	5.713e-03	1.450e-04	39.40	<2e-16 ***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.0001$: *s=sum, std=standard deviation, m=mean.*

Table 3 GLM outputs for NDVI change from 2000 to 2015 in Arunachal Pradesh

	Estimate	*Std. Error*	*z value*	*Pr(>|z|)*
Grid Scale 16 km^2				
(Intercept)	-1.554e+01	9.219e+01	-0.169	0.866215
Mean Annual Temperature (m)	2.670e+02	2.968e+01	**8.996**	< 2e-16 ***
Max. Temp of warmest month (m)	-1.461e+02	1.789e+01	-8.164	4.65e-15 ***
Min. Temp of coldest month (m)	-1.108e+02	1.411e+01	-7.857	3.95e-14 ***
Annual Precipitation (m)	1.522e-01	7.016e-02	2.169	0.030707 *
Annual Precipitation (s)	--3.331e-03	4.726e-04	-7.048	8.41e-12 ***
Prec. of Wettest Month (s)	5.868e-03	1.576e-03	3.723	0.000226 ***
Precipitation of Driest Month (m)	-5.051e+01	9.538e+00	-5.296	1.99e-07 ***
Prec. of Driest Quarter (s)	6.405e-02	9.937e-03	6.446	3.43e-10 ***
Grid Scale 4 km^2				
(Intercept)	-1.325e+00	8.606e-01	-1.539	0.124
Human Footprint (s)	-2.670e-02	5.413e-03	-4.932	8.38e-07 ***
Mean Annual Temperature (s)	8.583e-01	3.991e-02	21.509	< 2e-16 ***
Max. Temp of warmest month (s)	-5.047e-01	2.316e-02	**-21.796**	< 2e-16 ***
Min. Temp of coldest month (s)	-3.744e-01	1.863e-02	-20.096	< 2e-16 ***
Temperature Annual Range (std)	2.668e+01	1.590e+00	16.784	< 2e-16 ***
Annual Precipitation (s)	-1.289e-03	6.608e-05	-19.509	< 2e-16 ***
Precipitation of Driest Month (std)	-1.052e+01	5.521e-01	-19.055	< 2e-16 ***
Precipitation of Driest Month (s)	-2.474e-01	1.436e-02	-17.226	< 2e-16 ***
Prec. of Driest Quarter (s)	9.136e-02	4.459e-03	20.489	< 2e-16 ***
Grid Scale 1 km^2				

(Intercept)	1.289e-02	3.658e-02	0.352	0.725
Mean Annual Temperature (m)	1.505e+00	1.626e-02	**92.543**	< 2e-16 ***
Max. Temp of warmest month (m)	-8.251e-01	9.779e-03	-84.376	< 2e-16 ***
Min. Temp of coldest month (m)	-6.407e-01	7.630e-03	-83.977	< 2e-16 ***
Annual Precipitation (m)	-4.341e-03	7.617e-05	-56.989	< 2e-16 ***
Prec. of Wettest Month(m)	8.189e-03	2.561e-04	31.978	< 2e-16 ***
Prec. of Driest Month (m)	-3.496e-01	6.468e-03	-54.051	< 2e-16 ***
Prec. of Driest Quarter (m)	1.265e-01	2.057e-03	61.486	< 2e-16 ***

* *p* < 0.05; ** *p* < 0.01; *** *p* < 0.0001: *s=sum, std=standard deviation, m=mean.*

Table 4 GLM outputs for NDVI change from 2000 to 2015 in Sikkim

	Estimate	***Std. Error***	***z value***	***Pr(>|z|)***
Grid Scale 16 km^2				
(Intercept)	-8.017e+00	2.023e+01	-0.396	0.69498
Human Footprint (s)	-9.523e-02	1.879e-02	**-5.069**	2.30e-05 ***
Mean Annual Temperature (std)	1.669e+02	8.023e+01	2.080	0.04680 *
Mean Annual Temperature (s)	-1.674e+00	3.609e-01	-4.640	7.42e-05 ***
Max. Temp of warmest month (std)	-1.501e+02	7.479e+01	-2.007	0.05444
Max. Temp of warmest month (s)	9.669e-01	2.131e-01	4.538	9.79e-05 ***
Min. Temp of coldest month (s)	6.995e-01	1.507e-01	4.641	7.40e-05 ***
Min. Temp of coldest month (std)	-9.849e+01	3.725e+01	-2.644	0.01327 *
Annual Precipitation (s)	7.457e-04	2.708e-04	2.754	0.01023 *
Prec. of Wettest Month (m)	2.020e-01	9.717e-02	2.079	0.04693 *
Prec. of Wettest Month (std)	-3.113e+00	1.091e+00	-2.852	0.00807 **
Grid Scale 4 km^2				
(Intercept)	2.122e+00	1.009e+00	2.103	0.036 *
Human Footprint (s)	-4.268e-02	5.970e-03	-7.150	3.23e-12 ***
Mean Annual Temperature (s)	-1.575e+00	1.397e-01	-11.274	< 2e-16 ***
Max. Temp of warmest month (s)	9.026e-01	8.194e-02	11.015	< 2e-16 ***
Min. Temp of coldest month (s)	6.587e-01	5.839e-02	**11.282**	< 2e-16 ***
Temperature Annual Range (std)	-1.633e+01	1.930e+00	-8.460	3.20e-16 ***
Annual Precipitation (std)	1.416e-01	2.433e-02	5.820	1.07e-08 ***
Annual Precipitation (s)	7.110e-04	9.096e-05	7.817	3.42e-14 ***
Prec. of Wettest Month (std)	-3.040e-01	6.019e-02	-5.051	6.24e-07 ***
Grid Scale 1 km^2				
(Intercept)	0.0127837	0.0484738	0.264	0.79200
Human Footprint (m)	-0.0280033	0.0017217	-16.264	< 2e-16 ***
Mean Annual Temperature (m)	-2.0110853	0.0596755	-33.700	< 2e-16 ***
Mean Annual Temperature (std)	0.2907919	0.0508477	5.719	1.12e-08 ***
Max. Temp of warmest month (m)	1.1521623	0.0343421	33.550	< 2e-16 ***
Min. Temp of coldest month (m)	0.8444531	0.0244059	**34.600**	< 2e-16 ***
Annual Precipitation (std)	-0.0063692	0.0014721	-4.327	1.53e-05 ***
Prec. of Wettest Month (m)	0.0031791	0.0001214	26.191	< 2e-16 ***
Prec. of Wettest Month (std)	0.0113664	0.0042609	2.668	0.00766 **

* *p* < 0.05; ** *p* < 0.01; *** *p* < 0.0001: *s=sum, std=standard deviation, m=mean.*

Table 5: GLM outputs for NDVI change from 2000 to 2015 in North Bengal

	Estimate	***Std. Error***	***z value***	***Pr(>|z|)***
Grid Scale 16 km^2				
(Intercept)	12.83018	17.73005	0.724	0.472593
Mean Annual Temperature (s)	-0.84376	0.15578	-5.416	1.66e-06 ***
Isothermality (s)	0.38159	0.06505	**5.866**	3.33e-07 ***
Min. Temp of coldest month (s)	0.58016	0.14579	3.979	0.000219 ***
Precipitation of Driest Month (s)	0.35481	0.09270	3.828	0.000355 ***
Prec. of Driest Quarter (s)	-0.21239	0.03936	-5.396	1.78e-06 ***
Grid Scale 4 km^2				
(Intercept)	-0.4436116	1.1690398	-0.379	0.7045
Human Footprint (s)	-0.0273059	0.0049840	-5.479	6.14e-08 ***
Mean Annual Temperature (s)	-1.7749544	0.1959964	**-9.056**	< 2e-16 ***
Isothermality (s)	0.0561210	0.0244016	2.300	0.0218 *
Max.Temp of warmest month (s)	0.9680304	0.1224282	7.907	1.14e-14 ***
Min. Temp of coldest month (s)	0.8754308	0.0945708	9.257	< 2e-16 ***
Annual Precipitation (s)	0.0013377	0.0002912	4.593	5.25e-06 ***
Prec. of Wettest Month (s)	-0.0047657	0.0008773	-5.432	7.88e-08 ***
Prec. of Driest Quarter (s)	-0.0228068	0.0110440	-2.065	0.0393 *
Grid Scale 1 km^2				
(Intercept)	-3.632e-01	5.466e-02	-6.646	3.18e-11 ***
Elevation (m)	4.501e-04	4.196e-05	10.728	< 2e-16 ***
Slope (m)	9.660e-03	3.639e-03	2.655	0.007947 **
Slope (std)	3.365e-02	1.004e-02	3.352	0.000805 ***
Night Light (s)	-1.694e-02	1.253e-03	-13.519	< 2e-16 ***
Min. Temp of coldest month (m)	1.734e-01	9.212e-03	**18.821**	< 2e-16 ***
Annual Precipitation (m)	-3.730e-04	9.253e-05	-4.031	5.59e-05 ***
Prec. of Wettest Month (m)	-1.620e-03	3.500e-04	-4.627	3.76e-06 ***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.0001$: *s=sum, std=standard deviation, m=mean.*

Chapter 11

Climate Change Scenarios and Visualization

11.1 Introduction

India's natural resource base, including water resources, forestry and agriculture are likely predicted to be impacted by the changes in precipitation, temperatures, monsoon timings, and extreme events. Climate change may pose an additional stress on ecological and socioeconomic systems that already face tremendous pressures from rapid urbanization, industrialization and economic development. In order to better anticipate potential impacts of climate change, the decision-makers and resource managers require information regarding future changes in climate and its variability. Climate models are the primary tools available for making climate predictions on seasonal to decadal time scales and for making climate projections of future climate over the coming century and beyond (Pachauri et al., 2014).

Climate models are mathematical representations of the climate system in the form of 3D grid cells that contain climate-related physical information about a particular location. These models are carefully tested, and model simulations are compared to observational data – both historical and current for validation. General Circulation Models (GCM) are the 'standard' climate models extensively used and run typically on a horizontal resolution of around 200 km or even more.

11.2 Climate models and scenarios

A variety of experiments have been performed by different modeling groups in the world to simulate expected climate change patterns using different emission scenarios prepared under the Intergovernmental Panel on Climate Change (IPCC) coordination. In the past, climate projections for India have relied on the CMIP3 models and four families of emission pathways, namely A1, B1, A2 and B2 based on different socio-economic development assumptions. Now, the scientific community has developed a set of new emission scenarios termed as representative concentration pathways (RCPs). These emission scenarios represent how the greenhouse gas (carbon dioxide, methane, nitrous oxide) emissions, and thus the accumulation of greenhouse gases in the atmosphere, might unfold over the next century.

RCPs represent pathways of radiative forcing formulated such that they depict the full range of stabilization, mitigation and baseline emission scenarios available in the literature. There are four RCP scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (Table 1). The impacts of land use and land cover change on the environment and climate are explicitly included as part of the Representative Concentration Pathways (Moss et al., 2010).

Table 1 New Emission Scenarios - the Representative Concentration Pathways

Emission Scenarios	**Description**	**Developed by**
RCP2.6	Aggressive mitigation Emissions halved by 2050	IMAGE modeling team of the Netherlands Environmental Assessment Agency
RCP4.5	Strong mitigation Emissions stabilize at half today’s levels by 2080	MiniCAM modeling team at the Pacific Northwest National Laboratory’s Joint Global Change Research Institute
RCP6.0	Some mitigation Emissions rise to 2080 then fall	AIM modeling team at the National Institute for Environmental Studies), Japan
RCP8.5	Business as usual Emissions continue to rise at current rates	MESSAGE modeling team and the IIASA Integrated Assessment Framework at the International Institute for Applied Systems Analysis (IIASA), Austria

Source: Chaturvedi et al., 2012

11.2.1 WorldClim Projections

The climate projections from WorldClim provide outputs that that have been statistically downscaled from the most recent Global Climate Models (GCM’s) that are used in the Fifth Assessment IPCC report, for four representative concentration pathways (RCPs). The GCM outputs are downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline 'current' climate at four different spatial resolutions. The variables include monthly minimum and maximum temperature, precipitation, and 'bioclimatic' variables for two time periods that is 2050 (average for 2041-2060) and 2070 (average for 2061-2080). The projections use the latest RCPs 2.6, 4.5, 6.0 and 8.5. The climatic data is provided in three forms: 1) Current conditions (interpolations of observed data, representative of 1950-2000), 2) Future conditions: downscaled global climate model (GCM) data from CMIP5 (IPPC Fifth Assessment) and 3) Past conditions (downscaled global climate model output).

11.2.2 Climate change projections for Asia-Pacific

At the global level, surface temperature is projected to rise over the 21st century under all emission scenarios (IPCC, 2014). The increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is likely to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.5. It is very likely that heat waves will occur more often and last longer, and extreme precipitation events will become more intense and frequent in many regions.

In the Asia-pacific region, it is stipulated based on the CMIP5 simulations that warming is very likely in the mid- and late-21st century under all RCP scenarios. Ensemble-mean changes in mean annual temperature exceed 2°C above the late-20th-century baseline over most land areas in the mid-21st century under RCP8.5 and range from greater than 3°C over South and Southeast Asia. The ensemble-mean changes are less than 2°C above the late-20th-century baseline in both the mid and late-21st century under RCP2.6. Precipitation increases are very likely at higher latitudes by the mid- 21st century under the RCP8.5 scenario, and over eastern and southern areas by the late-21st century. Under the RCP2.6 scenario, increases are likely at high latitudes by the mid-21st century, while it is likely that changes at low latitudes will not substantially exceed natural variability.

The Himalaya is one of the major hotspots of biodiversity in the world and is home to some of the unique landscapes, ecosystems and life forms. It has extensive coverage of geology, climate gradients (from tropical in the base to snow cover in the highest elevations) and elevation ranges which has produced distinctive landforms and unique eco-regions. The flora and fauna vary with altitude, rainfall and soil type. However, this region is very susceptible to natural disasters and impacts of climate change which have become a potential threat to its fragile landscapes (Parry et al., 2007). The Himalaya has been experiencing increasing temperatures in the last couple of decades (Xu et al., 2009). On the other hand, precipitation has inconsistencies with a decrease in some areas and increase in the other areas (Xu et al., 2009; Shrestha et al., 1999). These changes in temperature and precipitation patterns have profound effects on the phenological cycles of the plants at both the species as well as community levels (Xu et al., 2009; Shrestha et al., 2000). This chapter deals with two major objectives: (i) analyze the projected changes in temperature and precipitation in the six Indian Himalayan states and, (ii) study the future implications of these changes with respect to the national parks and their biodiversity. This study will facilitate the identification of administrative units for prioritizing the biodiversity conservation efforts in the Indian Himalayan Region.

11.3 Selection of climatic and bioclimatic variables

11.3.1 Datasets

The global datasets for average monthly temperature and precipitation for current and future conditions from WorldClim were used. The current conditions data includes the interpolations of observed and averaged monthly climate data from weather stations for the period 1960-1990; while the data for future conditions includes the downscaled global climate model (GCM) data from CMIP5 (IPPC Fifth Assessment) climate projections for four greenhouse gas scenarios also called as representative pathways (RCPs) (Hijmans et al., 2005). There are a total of 19 GCMs available for all four RCPs and for two time periods: short-term 2050s (average for 2041-2060) and long-term 2070s (average for 2061-2080). For this study, we selected RCPs 4.5 and 8.5 for the analysis and downloaded only those models whose projections for these two scenarios were available.

The datasets are available at different spatial resolutions (expressed as minutes or seconds of a degree of longitude and latitude): 10 minutes, 5 minutes, 2.5 minutes, 30 seconds. However, for the present study, we used the data at 30 seconds resolution for analysis (Hijmans et al., 2005). For delimiting the study area, the administrative boundaries from Survey of India were utilized.

11.3.2 Methods

For quantifying and analyzing the IPCC climate projections for the Indian Himalayan region, the global datasets of average monthly temperature and precipitation from WorldClim at 30 arc seconds resolution were used for current and future conditions. There are a total of 19 GCMs available for all four RCPs and for two time periods: short-term 2050s (average for2041-2060) and long-term 2070s (average for 2061-2080). An ensemble approach including 17 downscaled (1 km^2 spatial resolution from WorldClim database) General Circulation Models from IPCC-AR5 was adopted to project change maps from the baseline climate for RCP4.5 and RCP8.5. A flowchart of the adopted methodology is shown in Fig. 1.

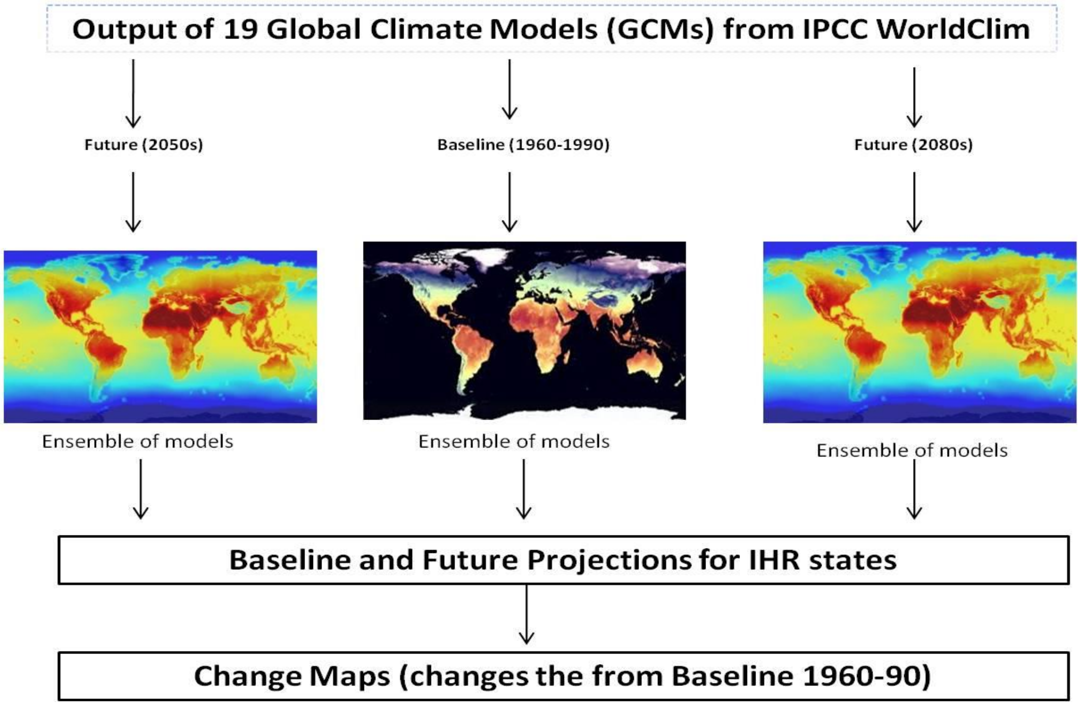

Fig. 1 Methodology adopted for the analysis

11.4 Trends and Scenarios

The analysis of instrumental records of more than one and a half century reveals that the earth has warmed by 0.74°C during the last 100 years, with 12 of the last 13 years being the warmest on record (INCCA Report, 2010). In the last few decades, the Himalaya has warmed at a rate higher than that in the last century (Diodato et al., 2011). The increase is 0.5 °C in annual average maximum temperature (Tmax) over 1971-2005 compared to 1901-1960. The western Indian Himalaya experienced a 0.9 °C rise over 102 years (1901-2003) (Dash et al., 2007). Over the northwest Indian Himalayan region there is 1.6 °C warming (0.16° C /decade) in the last century (Bhutiyani et al., 2007). There is an increasing trend in Tmax and seasonal average of daily maximum temperature for all seasons except monsoon over the lower Indus basin in the northwest Indian Himalaya (Singh et al., 2008). A basin-wide warming trend similar to global average Tav (0.6 °C/100 year for the 1901-2002 gridded dataset) for the Brahmaputra basin in the eastern Indian Himalaya has been reported (Immerzeel, 2008). The temperature is projected to rise by 0.5°C to more than 5°C (Kulkarni et al., 2013). The later quarters of the 21st century and recent decades appear to be warmer than earlier periods; and the higher altitude Himalayan and Trans-Himalayan zone are reported to be warming at higher rates. According to IPCC AR5 synthesis report, there is an increasing mean annual temperature trend at the country scale in South Asian region. The report also indicates that the number of cold days and nights have decreased, and the number of warm days and nights have increased across most of Asia since about 1950, and heat wave frequency has increased since the middle of the 20th century in large parts of Asia.

The seasonal mean rainfall shows inter-decadal variability, noticeably a declining trend with more frequent deficit monsoons (Kulkarni, 2012). The increase in the number of monsoon break days over India, and the decline in the number of monsoon depressions, is consistent with the overall decrease in seasonal mean rainfall. The frequency of heavy precipitation events is increasing, while light rain events are decreasing. There is a statistically significant downward trend in monsoon and average annual rainfall in the northwest Indian Himalaya during 1866-2006 (Bhutiyani et al., 2010). A similar trend is noted for 1960-2006 over the western Indian Himalaya region (Sontakke et al., 2008). A significantly decreasing winter precipitation (Dec-Feb) is observed in the region for 1975-2006 (Dimri and Dash, 2011).

There is a significant downward trend in winter precipitation (Jan-Feb) in Jammu & Kashmir and Uttarakhand during 1901-2003 period (Guhathakurta and Rajeevan, 2008). In contrast, significant increasing trends are observed in winter precipitation during 1961-1999 in the upper Indus Basin (Pakistan). In the same basin, there are spatially inconsistent and generally statistically insignificant seasonal precipitation trends during 1967-2005 (Khattak et al., 2011); increasing trend was found to be more than the decreasing trends. Increase in pre-monsoon (March-May) precipitation has been observed over the western Indian Himalaya during 1901-2003 (Guhathakurta & Rajeevan, 2008). Concluding, precipitation is decreasing in the western Indian Himalaya, but it is increasing in the upper Indus Basin (Pakistan).

In the western Indian Himalayas, there has been an increase in the number of warm days and decrease in the number of cold days during 1975-2006 (Dimri & Dash, 2011). Based on the analysis of daily data from 1910-2000, an increase in the frequency of extreme precipitation events over north-western Indian Himalaya has been observed (Sen Roy and Balling, 2004). The north-western Himalaya and northern parts of the Indo-Gangetic basin in the Himalayan foothills show increasing trends in precipitation extremes over all seasons (1980-2002) (Sen Roy, 2009). However, an increasing trend has been found only in maximum number of consecutive dry days (< 1mm water equivalent of snowfall) in winter (Dec-Feb) at eight stations across the western Indian Himalaya during 1975-2006. Decreasing trends in maximum number of consecutive wet days (days with 90th percentile of events with >1 mm water equivalent of snowfall) are observed at most of the same stations over the same period (Dimri and Dash, 2011). In summary, temperature related climatic extremes appear to be increasing across the Himalayas.

11.4.1 State-wise current and future climatic conditions

The climate of the Himalayan range is characterized by unique weather conditions and it has a huge influence on the meteorological conditions of the Indian sub-continent which has very moderate climatic conditions. The climate of the Indian Himalayan region ranges from tropical at the base of the mountain to permanent ice and snow at the highest elevations. The mean annual temperature and precipitation of the six major Indian Himalayan states for the baseline/current conditions are presented district wise in Table 2. These values represent the consolidated temperature and precipitation for the period of 1960-1990 and are also called as the baseline climate.

Global Climate Model (GCM) projections point to a warmer Himalayan region in the future with warming likely to be above the global average. CMIP5 models project a clear increase in temperature over India especially in winter, with enhanced warming during nights than days across northern India. In summer, extremely hot days and nights are projected to increase. High-resolution RCM and GCM projections show an overall increase of precipitation over a large area of peninsular India but a significant reduction in orographic rainfall in both seasonal mean and extreme events along the west coasts of India.

The climate change projections for all six Indian Himalayan States i.e., Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh, Sikkim and West Bengal are depicted in figures presented state wise (Fig. 2 - Fig. 7). The results projected increasing warming of above 3.1°C for all the IHR states in the long term RCP8.5 (Table 2). However, Jammu & Kashmir, Uttarakhand and Himachal Pradesh were projected to be most affected with maximum temperature increases of 5.7, 5.1 and 5.4°C respectively. The precipitation projections showed both increasing and decreasing spatial variations with maximum increase of up to 25%. Uttarakhand and Himachal are projected to be heavily impacted by precipitation increases of more than 590mm per year in the long term RCP8.5. As per the presented and analyzed data for the Indian Himalayan region, Appendix-I: Table 1 & Table 2 summarizes the district wise projected temperature and precipitation changes for the six Himalayan states of India in the RCP4.5 and RCP8.5 scenarios based on CMIP5.

Table 2 Temperature Projections for the IHR states

States	**Baseline**						**Projected Changes (from mean baseline value)**							
	Temperature (^{o}C)			***Precipitation (mm)***			***Temperature (^{o}C)***				***Precipitation (mm)***			
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**	**RCP45S**	**RCP85S**	**RCP45L**	**RCP85L**	**RCP45S**	**RCP85S**	**RCP45L**	**RCP85L**
J&K	2.03	-21.8	24.3	332.3	34	2003	2.81	3.51	3.53	5.25	7.09	18	13.8	28.8
HP	6.44	-11.9	24.2	1098.4	233	2934	2.57	3.23	3.25	4.84	42.5	111.67	92.3	144.76
UK	5.99	13	24.7	1416.8	533	2873	2.2	2.87	2.86	4.3	106.6	141.8	158.3	241.2
SIK	5.58	-16.7	23.7	1189.7	270	3181	2.2	2.7	2.8	4	39.22	26.7	84.32	116.44
WB	15.5	6.1	24.7	3249.2	1150	4650	1.9	2.4	2.4	3.7	108.13	87.44	240.09	339.03
AP	8.26	-9	24.1	1854.1	327	4118	2	2.51	2.57	3.78	87	82.1	158.6	180.7

J&K – Jammu & Kashmir; HP – Himachal Pradesh; UK – Uttarakhand; SIK– Sikkim; AP – Arunachal Pradesh; WB – West Bengal (Northern Districts)

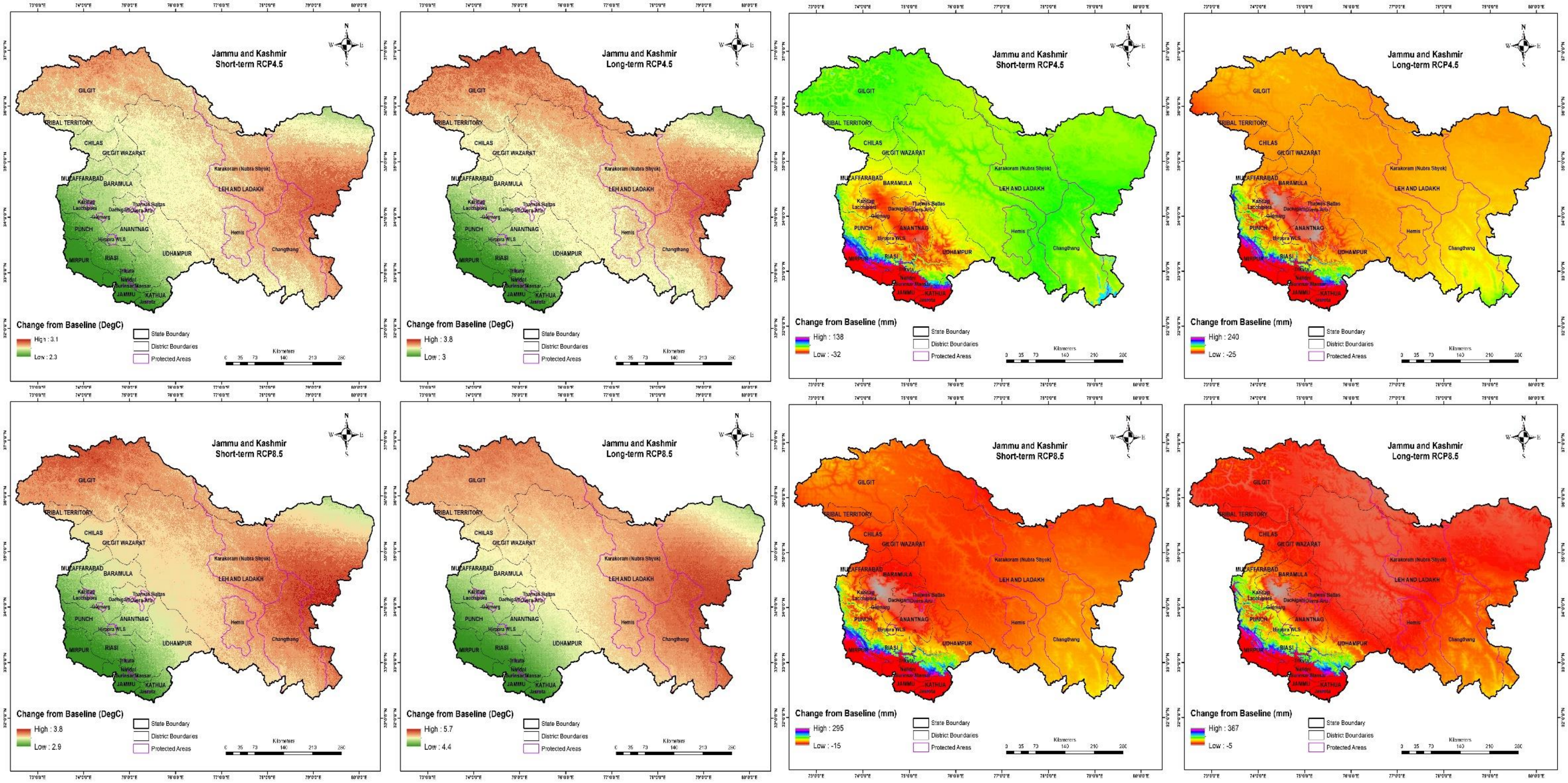

Fig. 2 Temperature and Precipitation projections for Jammu and Kashmir

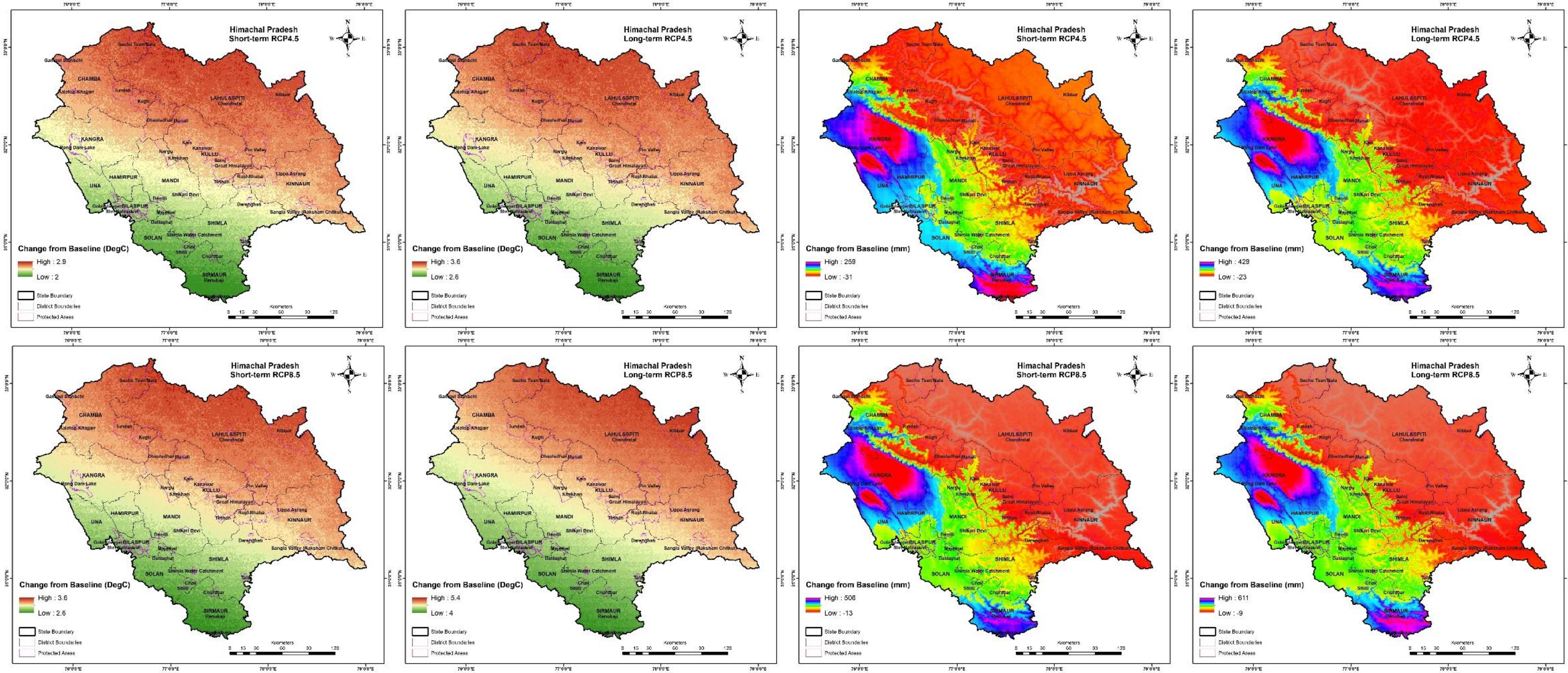

Fig. 3 Temperature and Precipitation projections for Himachal Pradesh

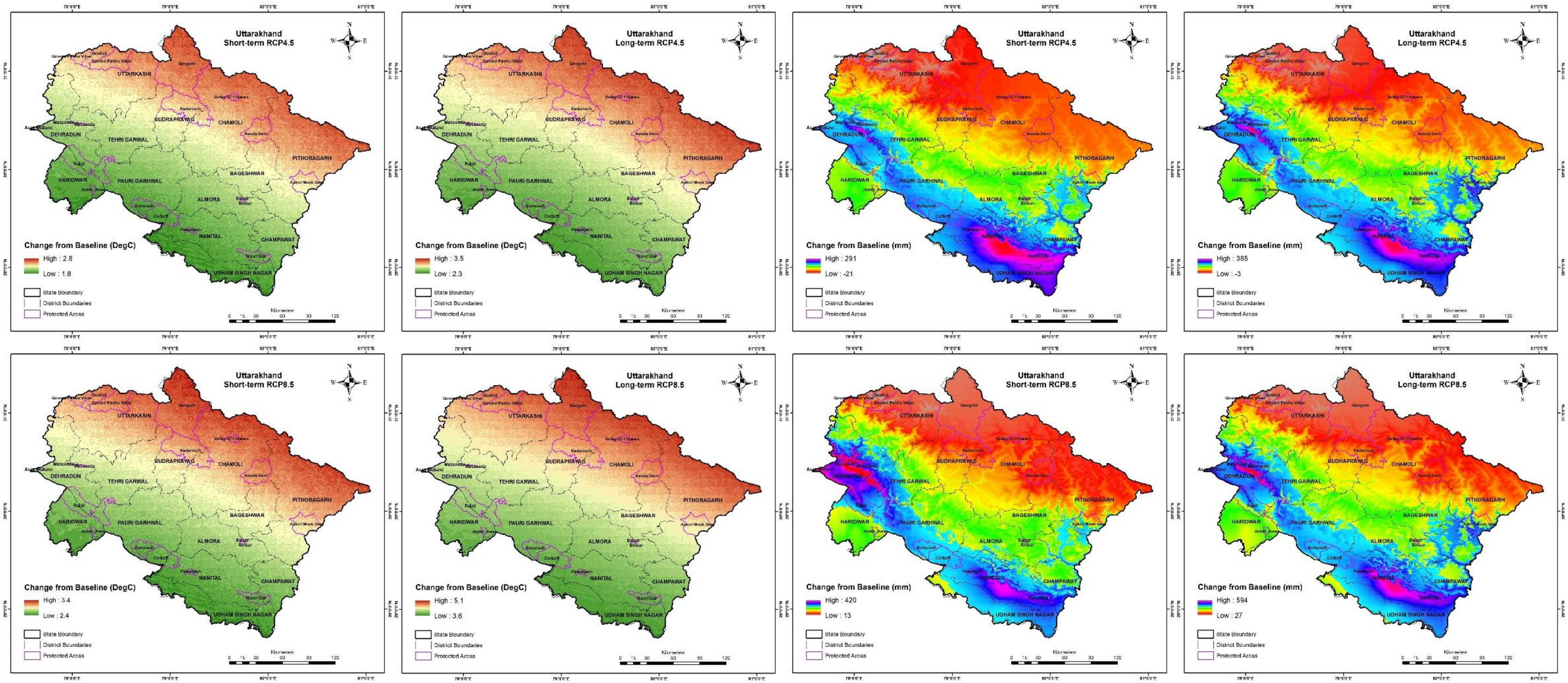

Fig. 4 Temperature and Precipitation projections for Uttarakhand

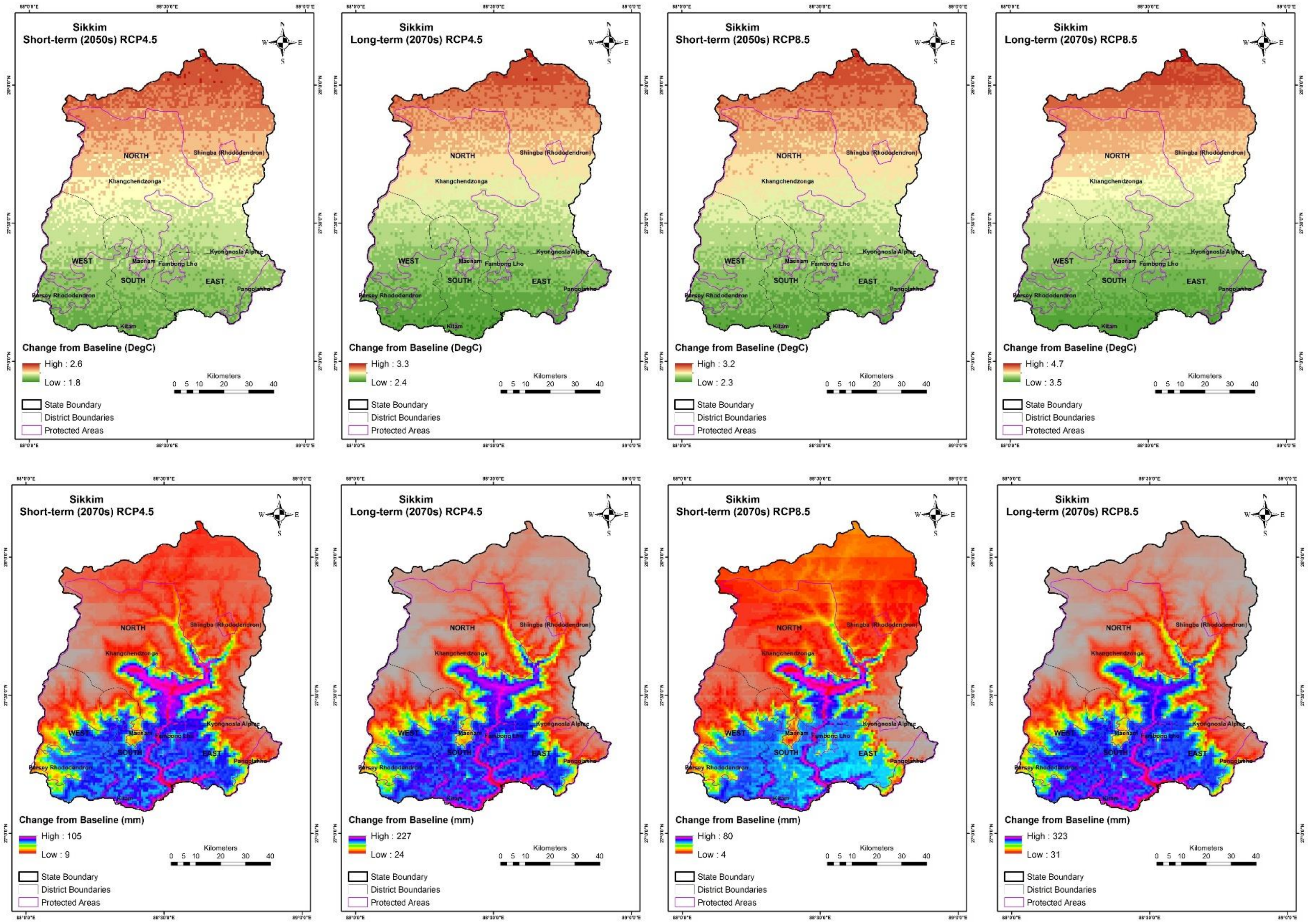

Fig. 5. Temperature and Precipitation projections for Sikkim

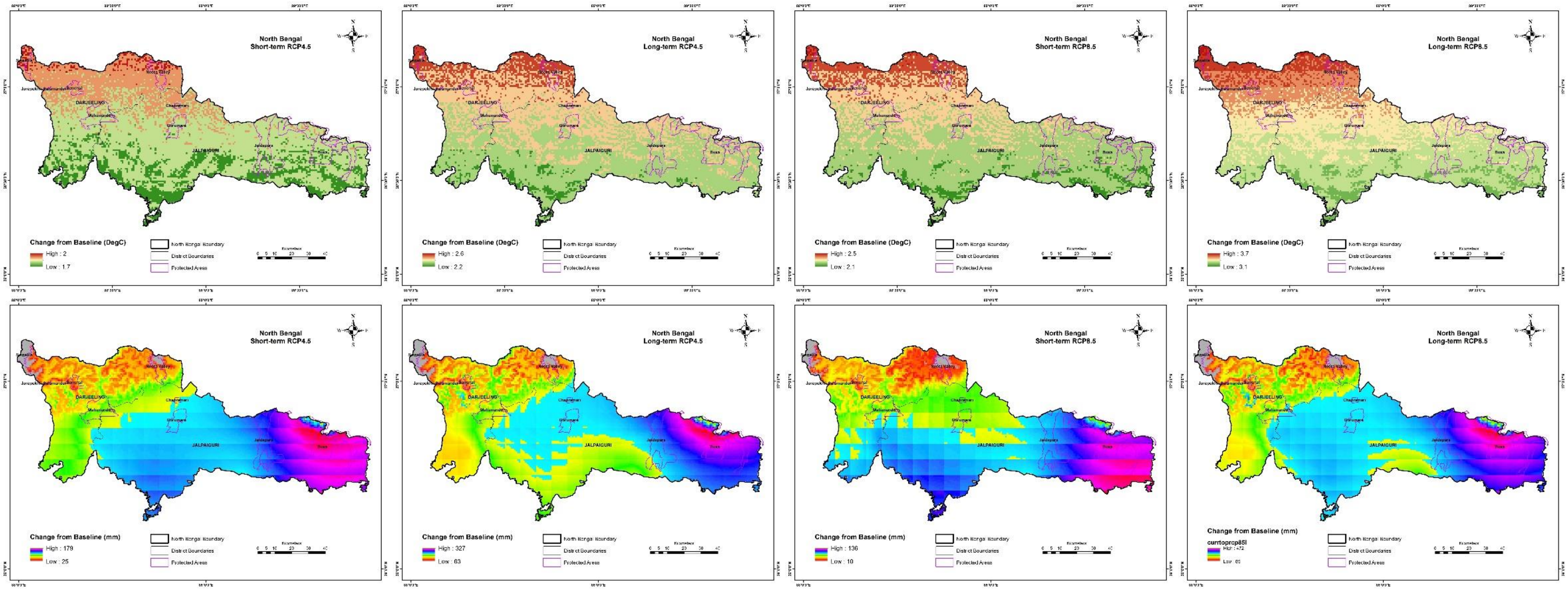

Fig. 6 Temperature and Precipitation projections for North Bengal

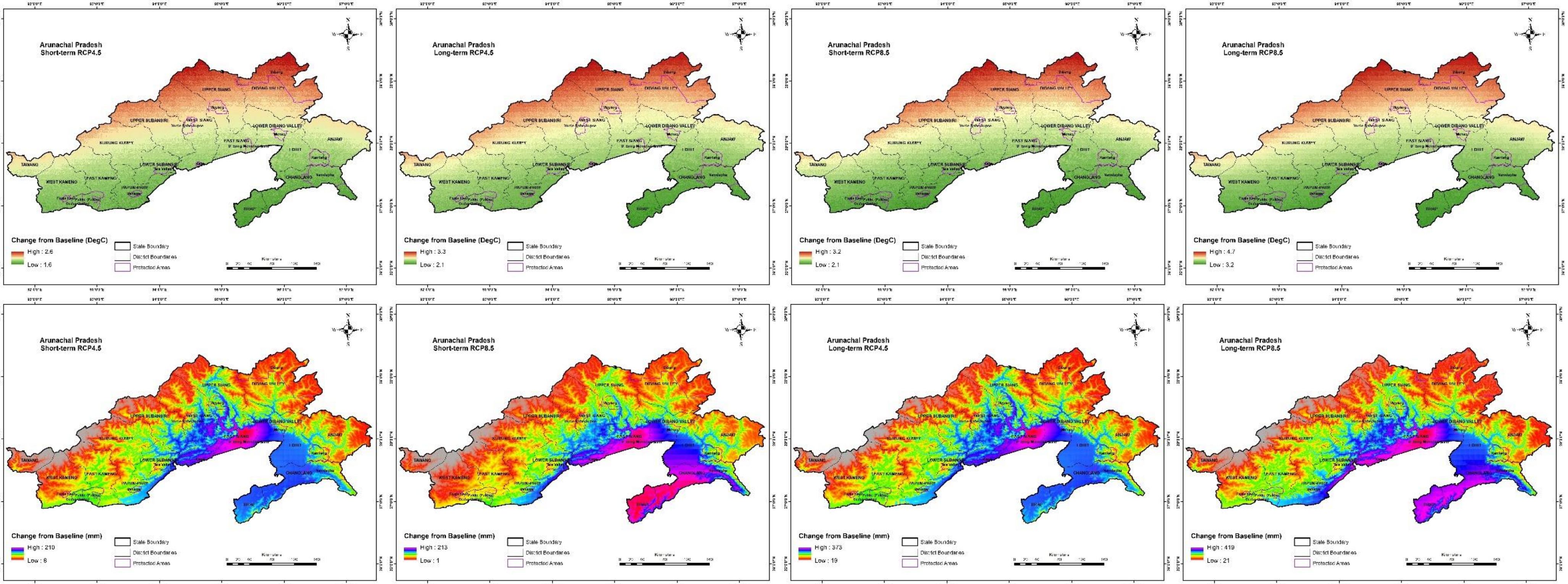

Fig. 7 Temperature and Precipitation projections for Arunachal Pradesh

11.5 Conclusion / Summary

In this study the use of ensemble mean of climate projections was advantageous in assessing the uncertainty of climate change arising due to high elevation gradients of the Indian Himalaya. Although, the uncertainty and reliability of the climate models can further be improved by incorporating more observations and considering new projections in future. The projected changes in temperature and precipitation in the Indian Himalaya indicated an overall warming trend (above 3.1°C in long term RCP 8.5) with prominent increasing temperature over the Western Himalayan states, namely, Jammu and Kashmir, Himachal Pradesh and Uttarakhand. Also, Uttarakhand and Himachal Pradesh will also be experiencing increased intensity of rainfall especially in the business as usual scenario i.e. RCP 8.5. In the Himalaya and its downstream areas, the communities largely depend on climate-sensitive sectors including agriculture, forestry, and fisheries for their sustenance. And increased rainfall coupled with changing temperature might impact the availability of these ecosystem services. These climate sensitive communities will experience the adverse impacts of climate change which are likely to be magnified by other factors including limited institutional linkages, under developed markets, absence of technology-transfer pathways, and lack of financial resources. Further, extreme events including droughts, coupled with warming as predicted using the projections may cause increased occurrence of forest fires, which are challenging for local governments and institutions to deal with, especially in the rough Himalayan terrains. Forests and terrestrial ecosystems in the Himalayan region, are increasingly assuming a more prominent role both as important carbon sinks and as an adaptation option. Forest ecosystems are critical for biodiversity, watershed protection, and the livelihoods of forest dependent communities, especially in the Himalayan river basins and hence will be largely impacted by changes in temperature and precipitation. Hence, it is important to make reliable and robust assessments of the projected climate changes using GCM's and their potential impact on these sensitive ecosystems.

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Appendix I

Table 1 Baseline (1960-1990) temperature and precipitation of the Indian Himalayan states

STATE/DISTRICT	Curr_temp	Curr_Tmin	Curr_TMax	Curr_Prcp	Curr_PMin	Curr_PMax
JAMMU & KASHMIR						
Leh And Ladakh	-4.57	-19.7	14.2	124.80	34	606
Gilgit	-2.94	-20.8	17.3	193.18	49	639
Tribal Territory	5.24	-6.3	18.9	368.92	273	499
Chilas	4.25	-21.8	18.8	400.31	183	571
Punch	14.22	-3	22.4	779.07	333	1245
Kathua	19.89	1.3	23.8	1532.80	735	2003
Gilgit Wazarat	-0.26	-10.9	16.3	344.12	162	630
Jammu	23.55	21	24.3	1222.31	807	1718
Udhampur	6.66	-11.4	23.3	838.14	199	1855
Muzaffarabad	8.00	-8.8	21.1	827.57	339	1607
Baramula	7.02	-6.2	14.5	748.06	282	1085
Anantnag	7.47	-7	14.6	826.97	269	1132
Riasi	16.83	-2.6	23.8	978.56	644	1543
Mirpur	22.25	17	24	949.42	593	1135
HIMACHAL PRADESH						
Bilaspur	22.00	16.4	23.9	1288.29	1102	1766
Chamba	8.22	-8.9	22.6	1208.68	258	2764
Hamirpur	21.69	19.7	23.2	1608.93	1154	2184
Kangra	17.51	-6.2	23.6	1768.41	440	2934
Kinnaur	1.10	-11.3	18.6	730.00	382	1912
Kullu	6.73	-9.5	21.2	1120.53	442	2236
Lahul&Spiti	-2.62	-11.7	12.3	442.31	233	1462

Mandi	17.37	4.9	22.8	1628.56	910	2202
Shimla	12.45	-4.4	22.2	1296.08	630	2263
Sirmaur	19.11	6.8	24	1773.99	1217	2364
Solan	20.34	13.9	24.2	1345.61	1076	1673
Una	22.71	20.2	23.8	1411.04	1023	2626
UTTARAKHAND						
Almora	16.21	11.2	22.7	1574.05	1290	1974
Bageshwar	12.39	-11.5	20.9	1488.91	739	2056
Chamoli	5.42	-13	21	1176.74	589	1813
Champawat	18.41	13.3	24.6	1634.19	1402	1940
Dehradun	19.41	9.4	23.6	1895.77	1269	2873
Haridwar	23.57	20.9	24.1	1232.07	985	2175
Nanital	19.65	11.5	24.4	1772.47	1348	2277
Pauri Garhwal	18.50	9.4	23.8	1640.48	1180	2127
Pithoragarh	7.07	-9.8	23.5	1241.38	635	2255
Rudraprayag	11.47	-12	21.9	1360.89	692	1677
Tehri Garwal	14.84	-10.4	23.2	1688.46	700	2736
Udham Singh Nagar	24.24	23.4	24.7	1451.37	1186	1855
Uttarkashi	5.35	-12.8	21.1	1104.66	534	2342
SIKKIM						
East	12.66	0.1	23.3	1932.63	478	3168
North	2.15	-16.7	22	721.34	274	2845
South	15.38	-1.2	23.7	2238.80	438	3181
West	10.32	-8.8	23.2	1671.49	345	2817
ARUNACHAL PRADESH						
Changlang	18.13	2.8	22.9	2677.02	949	3372
East Kameng	16.51	-5	24	1772.25	355	2616
East Siang	20.31	10	23.2	3114.82	1093	4118

Anjaw	9.80	-1.4	21.6	1525.26	714	3140
Kurung Kumey	13.27	-8.2	22.3	1440.36	327	3043
Tawang	6.70	-3	19.4	719.67	336	2438
Tirap	19.52	11.9	23.4	2470.25	1786	2707
Upper Subansiri	13.55	-2.9	23.1	1584.56	344	3267
West Kameng	13.39	-7.4	23.9	1420.84	362	2524
West Siang	15.89	0.5	23.4	2083.99	416	3536
Upper Siang	13.27	-1.1	22.9	1653.12	436	3882
Dibang Valley	8.59	-2.2	21.6	1127.97	552	3309
Papum-Pare	18.21	6.6	24	2133.16	678	3252
Lower Subansiri	17.75	10.7	23.4	2226.10	1047	3267
Lohit	19.35	2.5	22.9	2691.37	781	3142
Lower Dibang Valley	17.09	-0.1	23	2478.77	687	3714

Table 2 Temperature and Precipitation changes projected for the Indian Himalayan states

STATE/DISTRICT	**temp_45s**	**temp_85s**	**temp_45l**	**temp_85l**	**prcp_45s**	**prcp_85s**	**prcp_45l**	**prcp_85l**
JAMMU & KASHMIR								
Leh And Ladakh	2.86	3.57	3.57	5.36	5.56	8.61	7.12	13.99
Gilgit	2.88	3.62	3.63	5.40	6.05	7.44	4.25	11.27
Tribal Territory	2.80	3.53	3.56	5.31	4.28	6.48	1.73	13.52
Chilas	2.76	3.48	3.51	5.24	2.64	4.34	2.54	14.47
Punch	2.56	3.20	3.29	4.80	-4.36	21.84	14.02	50.90
Kathua	2.56	3.19	3.25	4.73	95.47	219.95	178.40	275.84
Gilgit Wazarat	2.76	3.49	3.51	5.24	2.63	3.67	3.51	13.35
Jammu	2.48	3.08	3.16	4.57	106.85	215.08	189.23	266.71

Udhampur	2.72	3.36	3.42	5.02	0.57	34.08	20.78	53.14
Muzaffarabad	2.66	3.32	3.42	5.02	-2.77	11.89	10.67	43.54
Baramula	2.71	3.39	3.46	5.10	-8.88	-1.26	-5.10	17.64
Anantnag	2.73	3.37	3.45	5.06	-13.59	1.63	-8.51	19.43
Riasi	2.56	3.17	3.26	4.73	14.47	68.42	52.38	101.92
Mirpur	2.46	3.07	3.17	4.59	55.02	123.31	115.58	175.24
HIMACHAL PRADESH								
Bilaspur	2.34	2.96	3.00	4.44	93.95	192.33	169.29	234.69
Chamba	2.71	3.37	3.40	5.00	25.49	100.47	74.06	129.01
Hamirpur	2.44	3.06	3.10	4.57	122.33	264.08	228.27	314.66
Kangra	2.56	3.21	3.25	4.76	122.48	281.09	231.51	336.73
Kinnaur	2.62	3.30	3.31	4.97	-1.57	23.52	16.57	38.88
Kullu	2.62	3.27	3.30	4.91	4.59	59.24	45.09	83.28
Lahul&Spiti	2.76	3.44	3.45	5.17	2.34	18.66	13.29	27.06
Mandi	2.48	3.12	3.15	4.67	64.30	174.94	154.74	227.53
Shimla	2.38	3.04	3.05	4.57	29.91	99.22	80.49	143.22
Sirmaur	2.14	2.79	2.78	4.22	141.58	258.04	226.88	351.34
Solan	2.24	2.87	2.89	4.32	96.35	186.39	168.47	240.66
Una	2.37	2.99	3.04	4.46	134.14	258.14	221.60	311.09
UTTARAKHAND								
Almora	2.08	2.71	2.66	4.06	146.25	169.21	209.28	312.59
Bageshwar	2.29	2.92	2.91	4.36	97.24	122.89	159.35	243.15
Chamoli	2.42	3.08	3.09	4.63	43.97	70.14	83.97	136.60
Champawat	2.04	2.64	2.64	3.95	186.88	205.49	253.79	366.34
Dehradun	2.13	2.78	2.76	4.21	153.64	253.49	227.97	360.97

Haridwar	1.92	2.56	2.51	3.91	135.94	185.02	181.64	260.65
Nanital	1.94	2.56	2.51	3.85	222.71	240.47	291.07	414.96
Pauri Garhwal	2.00	2.65	2.58	4.01	157.96	194.44	217.53	324.42
Pithoragarh	2.45	3.09	3.13	4.62	74.34	97.18	131.04	191.78
Rudraprayag	2.32	2.98	2.97	4.48	48.06	83.38	87.57	152.76
Tehri Garwal	2.20	2.85	2.83	4.31	109.34	170.66	164.08	269.12
Udham Singh Nagar	1.87	2.47	2.43	3.73	217.24	224.83	265.31	366.66
Uttarkashi	2.45	3.12	3.13	4.69	24.35	66.55	55.20	107.25
SIKKIM								
East	2.00	2.49	2.57	3.71	129.88	34.96	129.88	181.10
North	2.29	2.83	2.92	4.20	54.52	19.66	54.52	71.97
South	2.00	2.49	2.57	3.72	155.03	45.77	155.03	220.72
West	2.03	2.53	2.61	3.79	113.99	34.25	113.99	163.94
ARUNACHAL PRADESH								
Changlang	1.75	2.23	2.25	3.39	137.68	168.32	246.91	310.92
East Kameng	1.87	2.34	2.43	3.56	69.58	53.52	133.85	166.77
East Siang	1.96	2.46	2.51	3.71	162.30	156.50	285.88	321.34
Anjaw	1.98	2.48	2.51	3.73	65.58	68.10	125.29	128.01
Kurung Kumey	2.04	2.55	2.62	3.84	59.26	42.77	110.72	123.33
Tawang	2.04	2.56	2.64	3.85	22.52	10.40	45.98	58.86
Tirap	1.70	2.16	2.18	3.30	146.88	194.91	261.45	355.30
Upper Subansiri	2.10	2.63	2.69	3.94	73.86	59.73	132.64	144.64
West Kameng	1.86	2.33	2.43	3.55	48.57	29.12	95.35	124.69
West Siang	2.08	2.60	2.66	3.89	105.27	94.98	186.02	206.53
Upper Siang	2.26	2.81	2.87	4.18	78.72	66.06	142.13	140.22

Dibang Valley	2.26	2.80	2.85	4.18	52.61	45.96	96.27	91.70
Papum-Pare	1.79	2.24	2.32	3.41	99.67	97.52	183.87	232.44
Lower Subansiri	1.86	2.33	2.40	3.54	107.24	99.39	192.75	235.24
Lohit	1.87	2.36	2.39	3.57	133.77	146.16	242.64	277.01
Lower Dibang Valley	2.00	2.50	2.55	3.77	119.15	113.93	217.28	230.43

Chapter 12

Climate Change and Landscape Change Vulnerabilities

12.1 Quality of Life Index

12.1.1 Introduction

Climate change has a profound impact on both natural ecosystems and human societies (Pachauri and Meyer, 2014) and also have differential effects on people and communities based on their geographical locations. Mountain ecosystems are characterized by sharp altitudinal gradients and extreme weather conditions rendering them to be geographically and ecologically unique ecosystems. Changes in climate in the mountains impacts the hydrology, vegetation, ecological conditions, and socio-economic settings (Whiteman, 2000; Xu and Melick, 2006). The social ecological systems in the mountain areas are characteristically influenced by factors including inaccessibility, fragility, marginality, diversity, biological niches, and high dependence of humans on natural resources (Jodha, 2000; Tsering et al., 2010; Bhatta et al., 2015). Hence, mountainous people are increasingly exposed to growing physical, social, and economic risks accelerating their vulnerabilities to extreme weather events. Vulnerability in the context of climate change is defined as an internal property of a system (i.e. bio-physical and socio-economic system). This includes sensitivity and lack of capacity to cope and adapt (Carter et al., 2007). Apart from highlighting vulnerabilities and fragilities of the mountain areas, there is also a need to emphasizing the resilience and strength of the mountain communities required to cope with the challenges posed by climate change (Wester et al., 2018). FAO estimated in a study that almost 88% of people residing in mountainous areas of the developing countries including India are rural poor. They majorly depend on agriculture and livestock as their source of livelihood. Mountain poverty is associated with social markers and inequality at the intersection of class, caste, ethnicity, gender, education, occupation, and employment status. Climate change impacts are largely determined by deep-rooted socioeconomic inequalities. As a result, they tend to be particularly detrimental to the most disadvantaged groups of society, which are hence disproportionately exposed and vulnerable to climate hazards. Hence, it is imperative to understand the underlying causes of poverty by addressing the household composition, socioeconomic status and their assets and liabilities. Poverty and inaccessibility are the major factors resulting in vulnerabilities associated with limited economic opportunities to the mountain dwelling people that intensifies the impacts of climate change on these communities.

Himalayan landscapes are characterized by sharp altitudinal gradients, micro-climate and are heterogenous. They are considered as the water towers of Asia and a major source of fresh water for India’s perennial rivers. The Himalaya is recognized as one among 34 global biodiversity hotspots reflecting its’ wide-array of ecological significance (Myers, 1988). The Indian Himalayan region (IHR) holds a repository of agro-biodiversity (including 675 edible plants and almost 1743 species of medicinal plants) which is fundamental for agricultural sustainability and human well-being (Singh, 2006). Natural and human disturbances including forest degradation, loss of vegetation and glacier recession exacerbates the severity of natural disasters including flooding in the Himalayas, rendering them to be ecologically sensitive (Rasul, 2014). The Himalaya being ecologically diverse and rich in endemism harbours the cultural diversity too. Local communities in the Himalayas often rely directly on natural resources for their livelihoods and subsistence and are therefore vulnerable to changes in local ecosystems arising due to climate change (Pandey and Jha, 2012). IHR has the highest population of poor people which may hinder the actual wellbeing outcomes, including adequate nutrition, food security, education and health (Sen, 1999) that can be amplified due to climate change in these areas. Hence, determining the well-being of people inhabiting the IHR is critical in enhancing our understanding towards identifying the vulnerable communities.

We adopted the approach of assessing the Quality of life (QoL) to address the well-being of the people. It stems from the desire to measure well-being and progress that macro level measurements like GDP fail to capture in terms of international development sector. It is a multi-dimensional concept that incorporates the facets of social and economic well-being of people in an area (Costanza et al., 2007). And can be applied at different scales from individual to national level depending upon the information available on the objective and subjective indicators of well-being. A QoL measure can be either subjective or objective, and in form of a set of indicators or an aggregate index. QoL measure focuses on people’s life condition in a given geographical area with majorly highlighting the importance of non-income components such as health, access to basic services, assets, education and work opportunities available to the individuals (Rogan, 2015; Burchi and Gnesi, 2016). The study on the QoL has gained interest from a variety of disciplines such as planning, geography, sociology, economics, psychology, political science, behavioural medicine, marketing and management (Sirgy & Samli 1995; Andrew 1999; Foo 2001; Rapley 2005). In ecological science an attempt was made to use the composite QoL index to map the district wise QoL in India based on ecological, social, and economic indicators (Prakash et al., 2016). In our study we developed a composite QoL Index for the districts of entire IHR based on secondary information available with Census of India containing the data that provides the description of the socio-economic condition of the households. The composite index was then utilized for identifying the districts that could be susceptible to climate change.

12.1.2 Methodology

We developed an aggregate Quality of Life Index (QoL) using an indicator-based approach (a set of indicators that allows for richer data collection, and freedom to include as many measurable attributes as possible) that simplifies the process of decision making and is more appealing to the policy makers. We used socio-economic secondary information from Population Census of India (2011) and identified the important indicators from the House-listing and Population enumeration data for the analysis at the district-level. A total of 17 indicators were used for the analysis which were grouped into five broad categories including: 1) living condition, 2) housing condition, 3) availability of assets, 4) education status and 5) job availability (Table 1).

Table 1 Details of the socio-economic indicators used for indicator-based analysis for calculating Quality of life (QoL).

S.No.	Category	Indicators
1.	Living condition	Number of households with condition of Census House as liveable
2.	Housing condition	Material of roof, Material of wall, Material of floor, Number of dwelling rooms
3.	Availability of assets	Ownership of house, Radio, Television, Computer, Landline, Mobile, Bicycle, Scooter, Car, Banking facility

4.	Education status	Literacy Rate
5.	Job availability	Working Population

Each indicator was measured as the percentage at district level in the Census data. To obtain a composite QoL Index each indicator was normalized using minimum maximum approach. Each indicator contributed to the 17 sub-indices to devise a composite QoL Index (dimensionless value) using the standard formula (Eq. 1):

$$I = \frac{Ia - Imin}{Imax - Imin} \qquad \text{(Eq. 1)}$$

where I is the normalized value of the indicator contributing to the sub-index; Ia is the actual value of the same indicator, with $Imin$ and $Imax$ representing the minimum and maximum values, respectively, of the indicator.

Assignment of weight to sub-indices that constitute the aggregate index was found to be arbitrary in several of these initiatives in past studies. So, after normalization each indicator was assigned an equal weight as all indicators were considered to be of equal priorities for having a good quality of life. Finally, an aggregated QoL Index was obtained by adding all 17 sub-indices together and then averaging them by total number of sub-indices.

12.1.3 Results

The QoL Index obtained for all the 55 districts of six states ranged from 0.16 to 7.00 (Table 2) reflecting a wide array of quality of life of the people in these districts as depicted in the map (Fig. 1). The map explains that most of the districts across the whole IHR are equipped with basic amenities for a secure life except a few districts having low QoL Index. All the districts in the state Himachal Pradesh have QoL Index above 0.50 and have literacy rate of 82.80%. As per Census of India, the total population of Himachal Pradesh is 68.64 lakh having a decadal population growth rate of 12.94 percent which is much lower than all India average of 17.64 percent during same decade. Rural regions contribute to 90% of the population and merely 10% people reside in the urban areas. The communities residing in rural areas differ from their urban counterparts in terms of occupations, earnings, literacy, poverty incidence, and dependency on government funds. These differences tend to shape economic and socio-cultural conditions as most of the rural population depends on agriculture for their livelihood. Distribution of workers profile shows that nearly 58% workers in the State are cultivators and 5% are agricultural labour reflecting huge dependency on agriculture/horticulture sector for livelihood. The district Kullu has highest dependency of workers on agriculture/horticulture (78%) for earning livelihood, followed by Mandi (70.5%), Chamba (70%), Sirmaur (69.2%), Hamirpur (64.5%), Shimla (64%), Bilaspur (63.8%), Kinnaur (63.1%) and Lahaul and Spiti (61.2%). In Kangra, Solan and Una workers (cultivators plus agricultural labour) dependence on agriculture/horticulture sector is less than the State average.

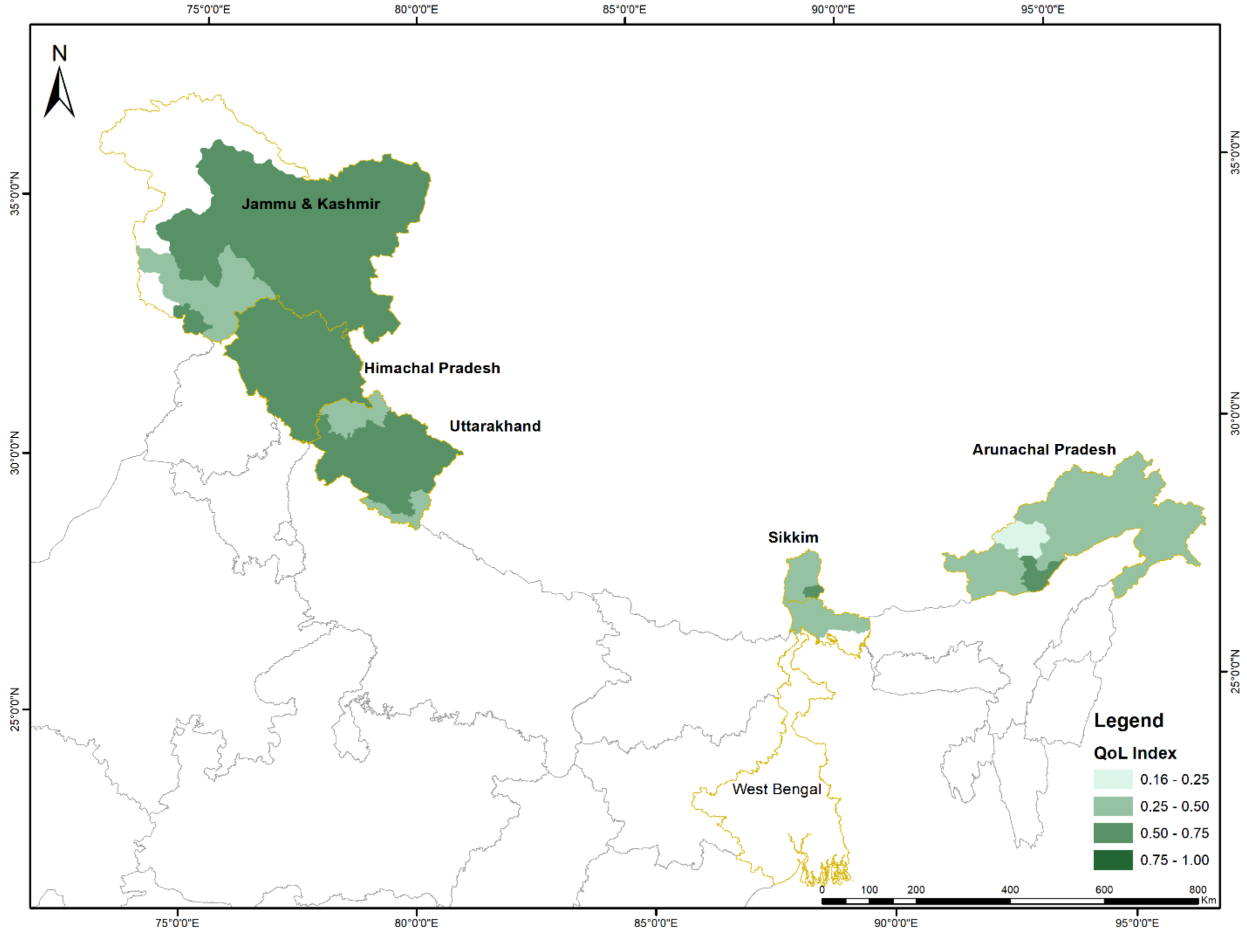


Fig. 1 Quality of Life Index map of 6 IHR states based on the assets and amenities as per Population Census of India data 2011.

The district Dehradun in the state of Uttarakhand shows the highest QoL Index (0.70). As per census of India, the percentage of urban population in the district is 55.52%, which is much higher than the state average of 30.23%. The overall literacy rate of Dehradun district is 84.25 % and has the highest male and female literacy rates at 92.15% and 83.87% respectively. The overall percentage of households having access to improved drinking water source is 99.5%. The percentage of main workers in the total workforce in Dehradun is 28.77% which is slightly higher than the State main workers (28.46%). Among the four categories, Cultivators form about 13.24% of all workers which form the second highest percent, while agricultural labourers form 6.55%. The category ‘Other Workers’ form 76.26% of the entire working population of the district which is the highest. It includes forms of employment in secondary and tertiary sector. The workers in household industry forms 3.95%.

The QoL Index in the state of Arunachal Pradesh mostly varies from 0.16 to 0.45 except only one district namely Papum-Pare having QoL Index more than 0.50. The overall literacy rate in the state is 65.38%. Agriculture and Horticulture is main sources of income in the district of Papum Pare, but many people have small business. The people practice subsistence agriculture. Jhum (shifting) cultivation in steep slopes and wet rice cultivation in low-lying areas is generally practiced. The district of Papum-pare is well connected by roads and have average literacy rate of 79.95%.

Kurung Kumey district in the state of Arunachal Pradesh has the lowest value i.e. 0.16 and reflects poor or no access to basic amenities required to have a good quality of life. The socio-economic profile of district depicts that it mostly occupied by tribal communities. Out of the total population of 92,076 of district, 97.5% resides in the rural areas and 2.5% in the urban areas. The main inhabitants belong to Nyishi tribe. There is another tribe which is known as the Puroik. Agriculture is the main occupation of the people followed by livestock keeping. The communities in the district directly or indirectly depends on agriculture. The district is still having very poor facilities of road connectivity due to which the development of the district could not be accelerated in all the places uniformly. The literacy rate and work participation of the district is low i.e. 48.8% and 41.3% respectively. Also, most of houses are mostly “kutcha houses” in which both walls and roof are made of materials, which have to be replaced frequently.

Table 2 Details of QoL Index values ranging from 0.16 to 0.70 for 55 districts under 6 IHR states from west to east of the Himalaya namely; Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, West Bengal and Arunachal Pradesh.

S.No	**States**	**Districts**	**Quality of Life Index (QoL)**
1	Jammu & Kashmir	Anantnag	0.51

		Baramula	0.52
		Jammu	0.65
		Kathua	0.49
		Leh and Ladakh	0.55
		Punch	0.35
		Riasi	0.39
		Udhampur	0.46
2	Himachal Pradesh	Bilaspur	0.68
		Chamba	0.54
		Hamirpur	0.66
		Kangra	0.62
		Kinnaur	0.62
		Kullu	0.61
		Lahul & Spiti	0.53
		Mandi	0.65
		Shimla	0.64
		Sirmaur	0.60
		Solan	0.68
		Una	0.65
3	Uttarakhand	Dehradun	0.70
		Haridwar	0.54
		Nainital	0.59
		Pauri Garhwal	0.54
		Pithoragarh	0.54
		Rudraprayag	0.55
		Tehri Garhwal	0.53
		Udham Singh Nagar	0.50
		Uttarkashi	0.50
		Almora	0.55
		Bageshwar	0.54
		Chamoli	0.54
		Champawat	0.46
4	Sikkim	East	0.56
		North	0.44
		South	0.47
		West	0.42
5	West Bengal (Hill Districts)	Darjeeling	0.47
		Jalpaiguri	0.30
6	Arunachal Pradesh	Anjaw	0.26
		Changlang	0.31
		Dibang Valley	0.29
		East Kameng	0.30
		East Siang	0.43
		Kurung Kumey	0.16
		Lohit	0.31
		Lower Dibang valley	0.36

		Lower Subansiri	0.45
		Papum-pare	0.57
		Tawang	0.41
		Tirap	0.30
		Upper Siang	0.36
		Upper Subansiri	0.28
		West Kameng	0.38
		West Siang	0.38

Vulnerability to climate change is majorly influenced by social, political, economic drivers and availability and utilization of natural resources. Therefore, all the communities inhabiting an area are not equally vulnerable and vulnerability varies across space and time (Füssel, 2010; Fraser et al., 2011). Vulnerability of livelihoods in mountainous agrarian communities also arises from geographic settings, demographic trends, socio-economic factors, access to resources and markets, unsustainable water consumption, farming practices, and lack of adaptive capacity (Hijioka et al., 2014). Climate change also affects the human health in Asia (Munslow and O'Dempsey, 2010), where the magnitude and type of health effects depend on diverse socioeconomic and demographic factors, health systems, the natural and built environment, land use changes, and migration, in relation to local resilience and adaptive capacity. Hence, understanding the socio-economic demographics of these mountainous communities is of paramount importance to address any adaptation or mitigation strategies (Aryal et al., 2014). QoL analyses guide a stronger research agenda and improve our understanding of human well-being issues in spatial explicit manner that in turn can be used to guide public policy towards the goal of enhancing human well-being across multiple scales, and across diverse cultures in long-term and sustainable manner in context of climate change. Instead of dealing economic and social systems in isolation, QoL approach integrates them together into one for management intervention purposes (Prakash et al., 2016).

12.1.4 Conclusion

Climate change impacts are majorly determined by deep-rooted socioeconomic inequalities. As a result, they tend to be particularly detrimental to the most disadvantaged groups of society, which are hence disproportionately exposed and vulnerable to climate hazards. Also, the communities living in the IHR are largely dependent on climate sensitive sectors including rainfed agriculture, grazing and have limited livelihood options. These communities experience higher marginalization because of limited physical infrastructure (road and transport, markets, power supply and communication) arising due to fragility of the mountain ecosystem. These constraints add up to the existing vulnerability of the IHR communities under fluctuating climate. The results of the analysis revealed that few districts of the IHR ranging below 0.50 needs to be provided with better adaptation strategies to cope with the climate induced stressors. Since, the basis of developing the QoL Index was mostly economic and social indicators, focus should be given for sustaining the livelihood practices and creating better economic opportunities and providing literacy and employment to these marginal communities. The comprehensive QoL Index map provides a synoptic view of available and existing community assets and lays the groundwork for planning the appropriate solutions which can intersect with the real community needs for climate change adaptation. The ability of communities to adapt to climate change is inextricably linked to their access to basic human rights including their buying capacities and standard of living and to the health of the ecosystems they depend on for their livelihoods and well-being. To build effective adaptation strategies and programs, an integrative effort must be undertaken to sustain and restore ecosystem functions and promote human rights under changing climate conditions.

12.2 Landscape Connectivity & Fragmentation

Landscape connectivity is crucial for many ecological processes, including dispersal, gene flow, demographic rescue, and movement of various species in response to climate change (Collingham & Huntley, 2000). Based on numerous published studies, around 75% of the natural forested areas across the world have either been cleared or dominated by human activity. Since the last ice age and the global rate of forest loss is currently reported to be 0.6% per year, as a result of resources extraction, and conversion of forested areas to cropland, settlement and other land use types which is leading to forest fragmentation, a decrease in productivity, an increase in forest isolation, and changes in community composition (Armenteras et al., 2003; Fahrig, 2003; Lele & Joshi, 2009). Studies have shown that, if not controlled, natural old-growth forests can be critically fragmented to the point at which they can neither maintain viable populations of flora and fauna, nor maintain their ecological integrity. Forest fragmentation, in which the forest is reduced to patches, can have a marked detrimental impact on biodiversity. Among others, it can result in homogenization, reduction in habitat quality for forest-interior species, and loss of forest health due to changes in microclimate and increased susceptibility to edge predators, parasites, and invasive species

(Fischer & Lindenmayer, 2007). Rare and patchily distributed species that require a larger range of a specific habitat are particularly affected by fragmentation.

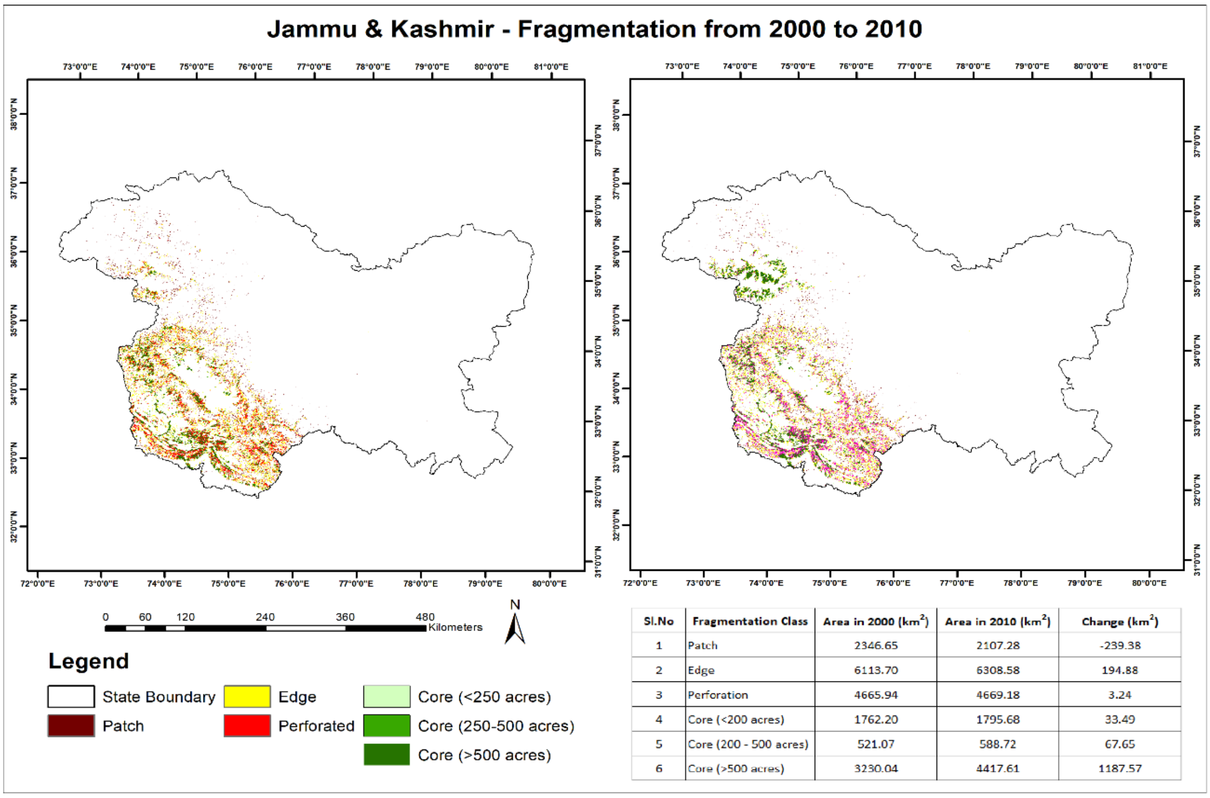
12.2.1 Data and Methods

We have used the GlobeLand30 dataset that covers a decade from 2000 to 2010 and was developed by the National Geomatics Centre of China (NGCC). This dataset provides global land cover data at 30m resolution. The accuracy assessment per class analyses reveals that Forest and Bare ground has an accuracy of 75 and 60%, respectively, while Water body, Cultivated land, and Grassland have the highest accuracy above 85%, and Wetland is the lowest with 8.3%. The overall accuracy is 78%, which falls into “substantial” category (Brovelli et al., 2015). The Landscape Fragmentation Tool (LFT v2.0) was used to quantify the forest integrity and was developed by Center for Land Use Education and Research, University of Connecticut. The land cover maps for the years 2000 and 2010 were reclassified into forest and non-forest classes. The fragmentation tool classifies forest class into four main categories: Patch, Edge, Perforated, and Core (Vogt et al., 2007).

The Indian Himalayan Region includes 6 states (Jammu and Kashmir, Himachal Pradesh, Uttarakhand, West Bengal, Sikkim and Arunachal Pradesh) with a combined land area of 4,96,464.32 km^2 and forested area covering 54.45 % of the geographical land area (FSI, 2017). The forest cover between 2000 and 2010 has increased in Jammu and Kashmir and West Bengal by 1107.70 km^2 and 147.67 km^2 respectively and decreased in Uttarakhand, Sikkim and Arunachal Pradesh by 531.60 km^2, 824.99 km^2, 1166.40 km^2 respectively. Interestingly, Himachal Pradesh had almost no change in forest cover between 2000 and 2010 with a small decrease of 10.30 km^2.

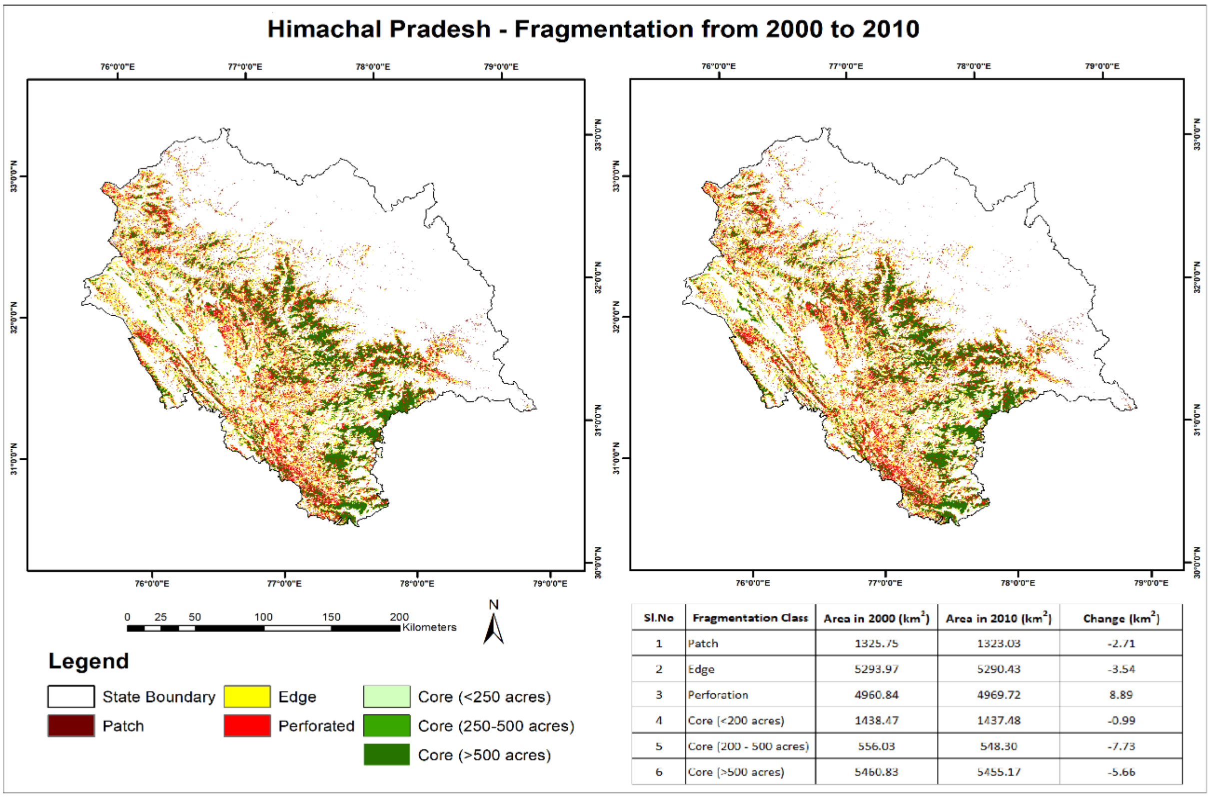
12.2.2 Results

Forest fragmentation analyses revealed a significant decrease in the large intact core area (>500 acres) in all the states except Jammu and Kashmir. The results reveal ongoing perforation inside the forest) in all the Indian Himalayan States. The perforations were the highest in Uttarakhand (1240.22 km^2) followed by Sikkim (531.43 km^2), Arunachal Pradesh (334.69 km^2), West Bengal (143.76 km^2), Himachal Pradesh (8.89 km^2) and Jammu and Kashmir (3.24 km^2) shown in Fig. 2-7 and Table 2.



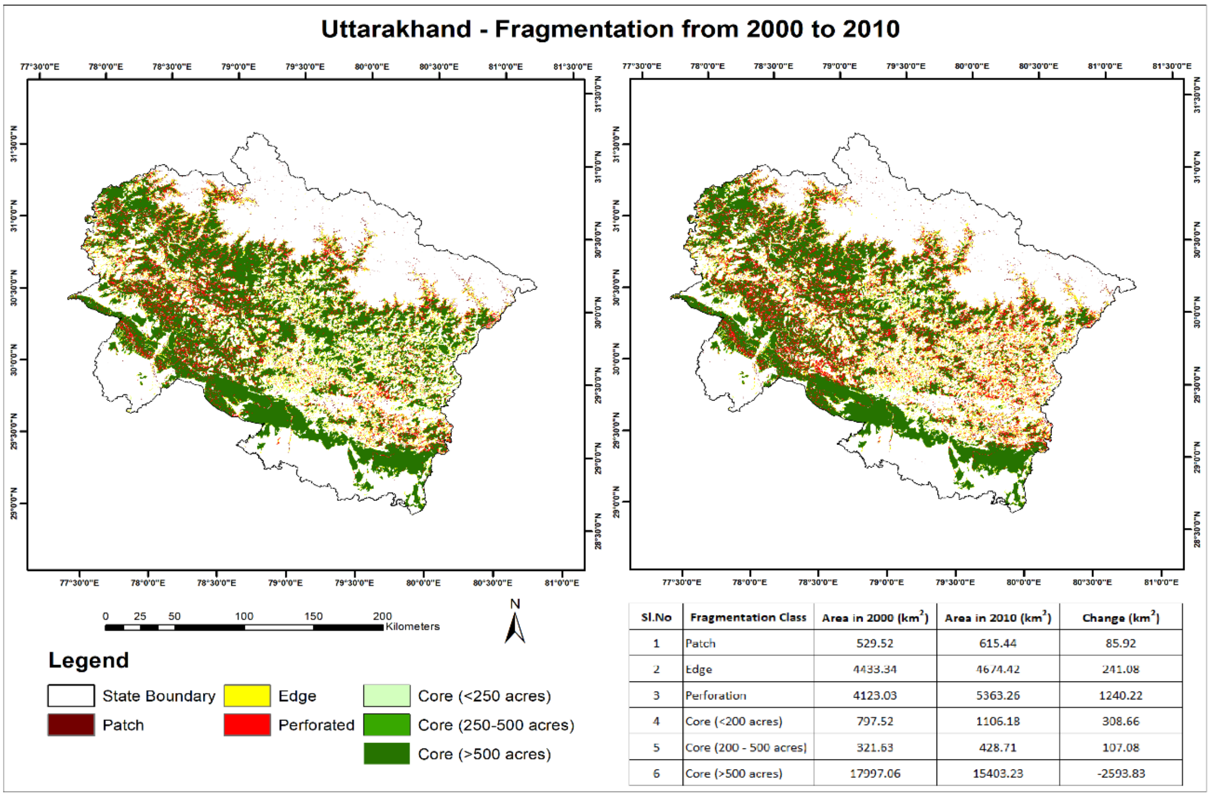
Sl.No	Fragmentation Class	Area in 2000 (km^2)	Area in 2010 (km^2)	Change (km^2)
1	Patch	2346.65	2107.28	-239.38
2	Edge	6113.70	6308.58	194.88
3	Perforation	4665.94	4669.18	3.24
4	Core (<200 acres)	1762.20	1795.68	33.49
5	Core (200 - 500 acres)	521.07	588.72	67.65
6	Core (>500 acres)	3230.04	4417.61	1187.57

Fig. 2 Fragmentation in Jammu & Kashmir between 2000 and 2010



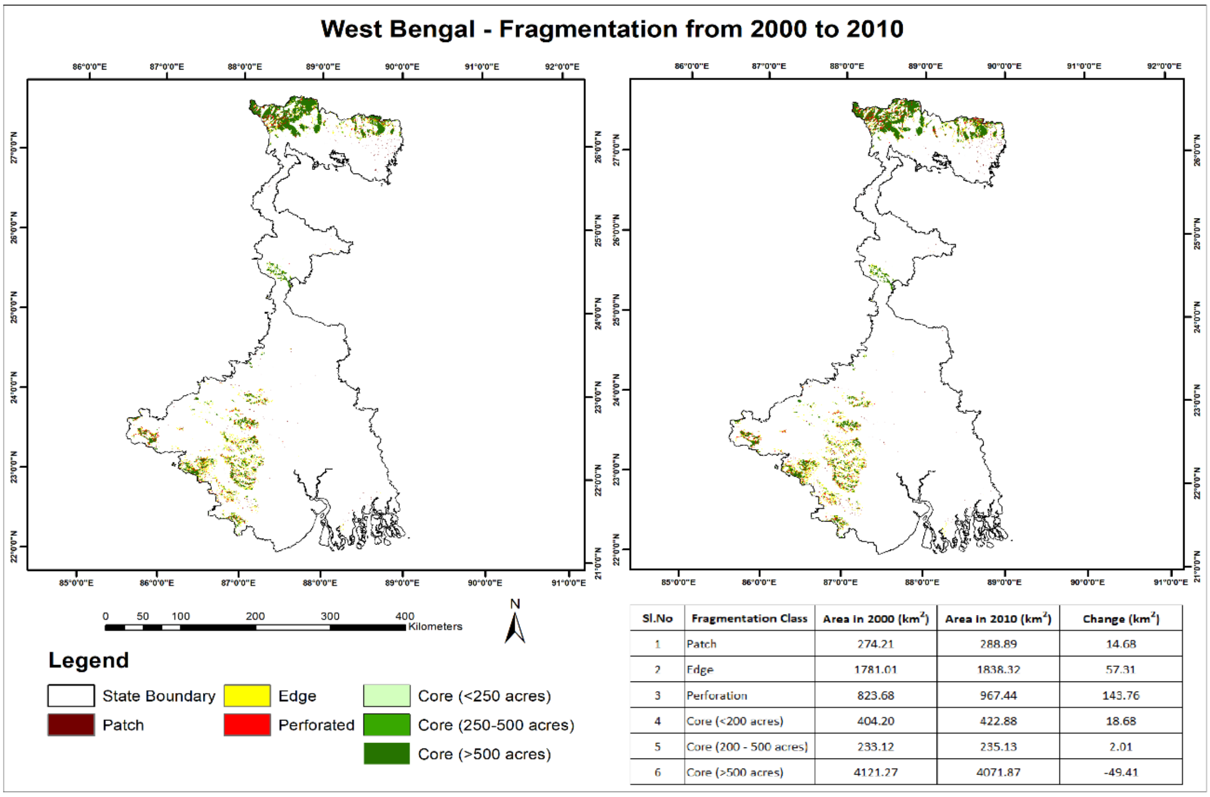
Sl.No	Fragmentation Class	Area in 2000 (km^2)	Area in 2010 (km^2)	Change (km^2)
1	Patch	1325.75	1323.03	-2.71
2	Edge	5293.97	5290.43	-3.54
3	Perforation	4960.84	4969.72	8.89
4	Core (<200 acres)	1438.47	1437.48	-0.99
5	Core (200 - 500 acres)	556.03	548.30	-7.73
6	Core (>500 acres)	5460.83	5455.17	-5.66

Fig. 3 Fragmentation in Himachal Pradesh between 2000 and 2010



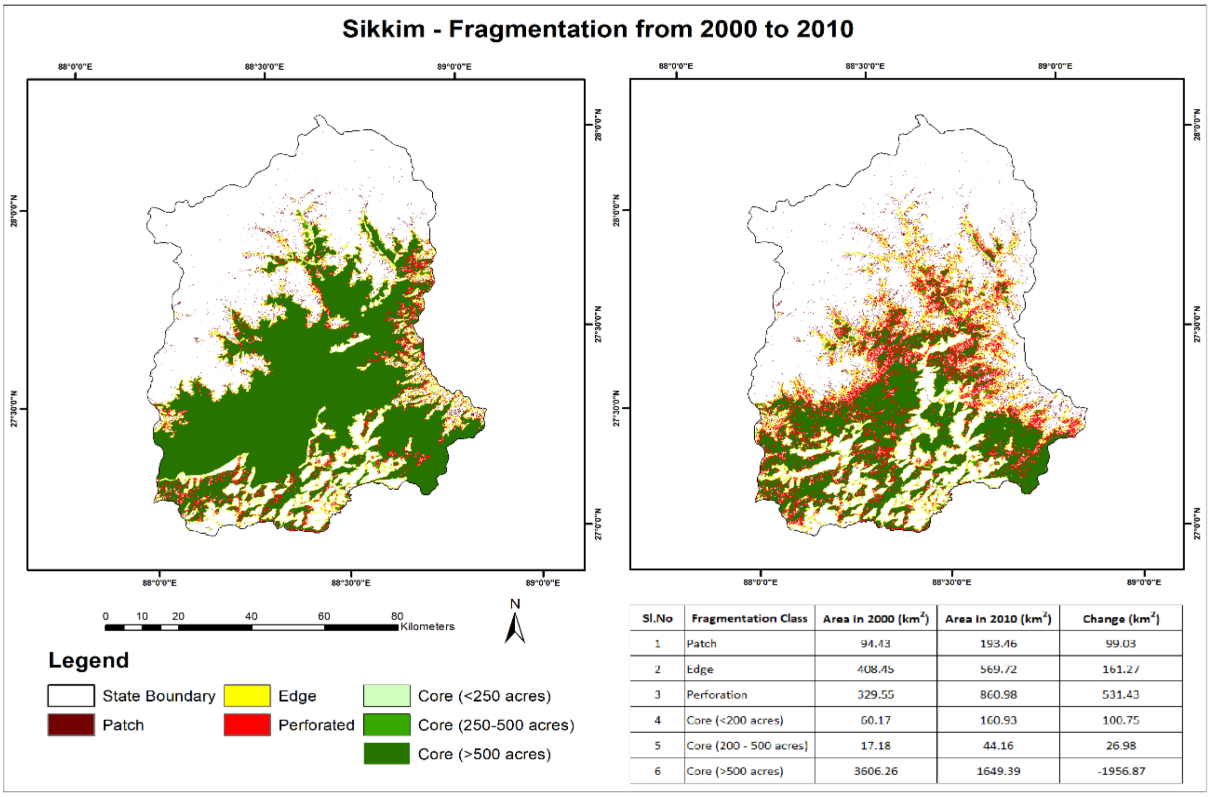
Sl.No	Fragmentation Class	Area in 2000 (km^2)	Area in 2010 (km^2)	Change (km^2)
1	Patch	529.52	615.44	85.92
2	Edge	4433.34	4674.42	241.08
3	Perforation	4123.03	5363.26	1240.22
4	Core (<200 acres)	797.52	1106.18	308.66
5	Core (200 - 500 acres)	321.63	428.71	107.08
6	Core (>500 acres)	17997.06	15403.23	-2593.83

Fig. 4. Fragmentation in Uttarakhand between 2000 and 2010



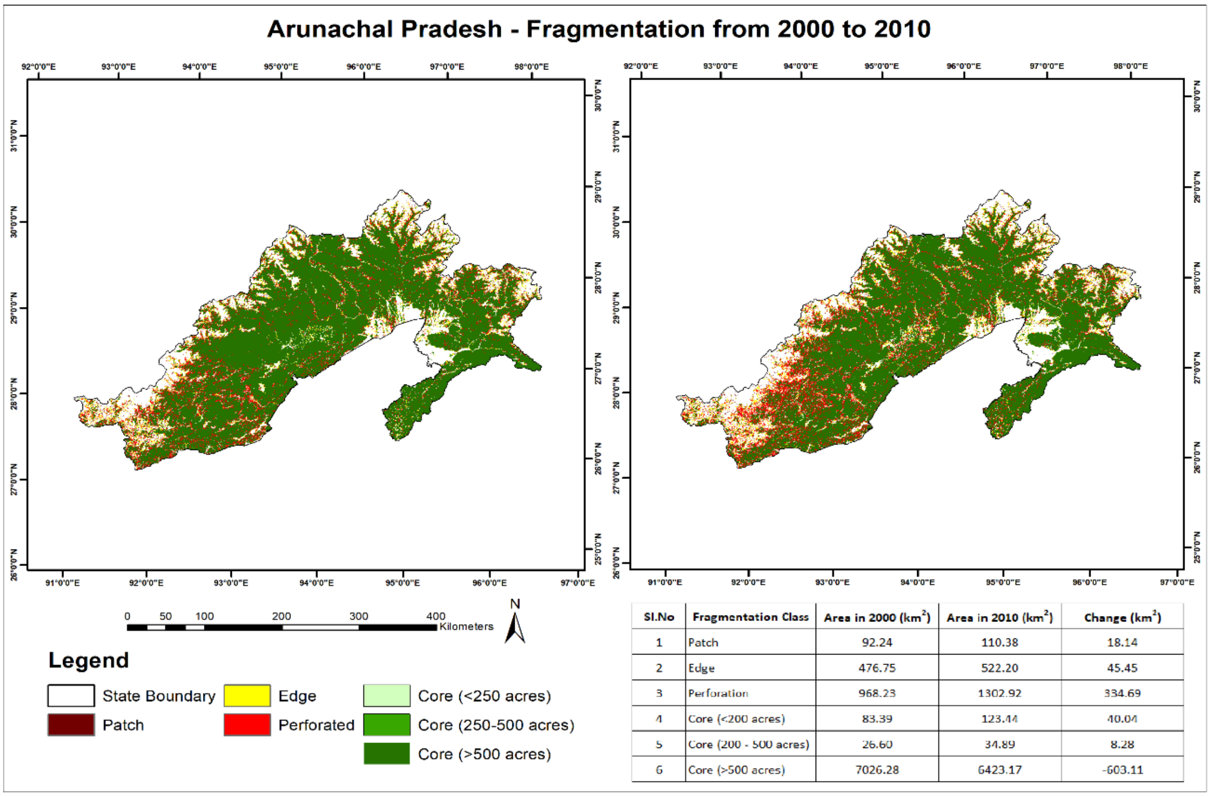
Sl.No	Fragmentation Class	Area in 2000 (km^2)	Area in 2010 (km^2)	Change (km^2)
1	Patch	274.21	288.89	14.68
2	Edge	1781.01	1838.32	57.31
3	Perforation	823.68	967.44	143.76
4	Core (<200 acres)	404.20	422.88	18.68
5	Core (200 - 500 acres)	233.12	235.13	2.01
6	Core (>500 acres)	4121.27	4071.87	-49.41

Fig. 5 Fragmentation in West Bengal between 2000 and 2010



Sl.No	Fragmentation Class	Area in 2000 (km^2)	Area in 2010 (km^2)	Change (km^2)
1	Patch	94.43	193.46	99.03
2	Edge	408.45	569.72	161.27
3	Perforation	329.55	860.98	531.43
4	Core (<200 acres)	60.17	160.93	100.75
5	Core (200 - 500 acres)	17.18	44.16	26.98
6	Core (>500 acres)	3606.26	1649.39	-1956.87

Fig. 6 Fragmentation in Sikkim between 2000 and 2010



Sl.No	Fragmentation Class	Area in 2000 (km^2)	Area in 2010 (km^2)	Change (km^2)
1	Patch	92.24	110.38	18.14
2	Edge	476.75	522.20	45.45
3	Perforation	968.23	1302.92	334.69
4	Core (<200 acres)	83.39	123.44	40.04
5	Core (200 - 500 acres)	26.60	34.89	8.28
6	Core (>500 acres)	7026.28	6423.17	-603.11

Fig. 7 Fragmentation in Arunachal Pradesh between 2000 and 2010

The large core forest (>500 acres) have reduced significantly in Uttarakhand (2593.83 km^2) followed by Sikkim (1956.87 km^2) and Arunachal Pradesh (603.11 km^2). West Bengal (49.41 km^2), Himachal Pradesh (5.66 km^2) had almost no change in the large core forest (>500 acres) and Jammu and Kashmir (1187.57 km^2) had increased large core forest (>500 acres).

Table 2 Forest Fragmentation in the Indian Himalayan States between 2000-2010

Jammu & Kashmir				
Sl.No	Fragmentation Class	Area in 2000 (km2)	Area in 2010 (km2)	Change (km2)
1	Patch	2346.65	2107.28	-239.38
2	Edge	6113.70	6308.58	194.88
3	Perforation	4665.94	4669.18	3.24
4	Core (<200 acres)	1762.20	1795.68	33.49
5	Core (200 - 500 acres)	521.07	588.72	67.65
6	Core (>500 acres)	3230.04	4417.61	1187.57

Himachal Pradesh				
Sl.No	Fragmentation Class	Area in 2000 (km2)	Area in 2010 (km2)	Change (km2)
1	Patch	1325.75	1323.03	-2.71
2	Edge	5293.97	5290.43	-3.54
3	Perforation	4960.84	4969.72	8.89
4	Core (<200 acres)	1438.47	1437.48	-0.99
5	Core (200 - 500 acres)	556.03	548.30	-7.73
6	Core (>500 acres)	5460.83	5455.17	-5.66

Uttarakhand				
Sl.No	Fragmentation Class	Area in 2000 (km2)	Area in 2010 (km2)	Change (km2)
1	Patch	529.52	615.44	85.92
2	Edge	4433.34	4674.42	241.08
3	Perforation	4123.03	5363.26	1240.22
4	Core (<200 acres)	797.52	1106.18	308.66
5	Core (200 - 500 acres)	321.63	428.71	107.08
6	Core (>500 acres)	17997.06	15403.23	-2593.83

West Bengal				
Sl.No	Fragmentation Class	Area in 2000 (km2)	Area in 2010 (km2)	Change (km2)
1	Patch	274.21	288.89	14.68
2	Edge	1781.01	1838.32	57.31
3	Perforation	823.68	967.44	143.76
4	Core (<200 acres)	404.20	422.88	18.68
5	Core (200 - 500 acres)	233.12	235.13	2.01

6	Core (>500 acres)	4121.27	4071.87	-49.41

Sikkim				
Sl.No	Fragmentation Class	Area in 2000 (km2)	Area in 2010 (km2)	Change (km2)
1	Patch	94.43	193.46	99.03
2	Edge	408.45	569.72	161.27
3	Perforation	329.55	860.98	531.43
4	Core (<200 acres)	60.17	160.93	100.75
5	Core (200 - 500 acres)	17.18	44.16	26.98
6	Core (>500 acres)	3606.26	1649.39	-1956.87

Arunachal Pradesh				
Sl.No	Fragmentation Class	Area in 2000 (km2)	Area in 2010 (km2)	Change (km2)
1	Patch	92.24	110.38	18.14
2	Edge	476.75	522.20	45.45
3	Perforation	968.23	1302.92	334.69
4	Core (<200 acres)	83.39	123.44	40.04
5	Core (200 - 500 acres)	26.60	34.89	8.28
6	Core (>500 acres)	7026.28	6423.17	-603.11

12.2.3 Conclusion

In order to enable landscape managers to manage fragmented landscapes adequately, the causes and ecological consequences of habitat fragmentation have to be fully understood. The impacts of forest fragmentation on biodiversity have been well studied and can be severe. In general, smaller more isolated fragments lose more species and larger, less dispersive species are lost more quickly from fragments. The effects of forest fragmentation on ecosystem functioning have been much less investigated. The results of the fragmentation study demonstrate that although there is no considerable forest decline in the Indian Himalayan States but the visible fragmentation events in the forests are significant and must be addressed. The integrity and intactness of the forests are of high importance value to the species inhabiting those areas and requires long-term monitoring to predict the trend and to curtail the perforations. Perforations in the forests can often lead to isolated patches that can lose its connections with the other forest areas. And further will be completely lost leading to species reduction and extinction. Prioritizing the target areas where maximum perforations have taken place will aid in better conservation and management practices in the Indian Himalayan States. Although this study gives a limited perspective on the possible causes and consequences of fragmentation, they contribute to the ongoing argument on landscape management and conservation at multiple scales. A more comprehensive view on fragmentation as well as more efficient landscape management plans are needed to avoid dispersion of valuable natural resources in the future. Future work should focus on robust long-term experimental studies to inform the design of ecosystems that sustain their function in the face of inevitable habitat change.

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Chapter 13

Technology Development and Geovisualization

13.1 Introduction

Anthropogenic GHG emissions have risen dramatically since 1970, with larger increases occurring between 2000–2010, despite a growing number of climate mitigation policies (Pachauri et al., 2018). Although most people are aware of climate change, and many are concerned about it (Nisbet et al., 2007), this concern does not always translate into action, even though individual actions can have a significant effect. Public participation can not only contribute to improvement of decisions but can also help in enhancing the capability of communities to solve problems and pursue common concerns. Arguably, a strong public participation in environmental governance could increase the commitment among stakeholders, which strengthens the compliance and enforcement of policies. Yet, despite the critical importance of public participation in policy making, such involvements are not as effective as may be desired for logical conclusion and efficient implementation of policies. The near nonexistence of visualization tools at the disposal of the general public to aid in visual understanding of the problem is the major cause factor for the non-involvement and negligible influence of the populace in policy making. Public participation refers to involvement in knowledge production and/or decision-making of those involved in, affected by, knowledgeable of, or having relevant expertise or experience on the issue at stake (Van Asselt & Rijkens Klomp, 2002). Public participation involves an element of control over decisions, through the decision-making process. It is sometimes assumed that conflicts over public policies and science are caused by citizen ignorance - a gap between citizen and expert knowledge, also known as a “knowledge deficit” (Stoutenborough & Vedlitz, 2014). Providing more detailed information to citizens about science and policy should increase citizen knowledge, which in turn will make citizens to think in line with natural scientists and policy experts (Rhodes et al., 2014). The major challenges faced in building awareness and bringing in local participation to the policy making process are the following:

1. The predominantly global nature of the issue and the information is not relevant for local users or communities.

2. The available scientific data is too complex for a common man to understand.

3. The available information is of a biophysical nature, little of which is converging on socioeconomic and livelihood scenarios.

4. The very few effective structured processes for public participation in the policy making.

5. Nonexistence of infrastructure and capacity to visualize the scientific data into more understandable 2D and 3D output.

With the alarming threats from climate change and other extreme events, the major portion of the Asia-Pacific region is facing a challenge of escalating exposure and vulnerability to changing climate and other related hazards (UNISDR, 2012). Developing countries, particularly, are chronically vulnerable and at risk to climatic hazards due to the high agglomeration of population, non-conducive economic activities and improper development encroaching onto hazard-prone areas (Mendelsohn & Dinar, 1999; Adger et al., 2003). Although the policymakers understand the immense importance of public participation, it is not always practiced and if practiced, it has minimum public influence over the policies made. Policies that ignore the input of those affected will often have poor implementation and ineffective outcomes. Participation also increases the level of awareness around an issue, stimulates public debate, and enhances knowledge. Engagement of non-academic stakeholders does not simply mean transferring information, but needs to occur through an interactive, participatory process to create ownership, accountability, and a willingness to act. Progress toward public participation in policy making seems to be more likely if information is localized, visualized, and co-constructed, which can be achieved by geovisualization.

13.2 Landscape Ecology and Visualization Laboratory (LEVL)

The ability of visual images to communicate messages quickly and powerfully has long been recognized and used as an instrument for data exploration and analysis. Among the various forms of visualization, geovisualization has some unique characteristics that could bring a consensus of the public in decision making. Landscape visualization (geovisualization) attempts to represent actual places and on-the-ground conditions in three-dimensional (3D) perspective views, with varying degrees of realism (Sheppard and Salter, 2004). There are many emerging technologies that need to be evaluated as to their suitability in assisting decision support and participation where geographical information is vital (Fig. 1).

There exists exciting possibilities for using the new visualization techniques to facilitate community participation through (a) informing (creating interactive web sites to educate the public), (b) consulting (generating feedback mechanisms at crucial stages in the design and development process in the policy making), (c) involving (exploring alternative scenarios and comparing the outcomes of different scenarios), and (d) empowering (influencing final policies through 'citizen juries' and online ballots through visualization outcomes) (Pettit et al., 2006).

Fig. 1 Photo of Inauguration of Landscape Ecology and Visualization Laboratory

In the context of public participation in the decision-making process, the potential benefits of geovisualization include:

1. The future predictive capabilities of GIS with realistic representation in the 2D and 3D form can provide 'windows into the future' for the public.

2. The ability to depict recognizable and familiar sites will help in localizing the information for better understanding of the future changes.

3. As per the audience's visualization needs, the data can be highlighted or simplified to provide different levels of realism.

4. The alternative solution can be tested alongside with the proposed solution.

5. Attractiveness due to novelty, dynamism, and interactivity of the medium.

An appreciable amount of research has been carried out to evaluate the impact of visualization in public participation and there is already considerable evidence for effectiveness of communications and usability of visualization in planning and decision support, including the ability to engage common people (Appleton & Lovett, 2003; Sheppard & Meitner, 2005; MacEachren, 2001; Lewis & Sheppard, 2006). Numerous researches have described the importance and effectiveness of visualization in achieving community engagement in the framework for climate change policy making (Sheppard et al., 2011). The results of these visioning projects were tested with the stakeholders, and the results show the effectiveness of geovisualization technology to increase engagement, build awareness of complex environmental issues related to local climate change, and foster participants' support for climate change policy. Despite the complexities, including high technical capacities, high set up cost, and addressing multiple considerations, the visualization tools can bridge the gap between complex scientific modelling outputs and local level realities on the ground to engage the community in decision making process.

The importance of 2D and 3D visualization is well recognized for mainstreaming public participation in the decision-making process. As a result, the NMSHE task force on "Micro Flora and Fauna, Wildlife and Animal Population" at the Wildlife Institute of India under the project entitled "Assessment and Monitoring of Climate Change Effects on Wildlife Species and Ecosystems for Developing Adaptation and Mitigation Strategies in the Indian Himalayan Region" has set up a visualization center "Landscape Ecology and Visualization Laboratory (LEVL)" with the objectives to simulate various climate change scenarios and to visualize potential effects on fauna and their habitats in the Indian Himalayan Region. The aim of this center will be to educate the stakeholders and to communicate to the public through 2D and 3D visualization outputs to influence the policy and decision making. This will have a huge implication on natural resources management policy making by bringing in the participation of multiple stake- holders and effective implementation of conservation actions in the current and future context. The design and equipment specifications for the Landscape Ecology and Visualization Laboratory (LEVL) were developed around three core principles: flexibility, infrastructure and current/ near-future uses. It is a large room that is easily configured into a variety of layouts, suitable for community engagement, interactive workshops, charrettes and large meetings.

13.3 Potential of the state-of-the-art facility

Geovisualization has the power to influence the perception and decisions of people, and therefore to influence participants in the participation process (Brink, 2007). It also has the power to facilitate communication between different actors involved in the process by promoting understanding and common agreement about basic facts (Al-Kodmany, 2001). The Landscape Ecology and Visualization Laboratory (LEVL) at Wildlife Institute, represents one approach that may assist local decision-making. Building on recent advances in scenario-building to bridge the gap between predictive, quantitative approaches and narrative based qualitative methods, the Visualization incorporates novel 3D visualization techniques with elements of participatory integrated assessment to explore images of the future under climate change for the Indian Himalayan Region (Fig. 2). The Local Climate Change Visualization can be achieved in a 3-step process:

i. Localize: translate global climate change data to regional and local scales into an understandable medium for local policy makers and the public;

ii. Spatialize: highlight the potential impacts of climate change in the landscapes where people live and work, and adaptation and mitigation options in these places, through spatial modelling and/or interpretive mapping at the local level;

iii. Visualize: communicate the information in a scientifically defensible and dramatic manner (using 3D simulation of recognizable places) that not only educates viewers on the realities of climate change but also emotionally motivates behavioural change at the individual and community level (Conroy, 2004; Sheppard, 2005a).

This visualization of the local scenarios will be based on the data availability, expert and local input, clear and compelling visual information, and the local narratives. The quantitative results from the numerous researches suggest that 3D imagery and interactive environments can change perceptions and increase both a sense of local responsibility and support for more radical mitigation and adaptation policies.

Bringing the realities of climate change to the local community level through images is technically and scientifically challenging. However, the results show that the connection of climate change impacts with local, i.e. personal and municipal concerns, is key to engage local communities to act on changing climate.

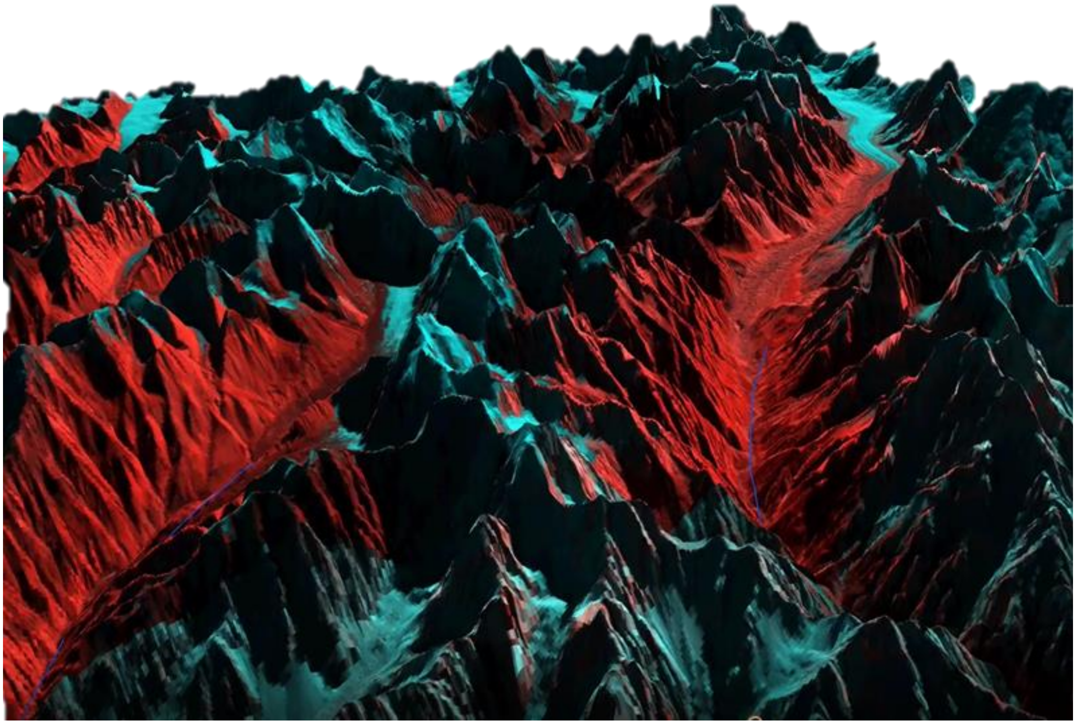

Fig. 2 3D Visualisation of Gangotri National Park

13.4 Future prospective

The influence of visual media of global problems, including climate change, natural disaster, terrorism, poverty, and others, affects the respondents emotionally in local scale rather than global scale. Based on many instances of observational research on audience response during visualization workshops, it was clear that the extensive use of realistic visualizations maintained a high level of engagement among the public participants. There is a better prospect for mobilizing stakeholders and include common people's interest and concern, if the impact of the effect of the policies can be demonstrated 'on the ground,' in familiar locations and upon landmarks and businesses. Linking global science to locally significant places with visualization serves as a powerful tool for decision-making (CSPR Report, 2009). Visualization tools are potentially too powerful and can bring the impacts of policies to home, to people in their back yard, making it personal through realistic views of their familiar landscape under possible future scenarios (Sheppard, 2006). This would ensure effective and well-informed stakeholder participation in the development of new policies and decisions.

The changing landscapes and reducing forest resources can be projected at the local and familiar region to influence the positive behavioural change towards mitigating changing climate. The Landscape Ecology and Visualization Laboratory (LEVL) through the geovisualization can not only be used to sensitise communities towards sustainable living and climate change awareness but can also be helpful in decision making process through before-after simulations and policy efficiency testing.

13.5 Conclusion

Visualization Tools are becoming popular, aiming at engaging local communities and policy makers so as to develop action plans towards adaptation/mitigations. These tools offer an interface between scientific analysis of system response and trajectory, and the immediate and long-term implications requiring policy and management interventions. The future visioning process will look to; Increase local climate change awareness and understanding of local risks, projected impacts, and adaptation and mitigation options; Enable community involvement in developing local climate change solutions; Develop and illustrate low-carbon adaptation options whose implications may be difficult for local residents to imagine; Identify and help overcome social barriers to climate change mitigation and adaptation; Communicate the urgency of mitigation; Stimulate meaningful discussion on alternative response options; Empower local citizens to make choices in their individual and collective lifestyles.

Scenarios analysis would be helpful to making science-based decisions to address climate related issues in the Indian Himalayan Region and would provide strong support for national and global negotiations. The working of LEVL is highly interactive involving the research personnel and the stakeholders, and it aids in formulation of local solutions and adaptation strategies.

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Chapter 14

Building Capacities, Networking and Sensitization

14.1 Introduction

It is well established that images of climate change can shape public perceptions, in some cases, predicting acceptance of climate change, or providing the impetus for strengthening environmental goals (Sheppard, 2005). A number of studies show that the images that come to mind when thinking of climate change tend to be abstract and psychologically distant, devoid of specific geographic, social or temporal details, and typically do not feature people (O’Neill et al., 2013; Rebich-Hespanha et al., 2014, Lück et al., 2016; Duan et al., 2017). From the perspective of reducing the “psychological distance” of climate change, visual imagery has the potential to “bring home” the seriousness of the issue and turn an abstract concept into something tangible and accessible. Some studies suggest that images of solutions have made people feel more able to do something about climate change than images of climate impacts, these images of solutions have also been found to evoke positive, high-arousal emotions such as enthusiasm and excitement (Leviston et al., 2014; Hart & Feldman, 2016; Metag et al., 2016).

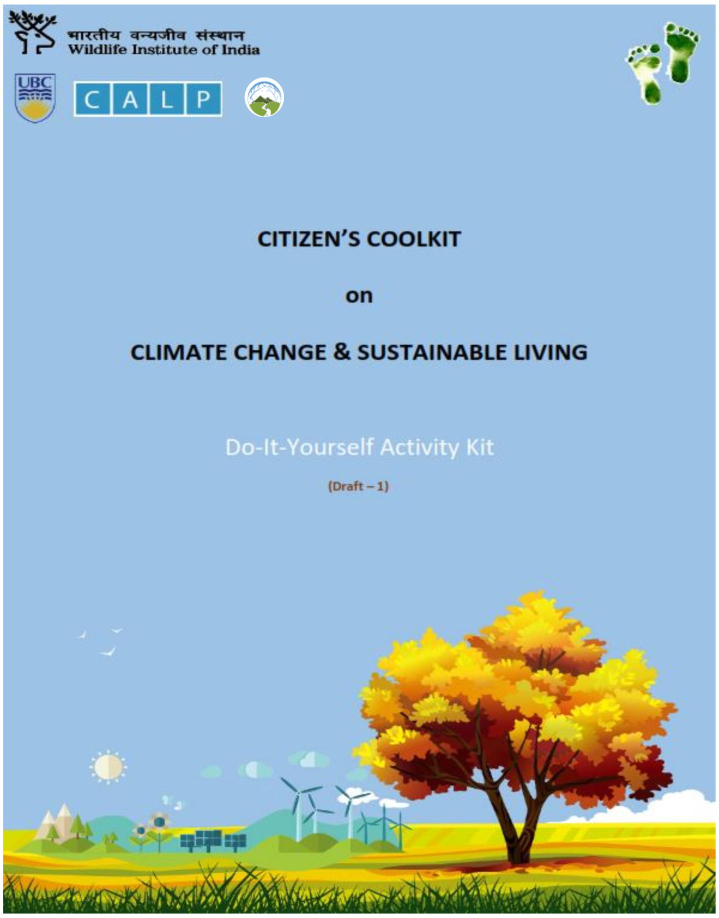
Education is an essential part of the global response to climate change. It helps young people understand and address the impact of global warming, encourages changes in their attitudes and behaviour and helps them adapt to climate change-related trends. The Climate Cool-kit aims to make climate change education a more central part of the community response to climate change. The programme aims to help people understand the impact of climate change in the local scale and increase "climate literacy" among young people.

14.2 Climate Cool-Kit

The Climate Cool-kit is a visual activity book that can be used by the school and university students to visualize the climate change impacts at their household and neighbourhood level (Fig. 1). The Cool-kit is designed with the objective of bringing the global issues such as climate change and unsustainable lifestyle to the local communities at their locations. The activities are framed so as to quantify and visualize the vulnerability of individual households and to show how by changing few lifestyle practices can greatly benefit the communities and neighbourhood.

The activities are categorised into 6 broad groups, that includes (1) starting a conversation on climate change vulnerabilities; (2) simple mapping activities to see the neighbourhood in climate change perspective; (3) rating of household and neighbourhood based on their vulnerabilities; (4) change of lifestyle practices to achieve more sustainable living; (5) designing and visualizing future scenario to compensate climate change impacts; (6) adoptable actions that can benefit.

The Climate Cool-kit is designed (i) to be used as an activity kit which can be used during the house parties or other neighbourhood gatherings or (ii) to be used as workshop material by schools and universities to raise awareness on climate change and sustainable living or (iii) to be used as an assignment material for regular classes in environmental science courses.



भारतीय वन्यजीव संस्थान
Wildlife Institute of India

UBC

C A L P

CITIZEN'S COOLKIT

on

CLIMATE CHANGE & SUSTAINABLE LIVING

Do-It-Yourself Activity Kit

(Draft – 1)

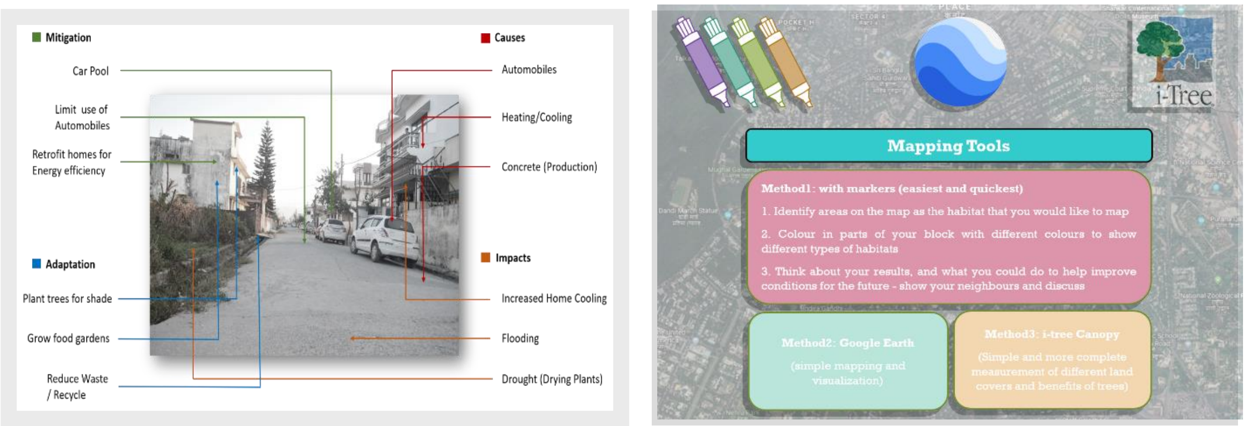
Fig. 1 Climate Cool-Kit Activity Book

The individual activities are designed with specific learning objective, the collecting stories activity is to recognize how much their neighbourhood has changed over the past decades, through facets like urban growth, changing lifestyles, green cover, number of trees and climate change impacts.

14.3 Climate Cool-Kit Workshop

Climate Cool-Kit has been implemented successfully with 153 students between the age group of 12 and 20 in two different workshops. The first workshop was conducted in two phases as a Neighbourhood Event on 10th & 11th of August 2019 at Subash Nagar, Dehradun. We have visited each household to promote the event and a total of 79 students along with their parents participated in the Climate Cool-Kit workshop. The second workshop was conducted at the Department of Civil Engineering, Graphic Era University, Dehradun on 29th of August 2019, with a total of 74 students from the 1st and 2nd year B.Tech Civil Engineering programme.

The workshop involves a Pre-Workshop Questionnaire followed by a short presentation on basic climate change science and about the Cool-Kit activities. Once the student completes the Cool-Kit activities and summarize their understandings and findings, they were asked to fill the Post- Workshop Questionnaire. In both the workshops the students participated in (i) Photo quiz that is designed to understand the climate change causes, impacts, mitigations and adaptions in the neighbourhoods, (ii) Map your neighbourhood activity: which is designed to address the landuse and land cover (LULC) changes caused by both climate change and anthropogenic pressure in the neighbourhood over a time period (Fig. 2) and (iii)



Method1: with markers (easiest and quickest)

1. Identify areas on the map as the habitat that you would like to map

2. Colour in parts of your block with different colours to show different types of habitats

3. Think about your results, and what you could do to help improve conditions for the future - show your neighbours and discuss

Method2: Google Earth

(simple mapping and visualization)

Method3: i-tree Canopy

(Simple and more complete measurement of different land covers and benefits of trees)

Fig. 2 Climate Cool-Kit Activities

Sort the trash activity: designed to differentiate between the everyday waste/trash that can be reused and recycled reducing environmental footprint.

The results from the comparison between Pre-Survey and Post-Survey questions (Table 1) demonstrate that participants experienced an increased awareness, knowledge or concern towards climate change issues as 89% (136 out of 153 participants) responded that the Cool-kit helped them better understand climate change and 91% (139 out of 153 participants) responded that the Cool-kit aided in better understanding the Sustainable lifestyle.

Table 1 Comparison Table between Pre-Survey and Post Survey

Questions	**Pre-Survey (%)**	**Post Survey (%)**
Knowledge on local climate change's effects	37.43	53.97
Concern on the global effects of climate change?	59.70	61.54
Concern on the local effects of climate change?	49.43	67.83
Importance of Sustainability?	37.56	51.63
Do you know India's INDC commitments?	0	64.00

14.4 Way-forward for long term linkages

Successful climate change adaptation and mitigation require appropriate knowledge, skills and behavior change that education can provide. Specifically, education can enable individuals and communities to make informed decisions and take action for climate resilient sustainable development. Policymakers have not fully engaged the education sector, even though existing climate change frameworks are in place that could utilize education as a mitigation and adaptation strategy. Two major climate treaties, The United Nations Framework Convention on Climate Change (UNFCCC), through Article 6, and the Kyoto Protocol to the United Nations Framework Convention on Climate Change, through Article 10 (e), explicitly recognize the role of education and call on governments to develop and implement education programs on climate change. This is complemented by the focus on education and knowledge as a priority for risk reduction within the Hyogo Framework for Action: Building the Resilience of Communities and Nations to Disasters, 2005-2015. Therefore, the local governments and policy makers have to form tools that are clear and coherent to fight against the climate change impacts.

In the global education community, several stakeholders, such as UNESCO, UNEP and UNICEF, are incorporating the climate change agenda in education and helping schools and communities integrate climate change education and environmental stewardship into the curriculum. However, this mechanism is not yet widely recognized by nor integrated into the efforts of the local administration and communities. There are two cross-cutting issues that are important in realizing the global response to climate change,

(1) Active participation of the community, especially children, as agents of change - Knowledge gained by students can further extend climate change mitigation and adaptation measures outside of the school and into the wider community. In this way, the students deliver leadership role through raising awareness about what they have learned and also in sharing information about how to address vulnerabilities and adapt to climate change impacts.

(2) Enhanced linkages with climate researchers - Educational institutes particularly the reputed schools and universities, can establish associations with climate research institutions to formulate educational policy and actions on climate change mitigation and adaptation. This opportunity can be mutually beneficial.

14.5 Conclusions / Summary

Climate change today is no longer the exclusive domain of scientific experts; it calls for action from all citizens. The human dimensions of climate change are important to consider when designing a program to encourage climate action. It is only via a combination of both top-down and bottom-up approaches that the unprecedented challenge of climate change can be effectively addressed, and one cannot be achieved without the other. Achieving ambitious policy targets for carbon reduction depends on societal engagement with climate change and GHG mitigation. There is an urgent need to continue developing our understanding of the ways in which people emotionally engage with climate change actions. Education motivates behaviour change solving short-term needs while cultivating curiosity that will inspire creative responses and avert similar future crises (UNICEF 2012). By education the students on climate change effects they become the most significant thinkers. Being the future leaders, they can drive change by communicating with fellow students, monitoring progress, celebrating successes and organizing events. Effective climate change education should emphasize the personal connection between the student, their neighbourhood, and climate change using active learning methods. A scientifically literate population can make better decisions about what and how they purchase, consume, dispose, and invest (Lester et al. 2006). These understanding must be developed and applied within well-targeted, well-funded communication campaigns. Numerous researches have shown that by providing tailored information, soliciting commitment, recruiting leaders from within social networks, giving feedback and using a variety of other social influence strategies can effectively increase climate-friendly behaviour in societies

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Chapter 15

Spatial Ecology: Conclusion and Discussion

Data on biodiversity, natural resources, and socioeconomics have been collected for decades by scientists and managers working on biodiversity conservation and on different parts of the country and with the rapid development in GIS (Geographic Information System) and its applications, more and more geographical databases have been developed, but data sharing and acquisition is still a big problem for the development of GIS applications. At a regional scale, the institutes that generate any spatial data must make the geographical data available for sharing. Gathering all the useful basic spatial data can be a difficult task, but it is feasible with an adequate Internet access and persistence. Existing data dissemination initiatives appear to meet these objectives, such as environmental monitoring, control of deforestation, promoting public awareness about forest conservation, or sharing data between institutions. From the already established initiatives such as Data Portal India , data dissemination for general users could be facilitated, through the map servers joined in a single interface for visualization, selection, and data downloading of spatial data.

The scale plays a very important role in ecosystem studies as different physical processes dominate at different scales. Different variables revealed that ecological phenomena do not operate at a single natural scale and show spatial, temporal as well as organizational variability (Levin, 1992). The mean annual temperature has a positive bearing on the productivity at the regional scales but at the smaller scale it has a negative influence. Seasonal variations and extremes in temperature influence significantly at the medium and finer scales. To understand such deviations, it is required to interface the processes occurring at different scales of time, space and ecological structure. Since ecological resources extend beyond the administrative boundaries and time lines, it would be appropriate to consider spatial and temporal scales based on natural features and ecological phenomenon (Nash & Adamson, 2014). An analysis conducted at one scale will not necessarily produce the same results as one conducted at a different scale. To overcome this, analyzing data at many different scales and then measuring how the results are influenced by changes in scale is the best possible solution. Therefore, there is a need to bridge the gap between theoretical concepts and practical applications for the selection of an appropriate scale for planning and decision making.

Climate is one of the most important determinant of vegetation patterns globally. Several studies have shown that climatic regimes determine the specific plant communities or functional types in a region. Climate has a significant influence on the distribution, structure, and ecology of forests (Kirschbaum et al., 1996) and it is therefore rational to assume that changes in climate will modify the distribution of forest ecosystems. A series of modelling studies show a potential for forest dieback towards the end of this century and beyond, especially in the tropics, boreal, and mountain regions (IPCC, 2007). According to IPCC (2014), many natural systems both on the land and in the ocean are facing climate change impacts causing irreversible changes including large-scale forest dieback and loss of biodiversity. Climate change is expected to be the dominant stressor on terrestrial ecosystems in the second half of the 21st century, especially under RCP 6.0 and 8.5. The impact of climate change on forests has serious implications for the people who depend on forest resources for their livelihoods. It is important to assess the likely impacts of projected climate change on both primary and plantation forests and to develop and implement adaptation strategies to enhance the resilience of forests to climate change.

There is a close relationship between quality of life and the environment. People's lives are strongly affected by the health of their physical environment. Environmental quality is a key factor in people's well-being because quality of life is strongly affected by the health of the physical environment (Coan & Holman, 2008). Preserving environmental and natural resources is one of the most important factors in ensuring the sustainability of well-being over time. Lifestyle and environmentally responsible behaviour have a significant impact on environmental quality, so several important indicators have to be selected to assess the patterns with regard to these that would lead to savings in resources and energy and increase the use of renewable energy sources, sewage disposal and waste recycling.

Forest fragmentation is a major conservation issue and is driven by interdependent components of forest loss and changes in their spatial patterns. Over the years, the Himalayan forests have experienced major changes, but data and documentation on patterns and causes of forest fragmentation are still patchy. Our results indicate forests in Himalaya are highly fragmented, showing alarming trends of increasing fragmentation over the last decade. This is particularly driven by agricultural expansion in the lower altitudes and reduction of forest edges to other natural land cover classes in the higher altitudes. Such changes can be associated with the increasing population in the Indian Himalayan Region which directly or indirectly depends on forests and forest-based resources.

Visualization is a key technology for presenting climate simulations and observations as well as related social and ecological data. Furthermore, mediating research results to decision makers and to the public in an easily understandable way is of growing importance. Visualization as a tool has been established in climate and climate impact research, communicating results between climate scientists and conveying results beyond the scientific community. However, recent developments in interactive visualization using alternative visual metaphors are not wide spread in the climate community. And the major task for future developments is to further bridge the gap between climate and visualization expertise and common public for the effective policy deliberations.

Climate change communication is a relatively new area of research in India. India is one of the most vulnerable countries to climate change, primarily because of its high incidence of poverty, illiteracy, and a large population (NAPCC, 2008). About a quarter of Indians live below the poverty line (with income at about $1.25 per day), and India is home to 30% of the world's poorest people (World Bank, 2015). Moreover, a large majority of the Indian public says that they know very little about the term climate change, which increases their vulnerability to a phenomenon that they may not understand or know how to respond to its impacts. While the number of scientific analyses of climate change in India appears to be increasing, a lack of public understanding and awareness is likely to result in low demand for government action on climate change and also failure of existing environmental policies. More research is needed to underscore the important factors that drive public knowledge and engagement with climate change in India, which could be helpful for the government and other environmental organizations.

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Chapter 16
Conservation Management, Policy Requirements and Future Research

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16.1 Introduction

The distribution, abundance and life history attributes of variety of IHR's wildlife have been shaped by its unique physiography, heterogeneous topography and climatic attributes. The region represents an extraordinary diversity and encompasses about half of India's forest cover which are home to about 5800 plants, 940 birds (26% of which are endemic) and 280 mammals (Chandra et al 2018). Around 200 species of reptiles and 80 species of amphibians found in the IHR with 6.5% of the reptile's endemic to IHR (Chandra et al. 2018). In view of freshwater fish diversity, the central (Nepal) Himalaya was known to be richest (181 species), followed by the western (167 species) and the eastern Himalaya (159) though the survey work is little comprehensive and there are several areas which remain unexplored and needs to be updated.

Concerningly, the rate of warming in the Himalaya is projected to be much higher than the global average warming rate of 0.4°C (Solomon, 2007). By the end of 21st century, the global circulation models (GCMs) output from the Coupled Model Intercomparison Project phase 3 and 5 estimated a projected temperature rise of 2.5–4 °C in eastern and 2.8–4.5 °C in western Himalaya. As per the South Asia Regional Climate Model (RCM, CORDEX-SA) a warming rate 0.23–0.52 °C/decade for minimum and maximum air temperature was also projected under RCP 4.5 and RCP 8.5 (Dimri et al. 2018). On the other hand, the precipitation trends across and within Himalaya is highly uncertain as suggested by previous studies based on different GCMs and RCM (Rajbhandari et al. 2015; Archer and Fowler 2004; Bhutiyani et al. 2010; Kulkarni et al. 2013; Bookhagen and Burbank 2006; Shrestha et al. 1999; Kumar et al., 2015; Mishra 2015, Dimri et al. 2015). The projected future precipitation from a multi-model ensemble of dynamically downscaled CORDEX-SA models (0.5° resolution) revealed a substantial rise in annual mean precipitation and a moderate increase in winter precipitation (Krishnan et al. 2020). While accounting for precipitation extremities, a significant increase have been projected in the annual total precipitation when the daily amount exceeds the 95th percentile of wet-day precipitation under RCP4.5 and RCP 8.5, suggests enhanced probabilities of extreme precipitation in future time periods (Krishnan et al. 2020). As the climate change continues in the region, major changes can also be expected in strength and timing of monsoons which is already indicated by increased frequency and magnitude of extreme weather events, such as intense rainfalls, flash floods and landslides during the past couple of years.

Given the intensity of threat due to climate change in this region, it is vital that the wildlife of IHR would be required to respond to these changes by adapting as per their physiological or behavioral traits or by shifting their distributional ranges to higher elevations. The species which are highly specialized for specific habitats and narrow thermal ranges would be expected to suffer most and their extinction cannot be ignored in the future time periods. In view of the current state of knowledge about climate change impact on wild flora and fauna of IHR, it is highly necessary to identify the potential impact of climate change instigate risk assessments for meaningful policy level strategies and actions.

16.2 Strategies to mitigate climate change effects on wildlife species

In the IHR, it is likely that the natural resources would experience gradual change due to shift in climate change velocities in the future time periods. Therefore, timely actions would be required to protect already threatened wild fauna due to range of anthropogenic factors as well as increasing frequency of extreme events. It is also important for the other Task Forces (TFs) working in IHR to share their experiences and knowledge base for the development of climate adaptive action and management approaches to tackle climate change risks more efficiently. The major steps taken under Task Force 4: Micro Flora and Fauna and Wildlife and Animal Population to impede our understanding on the impacts of climate change and to address gaps in regular data are as follows:

1. Owing to lacuna of assembled knowledge base on the status, distribution, abundance and ecological aspects of faunal and micro floral species for most parts of the Himalaya, a total of 5042 articles were compiled into a database on wild fauna and microflora of Indian Himalayan Region. A substantial rise in the total number of published research articles was observed in the last two decades. Climate change studies where observed in low numbers vis-à-vis other research areas. Basic ecology, distribution and taxonomy remained the major research topics across taxa.
2. More than 200 climate data-loggers have been deployed for long-term, fine-scale climate data generation in three Himalayan states viz. Himachal Pradesh, Uttarakhand and Sikkim. Innovative technologies such as: Open Top Chamber (OTC) based long term experimental setup have also been established for charting of long-term spatial and temporal trends in activity patterns of the soil microbial and microfaunal communities.
3. The regular data on major thematic groups, viz., terrestrial, aquatic, spatial and human ecology are being collected. The data on diversity, abundance and distribution patterns of different faunal groups have been generated based on intensive camera trapping and taxa-specific sampling techniques in unexplored and inaccessible areas of the selected Himalayan states.
4. Landscape Ecology and Visualization Laboratory (LEVL), was established as a part of NMSHE Programme, has setup a Spatial Database System that acts as a central data

repository for different thematic areas in the Indian Himalayan Region (IHR) and provides easy access to these data both within and outside the Wildlife Institute of India.

5. Database were developed in form of land use landcover, fragmentation, disturbance, bio-rich area has been generated for all the 6 Indian Himalayan States viz. Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Northern Districts of West Bengal and Arunachal Pradesh as a part of the spatial database and this information can be used for better planning, management and decision making. The spatial database has been generated for easier access, faster retrieval and data visualization of spatial data and for easier collaboration between the other taskforces.
6. Spatially-explicit predictions for climate habitat suitability in the current and future environments were developed for selected indicator icthyofauna (snow trout and brown trout), mammals (musk deer and blue sheep) and herpetofauna (Himalayan pit viper). The errors and uncertainties in different modeling techniques were calibrated by building multi-model ensemble.
7. Capacity building of field personnel from Himachal Pradesh, Uttarakhand and Sikkim forest department was carried out for skill enhancement. Research personnel (68 no.) were trained on species distribution modeling and vulnerability analysis using present and future climate scenarios. A total of 49 graduate and post graduate level students have done internships in different thematic areas and climate science.
8. To create awareness about the climate change education and sustainable living among the young students, a programme has been initiated through school level Do-It-Yourself (DIY) Activity book “Climate Cool-Kit”. So far this activity has reached out to over 200 students between 14 to 21 age group and has completed 2 workshops on climate change awareness and sustainable living practices. A wildlife watch series (1-5) has been developed utilizing the citizen science approach for information generation on climate change impacts on wildlife, aquatic resources, and ecosystem.

The research work done under the TF-4 has so far developed baseline and an improved understanding on climate-wildlife associations. The climate-driven warming would affect the wildlife resulting in future range shifts over a period of time, however projecting these changes accurately will require long term trends, high resolution climate data and robust models. Our long-term and well-designed monitoring efforts explicitly address several knowledge gaps and produce relevant information for meaningful policy and management decisions. Our primary focus under the TF-4 was to infer the species-specific habitat requirements, phenological attributes and distribution patterns in IHR along with development of predictive models for the current and future time periods. We expect that the current habitats of a range of taxa including mammals, birds, amphibians, fish and insects that depend on high-elevation, cold environments of IHR would change if the current rate of warming continues. In addition, species that are highly specialized and reliant on narrow range of habitats and elevations (for e.g. snow leopard, Himalayan black bear, brown bears, takin, musk deer, Tibetan wild ass, red panda and snow trout etc) will be highly disturbed if their natural habitat my shrink or deteriorate in the future environments. Therefore, policy-level planning for mitigating climate change effects on wildlife species should focus more on restoration and preservation of habitat quality in addition to maintaining a healthy wildlife population.

16.3 Action plans for climate change from the NMSHE output

The extensive monitoring and research work under the TF-4 of the NMSHE was primarily focused on three major river basins- Beas (Himachal Pradesh) in North-western Himalaya, Bhagirathi (Uttarakhand) in Western Himalaya and Teesta (Sikkim) in Eastern Himalaya which provided a context to understand the climate related impact and vulnerabilities. Based on a rigorous field work by the research personnel and dedicated team efforts, a large scale baseline data related to distribution of many of cryptic and abundant species, seasonal phenological trends, species-habitat requirements, potential climatic drivers and socio-economic vulnerabilities has been collected. Based on the research outputs a number of management considerations arise, which are essential for planning adaptive actions and strategies for long term sustenance of wildlife in IHR:

16.3.1 Maintenance and restoration of adequate habitats

The outputs with regard to projection of suitable climatic niche over the IHR facilitate identification of those landscapes and taxa for which climate change impacts may be experienced in near or far future, and therefore help to set adaptation priorities in the region. Our habitat suitability models for selected terrestrial and aquatic fauna suggested an extensive climatic suitability at varied elevational ranges across the latitudes in IHR. For instance, the suitable habitat conditions for the musk deer (Chapter 3) across the western, central and eastern Himalaya were projected to be around 108898 km^2. However, the continuous area of habitat suitability was more evident in western parts of the Himalaya. The areas of high suitability (>0.9) include high elevation ranges of the west and northwestern Himalaya in Uttarakhand, Himachal and Kashmir regions. The preferred elevation ranges of musk deer from the partial dependence plot revealed a narrow range between 3000-4000m. Similarly, the potential distribution of snow leopard and blue sheep were also estimated at IHR scale and the landscapes were characterized based on lowest to highest suitability. The research outputs provides a strong basis to identify climatically suitable habitat patches as well as those habitats where the climatic drivers such as temperature and precipitation can change beyond the preferred optima of the species should be taken as a priority, and managing such populations and habitats can be another step for *in-situ* conservation programs. Besides our strong predictions over the vast area of Himalaya, we contemplate that many thousands of projected suitable forested areas are still remain uninventoried for most of the cryptic wildlife species. The projected outputs under NMSHE also serve as a guide for conducting efficient filed surveys in those habitat patches, genetic inventories and facilitate long term monitoring programs to develop more robust range maps and to reduce uncertainties with regard to distribution and status of majority of wildlife species in IHR.

Among the other terrestrial organisms, the Himalayan pit viper occupies 45059694.11km^2 in the Himalayan region. This species is largely distributed in Western Himalaya. This region of Himalaya is drier than eastern parts of Himalaya which receives good amount of rainfall. Himalayan pit viper is closely associated with *Agkistrodon* genus which is evolved in colder and drier climate. Therefore, driest quarter of warmest month is contributing maximum to the distribution of Himalayan pit viper. Also, there is no other viper species in western Himalaya than Himalayan pit viper and the higher elevation niche remains empty for Himalayan pit viper to occupy. Among the aquatic organism, the snow trout (Chapter 4) potential distribution revealed that the western Himalaya offers majority of suitable areas, of which the main channel and tributaries of upper Ganga, Yamuna, Beas and Satluj river basins provide an extensive suitable habitat. The mid elevational ranges of Indus basin tributaries like Jhelum, Chenab, Ravi are found to be climatically suitable for snow trout. For the snow trout we recommend landscape prioritization towards the mid-elevation zones of Himalaya, which we predict as prime habitats for snow trout apart from being important for many other co-occurring genera *viz. Tor*, *Neolissochilus* and *Barilius*. We recommend regular state of art monitoring of Himalayan rivers, majority of which still stay unexplored.

16.3.2 Increasing the efficacy of existing PA networks

Apart from legal protection, the protected areas of IHR have an integral role to play in view of climate change by allowing the species to slowly adapt or disperse in absence of other anthropogenic alterations (Fig. 1). We assessed the protection coverage currently offered for endangered Himalayan musk deer *Moschus leucogaster* which has very narrow elevational range and their future survival could be considered challenging owing to their unique adaptation to high altitude cold environments, vegetation and precipitation patterns. We estimated the individual protection coverage (IPC %) provided by each PA for the musk deer by estimating the geographical area under the predicted suitable habitat (>0.9) and dividing it by its total geographical area under the PA boundary. According to our estimates, a total of 76 PAs were contributed for the musk deer potential geographic distribution in IHR, Nepal and Bhutan.

The overall protection coverage was estimated around 19% which covered a total geographical area of 20678.8 km^2 in the study region, of which, IHR provided the highest protection coverage (43.6%) for the musk followed by Bhutan (38.5%) and Nepal (17.8%) (Fig. 2). We also identified the contiguous PA networks located in the zones of highest suitability. For instance, in the north-western region of Himalaya i.e in Kashmir, the PAs are rather small and fragmented, however, the western region (Himachal Pradesh and Uttarakhand) represents larger and smaller zones of contiguous PA networks with IPC ranged between 25.2%-92.9%. In Himachal, the contiguous networks of six PAs include Kanwar WLS (92.9%), Tirthn WLS (82.4%), Sainj WLS (72.3%), Rupi Bhaba WLS (56.3%) and Great Himalayan NP (30.3%). Adjacent to that, Kugti WLS (77.3%), Nargu WLS (53.3%), Tundah WLS (58.1) and Dhauladhar WLS (44%) also provides a contiguous network of four PAs.

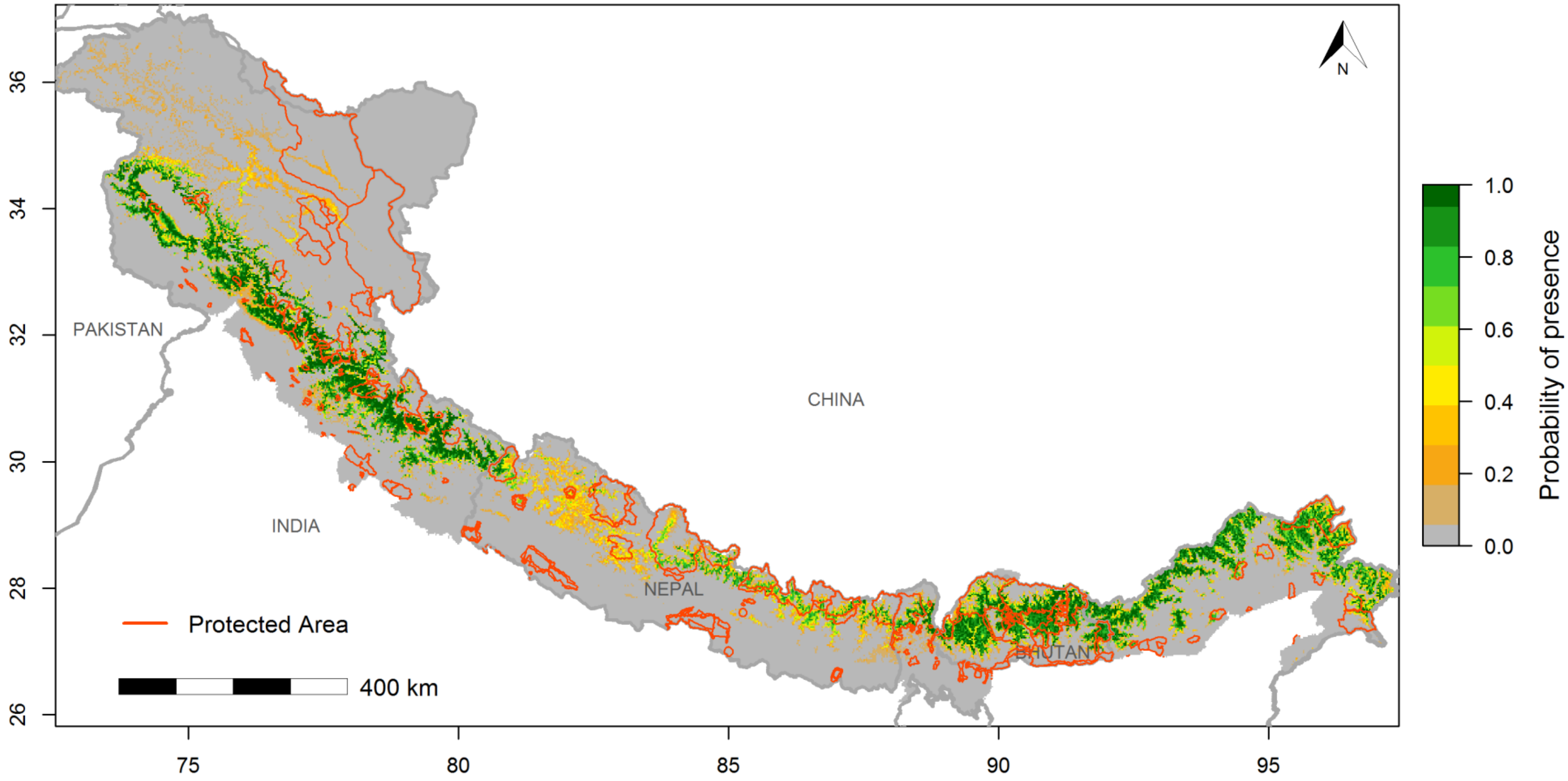

Fig. 1. Protected Area distribution along with the consensual current habitat suitability of HMD based on committee averaging of different modeling algorithms. Suitability values equal to 1 correspond to ideal environmental conditions and values equal to 0 correspond to suboptimum environmental conditions.

In Uttarakhand, Govind Pashu Vihar WLS (76.5%), Govind Pashu Vihar NP (25.3%) and Rakchham-Chitkul WLS (25.2%) were providing a contiguous network of three PAs. We also identified large patches of highly suitable habitats outside PAs, for instance, in the Uttarakhand region of India a very large continuous habitat located along with the PAs like Nanda Devi NP, Kedarnath NP and Valley of Flowers NP.

The study highlighted that despite considerable habitat suitability over a large area; only 19% of the suitable habitats were administratively protected under 79 PAs and thus there is a larger scope for musk deer is remains to be represented under newly established PA boundaries. For instance, we identified large patches of highly suitable habitats outside PAs. Considering the Uttarakhand state alone, a very large continuum of musk deer suitable habitats are located across the PAs like Nanda Devi NP, Kedarnath NP and Valley of Flowers NP. A large and highly suitable continuous habitat is also bounded by the protected limits of Gangotri NP, Kedarnath NP and Govind Pashu Vihar WLS. The PAs in Arunachal Pradesh and Kashmir regions of India were found to be fragmented and most of the potential habitats lie under unprotected boundaries.

The representation of current protection coverage for the musk deer is alarming and we recommend increasing the effective size of PAs or establishing newly protected land that would enhance the possibility of their survival. The overriding situations like indiscriminate poaching of musk deer need urgent attention, and therefore such sort of legal mechanism should also be accounted for.

As we demonstrated, many of the larger PAs has very low IPC% in terms of providing suitable habitat for HMD. Nevertheless, improved estimates of population density, occupancy patterns would be required for such PAs to better maintain the population viability in addition to maintenance or recovery of forested areas. We also suggest an effective management evaluation close monitoring programs in such PAs that would preserve not only the target species we studied here but also to maximize the chance for active conservation of many of the endemic fauna of the Himalaya.

Fig. 2. Individual Protection Coverage (IPC %) with respect to the potential binary habitat suitability of HMD color coded as per their geographic regions: western, central and eastern Himalaya. Increasing bubble sizes are indicative of higher IPC offered by the Protected Areas (PAs). The PA categories are added as abbreviations to labels where NP=National Parks, WLS= Wildlife Sanctuary, BZ= Buffer Zones, CA=Conservation Area, BC=Biological Corridor CP=Conservation Park and RS= Ramsar Site.

12.3.3 Identifying climate refugia and ensuring connectivity

Many species including plants, birds, butterflies and mammals have been recorded to track their thermal niche by shifting their range pole-ward and towards the higher altitudes (Hickling et al., 2006; Heino et al., 2009; La Sorte and Jetz, 2010; Chen et al., 2011; Luo et al., 2015). As climate change is already impacting majority of the taxa worldwide, the most cost-effective solution under such circumstances is to identify and protect those landscapes and river channels that will harbour many species from the terrible impacts of climate change in future time periods.

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Identifying such locations, where species can persist or provide translocation opportunities would be the best strategy to minimize future biodiversity loss from the already threatened landscapes of IHR. However, to delineating refugia of a given species have several inherent limitations such as modeling accuracy and complex abiotic and biotic processes. This also includes the species’ ability to track their thermal niche though many species are extremely limited in their rates of range-shift. For this objective, we aimed to identify the location of climate change refugia across the IHR for two terrestrial (musk deer, Himalayan pit viper) and an aquatic species (snow trout).

For musk deer, we emphasize areas of high suitability and future refugia within contiguous PA networks that could be used as strongholds, where management interventions could play a significant role in minimizing the effect of climate change. In such areas, efficient adaptive practices would be required such as strengthening the connectivity, raising the protection level and reduction of human-mediated disturbances. Though we predict that the species would move towards the higher elevation for a certain extent as a consequence of climate change, however the future refugia would not be available throughout its current potential range in the Himalaya. We assume that our predicted future refugia within the PA network would serve as the greatest opportunity for the species to migrate and survive. Considering only the extreme emission scenario (RCP 8.5) we identified two major geographical zones with an extensive PA network which could serve as optimal potential refugia for the musk deer in the year 2050. This include (a) 15 PA networks in Western Himalaya (Fig. 8): (i) Gangotri NP, (i) Kedarnath WLS, (ii) Nanda Devi NP, (iii) Valley of Flowers NP, (iv and v) Govind Pashu Vihar WLS and NP, (vi) Rakchham-Chitkul WLS, (vii) Pin Valley NP, (viii) Great Himalayan NP, (ix) Rupi Bhaba WLS, (x) Sainj WLS, (xi) Tirthn WLS, (xii) Asrang WLS, (xiii) Daranghati WLS and (xiv) Kanavar WLS and (b) Seven PA networks in East Nepal, Sikkim and Bhutan: (i) Bumdeling WLS, (ii) Wangchuck Centennial Park, (iii) Jigme Dorji NP, (iv) Biological Corridor (v) Torsa Strict Nature Reserve, (vi) Jigme Signye Wangchuck NP, (vii) Kangchendzonga NP and Kanchenjunga CA (Fig. 3).

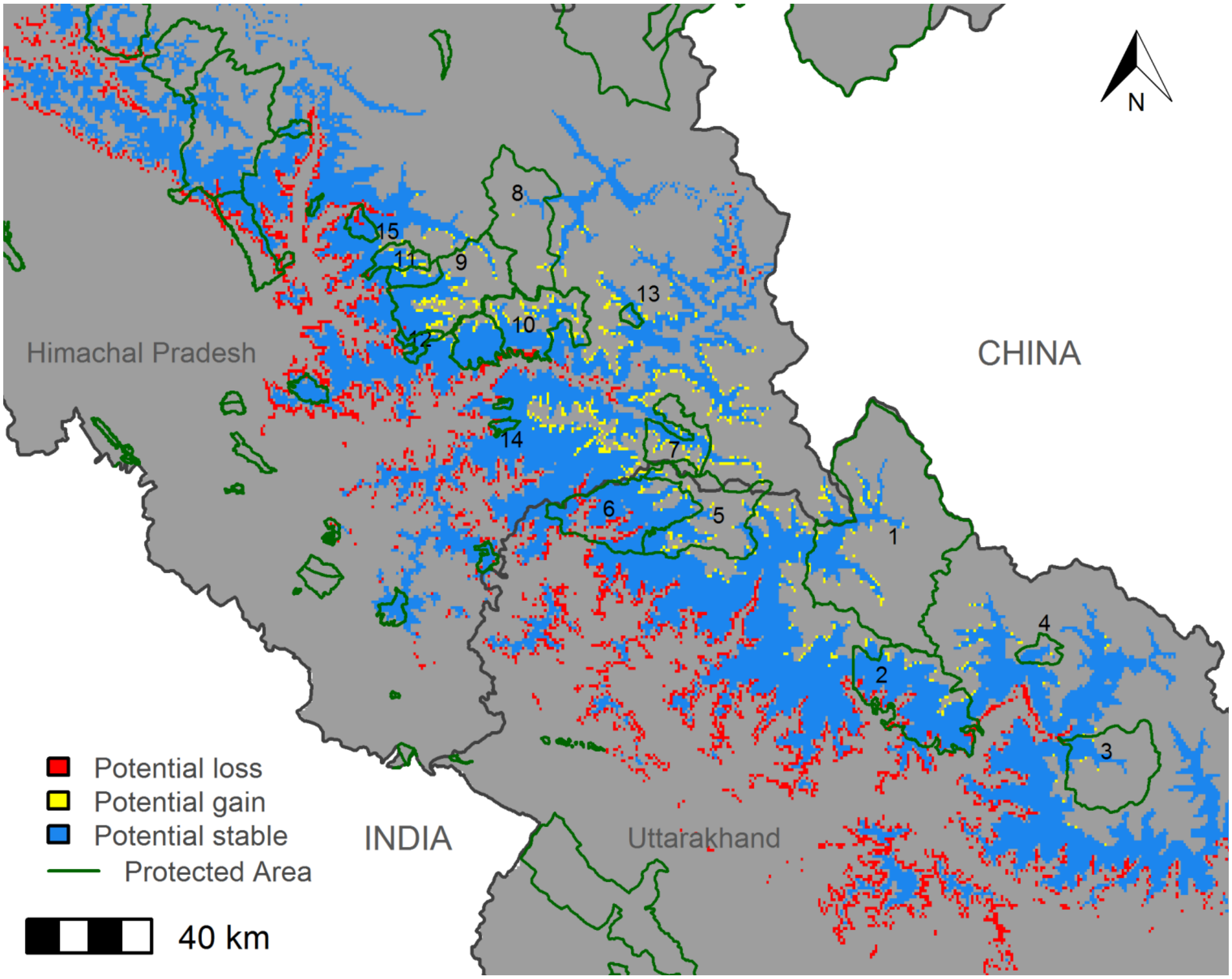


Fig. 3 PA networks identified as optimal future refugia for HMD in the year 2050 under RCP 8.5 in the western Himalaya. These include 15 PA networks: (1) Gangotri NP, (2) Kedarnath WLS, (3) Nanda Devi NP, (4) Valley of Flowers NP, (5) Govind Pashu Vihar WLS and (6) NP, (7) Rakchham-Chitkul WLS, (8) Pin Valley NP, (9) Great Himalayan NP, (10) Rupi Bhaba WLS, (11) Sainj WLS, (12) Tirthn WLS, (13) Asrang WLS, (14) Daranghati WLS and (15) Kanavar WLS. Large patches of suitable habitats can also be seen outside PA boundaries.

The taxa most vulnerable to any climatically imposed reductions in suitable habitat are likely to be those that have: (1) highly specialized habitat requirements, (2) ‘slow’ life histories (delayed maturation, low reproductive rate), thereby reducing their ability to recover from population reductions, (3) low dispersal rates, making it difficult to colonize suitable areas outside the existing range, and (4) are already under pressure from other anthropogenic processes. One taxon that meets all of these criteria is the Himalayan Pit Viper which predicted to be largely distributed in western Himalaya. In most of the distant and near future scenario there is an increase in the species range. This increase in range is mostly observed in lower elevation zone. As it is known lower limits of Himalaya is much more populated by other reptilian species than upper limits. It can be presumed that changes in the distribution may lead to competition of the species with the other viper species of lower elevation. With low elevation dwelling species such as Himalayan white lipped pit viper which is known to be distributed up to 2000m in western Himalaya. Such overlap may lift to intense competition with resources and may have ecological consequences on the its survival and population build up. Its distribution will largely overlap with human habitation. Being a venomous species, incidence of snake bite may rise and at same time persecution of the individual of the species may also rise alarmingly. Areas of higher elevation within the current range will be most important for persistence of this species because they will remain relatively moist and cool even under climate change and will match the current climate envelope. Conservation efforts should focus on areas where suitable climate space may persist under climate warming scenarios. Long-term monitoring programs should be established both in these areas and where populations are predicted to become extirpated, so that we can accurately determine changes in the distribution of this species throughout its range.

We also predicted potential future refugia for vulnerable freshwater species snow trout and predicted that the species range to increase towards higher elevation, while most habitats placed lower than 1000m would be concurrently lost, considering the intensity of different emission scenarios and time periods (Fig. 4). The elevation between 1000-1500m was also predicted to be vulnerable for snow trout, where the loss (2-8%) was constantly higher than the gained habitats in either of the RCPs and time periods. A continuous gain of habitat was always recorded at elevation between 2000-2500m and 2500-3000m regardless of which RCPs were used in the years 2050 and 2070. Our predictions reveal that the high-altitude tributaries of Jhelum, Chenab, Satluj, Beas and the upper Ganges basin would potentially contribute as snow trout refugia in the future environments. However, the range expansion strongly depends on the provisioning of suitable dispersal corridors as well as the species' potential to move to favourable environments.

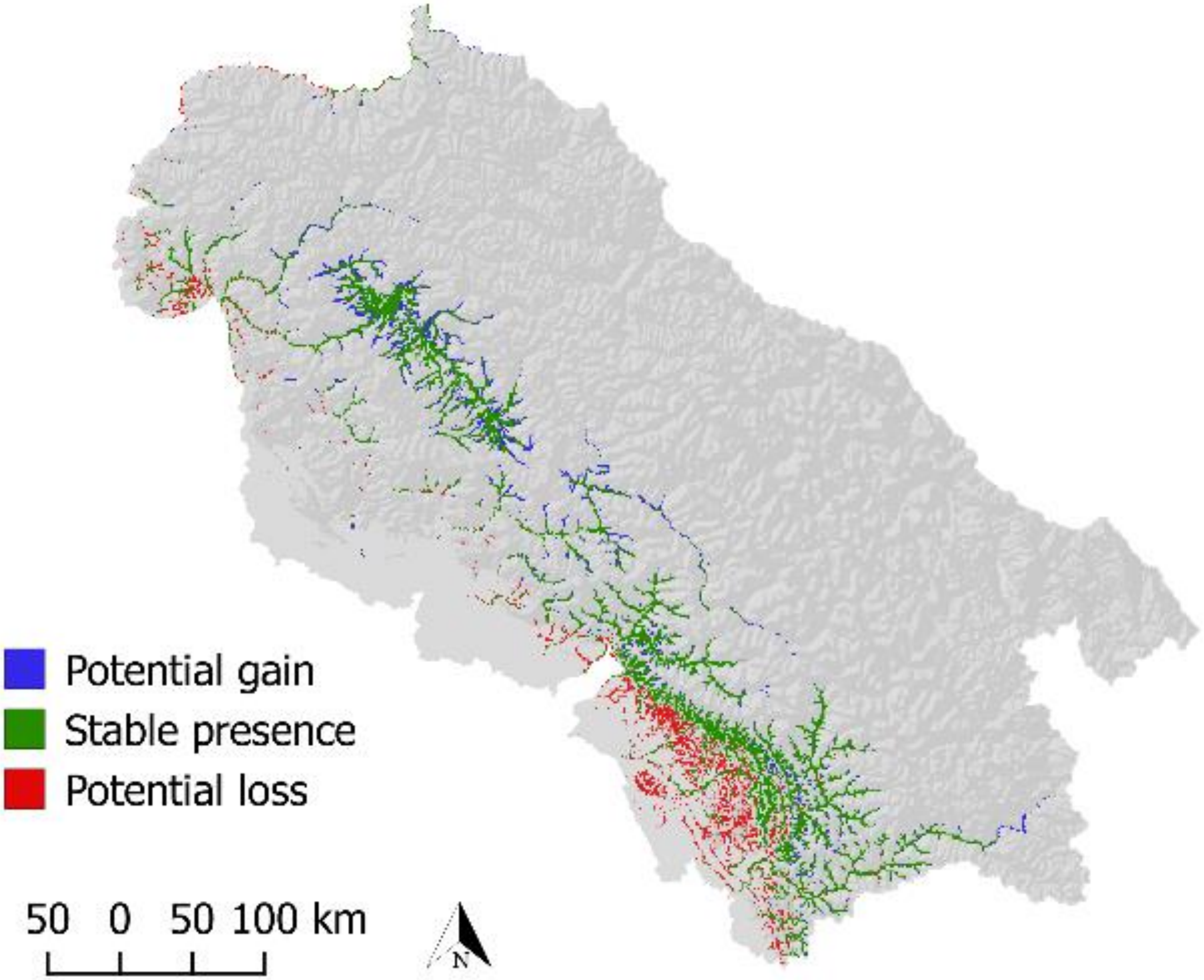


Fig. 4. Predicted range shifts and climate refugia for the snow trout under future climate change in the catchments of Indus in the western Himalaya based on the ensemble of five general circulation models (GCMs), under RCP 8.5 for the year 2050. Though losses are expected to be more as compared to gain, the future refugia can be seen in the upper portions of the basin.

16.3.4 Management of non-native species

Exotic species invasion is increasingly recognized as one of the greatest threats to biodiversity (Simberloff et al., 2012). Globally, the risk of invasion was predicted to be further exacerbated as a consequence of climate change (Walther et al., 2009; Bradley et al., 2012). In the IHR, among various invasive plant species, *Lantana camara*, *Ageratina adenophora*, *Parthenium hysterophorus* and *Ageratum conyzoides* are posing negative impact and encroaching upon large areas of IHR (Dobhal et al. 2011, Mungi et al., 2018, Mungi et al. 2020). Among aquatic species, the common carp (*Cyprinus carpio)* and brown trout (*Salmo trutta fario*) are being considered important for the aquaculture production system, commercial wild harvesting and recreational fisheries in the Himalayan states. However, overstocking in rivers is also debated in connection with its potential impact on native fishes specially schizothoracines that were declined drastically in previous years (Vishwanath, 2010). Therefore, monitoring this species as a threat to native fishes would help to take precautionary measures to prevent or minimize the impact of this species on native species that are already threatened by climate change.

Common Carp (*Cyprinus carpio*) (Photo by J.A. Johnson)

Brown Trout (*Salmo trutta fario*) (Photo by Vineet K. Dubey)

In the Himalaya, population of brown trout is well established in many river systems. One such river is Tirthan, which is abode to the exotic-invasive brown trout and native snow trout. This river is one of the most pristine rivers and a no-go area for hydropower development due to strong protest by the local communities. As it stands, the river is popular as an “angling reserve” specifically for brown trout due to provision of limited day-based licenses by the National Park and State Fisheries authorities for sustainable angling, however no scientific study is available so far about its distributional range, abundance and its potential impact on native populations which is crucial for sustainable management. The findings under the aquatic component of NMSHE indicate a disruption in the spatial distribution of native snow trout across river stretch, with significantly isolated records in the 5th order streams that were predominantly occupied by the invasive brown trout. The strikingly lower numbers of the snow trout adults further heighten concerns on the sustenance of the native population. We highlight the 3rd and 4th order tributaries as potential refuge sites for the native snow trout owing to a much higher abundance of their fingerlings regardless of the overlap with the invasive brown trout.

Considering the strong territorial nature of brown trout, our results suggests that the substantial occupied ranges of the brown trout Tirthan can pose population and community level risk for the natives (Fig. 6). Though evidence of brown trout predation on the fingerlings of snow trout was recorded intermittently during our surveys, the greater overlap in their suitable habitats can increase the chances of predation. We recommend regular monitoring of abundance and size structure of both the population to better facilitate informed scientific decision about level and frequency of stocking. Based on our findings we suggest having a ‘Invasive Species Act’ to prevent and manage invasive species in India. Further, stocking of non-native brown trout needs to be discouraged in the Himalaya.

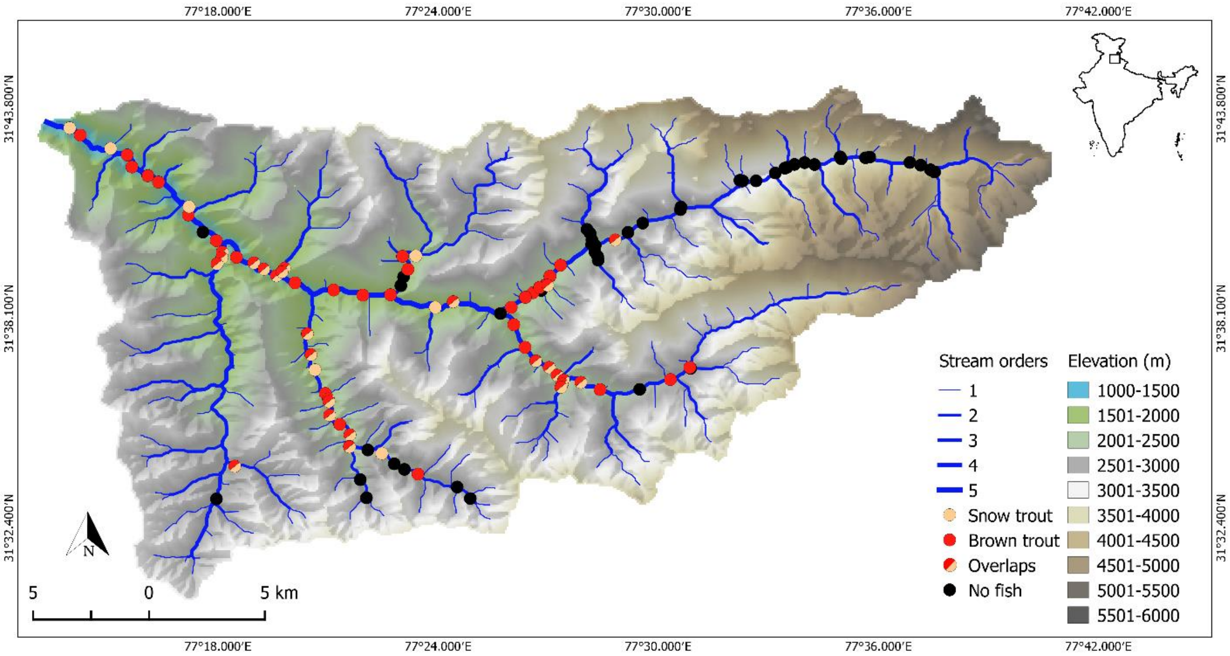
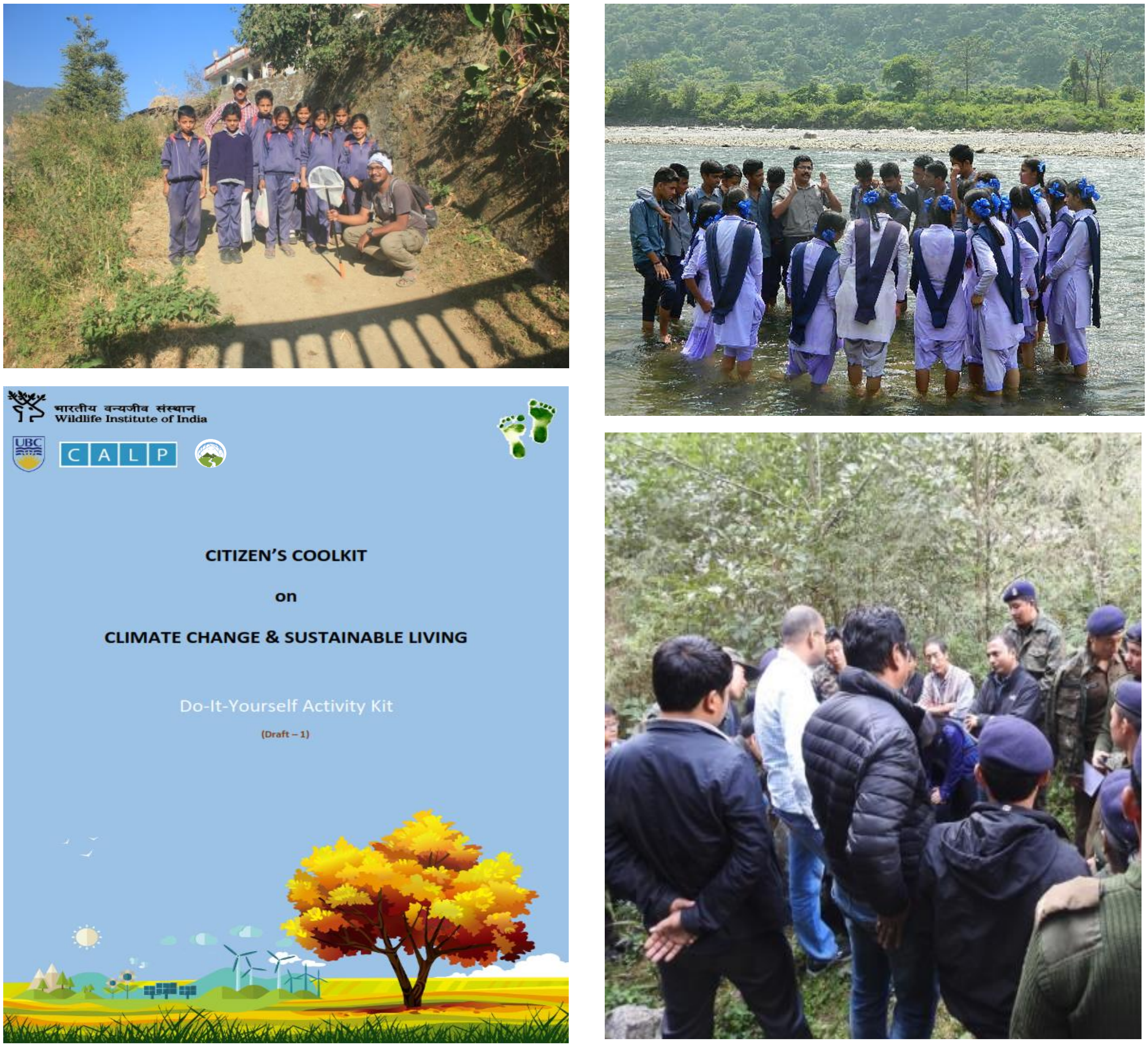


Fig. 6. Map of the Tirthan river watershed showing the overlapping habitats of native snow trout and non-native brown trout

16.3.5 Collaborative efforts and awareness

Maintenance of the sustainable Himalayan ecosystem has several challenges and there are no-one size fits for all solution in view of climate change. For long term conservation of unique wildlife resources including mitigating the impact of climate change we need the Himalayan ecosystem to be healthy, less altered, less modified, and productive. Climate change has already begun and the recent couple of studies stressed that the impact would be many depending upon the climate change velocity. Therefore, collaborative effort from different stakeholders as well as effective community awareness would be required for strengthening the climate adaptation process and practices. It is critical that we recognize the importance of natural resources being provided by Himalaya and ensure its protection for generations to come.



भारतीय वन्यजीव संस्थान
Wildlife Institute of India

UBC

CALP

CITIZEN'S COOLKIT

on

CLIMATE CHANGE & SUSTAINABLE LIVING

Do-It-Yourself Activity Kit

(Draft – 1)

Climate change awareness and training programmes

In order to support local community to become resilient to anticipated climate change, it is important to understand the vulnerabilities from a local perspective and it should be reflected in relevant development strategies. The NMSHE through its various training programs and workshops within the institute and also in forest departments of states like Sikkim and Uttarakhand, citizen science documentation such as Wildlife Watch Series (I-V) and climate cool- kit, contributed towards awareness in understating the climate change impact on wildlife ecosystem services thus enabling climate resilience by gradual climate change adaptation. Education is an essential part of the global response to climate change. It helps young people understand and address the impact of global warming, encourages changes in their attitudes and behavior and helps them adapt to climate change-related trends. The Climate Cool-kit was developed with an aim to make climate change education. The programme helped students to understand the impact of climate change in the local scale and increase "climate literacy" among young people. The climate change related education programmes and outreach activities in the rural, semi-urban and urban areas of IHR would facilitate several adaptation options for e.g. rain water harvesting, adaptive agricultural practices and food supply decisions. The dedicated educational programs for young students and local communities would enhance the awareness about climate change and its impact on people and ecosystem Himalaya.

16.3.6 Maintaining the flow of ecosystem services

Most of the villages and households in the Indian Himalayan region are dependent on the ecosystem services of the region. Therefore, for maintaining the flow of ecosystem services for the well-being of the inhabitants, regular monitoring of availability and flow of ecosystem services to the community needs to be assessed. As most of the households in Indian Himalayan region are small holder farmers, so their decision on cropping right crop at right time is important for cropping success. Subsequently, policy intervention and implementation for decision support system on seasonal cropping is needed for stabilizing the household economy of the region.

16.4 Incessant research requirements

Climate change will test the physiological limits of all the species across the globe. While some species will eventually adapt to climate change due to their resilience, others will go extinct owing to their inabilities to adapt. This would result in a homogenous biodiversity (i.e an overall drastic reduction in the diverse flora and fauna the globe sustains), with only a small percentage of extant species. Our understanding with regard to the magnitude and direction of climate change impact on flora and fauna of the Himalaya is mostly little understood. This ranged of from changing species phenology, biotic interactions, disease outbursts, migration, local adaptation or extinctions. In addition to that there are other several anthropogenic factors such as habitat fragmentation; degradation would also govern the species survival in different ways.

Identifying which species require immediate attention, considering their narrow tolerance, limited dispersal abilities, restricted distribution and vulnerability towards climate change would determine the priorities for action and measure to be taken. In addition, as we developed species distribution models for priority species like musk deer, snow trout and Himalayan pit viper over the vast area of Himalaya, we contemplate that many thousands of suitable forested areas still remain uninventoried for many other highly cryptic species. Consequently, our strong predictions here could serve as a guide for conducting efficient filed surveys, genetic inventories and facilitate long term monitoring programs to develop more robust habitat range maps and also to reduce uncertainties with regard to distribution and status of many species in the Himalaya. We recommend use of fine-scale temperature data for future species distribution modeling process. This will facilitate to identify suitable refugia at much finer scale especially for low ranging species. The regional refugia identification would provide ways for better conservation planning framework in view of climate change. The Protected Areas of IHR can act as a stronghold, where management interventions could play a significant role in minimizing the effect of climate change. It is recommended that analysis of downscaled data at regional scale be carried out to better emphasize the regions specific conservation actions.

16.5 Future challenges and limitations

The next steps required to understand the complex climate-wildlife interactions and species distribution modelling in IHR should include extensive long term data and appropriate statistical approaches. This will generate a realistic basis to better estimates the vulnerability to climate change in IHR. Despite our strong predictions obtained from a conjunction of higher performance modeling algorithms and multiple GCMs, we cannot claim that our predictive models are devoid of uncertainties related to SDMs and GCMs outputs. Moreover, there are deep uncertainties involved in the complex interplay of climatic conditions, species response, anthropogenic drivers and time-related demographic conditions (Araújo and Luoto 2007, Anderson et al. 2009). For instance, we do not know the adaptive response of target species to the likely changes in future environmental conditions. The climate change velocity would be likely to differ among landscapes and therefore the populations would be required to be commensurate with their moving optima through space and time (Baisero et al 2020, Brito-Morales et al. 2020). Besides this, the Himalaya is subjected to extreme events such as forest fires, intense rainfall, landslides, and multitude of anthropogenic stressors like rampant deforestation, massive hydropower dam developments (Pandit et al. 2007, Bhardwaj, et al. 2019, Bar et al. 2020) and increasing road networks (Ministry of Road Transportation and Highways, 2017), which might further alter the future distribution of many wild species. Lastly, we hypothesize that an unlimited dispersal, given the full opportunity of connectivity among current and future habitats, however, we did not examine the potential effect of barriers such as rivers, deep gorges, terrain and highways that would probably act as a barrier and can overestimate our projections.

16.6 Conclusion/Summary

Climate change has already begun and the country is currently facing its likelihood. In face of such a colossal challenge where our species is likely to be suffering in the upcoming time periods, we urgently need appropriate and immediate actions. In last couple of years, an increasing number of institutions under the programmes like NMSHE and NMHS, nongovernmental organizations and researchers are overtly focusing on climate change; and thus there is an ample need for cross-organization communications. A common platform is therefore required for data and knowledge sharing that will acquaint managers with appropriate strategic information for decision making process.

The Himalayan region has been warming at a rate much higher than global average, thus accelerating serious challenges for its flora and fauna. Empirical evidences of climate driven responses of many mountainous taxa have been documented worldwide with responses manifest as dispersal towards higher elevation, latitudinal range shifts, change in phenology and timing of migratory patterns, range contraction and local extinctions (Rieman et al. 2007, Rubidge et al. 2012, Eby et al. 2014). The outputs from the NMSHE project suggest that taxa in the montane environment like Himalaya would ultimately be influenced by the ongoing climate change effects, the fate of which still remains unclear. Therefore, it is imperative to prioritize the research agendas, ongoing development policies and wildlife conservation practices. Protected area management in IHR is already in use which has its own legal framework for protecting the species apart from routine population census, monitoring of predation pressures, raising the protection level and reduction of human-mediated disturbances. Programmes such as Management Effective Evaluation (MEE) for the Protected Areas (PAs) by the Wildlife Institute of India (WII) and continuous wildlife monitoring by the National Tiger Conservation Authority

(NTCA) require incorporation of climate impact assessment database generation apart from their traditional management approaches. Better monitoring programs should incorporate the population trends, robust genetic inventories and corridor/connectivity linkages among habitats and populations. The routine traditional monitoring approaches should be better equipped with modern technologies for effective data generation and renewed greater protection to minimize new risk from climate change.

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