NMHS-Himalayan Institutional Fellowship Grant

FINAL TECHNICAL REPORT (FTR)

NMHS Reference No.:	GBPI/NMHS/HF/RA/2015-16/	**Date of Submission:**	1	0	0	2	2	0	2	1

HIMALAYAN RESEARCH FELLOWSHIP

Sanctioned Fellowship Duration: *from* (**01.04.2016**) *to* (**31.03.2019**).

Extended Fellowship Duration (if applicable): *from* (01.04.2019) *to* (31.07.2019).

***Submitted to*:**
Er. Kireet Kumar
Scientist 'G' and Nodal Officer, NMHS-PMU
National Mission on Himalayan Studies, GBP NIHE HQs
Ministry of Environment, Forest & Climate Change (MoEF&CC), New Delhi
E-mail: nmhspmu2016@gmail.com; kireet@gbpihed.nic.in; shard.sapra@nic.in

***Submitted by*:**
Siddhartha Krishnan, PhD
Covenor, Academy for Conservation Science and Sustainability Studies
ATREE, Royal Enclave, Sriramapura, Jakkur P.O., Bangalore 560064
080-23635555
academy.office@atree.org

GENERAL INSTRUCTIONS:

1. The Final Technical Report (FTR) has to be commenced from the date of start of the Institutional Fellowship (as per the Sanction Order issued at the start of the Fellowship) till its completion. Each detail has to comply with the NMHS Sanction Order.

2. The FTR should be neatly typed (in Arial with font size 11 with 1.5 spacing between the lines) with all details as per the enclosed format for direct reproduction by photo-offset process. Colored Photographs (4-5 good action photographs), tables and graphs should be accommodated within the report or should be annexed with captions. Sketches and diagrammatic illustrations may also be given giving step-by-step details about the methodology followed in technology development/modulation, transfer and training. Any correction or rewriting should be avoided. Please give information under each head in serial order.

3. Training/ Capacity Building Manuals (with detailed contents of training programme, technical details and techniques involved) or any such display material related to fellowship activities along with slides, charts, photographs should be sent at the NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora 263643, Uttarakhand. In all Knowledge Products, the Grant/ Fund support of the NMHS should be duly acknowledged.

4. The FTR Format is in sync with many other essential requirements and norms desired by the Govt. of India time-to-time, so each section of the NMHS-FTR needs to duly filled by the Fellowship Coordinator/ PI and verified by the Head of the Implementing Institution/ University.

5. Five (5) bound hard copies of the NMHS-Institutional Fellowship Final Technical Report (FTR) and a soft copy should be submitted to the **Nodal Officer, NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora, Uttarakhand** *via* e-mail nmhspmu2016@gmail.com.

The FTR is to be submitted into following two parts:

Part A – Cumulative Fellowship Summary Report

Part B – Comprehensive Report

Following Financial and other necessary documents/certificates need to be submitted duly signed and verified along with Final Technical Report (FTR):

Annexure I	Consolidated and Audited Utilization Certificate (UC) & Statement of Expenditure (SE), including interest earned for the last Fiscal year including the duly filled GFR-19A (with year-wise break-up)
Annexure II	Consolidated Interest Earned Certificate
Annexure III	Consolidated Manpower Certificate and Direct Benefit Transfer (DBT) Details showing the education background, i.e. NET/GATE etc. qualified or not, Date of joining and leaving, Salary paid per month and per annum (with break up as per the Sanction Order and year-wise).
Annexure IV	Details and Declaration of Refund of Any Unspent Balance as Real-Time Gross System (RTGS) in favor of NMHS GIA General
Annexure V	Details of Technology Transfer and Intellectual Property Rights developed.

DSL: *Date of Sanction Letter*							
3	0	0	3	2	0	1	6

DFC: *Date of Fellowship Completion*							
3	1	0	7	2	0	1	9

PART A: CUMULATIVE SUMMARY REPORT

1. DETAILS OF ASSOCIATESHIP/FELLOWSHIPS

1.1. Contact Details of Institution/University

NMHS Fellowship Grant ID/ Ref. No.:	GBPI/NMHS/HF/RA/2015-16/
Name of the Institution/ University:	Ashoka Trust for Research in Ecology and the Environment
Name of the Coordinating PI:	Dr. Siddhartha Krishnan
Point of Contacts (Contact Details, Ph. No., E-mail):	Ph: 080-23635555; Extn:217 Email: siddhartha.krishnan@atree.org

1.2. Research Title and Area Details

i.	Institutional Fellowship Title:	Himalayan Research Fellowships				
ii.	IHR State(s) in which Fellowship was implemented:	Sikkim, Arunachal Pradesh, West Bengal, Uttarakhand				
iv.	Scale of Fellowship Operation	Local:		Regional:		Pan-Himalayan:
iii.	Study Sites covered (*site/location maps to be attached*)	--- Please refer the attachments ---				
v.	Total Budget Outlay (Crore):	INR Rs.1,75,82,400/-				

1.3. Details Himalayan Research /Project Associates/Fellows inducted

Type of Fellowship	Nos.	Work Duration	
		From	To
Research Associates	2	01/04/2016	31/07/2019
	1	01/04/2016	31/03/2019
Jr. Research Fellows	1	1/04/2016	1/03/2019
Project Fellows	6	1/04/2016	31/07/2019

2. Research Outcomes

2.1. Abstract

The Eastern Himalayas (EH) in the Indian Himalayan Region (IHR) is a globally important biodiversity landscape and includes several Global 200 ecoregions, two Endemic Bird Areas, and several centres for plant diversity. Spanning a wide altitude range (500-8000 m above msl) the EH contains tropical and sub-alpine forests, alpine meadows and wetlands. While livelihoods in the EH are dependent on agriculture and agroforestry, millions remain directly dependent on the natural resources that these ecosystems provide. Despite these benefits, ecosystems and livelihoods in the EH have been threatened by a rapid increase in developmental activities including hydropower projects, land use intensification and urban sprawl.

This rich natural and cultural history makes the EH ideal for interdisciplinary and disciplinary research that examines the challenge of pursuing sustainable development. Ten ATREE PhD students, comprising 3 Himalayan RAs—Aniruddha Marathe (AM), Anirban Datta-Roy (ADR), Vidyadhar Atkore(VA)—and 7 Himalayan Junior Research/Project Fellows—Annesha Chowdhury (AC), Barkha Subba (BS), Manish Kumar (MK), Rinan Shah (RS), Shweta Basnett (SB), Urbashi Pradhan (UP), Yangchenla Bhutia (YP)—benefited from the NMHS grant.

Objectives/Aim

i. To assess the opportunities for supplementary livelihood options in remote eastern Himalayan communities towards promotion of eco-agricultural landscapes

ii. To quantify the ability of the tea-forest landscape to support biodiversity associated services and human well-being

iii. To identify the trade-offs between biodiversity, ecosystem services and wellbeing in the tea-forest landscape

iv. To arrive at a desirable social-ecological identity for the landscape

v. To understand the causes and effects of the domestic water scarcity in the eastern Himalayan towns

vi. To examine fish diversity and impacts of hydropower dam on the native fish community composition

vii. To assess climate variability and change in Sikkim Himalaya and its potential impacts on hydrological flows

viii. To quantify the effect of climate change of a few specific *Rhododendrons* of higher elevation

ix. To identify the pollinators of a few specific *Rhododendrons* of higher elevation

x. To provide information for the conservation planners to adopt a strategy at a species level for conserving *Rhododendrons* in the face of climate change.

xi. To evaluate the influence habitat variables which are not only of ecological interest but will also provide insight for conservation of stream dwelling frogs and their habitats

xii. To address knowledge gaps regarding ant communities in Eastern Himalayan Region by quantifying the changes in communities across elevation gradient and offering ecological hypothesis for explaining the patterns

xiii. To understand role of fragmented habitats outside protected areas in supporting biodiversity through higher order interaction such as pollination

xiv. To examine the regeneration status of Oak and its related species along the elevational gradient in Sikkim Himalaya

Methodologies and Approach

As part of the methodologies, a combination of natural science and social science methods to collect the data were adopted. These included faunal documentation, vegetation assessments, mammal survey, bird survey, participatory rural appraisal (PRA), household surveys, GPS locations, nested hierarchical study design, Time-series analysis, Pollinator sampling and stratified random sampling.

Key Results

i. Aniruddha's study recorded 61% of all ant species found in Arunachal Pradesh.
ii. Anirban's study identified alternative livelihood options using surveys and discussions with all stakeholders, while omitting impractical options.
iii. Anirban also identified environmentally benign alternative livelihoods involving tourism through consultations with village authorities that discussed the limitations and problems of these livelihood options.
iv. Rinan's study concluded that springs in Darjeeling do not come under the ambit of any state agency despite being the main source for all state and non-state water supplies. Her study created a successful repository of urban springs.
v. Shweta's study characterised Rhododendron species distribution, including the current and future distribution of that of narrow-ranging *R. setosum* and wide-ranging *R. lepidotum*. A database on *Rhododendron* pollinators was also submitted.

Conclusion and Recommendations

i. While ecotourism and other associated activities are important alternative livelihoods, it is also important to remember that biodiversity conservation should be given top priority. Any activity that may impact the biodiversity of the region should be stopped.
ii. In order for tea-plantation forest mosaic landscapes to be able to support biodiversity and human well-being, the landscape needs to be managed with a focus on the matrix as a whole and not just setting natural areas aside for conservation. This will (i) foster optimal conditions for achieving the desired levels of human well-being and (ii) enhance the chances of the persistence of existing biodiversity in the landscape through better, scientifically informed management decisions.
iii. There is a need to look at local resources such as springs and increase the formal water infrastructure but also consider the access of poorer sections of the society to water.
iv. A habitat conservation plan needs to be developed for conserving native and endemic fish species and removing invasive fish species from the Ranganadi Dam.
v. Climate monitoring infrastructure needs better maintenance and more stations need to be established to develop regionally accurate climate models for predicting climate change in Sikkim Himalaya.
vi. Conservation planners need to adopt a strategy at a species level for conserving *Rhododendrons* in the face of climate change.
vii. The importance of pollinators, their food and habitat should be highlighted to local communities and especially to farmers. This will help (i) safeguard farm yields, (ii) influence the socio economic well-being of communities and (iii) help in the conservation of pollinators.
viii. The results of the study on amphibians could be used to assess the adequacy of the current system of protected areas for stream breeding frogs in Sikkim, and to identify certain classes of habitat that may be at risk from urban development and hydel power projects.
ix. More effort needs to be invested on inventorying ants in future, with comparable sampling techniques. This will be helpful in understanding drivers behind elevational gradients in biodiversity across larger spatial scales.
x. An urgent restoration program is required for ensuring the health of the oak ecosystem in Sikkim. This could include (i) setting up a nursery and (ii) using shelter tubes to improve seedling establishment in the forest.

2.2. Objective-wise Major Achievements

S. No.	Cumulative Objectives	Major achievements (in bullets points)
1. [HRA-AM]	1. To understand drivers of ant species richness across elevation gradient 2. To understand effect of diversity in species pool on species turnover or beta diversity 3. To examine patterns in species composition in light of species ecology, climatic gradients and spatial variables	1. The study helps understand patterns in the elevational diversity of ant species in the EH and predict extinction threats, range shifts and changes due to climate change. 2. Body size, resource specialization, and life history strategies interact with temperature gradients to produce observed patterns. 3. Range-restricted tropical specialist species are the most diverse ant communities in the EH and most likely to be affected by climate change.
2. [HRA-ADR]	1. What are the potential areas across the EH where supplementary livelihood options could be implemented? 2. What income generating eco-tourism activities can be implemented in these areas? 3. Who are the primary stakeholders responsible for the implementation of these activities and what factors determine their support? 4. How do alternate livelihood options influence people's well-being in selected study sites?	1. A study site was identified in the Upper Siang district. 2. Potential ecotourism activities are (a) butterfly & bird watching, (b) trekking & photography in scenic landscapes, (c) angling & camping by the Siang River and (d) organic products & handicrafts 3. The stakeholders are: (a) Adi Kebang (traditional institution), (b) panchayat representatives, (c) teachers, (d) young people and (e) women's groups. 4. Livelihood options will (a) provide relief as farmers decide between engaging with the market and retaining subsistence cultivation and (b) provide employment to educated youth. Handicraft and organic product sales to visitors will bypass market availability, communication and transport constraints. Field-based activities (trekking or bird watching) will incentivize village maintenance.
3. [HRA-VA]	1. Quantify the relationship between biophysical factors on fish richness and relative abundance. 2. Evaluate the impact of altered flow regime below the dams on the certain life-history and reproductive guilds of fishes. 3. Study the impact of dams on genetic diversity of key native fish species.	1. Fish diversity varied across habitat, season and with respect to dam position. Total alkalinity influenced species richness and relative abundance significantly; other variables did not. 2. Three reproductive guilds declined downstream of the dam. Water temperature, conductivity, total alkalinity was higher downstream of the dam possibly due to limited riparian vegetation, stream-bed exposure, flow alteration and sub-surface geology.

	4. Examine the species recovery downstream of a dam	3. The impact of dams on genetic diversity of native fish could not be assessed but samples of selected species have been preserved at the ATREE Conservation & Genetics Lab. 4. Species recovery is evident 20 km downstream of the dam possibly due to the refuge provided by undammed tributaries.
4. [HJPF -AC]	1. To quantify the ability of the tea-forest landscape to support biodiversity associated services and human wellbeing. 2. To identify the trade-offs between biodiversity, ecosystem services and wellbeing in the tea-forest landscape. 3. Based on the current scenario, to arrive at a desirable social-ecological identity for the landscape.	1. The tea-forest landscape supports 17 mammal, & 174 bird species, 40 endemic trees and 640 soil arthropod morphospecies. Fuelwood is used by 98%; NTFP by 61.25% and spiritual or recreational benefits by 81.25% of respondents. 2. Low-income and poor households are highly dependent on native ecosystems for fuelwood and fodder, but forest access is restricted. 3. Community ecology parameters are being quantified over 300 sampling points and are to be used to develop a spatial representation of friendly and unfriendly zones.
5. [HJRF -RS]	1. To understand the causes and effects of domestic water scarcity in EH towns. 2. Assess biophysical and human induced changes in and around water sources and the region to which the water is supplied and the extent of water utilization. 3. Assess the effects in terms of the availability and accessibility of water, the definition of well-being and sufficiency for communities. 4. Investigate the political and economic drivers for the manifestation of scarcity.	1. Changes in rainfall do not impact water availability significantly and water infrastructure are ineffectively executed. 2. Seasonal population increases coinciding with the dry season make water acquisition difficult and availability across water institutions is not uniform. 3. Accessibility to water is highly skewed although availability is good. Household spatial and socio-economic characteristics affect access to water. 4. State-led investments do not improve water availability for communities.
6. [HJPF -SB]	1. To estimate the areas of climatically suitable conditions of *Rhodendron. lepidotum*) and *R.setosum*.	1. Altitude has a major influence on both species and habitat is suitable between 2200–4200 m; suitable habitat for *R. setosum* extends to 6600 m.

	2. To evaluate the role of global climate change in determining the distribution of these species in the Himalayas by projecting it to two scenarios for the 2050s. 3. To identify the pollinators of selected Rhododendrons	2. By the 2050s, suitable habitat is expected to reduce for wide-ranging *R. lepidotum,* but increase for narrow ranging *R. setosum*. 3. Below the treeline, Rhododendrons were visited relatively more by birds. Above the treeline, *R. anthopogon*, *R. setosum* and *R. lepidotum* were visited by bumblebees and flies. From 3900–4000 m, *R. wightii* and *R. aeruginosum* were largely visited by flies.
7. [HJPF-UP]	1. To understand the role of fragmented habitats outside protected areas in supporting biodiversity through higher order interactions such as pollination. 2. To estimate major pollinator food plants in fragmented forests. 3. To understand people's perception of biodiversity, pollination service and their willingness to conserve forest patches.	1. Twenty-eight species of insects (from Hymenoptera, Diptera, Hemiptera and Coleoptera) were collected and identified in the laboratory. 2. A total of 671 individuals representing 48 tree species were recorded in 90 plots across nine sites. 3. Interviews highlighted the declining abundance and diversity of pollinators and pollinator food plants in the landscape. Communities felt the need to protect and conserve forest fragment status of pollinators in the landscape, their food plants and are willing to participate in it.
8. [HJPF-MK]	1. What are the drivers of spatial and temporal variability in precipitation patterns across Sikkim Himalaya? 2. What are the predicted hydrological responses of springs and streams in the context of climate variability and climate change in the Sikkim Himalayas?	1. Annual rainfall and rainy days in the Sikkim Himalayas have declined at lower elevations, but increased at higher elevations in summer. The frequency of high-intensity precipitation events and large storms have increased in the recent decades over south and east Sikkim. 2. Vegetation exerts a significant control on streamflow, especially in dry seasons. Springs under forested catchments have steadier low-flow discharges than springs under agricultural catchments.
9. [HJPF-YB]	1. To examine seedling frequency, seed viability and variability of seed across different Oak species?	1. In general, oaks in the Sikkim Himalayas are characterised by poor regeneration. Two genera, *Quercus* and *Lithocarpus* have low seedling frequency despite having higher seed volume. 2. The study sites were dominated by *Castanopsis*, which has high seed viability. 3. The genus Castanopsis is the dominant forest's trees with relatively higher stem density occurring between forests ranging from 900m to 2700m a.s.l. in the Sikkim Himalaya.

6. [HJPF-BS]	1. What is the influence of habitat variables on species richness of frogs? 2. What is the influence of spatial position and environmental variables on composition of frog assemblages?	1. The mean temperature of warmest months and riparian vegetation cover were significantly correlated with species richness of stream-breeding frogs. 2. Environmental variation had the largest effect on the composition of frog assemblages in hill streams, but biotic processes may influence frog assemblage composition when sites are geographically closer.

2.3. Outputs in terms of Quantifiable Deliverables*

S. No.	Quantifiable Deliverables*	Monitoring Indicators*	Quantified Output/ Outcome achieved	Deviations made, if any, and reason thereof:
1. (HRA-AM)	1. Database on ant species in Sikkim Himalaya 2. Identification of areas for conservation and use	1. Drivers of beta-diversity of ant communities across elevation gradients in Eastern Himalaya.	1. The study recorded 61% of all ant species found in Arunachal Pradesh. 2. The study is the 1st quantitative ecological analysis of insect data from the EH providing rare location specific biodiversity inventories and biodiversity patterns.	The study was not executed in Sikkim due to the presence of sharper environmental gradients.
2. (HRA-ADR)	1. Alternative livelihood means giving emphasis on green job creation 2. Value addition in local products and value chain establishment	1. Suitability based on discussions and literature review. 2. Acceptance by people and tourists	1. Alternative livelihood options were identified using surveys and discussions with all stakeholders. Impractical options were omitted. 2. Value addition & value chain establishment could not be achieved. Factors that influence the success of the value chain were discussed	1. None 2. Value addition and value change establishment require the support of all sections of the society. The novelty of this concept in Upper Siang meant that the timeframe of 2-3 years coupled with logistical constraints were inadequate to

				proceed beyond creating consensus.
3. (HRA-VA)	1. Exploration of the relationship between species richness/abundance and stream characteristics (channel morphology, average velocity, water temperature, dissolved oxygen, disturbance. 2. Literature review on fish guilds and important life-history traits.		1. The Ranganadi Dam significantly affected the spatial distribution of native fish communities. 2. The literature review on fish guilds and important life-history traits was completed	1. We were unable to procure stream discharge data from the dam authorities despite following due procedure.
4. (HJPF-AC)	1. Identification of sites for long-term environmental monitoring. 2. Relevant institutions identified and engaged. 3. Mainstreaming of long-term monitoring and building scientific evidence base across key sectors achieved.	1. Number of LTEM sites established/investigated/robust data-sets generated 2. Extent of scientific evidence generated across key sectors.	1. Thirteen sites were identified within the tea-forest landscape. 2. West Bengal Forest Dept, Darjeeling Tea Assoc, Indian Tea Assoc, Tea Res. Inst, Uttar Banga Krishi Viswavidyalaya were identified as relevant institutions. 3. Two popular articles published in Down to Earth and 1 in Eartha magazine.	None
5. (HJRF-RS)	1. Water institutions and sources have been recorded with springs & tanker sources 2. Clusters of households with access has been identified and household interviews carried out	1. Water institutions and sources identified 2. Interviews with key informants, mapping transect		

	3. Rainfall data analysis	walks of springs and public utilities conducted.		
6. (HJPF-SB)	1. Identified Rhododendron species distribution, with the help of vegetation plots and secondary literature. 2. Identified the current and future distribution of narrow (*R. setosum*) and wide ranging (*R. lepidotum*) *Rhododendron* species. 3. Database on Pollinators of Himalayan Rhododendron	1. The distribution range of 10 Rhododendrons was mapped in Kyongnosla alpine Sanctuary, Sikkim. 2. Occurrence data were compiled from secondary sources including the Global Biodiversity Information Facility.	1. From 3400–3800 m 5 rhododendrons were recorded; another 5 were observed above the treeline (3900–4200m). 2. Ecological niche models suggest that *R. lepidotum* is likely to lose suitable habitat by 2050, but increase for *R. setosum*. 3. Four bees pollinate *R. setosum*, *R. lepidotum* & *R. anthopogon*. Birds were chief pollinators for other rhododendrons. Flies were noted at all altitudes.	
7. (HJPF-UP)	2. To understand the status of pollinators in Sikkim 3. To locate habitat of wild pollinators in Southern part of Sikkim		1. The status of pollinators of the Sikkim mandarin orange published as a journal article 2. Nine forest fragments were assessed for diversity.	
8. (HJPF-MK)	1. Maintaining 5 longterm spring and stream monitoring sites.		1. Each site has 1 automated discharge measuring station, rain gauges and soil moisture sensors 2. Automatic weather stations maintained at 3 sites.	

9. (HJPF-YB)	1. Insights on seed regeneration ability and its influence on species distribution along environmental gradients 2. Examination of species adaptations to environmental gradients through changes to the seed bank.		1. The size-class distribution of *Quercus* and *Lithocarpus* suggests that these genera are facing significant regeneration bottlenecks. 2. Mid-elevation forests are dominated by *Castanopsis*.	

(*) As stated in the Sanction Letter issued by the NMHS-PMU.

2.4. Strategic Steps with respect to Outcomes (in bullets)

S. No.	Particulars	Number/ Brief Details	Remarks/ Enclosures
1.	New Methodology developed:	1. Validation procedure for satellite and gauge-interpolated data [HJPF-MK]	
2.	New Models/ Process/ Strategy developed:	2. New relationship on life-history traits and reproductive traits of key fish species under exploration [HRA-VA]	1. See attachment HRA-VA-02 and HRA-VA-05.
3.	New Species identified:		1. HRA-ADR reported new distributions for species. 2. HJPF-BS reported new distributions for 2 amphibian species.
4.	New Database established:	1. HRA-AM constructed a comprehensive ant checklist from the Eaglenest Wildlife Sanctuary. 2. HRA-ADR constructed comprehensive checklists for birds and butterflies from the Upper Siang 3. HRA-VA collated new data on 26 fish species in 10 streams in the Ranganadi sub-basin. 4. HJPF-AC identified 17 mammals & 174 bird species, and 674 soil arthropod morphospecies. 5. HJPF-SB (a) built ecological niche models for *Rhododendron setosum* and	1. See attachment HRA-AM_insects.pdf. 2. See attachment HRA-ADR_butterflies and HRA-ADR_birds 3. See attachment HRA-VA-02. 4. See attachments HJPF-AC-01.xlsx, HJPF-AC-02.pdf, HJPF-AC-03.pdf 5. See attachment HJPF-SB-01.doc for list of pollinators. 6. See attachment HJPF-UP_listofpollinators and

		R. lepidotum for (i) present climate & (ii) 2050s climate and (b) identified pollinators of 10 high elevation Rhododendrons. 6. HJPF-UP developed a list of Sikkim mandarin orange pollinators and pollinator food plants	HJPF-UP_PollinatorFoodPlantlist_Sikkim
5.	New Patent, if any:		
	1. Filed (Indian/ International)		
	2. Granted (Indian/ International)		
	3. Technology Transfer (if any)		
6.	Others, if any:	1. HJPF-YB recommends (i) setting up a nursery to raise oak seedlings and, (ii) protecting established seedlings in the forest using shelter tubes.	

3. TECHNOLOGICAL INTERVENTION

S. No.	Type of Intervention	Brief Narration on the interventions	Unit Details (No. of villagers benefited / Area Developed)
1.	Development and deployment of indigenous technology		
2.	Diffusion of High-end Technology in the region	1. Interest in cultivating indigenous fish for a small enterprise.	2 individuals
3.	Induction of New Technology in the region		
4.	Publication of Technological / Process Manuals		
	Others (if any)		

4. **NEW DATA GENERATED OVER THE BASELINE DATA**

S. No.	New Data Details	Existing Baseline	Additionality and Utilisation of New data (*attach supplementary documents*)
1.	Ant inventory of Eaglenest Wildlife Sanctuary (HRA-AM)		
2.	(a) Birds of Upper Siang district and, (b) Butterflies of Upper Siang region [HRA-ADR]	(a) Assorted reports and publications (b) Unverified reports; no major scientific publication [HRA-ADR]	(a) Updated avifauna lists, (b) New butterfly list from the region [HRA-ADR]
3.	(a) Fish life-history and reproductive traits of the Ranganadi sub-basin (b) Relationship of fish with respect to hydrological dams [HRA-VA].	None	The relationship between fish life-history traits and reproductive traits with water chemistry and dam position may provide additional insights for endemic and native freshwater fish in the EH. [HRA-VA]
4.	(a) Bird species, (b) mammal species and (c) soil arthropod lists [HJPF-AC]	No baseline for (a) bird and (c) soil arthropod lists; (b) Himalayan Black bear and Chinese pangolins reported in previous studies	Evidence for tea-forest landscape use by birds, mammals and soil arthropods.
5.	(a) Insect pollinators of the Sikkim mandarin orange [HJPF-UP], (b) food plants for pollinators in fragmented forests.	None	
6.	(a) Springflow and (b), climate monitoring from 2016–2019 [HJPF-MK].	Springflow and climate data from 2011–2016.	These are the 1st springflow monitoring sites in the EH and provide a framework to guide future work. The Sikkim Govt. has initiated a project on monitoring 10 springs using these protocols.
7.	Checklist of amphibian fauna in Sikkim [HJPF-BS].	None	

5. Linkages with Regional & National Priorities (SDGs, INDC)/ Collaborations

S. No.	Linkages / Collaborations	Details	No. of Publ./ Events Held	Beneficiaries
1.	Sustainable Development Goals (SDGs)	1. HRA-AM: The conservation of ecosystems supporting any biodiversity falls under SDG 15. 2. HRA-ADR: Ecotourism and sustainable alternate livelihoods fall under SDGs 8, 12 17. 3. HRA-VA: The impact of hydropower dams on fish fall under SDGs 7, 9 and 14. 4. HJPF-AC: The training programmes and fieldwork fall under SDGs 2, 3, 11, 12 and 15. 5. HJRF-RS: The equitable and reliable provision of water to towns in the EH falls under the SDGs 6, 10, 12 and 11. 6. HJPF-SB: The expected change in suitable habitat for Rhododendrons falls under SDGs 13 and 14. 7. HJPF-UP: The importance of pollinators for maintaining horticultural production falls under SDGs 12 and 15. 8. HJPF-MK: The importance of monitoring streamflow especially in response to climate change falls under SDGs 6 and 13. 9. HJPF-YK: The successful establishment of oak seedlings into mature trees falls under SDG 15. 10. HJPF-BS: The conservation of threatened amphibians, which are often sensitive to climate change falls under the SDGs 13, 14 and 15.		1. DEFAP, Sikkim; researchers 2. Dept. of Tourism, AR; NGOs 3. WRD, GoAP; MoEFCC, researchers 4. Min. of Comm. & Ind.; Tea Board 5. Darjeeling Municipality 6. For. & Env. Dept., SK; researchers 7. Hort. Dept., SK; orange growers 8. Water Res. Dept., SK; researchers, communities 9. DEFAP; Sikkim; researchers. 10. DEFAP; Sikkim; Zoology Dept., Sikkim Univ., researchers.
2.	Climate Change/INDC targets	1. HRA-AM: Biodiversity conservation of Himalayan ecosystems is an important component of India's climate change adaptation strategy (INDC target).		1. HRA-AM: DEFAP; MoEFCC 2. HRA-ADR: Dept. of Tourism, AR; MoEFCC; NGOs;

		2. HRA-ADR: Ecotourism and sustainable alternate livelihoods can help achieve cleaner economic growth (INDC target). 3. HRA-VA: The influence of dams on native and endemic fish must be considered for sustainably meeting India's renewable energy goals (INDC target). 4. HJPF-AC: Tea estate forests serve as a key carbon sink after the adoption of sustainable practices (INDC target). 5. HJRF-RS: Adapting to climate change is going to require enhanced investments in water resources in the EH towns (INDC target). 6. HJPF-SB: Biodiversity conservation of Himalayan ecosystems is an important component of India's climate change adaptation strategy (INDC target). 7. HJPF-UP: Maintaining pollination services is an important component of India's climate change adaptation strategy for agriculture (INDC target). 8. HJPF-MK: Monitoring streamflow is an important component of India's climate change adaptation strategy for water resources and the IHR (INDC target). 9. HJPF-YB: The successful establishment of oak seedlings is an important component of India's climate change adaptation strategy by enhancing the forest carbon sink (INDC target). 10. HJPF-BS: The conservation of Himalayan biodiversity is an important component of India's climate change adaptation strategy (INDC target).		local communities. 3. HRA-VA: Water Res. Dept., GoAP; MoEFCC; hydrologists 4. HJPF-AC: Min. of Comm. & Ind.; Tea Board; tea growers; MoEFCC 5. HJRF-RS: Public Health Eng. Dept, WB,. 6. HJPF-SB: For. & Env. Dept., SK; MoEFCC 7. HJPF-UP: Horticulture Dept., SK; MoEFCC 8. HJPF: MK: Water Res. Dept., SK; MoEFCC; researchers, communities 9. HJPF-YB: MoEFCC; researchers. 10. HJPF-BS: MoEFCC; researchers.
3.	International Commitments	1. HRA-AM: Aichi Target 11 & 12. 2. HRA-ADR: Aichi Target 10, 14 & 17. 3. HRA-VA: Aichi Target 14 & 17. 4. HJPF-AC: Aichi Target 3, 4, & 7. 5. HJRF-RS: Aichi Target 14. 6. HJPF-SB: Aichi Target 1 & 10.		MoEFCC and NBA

		7. HJPF-UP: Aichi Target 1, 3, 7 & 14. 8. HJPF-MK: Aichi Target 14 & 18. 9. HJPF-YB: Aichi Target 14 & 15. 10. HJPF-BS: Aichi Target 1, 12 & 19.		
4.	National Policies	1. HRA-AM. National Biodiversity Target 6 and 11. 2. HRA-ADR: National Biodiversity Target 3, 6 and 11. 3. HRA-VA: National Biodiversity Target 6 and 8. 4. HJPF-AC: National Biodiversity Target 5 and 8. 5. HJRF-RS: National Biodiversity Target 8. 6. HJPF-SB: National Biodiversity Target 3 and 6. 7. HJPF-UP: National Biodiversity Target 3, 5 and 6. 8. HJPF-MK: National Biodiversity Target 8, and 11. 9. HJPF-YB: National Biodiversity Target 3. 10. HJPF-YB: National Biodiversity Target 6.		MoEFCC and NBA
5.	Others collaborations	1. HJPF-MK developed collaborations with local organisations [Central Himalayan Rural Action Group (CHIRAG)] in Uttarakhand & state agencies in Sikkim and Uttarakhand for action research on conserving Himalayan Springs [Rural Mgmt. and Dev. Dept., Govt. of Sikkim		Three villages each in Sikkim and Uttarakhand

6. FINANCIAL SUMMARY (CUMULATIVE)*

*Please attach the **consolidated and audited Utilization Certificate (UC) and Consolidated and *Year-wise* Statement of Expenditure (SE)** separately, *ref*. **Annexure I.**

7. Quantification of Overall Research Progress

S. No	Parameters	Total (Numeric)	Attachments* with remarks
1.	IHR State(s) Covered:	4	Arunachal Pradesh [HRA-AM, HRA-ADR, HRA-VA], Sikkim [HJPF-MK, HJRF-RS, HJPF-SB, HJPF-YB, HJPF-BS], Uttarakhand [HJPF-MK], West Bengal [HJPF-AC, HJRF-RS]
2.	Fellowship Site/ LTEM Plots developed:	18	1. HJPF-AC identified 13 LTEM sites (attachment HJPF-AC-04.pdf) 2. HJPF-MK identified 3 LTEM sites in Sikkim and 2 in Uttarakhand
3.	New Methods/ Model Developed:		
4.	New Database generated:	11	1. Ants (HRA-AM_insects.pdf) 2. Birds (HRA-ADR_birds.pdf, HJPF-AC-02.pdf) 3. Butterflies (HRA-ADR_butterflies.pdf); 4. Fish (HRA-VA_fish.pdf) 5. Mammals (HJPF-AC-02.pdf) 6. Soil arthropods (HJPF-AC-03.pdf) 7. Pollinators (HJPF-SB-01.doc, HJPF-UP_list of pollinators.pdf) 8. Food plants of pollinators (HJPF-UP_PollinatorFoodPlantList_Sikkim.pdf) 9. Amphibians (HJRF-BS-01.pdf)
5.	Types of Database generated:		1. [HRA-AM] Ants of Eaglenest Wildlife Sanctuary. 2. [HRA-ADR] 157 birds of Upper Siang district and, (b) 50 butterflies of Upper Siang region 3. [HRA-VA] 26 fish species in Ranganadi sub-basin 4. [HJPF-AC] 17 mammal, 174 bird and 640 soil arthropod morphospecies in Darjeeling tea landscape 5. [HJPF-UP] 45 food plants of pollinators and 25 pollinators of the Sikkim mandarin orange. 6. [HJPF-BS] 23 amphibians (including 2 new records) from Sikkim.
6.	No. of Species Collected:	265 species	157 ant species [HRA-AM]; 26 fish species [HRA-VA]; 10 rhododendrons & 16 rhododendron pollinators [HRA-SB]; 25 Sikkim mandarin orange pollinators (HJPF-UP); acorns from 8 species from the

			Fagaceae family (HJPF-YB; 23 amphibian species (HJPF-BS).
7.	New Species identified:		
8.	Scientific Manpower Developed (PhDs awarded/ JRFs/ SRFs/ RAs):		1. 4 PhDs awarded (HRA-AM, HRA-ADR, HRA-VA, HJPF-UP) 2. HJRF-RS was promoted to an SRF during the project after successfully clearing an internal review.
9.	No. of SC Himalayan Researchers benefited:		
10.	No. of ST Himalayan Researchers benefited:		
11.	No. of Women Himalayan Researchers empowered:	6	
12.	No. of Knowledge Products developed:	25	
13.	No. of Workshops participated:		1. Him. Researchers Consortium [HRA-AM, HRA-ADR, HJRF-RS, HJPF-MK, HJPF-UP, HRA-VA] 2. Natl. Sem. cum Mon. and Eval. Workshop [HRA-VA] 3. Cert. Course in Systems Dynamics [HJPF-AC] 4. HI-AWARE Acad. for Doctoral Students Kathmandu, Nepal, Nov 2016 [see HJRF-RS-03.pdf] 5. American Geophysical Union, Fall Meeting, Dec 2016 [see HJPF-MK-01.pdf, HJPF-MK-02.pdf] 6. International Mountain Conference, Innsbruck Austria, Sep 2019 [see HJPF-MK-03.pdf]
14.	No. of Trainings participated:		1. Intl. Train. and Tools and Approaches for Citywide Water and Sanitation Mgmt., CSE, New Delhi [July 2018; HJRF-RS] 2. Writing workshop for special issue on Himalayan springs, ICIMOD, Kathmandu, [March 2018; HJPF-MK] 3. Summer school for students, International Mountain Conference, Innsbruck, Austria, [September 2019; HJPF-MK]
15.	Technical/ Training Manuals prepared:		1. Training and Awareness Prog. on For. Cons., For. Appreciation, Wildlife & Nat. Res. Mgmt. for workers in tea estates [HJPF-AC] 2.

	Others (if any):		1. Got the IUFRO-EFI YSI scholarship 2019 to Germany for 3months. 2. Participated in wood biology training in Germany at HNE Eberswalde, Germany.

***** Please attach the soft copies of supporting documents word files and data files in excel.

8. Knowledge Products and Publications*

S. No.	Publication/ Knowledge Products	Number		Total Impact Factor	Remarks/ Enclosures**
		National	International		
1.	Journal Research Articles/ Special Issue (Peer-reviewed/ Google Scholar)		5	8.9 (2.7+0.7+2.7 +0.7+2.1)	1. Marathe A, Priyadarsanan DR, Krishnaswamy J, Shanker K (2020) Spatial and climatic variables independently drive elevational gradients in ant species richness in the Eastern Himalaya. *PLoS ONE* 15(1): e0227628. https://doi.org/10.1371/journal.pone.0227628 2. Shah, Rinan, and Shrinivas Badiger. 2018. "Conundrum or Paradox: Deconstructing the Spurious Case of Water Scarcity in the Himalayan Region through an Institutional Economics Narrative." *Water Policy*, 1–16. https://doi.org/10.2166/wp.2018.115 3. Basnett, S., Ganesan, R. & Devy, S.M. Floral traits determine pollinator visitation in *Rhododendron* species across an elevation gradient in the Sikkim Himalaya. *Alp Botany* **129,** 81–94 (2019). https://doi.org/10.1007/s00035-019-00225-3 4. Pradhan, U. & M.S. Devy (2018). Pollinators of Sikkim Mandarin Orange Citrus reticulata (Sapindales: Rutaceae). Journal of Threatened Taxa 11(5): 13625–13628. https://doi.org/10.11609/jott.4528.11.5.13625-13628 5. Bhutia, Y.; Gudasalamani, R.; Ganesan, R.; Saha, S. Assessing Forest Structure and

					Composition along the Altitudinal Gradient in the State of Sikkim, Eastern Himalayas, India. Forests 2019, 10, 633. https://doi.org/10.3390/f10080633
2.	Book Chapter(s)/ Books:				
3.	Technical Reports/ Popular Articles				1. Chowdhury, A. (2017). What going organic means for biodiversity conservation and human wellbeing in Darjeeling's tea estates. *Eartha: environment, development, sustainability*. 2. Chowdhury, A. "Tea tag takeaway" Down to Earth, July 29, 2016. https://www.downtoearth.org.in/news/economy/tea-tag-takeaway-55105 (accessed July 15, 2019). 3. Chowdhury, A. "Why we need to listen to hunters" Down to Earth, October 15, 2017. https://www.downtoearth.org.in/blog/wildlife-biodiversity/why-we-need-to-listen-to-hunters-58888 (accessed July 15, 2019). 4. Shah, R. Contextualizing Water Scarcity in Urban Mountain Towns: The Case of Darjeeling. City Observer, 72-81. 2018. https://issuu.com/urbandesigncollective/docs/city_observer_volume_4_issue_2_31st (accessed July 15, 2019)
4.	Training Manual (Skill Development/ Capacity Building)				
5.	Papers presented in Conferences / Seminars				1. [HRA-AM]: Paper presented at 1st HRC, Dehradun, Uttarakhand (Mar 2018) 2. [HRA-ADR, HJRF-RS, HJPF-MK, HJPF-UP]: Paper presented at 2nd HRC, Gangtok, Sikkim (Nov 2018).

					3. [HRA-VA]: Paper presented at 1st HRC, Dehradun, Uttarakhand (Mar 2018) and at National Seminar-cum-Monitoring & Evaluation (M&E) Workshop in Almora (January 2019). 4. [HJPF-AC]: Paper presented at SCCS New York, USA [October 2019; see HJPF004-AC-05.pdf] 5. [HJPF-AC]: Paper presented at Sus. & Devel. Conf. Ann Arbor, Michigan, USA [October 2019; see HJPF-AC-06.pdf] 6. [HJRF-RS]: Paper presented at 9th International Perspective on Water Resources and the Environment in Wuhan, China (January 2017; see HJRF-RS-01.png) 7. [HJRF-RS]: Paper presented at World Water Week, organised by the Stockholm International Water Institute, Stockholm Sweden (August 2019; see HJRF-RS-02.pdf) 8. [HJPF-MK]: Paper presented at American Geophysical Union (AGU) Fall meeting, San Francisco, USA (December, 2016; see HJPF-MK-01.pdf, HJPF-MK-02.pdf). 9. [HJPF-YB]: International Conference on Plants & Environmental Pollution (ICPEP-6), Lucknow, India (November, 2018) 10. [HJPF-YB]: International "Symposium on Evergreen Oak Forests in the Eastern Himalayas" Gangtok, India (November, 2019).
6.	Policy Drafts (if any)				
7.	Others (specify)				1. HRA-AM: PhD completed with duly acknowledged assistance from NMHS (see attachment HRA-AM_Thesis acknowledgement) 2. HRA-ADR: PhD completed with duly acknowledged assistance from NMHS

					(see attachment HRA-ADR_Thesis acknowledgement) 3. HRA-VA: PhD completed with duly acknowledged assistance from NMHS (see attachment HRA-VA_Thesis acknowledgement) 4. HJPF-SB: PhD completed with duly acknowledged assistance from NMHS (see attachment HJPF-SB_Thesis acknowledgement) 5. HJPF-UP: PhD completed with duly acknowledged assistance from NMHS (see attachment HJPF-UP_Thesis acknowledgement) 6. HJPF-BS: PhD completed with duly acknowledged assistance from NMHS (see attachment HJPF-BS_Thesis acknowledgement)

*Please append the list of KPs/ publications (with impact factor and URL link details) with due Acknowledgement to NMHS.

**Please provide supporting copies of the published documents.

9. Recommendation on Utility of Research Findings, Replicability and Exit Strategy

9.1. Utility of the Fellowship Findings

S. No.	*Research Questions Addressed*	*Succinct Answers (within 150–200 words)*
1. [HRA-AM]	1. To understand drivers of ant species richness across elevation gradient 2. To understand effect of diversity in species pool on species turnover or beta diversity 3. To examine patterns in species composition in light of species ecology, climatic gradients and spatial variables	1. Ant species richness patterns in the Eaglenest Wildlife Sanctuary (EWS) are a result of strong climatic gradients and not habitat conditions or disturbance. 2. Species turnover in ant communities in EWS is driven by species pool changes caused by climatic constraints at higher elevations. 3. The most abundant and species rich functional ant groups in this study were Generalized Myrmicinae, and Opportunists while Cold Climate Specialists were the least abundant.
2.	4. What are the potential areas across the EH where	1. Criteria used to identify study site can be used across the IHR.

[HRA-ADR]	supplementary livelihood options could be implemented? 5. What income generating eco-tourism activities can be implemented in these areas? 6. Who are the primary stakeholders responsible for the implementation of these activities and what factors determine their support? 7. How do alternate livelihood options influence people's well-being in selected study sites?	2. Nature-based tourism has been found to be effective globally and offers promise. 3. The detailed examination of the dynamics of stakeholder interactions in the village would help understand and confront similar issues in other parts of the IHR. 4. The suggested alternative livelihood options will (a) encourage young educated villagers to return to the village and (b) cash can help peoples meet medical or educational needs.
3. [HRA-VA]	1. What is the community structure of native freshwater fishes of Ranganadi sub-basin? 2. How does a hydropower dam affect water chemistry and certain life-history and reproductive guilds of fishes? 3. What is the species recovery below hydropower dam?	1. Twenty-six fish species belonging to 3 orders and 7 families were recorded. Species diversity varied across habitat, season and dam position. 2. Three reproductive guilds (Lithopelagophils, Lithophils and Phytolithophils) declined downstream the dam. Water temperature, electrical conductivity and total alkalinity were higher below the dam; total alkalinity significantly influenced species richness and relative abundance. 3. Total and endemic species recovered 20 km downstream of the dam. Fish abundances in 'pools' was highest followed by 'riffles' and 'run' and other key life-history traits varied across the upstream-downstream gradient.
4. [HJPF-AC]	1. Does the tea-forest landscape have the ability to support biodiversity associated services and human wellbeing? 2. Are there the trade-offs between biodiversity, ecosystem services and wellbeing in the tea-forest landscape?	1. The tea-forest landscape supports 17 mammal & 174 bird species, 40 endemic trees and 640 soil arthropod morphospecies. Fuelwood is used by 98%; NTFP by 61.25% and spiritual or recreational benefits by 81.25% of respondents. 2. Low-income households are highly dependent on ecosystems. Tea estates restrict forest access due to certification-related conservation policies leading to trade-offs between human wellbeing and biodiversity conservation.

5. [HJRF-RS]	1. To understand the causes and effects of domestic water scarcity in EH towns. 2. Assess biophysical and human induces changes in and around water sources and the region to which the water is supplied and the extent of water utilization. 3. Assess the effects in terms of the availability and accessibility of water, the definition of well-being and sufficiency for communities. 4. Investigate the political and economic drivers for the manifestation of scarcity.	1. Changes in rainfall do not impact water availability significantly and water infrastructure are ineffectively executed. 2. Seasonal population increases coinciding with the dry season make water acquisition difficult and availability across water institutions is not uniform. 3. Accessibility to water is highly skewed although availability is good. Household spatial and socio-economic characteristics affect access to water. 4. State-led investments do not improve water availability for communities.
6. [HJPF-SB]	1. What is the present distribution of two Himalayan Rhododendron species? 2. How their distribution is affected in the future climatic condition? 3. What are the potential pollinators of high elevation Rhododendron species	1. Altitude has a major influence on both species. For *R. lepidotum*, habitat suitability is from 2200–4200m and for *R. setosum*, up to 6600 m. 2. By 2050, suitable habitat for *R. lepidotum* decreases (from 901,176 km^2 to 122,494 km^2) but increases for *R. setosum* (from 687,338 km^2 to 907,011 km^2). 3. In contrast to species growing above the treeline, *R. anthopogon, R. setosum* and *R. lepidotum* were visited by bumblebees and flies. These species also had the highest concentrations of nectar, shortest corolla length and shorter distance between the stamen and stigma.
7. [HJPF-UP]	1. To understand role of fragmented habitats outside protected areas in supporting biodiversity through higher order interactions such as pollination. 2. To estimate major pollinator food plants in fragmented forests. 3. To understand people's perception of biodiversity, pollination service and their willingness to conserve forest patches.	1. Twenty-eight species of insects (from Hymenoptera, Diptera, Hemiptera and Coleoptera) were collected and identified in the laboratory. 2. A total of 671 individuals representing 48 tree species were recorded in 90 plots across nine sites. 3. Interviews highlighted the declining abundance and diversity of pollinators and pollinator food plant in the landscape. Communities felt the need to protect and conserve forest fragment status of pollinators in the landscape, their food plants and are willing to participate for it.

8. [HJPF-MK]	1. What are the drivers of spatial and temporal variability in precipitation patterns across Sikkim Himalaya? 2. What are the predicted hydrological responses of springs and streams in the context of climate variability and climate change in the Sikkim Himalayas	1. Rainfall in Sikkim Himalaya appears to be driven by orographic and monsoonal patterns and rainfall displays a strong multi-decadal cyclic pattern. Light rainfall (< 25 mm/day) has increased over west, central and north Sikkim. The recent increase in large storms over south and east Sikkim makes these areas vulnerable to landslides and flash floods. 2. The extent and timing of hydrological control by vegetation varies with forest type but springs under forested catchments have steadier low-flow discharges than those under agriculture. This supports existing community knowledge that springs from forested areas are more perennial than others.
9. [HJPF-YB]	1. To examine seedling frequency, seed viability and variability of seed across different Oak species?	1. In general, oaks in the Sikkim Himalayas are characterised by poor regeneration. Two genera, *Quercus* and *Lithocarpus* have low seedling frequency despite having higher seed volume. 2. Forests between 900–2700 masl are dominated by *Castanopsis* and were observed to have high seed viability.
5. [HJPF-BS]	2. What is the influence of habitat variables on species richness of frogs? 3. What is the influence of spatial position and environmental variables on composition of frog assemblages?	1. The mean temperature of the warmest months (MTWMs) and riparian vegetation cover significantly explained species richness stream breeding frog assemblages. 2. Redundancy analysis suggests that the environment (precipitation, MTWMs and riparian vegetation) and biotic processes (dispersal, competition and diseases) determined the frog species distribution and abundance and species assemblage composition.

9.2. Recommendations on Replicability and Exit Strategy:

Particulars	Recommendations
Replicability of Fellowship, if any	[HRA-AM] 1. The ant data contributed and models developed will remain useful well beyond the scope of this study and insect collections curated will guide future taxonomic studies.

2. The study provides sampling strategies for rapid assessment of leaf-litter insect diversity for future studies.

[HRA-ADR]

1. Nature based ecotourism has potential in other sites with rich biodiversity, scenic landscapes and an amenable local community.
2. Responsible ecotourism must balance tourist needs and local customs and practices. Tourist schedules should be willing to adapt to local livelihoods and priorities and must be appreciative of local cultures and rules.
3. Proper training is required for villagers to host tourists. This should be conducted by experienced practitioners.
4. The support from the local institutions and elders is vital for the sustainability of these initiatives.

[HRA-VA]

1. Dam authorities did not release stream discharge data despite following due procedure; this information would have helped communicate our findings to highly cited, international peer-reviewed journals.
2. Future research should evaluate the influence of undammed tributaries as refuge for stream fishes downstream of a dam.

[HJPF-SB]

1. Previous studies have rarely studied future distributions of plants and pollinators across multiple species and altitudinal gradients. More research is needed to confirm observations.
2. Future research should span multiple genera and inter- and intra-specific variations in species distributions and floral traits.

[HJPF-UP]

1. Understanding pollinators and their requirement will help enhance the yield of cash crops in Sikkim and the IHR. Similar research should be encouraged in other parts of IHR to improve the current understanding of pollinators.

[HJPF-MK]

1. The sites are first of its kind in the EH providing a framework to guide future work by other agencies in the region.
2. The Sikkim Govt. has also initiated a project on monitoring 10 springs using the same monitoring design with technical help of our research group.

[HJPF-YB]

1. The current study is the first to provide a quantitative investigation of the regeneration status of oaks and related species in the Sikkim Himalaya.

	[HJPF-BS] 1. The present study could be used to assess the adequacy of the current protected area network for stream breeding frogs in Sikkim. 2. Future studies should continue to assess the influence of riparian vegetation, climate and water quality on the composition of amphibian assemblages as these could serve as a simple way of ensuring suitable habitat for amphibians in a region.
Exit Strategy:	[HRA-AM] ● Despite the intentional choice of a small spatial scale, future studies could investigate patterns across multiple river valleys, or longitudes. ● ATREE has broader interests in the EH and the inventory and biodiversity analysis can be continued in the future. [HRA-ADR] ● Support from relevant government departments is vital for the sustenance of such initiatives. ● Outreach is required to publicise ecotourism options among adventurous and outdoor focused travellers within India. ● Maintaining rapport with the locals is essential and periodic outreach programs can help solve site-specific issues. ● Safeguarding biodiversity must be ensured and direct (wildlife trade) and indirect (invasive species introductions) activities that threaten biodiversity must be stopped. [HRA-VA] ● Hydropower dams significantly affect the distribution of native fish communities and authorities must consider the distance for fish species recovery while planning subsequent dams. ● There was some interest (2 individuals) in cultivating indigenous fish for developing a small enterprise but technical guidance on aquaculture is needed. [HJPF-AC] ● Capacity building must be combined with local knowledge so that faunal and floral assessments can continue even in the absence of researchers. [HJPF-SB] ● Future research should span multiple genera and inter- and intra-specific variations in species distributions and floral traits. [HJPF-UP]

	● Local farmers and agriculture, horticulture and floriculture departments will benefit from an enhanced understanding of pollinators. [HJPF-MK] ● These sites are likely to be develop as long-term ecohydrological monitoring stations in Himalaya. A comprehensive understanding of springs and streams in Himalaya, however, will require the establishment of similar long-term monitoring sites across the IHR to improve the current understanding of short-scale processes [HJPF-YB] ● The study recommends an urgent restoration program by (i) setting up a nursery for raising oak seedlings (*Quercus* and *Lithocarpus*) and, (ii) using shelter tubes to aid seedling establishment and improve the overall functioning of the forest ecosystem. [HJPF-BS] ● The study can be used to identify habitats of stream breeding frogs in Sikkim that may be at risk from urban development and hydel power projects.

(**NMHS FELLOWSHIP COORDINATOR**)
(Signed and Stamped)

Place:
Date:

(**HEAD OF THE INSTITUTION**)
(Signed and Stamped)

PART B: COMPREHENSIVE REPORT

4. Executive Summary

The Eastern Himalayas (EH) in the Indian Himalayan Region (IHR) is a globally important biodiversity landscape and includes several Global 200 ecoregions, two Endemic Bird Areas, and several centres for plant diversity. Spanning a wide altitude range (500-8000 m above msl), the EH contains tropical and sub-alpine forests, alpine meadows and wetlands. While livelihoods in the EH are dependent on agriculture and agroforestry, millions remain directly dependent on the natural resources that these ecosystems provide. Despite these benefits, ecosystems and livelihoods in the EH have been threatened by a rapid increase in developmental activities including hydropower projects, land use intensification and urban sprawl.

This rich natural and cultural history makes the EH ideal for interdisciplinary and disciplinary research that examines the challenge of pursuing sustainable development. Ten ATREE PhD students, comprising 3 Himalayan RAs—Aniruddha Marathe (AM), Anirban Datta-Roy (ADR), Vidyadhar Atkore(VA)—and 7 Himalayan Junior Research/Project Fellows—Annesha Chowdhury (AC), Barkha Subba (BS), Manish Kumar (MK), Rinan Shah (RS), Shweta Basnett (SB), Urbashi Pradhan (UP), Yangchenla Bhutia (YP)—benefited from the NMHS grant. This executive summary thematically outlines the research conducted by these students in the EH.

a. Ecosystems and Resilience

For centuries, communities in the EH have met their needs through subsistence agriculture and forest products. In the last few decades, however, this situation has changed rapidly with the adoption of the global development model and market-based livelihoods promoted through government policies that stress livelihoods and ecosystems in the EH. Nature-based livelihoods (e.g. ecotourism) that promote non-extractive use of a landscape offer an alternative. This has been attempted successfully across the world in Latin America, Africa and Asia through ecotourism and similar activities. These successful projects have shown that it may be possible to balance community development, maintenance of biodiversity and greater awareness and appreciation of the region among visitors. In India, along with a niche group of nature-based tourism, there is a great opportunity to promote a greater understanding of mountain communities among the growing urban middle class who like to travel.

b. Water

In spite of getting two monsoons per year, the Eastern Himalayan Region (EHR) faces water poverty; this is a paradoxical situation. Due to the geography and low level of development in this part of the country, there is a need to understand the manifestation of such water scarcity in a volumetrically water-rich region. Small changes in climatic conditions can have profound impacts on biodiversity, water, availability and agricultural hazards in mountainous regions. Potential changes that a hydrological cycle can undergo in mountain ecosystems depend on the sensitivity of these ecosystems. Springs are common property resources, but with increasing urbanization, people are extending their properties to incorporate the springs resulting in its privatization. The government has introduced various schemes and laws to initiate and encourage water resources management. The implementation of such schemes in the hilly terrain may or not be with the same efficiency as other parts of the state or the country. Additionally, it is important to understand the role of hydropower dams on aquatic communities as the construction of these dams in the region have increased.

c. Climate Change

The Himalayan climatology is primarily governed by elevation and local biophysical parameters. Modeling the variability in temperature is easier than rainfall, which is less correlated with elevation and requires finer resolution data. Coarse scale regional climate studies have limited applicability in terms of informing local climate mitigation and adaptation efforts. In this context, MK has assessed climate variability and change in Sikkim Himalaya using long-term (1901-2002) monthly records of rainfall and temperature available at district-level. A time series analysis was done using a combination of time-series and anomaly plots; and Sen slope was estimated to understand the trend.

Climate change has affected many ecosystems and taxonomic groups worldwide. The species range is one of the important ecological factors that are affected in response to climate change. Species with restricted range distributions may be more vulnerable to the changes in climatic factors that determine the boundaries of their distributions. SB assesses the distribution ranges of *Rhododendron* which form the dominant component of the high-altitude plants distributed across the wide elevation range of 1800m to 5000m which makes them a model species for climate change related study.

d. Biodiversity and Ecosystems

Determining how many species are present in a particular habitat, their community composition and the different factors influencing species composition and distribution are critical questions in ecology and conservation biology. BS's study evaluated the relative influence of environmental variables and spatial position, as a reflection of biotic processes, on the richness and composition of frog assemblages at hill streams in Sikkim.

Insect pollinators play an important role in provisioning pollination service which sustains both wild and cash crops, however they are also declining across the globe. The Sikkim Himalaya is known to be home to numerous taxa, however, the study on pollinators of Sikkim is very limited. UP's study explored the diversity of pollinators and their food availability in the fragmented forest of Sikkim.

Ants (Hymenoptera: Formicidae) are highly diverse and widespread insects in most terrestrial ecosystems. However, there are no structured inventories or, quantitative estimates of diversity, or studies on ant ecology from the entire Eastern Himalayan region. AM's study addressed these knowledge gaps by quantifying the changes in ant communities across elevation gradients and offering ecological hypotheses for explaining the patterns.

e. Agriculture in Forest-Agriculture Interfaces

The Oak and its related species (Fagaceae) are significant for the Himalayan region. They are reported as the dominant forest trees of the mid-elevation forests. Besides, they are highly valued by people in the Himalayas for its diverse use in agricultural practices. However, these forests are in major threat globally and the Himalayas. A study examines the regeneration status of Oak and its related species along the elevational gradient in Sikkim Himalaya.

5. OVERALL OBJECTIVES/AIMS

i. To assess the opportunities for supplementary livelihood options in remote eastern Himalayan communities towards promotion of eco-agricultural landscapes

ii. To quantify the ability of the tea-forest landscape to support biodiversity associated services and human well-being

iii. To identify the trade-offs between biodiversity, ecosystem services and wellbeing in the tea-forest landscape

iv. To arrive at a desirable social- ecological identity for the landscape

v. To understand the causes and effects of the domestic water scarcity in the eastern Himalayan towns

vi. To examine fish diversity and impacts of hydropower dam on the native fish community composition

vii. To assess climate variability and change in Sikkim Himalaya and its potential impacts on hydrological flows

viii. To quantify the effect of climate change of a few specific *Rhododendrons* of higher elevation

ix. To identify the pollinators of a few specific *Rhododendrons* of higher elevation

x. To provide information for the conservation planners to adopt a strategy at a species level for conserving *Rhododendrons* in the face of climate change.

xi. To evaluate the influence habitat variables which are not only of ecological interest but will also provide insight for conservation of stream dwelling frogs and their habitats

xii. To address knowledge gaps regarding ant communities in Eastern Himalayan Region by quantifying the changes in communities across elevation gradient and offering ecological hypothesis for explaining the patterns

xiii. To understand role of fragmented habitats outside protected areas in supporting biodiversity through higher order interaction such as pollination

xiv. To examine the regeneration status of Oak and its related species along the elevational gradient in Sikkim Himalaya

6. METHODOLOGY

As part of the methodologies, a combination of natural science and social science methods to collect the data was adopted. This comprised the following:

Faunal documentation: Walks were conducted along established trails and roads to observe the avian and lepidopteran fauna of the region within forests, mixed use landscapes and a variety of habitats. In addition to the structured walks, any opportunistic sightings of fauna while traveling were also recorded along with the location and other parameters.

***Vegetation assessments*: This included laying 4 nested vegetation plots measuring 5 m X 5 m at an interval of 250m within the 1 km trail to enumerate all trees and shrubs. A 1 m X 1 m nested subplot, randomly placed inside each 5 m X 5 m plot was laid to enumerate all herb species, percentage grass cover.

Mammal survey*:* The survey of mammals involved using camera traps and sign surveys(Lyra-Jorge et al., 2009) along trails.

Bird survey: Bird surveys involve point counts every 250 m along the 1 km transect. All bird s*pecies* along with activity within a 30 m radius w*ill be n*oted for 10m *and co*nducted between 6.00–9.00 am.

Soil arthropod survey: Pitfall traps containing 70% alcohol were placed every 250 m along every 1 km trail.

Participatory Rural Appraisal (PRA) was used to assess community use and level of dependence on ecosystem goods and services

Household surveys focusing on agricultural and livelihood practices were conducted to gain a better understanding of the current livelihood practices and the impact of alternatives for their well-being.

GPS locations (by GPS logging) and other information for springs and other water sources for public and private supplies were collected.

Using a ***nested hierarchical study design*** approach stream segments each of 100 m long were sampled from headwater to downstream of a dam and adjoining tributaries of Ranganadi river to cover spatial extent. Fishes were sampled using traditional methods of castnet with different mesh size.

Time-series analysis was conducted on a combination of primary and secondary, including remote-sensing, data on rainfall, streamflow and climatic parameters to understand long-term trends in Sikkim.

Species distribution modelling was used to assess the response of *Rhododendrons* to current and future climate conditions for the year 2050 under the moderate (rcp 4.5) and extreme (rcp 8.5) climate change scenario.

Pollinator sampling across elevation gradient (700-1500 m above msl), vegetation sampling to understand pollinator food plant in the fragmented forest of Sikkim and household survey to understand the perception of local community regarding pollinators, their food plant and willingness to participate for the conservation of fragmented forest for continued flow of pollination service in the landscape were conducted.

54 sites at forest streams were studied to cover the range of mean temperature of the warmest months (MTWMs 4°C–30°C), average precipitation of the warmest months (PWMs; 186–2500 mm) and different stream orders within the study area. Majority of the frog species in the area were most active, and thus most likely to respond directly to ambient temperature and moisture during the warmest quarter of the year (May to Sept). Both MTWMs and PWMs were calculated from long term climatic data using WorldClim, a bioclimatic prediction system.

Mid-elevation of Sikkim Himalaya, ranging from 900m to 2700m a.s. were selected, because it represents the potential distribution range of Oaks and their related species. ***Stratified random sampling*** was conducted after demarcating the forest between 900m to 2700m.

7. IMPACT ON IHR

Projects identified activities like bird watching, butterfly watching and walking on nature trails as important alternative livelihoods and which will directly influence local people to maintain the biodiversity of their region. Through training programs, the students were able to impart knowledge and provide a scientific basis to sustainable and scientific management of the Natural Resources in the region which is mainly the forests, the tea ecosystem itself and rivers. Inspired by one of the research projects in Sikkim, the Sikkim government initiated a project on monitoring 10 springs using the same monitoring design with technical help of the research group. The results of one study could be used to assess the adequacy of the current system of protected areas for stream breeding frogs in Sikkim, and to identify certain classes of habitat that may be at risk from urban development and hydel power projects. The study on insect taxa provides the first quantitative ecological analysis of data on the same from Eastern Himalaya. It provides sampling strategies for rapid assessment of leaf-litter insect diversity, which could be useful in the future studies. This work will be most valuable if it is the first of many such efforts that will help further existing knowledge about community assembly in Eastern Himalaya.The study on Rhododendrons has estimated the future and present distribution of a widely distributed (*R. lepidoptum*) and a narrowly distributed (*R.setosum*) species. Overall, the result suggests that future climate change will alter the distribution of these species. And for the conservation of *Rhododendrons* in the face of climate change, a conservation strategy needs to be adopted at a species level.

8. CONCLUSION AND RECOMMENDATIONS

i. While ecotourism and other associated activities are important alternative livelihoods, it is also important to remember that biodiversity conservation should be given top priority. Any activity that may impact the biodiversity of the region should be stopped.

ii. In order for tea-plantation forest mosaic landscapes to be able to support biodiversity and human well-being, needs to be managed with a focus on the matrix and the tea forest ecosystem as a whole and not just natural areas set aside for conservation. Such a perspective, will not only enhance the chances of persistence of existing biodiversity in the landscape through better, scientifically informed management decisions but foster good conditions for achieving minimum levels of human well-being.

iii. There is a need to look at local resources such as springs and increase the formal water infrastructure but also consider how the poorer sections of society are able to access it.

iv. Develop habitat conservation plan for native and endemic fish species and remove invasive fish species from the Ranganadi dam reservoir.

v. Better maintenance of the existing climate monitoring infrastructure along with establishing more stations to develop regionally accurate climate models for predicting climate change in Sikkim Himalaya.

vi. Conservation planners to adopt a strategy at a species level for conserving *Rhododendrons* in the face of climate change.

vii. Importance of pollinators and their food and habitat should be highlighted to local communities, specially farming communities which will not only help in the conservation of pollinators but in also safeguarding yield of farm crops influencing socio economic well-being of the communities in the hills.

viii. The results of the study on amphibians could be used to assess the adequacy of the current system of protected areas for stream breeding frogs in Sikkim, and to identify certain classes of habitat that may be at risk from urban development and hydel power projects.

ix. More inventory effort on ants in future, with comparable sampling techniques, will be helpful in understanding drivers behind elevational gradients in biodiversity across larger spatial scales.

x. An urgent restoration program, for instance setting up a nursery, protection of established seedlings in the forest using shelter tubes to improve seedling establishment, and the overall functioning of the forest ecosystem is the need of the hour.

Fellowship Report No.: 1 of 10

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HRA	Anirban Datta-Roy	April 1, 2016	July 31, 2019	Supplementary livelihood options for local communities and other rural populations	Dr. Nitin Rai, Fellow at ATREE, Bangalore

9. ANIRBAN DATTA ROY

1. Introduction

This project was conceptualised in response to the increasing problem of change and rapid development among the mountain communities in the eastern Himalayas that threaten to leave them vulnerable to market forces unfamiliar to them. Alternative livelihoods that are environmentally friendly and also provide complete control of the process to the local inhabitants are available in the form of ecotourism and other 'green jobs'. The presence of high levels of faunal diversity and increasing interest from birdwatchers and amateur photographers make the IHR region a good location for nature-based ecotourism initiatives. The holistic nature of this project involves the collation of ecological, social, institutional data along with an exhaustive review of secondary literature. I identify four major activities that include nature-based tourism, homestays, trekking and sale of handicrafts and other locally made items. To understand the challenges involved in implementing some of these initiatives, I also visited successful sites in Sikkim and West Bengal to study their best practices. The complexities of each activity and the potential challenges uncovered through this study demonstrate the need for detailed field research on ecotourism potential before their actual implementation.

The primary baseline for the project revolves around the importance of alternative livelihoods among Himalayan communities who are dealing with largescale changes to their livelihoods. The reason for these changes can be diverse but are usually a consequence of government policies driven by the forces of globalization and markets. Regular subsistence livelihood activities in the hills are replaced by market-based ones which are unfamiliar to communities. This can lead to tremendous strain on the well-being of communities and expose themselves to alienation from their own land. As a solution to this, nature based alternative livelihood practices have been promoted among mountain communities in many places of the world in the form of ecotourism and other associated nature-based activities.

The origin of the term 'ecotourism' came from Hetzer (1965) who used it to refer to the four 'principles' of responsible tourism - minimizing environmental impact, respecting local cultures, maximizing benefits to local people and maximizing tourist satisfaction. On the origin of ecotourism, Honey (2008) writes that it arose from 'within the womb' of the environmental movement in the period 1970 to 1985. Environmental concerns were on the rise and there was also a general dissatisfaction with the standard mass tourism model. Ecotourism was especially seen to be conducive to less developed countries which would allow them to earn foreign exchange and also minimize destructive use of natural resources.

Early definitions of ecotourism that emerged from Ceballos-Lascurain (1987) and Boo (1990) centred on the tourist's desire for nature-based experiences. Subsequently, an important addition to this approach has been the concept of sustainable development as highlighted by Wight (1993). Blamey (2001) offers three core ideas of ecotourism - nature based, environmentally and culturally educative, sustainably managed.

Ecotourism has been recognised for these qualities across the world and has been successful in various developing countries blessed with natural beauty - such as Kenya, Costa Rica and South Africa. Ecotourism got a further boost when the United Nations General Assembly declared 2002 as the International year of Ecotourism (1998).

In India, the importance of ecotourism was recognised early by the government and 'Policy Guidelines' were established in 1998. Currently, the Ministry of Tourism defines it broadly as tourism which is ecologically sustainable. The general principles circulated by the Ministry make specific mention of the fact that local communities need to be involved leading to their development and that the type and scale of tourism should be 'compatible with the environment and socio-cultural characteristics of the local community' (Fennell, 2015). Ecotourism in India has been prominently successful in the states of Kerala, Karnataka, Himachal Pradesh and Sikkim. The Department of Tourism identified six ecotourism circuits, one of which includes northeast India. There is a growing interest in the mountains of northeast India for ecotourism and has led to the emergence of Nagaland, Meghalaya and Arunachal Pradesh as potential destinations (Devi, Devi, & College, 2012).

In a recent review of the research related to tourism around protected areas, Puri et al. (2018) identified the broad themes under which research on ecotourism has taken place and attempted to find gaps. The three broad themes identified by them were – potential for ecotourism, impact assessment of nature based tourism and evaluation of an established ecotourism initiative. The majority of the reviewed studies dealt with finding 'potential for ecotourism'. However, more than half of these studies could not provide reliable qualitative or quantitative estimates that would allow a better understanding of the potential site. The authors stressed the need for adequate information on the biological wealth of the ecotourism region is as important as the social and cultural information of the local people.

I reviewed various studies on ecotourism conducted in India and nearby countries with a special emphasis on studies involved in identifying potential ecotourism sites. Studies have primarily relied on secondary data and closed ended questionnaires with some studies relying entirely upon remote sensing and satellite imagery. A list of these studies and their details are provided in Annexure

I concentrated on the most relevant studies, i.e. studies that attempted to draw a correlation between ecotourism and livelihood options for locals. The gaps identified from the literature review of these studies was the lack of institutional support for such activities, failure to gain cultural acceptance from the community for the planned activities and the problems associated with lack of local leadership support. Thus there appear to be multiple factors that can be responsible for destabilising a project to introduce alternative livelihood activities within these tight-knit mountain communities. Without a proper understanding of the status of these challenges, an intervention is unlikely to succeed.

The globalization process and the associated effects are felt most by rural people and these changes are seen to influence all aspects of their lives, including the social and economic components. Specifically, these changes can seriously affect their livelihood options through increasing commercialization of agriculture, land degradation, labour migration and changing notions of household necessity and luxury (Mertz, Wadley, & Christensen, 2005; Wadley, 2002). The people who face the most economic and social pressures are the indigenous forest dwellers practicing subsistence livelihoods.

Traditional tribal societies involved in subsistence livelihoods of agriculture and animal husbandry are strongly dependent on the forest and forest related activities such as hunting and gathering of food, fodder, fuel wood and medicinal plant collection as well as forest-linked traditional farming practices such as swidden and a variety of other complicated agricultural practices (Ramakrishnan & Kushwaha, 2001). These practices are based on local and indigenous knowledge and practice, many of which follow a tradition of conservation. This Traditional Ecological Knowledge (TEK) evolves as an adaptive process and is handed down by generations through cultural transmission. In various cases around the world, high biodiversity can be attributed to traditional livelihood practices which maintain a diversity of species and landscapes resulting in multifunctional cultural landscapes. Agroforestry systems which have a diversity of crops and trees together instead of monocultures have been seen to harbour high species richness.

Globalization can act upon such communities in different ways and through different avenues. One of the major impacts of such scenarios is through increased commercialization, trans-border trade and the evolution of new economic, social and political alignments. Although these particular conditions may not be completely new to various communities, their effect is magnified in the modern world. This is primarily because the major catalyst for these changes is the state which leaves little room for choice. Communities are forced to accept and adapt to government sponsored programmes which have the ability to alter and influence their existing livelihoods.

The cultural, social and economic changes faced by indigenous communities as a result of globalization and rapid industrialization leave them vulnerable as they have adapted to new livelihoods and markets in a short period of time. They are often forced to abandon the safety of their traditional livelihoods and their relationship with nature. The increasing importance of cash leaves them with no choice but to engage with the market or look for jobs. In the process there is a gradual sense of alienation among the younger generation that severs their cultural and social bonds.

Alternatives to such a situation have been proposed through activities that allow local people to maintain their traditional lifestyles and harmony with nature and still financially benefit from it (Blamey, 2001). Ecotourism is seen to be a win-win situation where tourists visit untouched natural sites and stay with local villagers to appreciate nature and local livelihoods and culture while causing minimum disruption. Ecotourism has met with much success across the world and provides a valuable interface between indigenous communities and urban tourists. This has been especially popular among mountain communities and hence holds great promise among the communities of the eastern Himalayas.

Northeast India, part of the Eastern Himalayas has been recognised as an area of exceptional faunal and floral richness by assigning it the role of a global biodiversity hotspot (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). Developmental forces such as mining, large dams and a movement to monocultures and cash crops in this region are slowly moving towards the biodiversity-rich yet fragile areas in the uplands of northeast India. The changing conditions can result in increasing constraints on the livelihoods of the local people as well as more threats from the outside in the form of uncontrolled resource exploitation. The developmental processes have the capacity to negatively impact mountain communities in the eastern Himalayas, many of whom still continue to practice largely subsistence livelihoods. These impacts among the mountain dwelling communities in the eastern Himalayas have hardly been studied although the changes are increasing in magnitude and seriously impacting their livelihoods and resilience. Within northeast India, the state of Arunachal Pradesh holds special interest for a variety of reasons that are of relevance to this project.

Apart from being one of the most bio diverse regions in the world, Arunachal Pradesh is also an area that is seeing tremendous developmental changes in recent times. The pace of these developmental schemes has not given adequate time for local communities to adapt. Consequently people are torn between their traditional livelihood practices and the rapidly appearing market based opportunities. At the same time there is a great deal of interest in the astounding biodiversity of this region, and especially the rich bird life. Since 2006, two new species of birds have been discovered in this region – the Bugun Liocichla (Athreya, 2006) and the recent Himalayan Forest Thrush (Alström et al., 2016) while a whole range of rare birds routinely attract ornithologists, photographers and bird watchers alike. In addition to this, Arunachal Pradesh is famed for the natural beauty of its landscapes as well as the cultural and linguistic diversity of its inhabiting tribes. These characteristics provide an important incentive to attract people for alternative livelihood options that focus on ecologically benign activities that can also provide support to the people of the region.

The primary research question for this study was to assess the opportunities for supplementary livelihood options in remote eastern Himalayan communities towards promotion of eco-agricultural landscapes.

The objectives of the study are defined by the questions below:

- What are the potential areas across the eastern Himalayas where supplementary livelihood options could be implemented?

- What are the primary income generating eco-tourism related activities that can be implemented in these areas?
- Who are the primary stakeholders responsible for the implementation of such activities and what factors determine their support for the same?
- How do alternative livelihood options influence people's well-being in selected study sites?

The study was conducted across two different regions – Upper Siang district in Arunachal Pradesh and in the region of Sikkim and northern West Bengal. While the majority of the work was done in Arunachal Pradesh, sites in Sikkim and West Bengal were visited for short durations to gather rapid information.

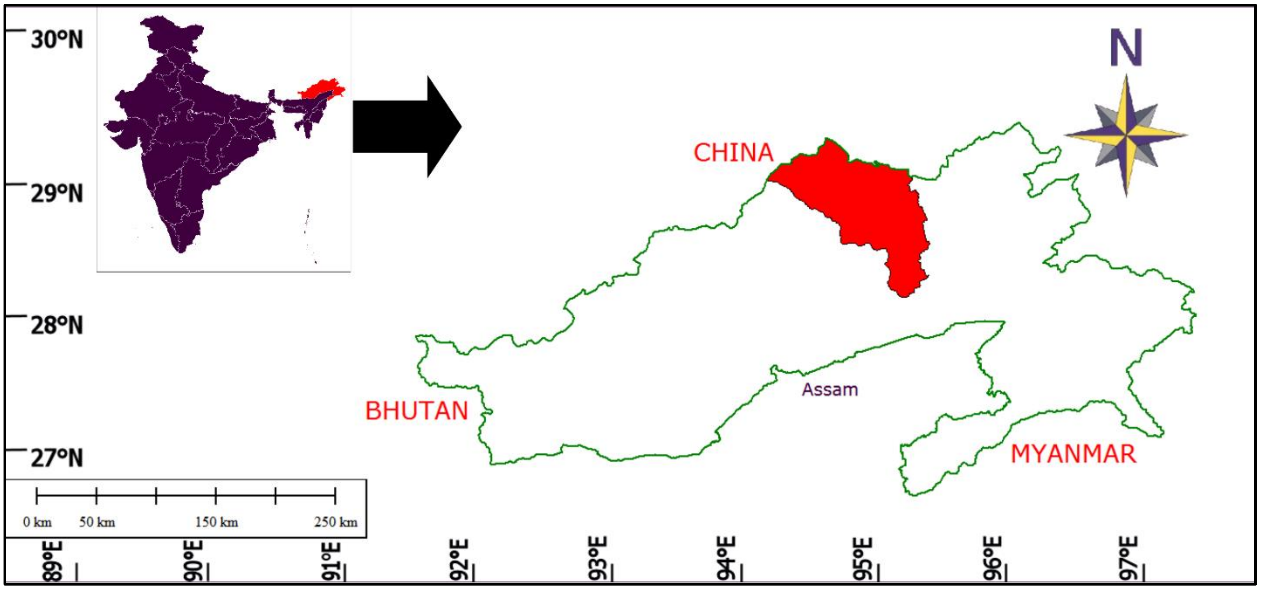
The methods included a search for relevant secondary data as well as field surveys and qualitative interviews, focus groups discussions and consultations.

1. Selection of study site: Selection for the study site was done through survey of potential areas within the Siang valley in Upper Siang district. After the preliminary surveys, the prioritization for the final study site area was made based on the natural history values of the area, potential for other tourist activities, especially nature based tourism. Apart from this we also considered social issues such as the receptiveness of local people to outsiders and the general safety and security for potential guests and visitors. Personal experiences based on the prior visits of the researcher to this region also helped narrow down to the locations and village that were considered most amenable to this project. Apart from this, exploratory field surveys were done by walking along existing trails and looking for birds and other wildlife signs as well as identifying scenic spots.
2. Qualitative Data collection: After the selection of the study site, qualitative data was collected to understand the social situation and to gain a better understanding of people's attitudes and problems in the region. Interviews were conducted to gain an insight into a variety of issues, including the maintenance of existing ecotourism ventures in Sikkim and North Bengal. These were in the form of Semi structured interviews, focus group discussion and key informant interviews.
3. Faunal documentation: Walks were conducted along established trails and roads to observe the avian and lepidopteran fauna of the region within forests, mixed use landscapes and a variety of habitats. In addition to the structured walks, any opportunistic sightings of fauna while traveling were also recorded along with the location and other parameters.
4. Household surveys focusing on agricultural and livelihood practices were conducted to gain a better understanding of the current livelihood practices and the impact of alternatives for their well-being
5. Secondary information in the form of policy documents, reports etc. (Ecotourism, Development impacts) were collected and reviewed extensively to gain an understanding of the motivations behind these schemes and how they were expected to impact local livelihoods. Existing studies in other parts of northeast India on the impact of development policies on local livelihoods were also studied in detail.

a. 2. Methodologies, Strategy and Approach

The study was conducted across two different regions – Upper Siang district in Arunachal Pradesh and in the region of Sikkim and northern West Bengal. I will describe the two areas separately. While the majority of the work was done in Arunachal Pradesh, sites in Sikkim and West Bengal were visited for short durations to gather rapid information.

Upper Siang district:



In Arunachal Pradesh, the study was primarily situated in the village of Bomdo in the district of Upper Siang .Upper Siang is one of the northern districts of Arunachal Pradesh which shares a rugged, mountainous border with China from where the Tsangpo River enters India as the Siang. The Siang continues down into the plains as the main source for the Brahmaputra River. It passes through the three Siang districts (East, West and Upper Siang) which take their name from the river and earlier constituted the Siang District. Upper Siang emerged in the year 1994 as an independent district, having been formed from East Siang.

Upper Siang also has one of the least population densities in the country with the 2011 Census providing the figure of 5.4 persons per sq. km. People mostly inhabit the river valleys with habitations confined primarily between 500 masl - 1500 masl. Upper Siang, like the other Siang districts is dominated by the Adi tribe along with the Membas, Khambas and Idu Mishmi who inhabit the border areas to the north of the district. Among the Adi, the major sub-tribes of this region are the Ashings (on the right bank of the Siang) and the Shimongs (on the left bank) with a few villages of the Tangam sub-tribe in the north. My study was restricted to the Ashing village of Bomdo on the right bank.

People here have been practising swidden cultivation along with hunting, fishing and collection of minor forest products. Historically, people of this region bartered animal products and dyes with Tibetans to the north in return for salt, metal plates, beads and bells. For the Adi, this involved crossing the Namcha Barwa mountain range on foot carrying massive loads on their backs, with trips lasting for almost a month. Swidden cultivation allows the people to grow local varieties of rice, millets, vegetables that is used exclusively for subsistence. People also raise pigs, chicken, goats in the village while the semi-domesticated bovid, the mithun (*Bos frontalis*) is an integral part of their cultural and socio-economic lives. A system of social norms and customs are maintained by the traditional local institution, the kebang composed of village elders. A majority of the Adi people subscribe to their traditional animistic beliefs which are now collectively termed as the Donyi-Polo belief system.

Sikkim and northern West Bengal:

I visited three locations in these two states to evaluate existing ecotourism and homestay facilities that had been running successfully for more than a decade. These locations are:

1. *Latpanchar, northern West Bengal* – This area is situated at the northern border of the Mahananda WLS and consists of a few villages that were earlier established by the British for Cinchona cultivation.

Figure 2: Latpanchar bird tourism area in West Bengal

2. *Yuksom, West Sikkim* – This is one of the oldest and most successful ecotourism initiatives situated near the Kanchenjunga Biosphere Reserve and managed by the Kanchenjunga Conservation Committee, a local NGO. The village of Yuksom offers trekking routes, bird watching and homestays.

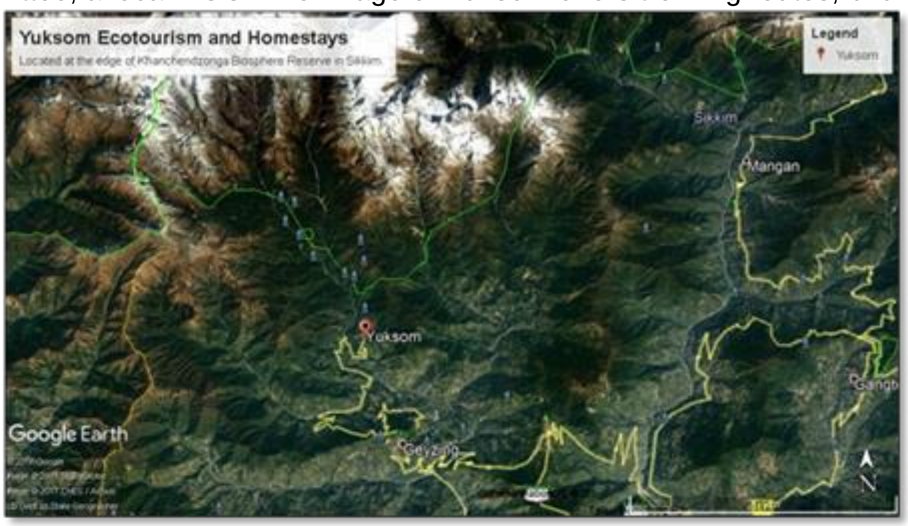


Figure 3: Yuksom Ecotourism Zone near Kanchenjunga Biosphere Reserve

The project is based on ecological and qualitative data collected from two different sources. The primary source of the data has been the region of Upper Siang in the state of Arunachal Pradesh where detailed interviews were conducted in a selected village to determine the potential for ecotourism activities and the social and economic challenges associated with it.
Apart from this, interviews were also conducted in some successful ecotourism initiatives in the state of Sikkim and northern West Bengal to gain insights into the factors that made them succeed and to understand the lessons learnt in the process.

I relied on semi-structured interviews, focus group discussions, and key-informant interviews and used each method according to the appropriate context and the nature of information required. For queries on specific issues, snowball sampling method was employed to identify the key respondents. Apart from these, extended stays in the villages and participation in festivals and community activities within the villages also provided me first-hand knowledge of the cultural and social dynamics within the prospective ecotourism sites. I also interviewed willing women respondents who shared their experience of weaving, selling of small forest produce in local markets and other value additions.

Apart from the qualitative data, I also conducted short survey walks and recorded opportunistic sightings of birds and butterflies along with photo-documentation of fauna and the landscape.

I accompanied trained guides in the established ecotourism sites in Sikkim on heritage walks or bird watching walks. During these walks I not only recorded the wildlife but also engaged with the guides to understand the level of their knowledge on fauna as well as the process by which they had been trained. These conversations were in the form of opportunistic interactions and did not follow any specific questionnaire format although they can be categorised as semi-structured interviews.

In Arunachal Pradesh, I interacted with 64 individuals which included villagers, government officials, shopkeepers and individuals belonging to the General Reserve Engineering Force (GREF).As mentioned above, I used a variety of qualitative methods to gather information on relevant topics.

In Sikkim and West Bengal I interacted with 18 individuals who included owners of homestays and people who had started bird-based ecotourism initiatives. The guides who conducted the nature walks as well as other support staff were also interviewed. I also had informal conversations with nearby shopkeepers, drivers of shared passenger vehicles, and tourists who had come to visit these areas to understand the positives and negatives associated with the particular site.

Interviews were recorded with a digital voice recorder whenever possible. This was then transcribed onto a word processing program where primary themes and issues were highlighted for detailed analysis. In the absence of audio recordings, conversations and observations were noted in a diary which was transcribed onto a word processing program later.

I also sourced secondary data from newspapers, magazines, reports and websites on recent developments in Arunachal Pradesh. Specifically, I looked for details on the impact of development and growth initiatives, their impact on local livelihoods and culture and the growth of ecotourism and other tourism related activities within the state.

I relied on semi-structured interviews, focus group discussions, and key-informant interviews and used each method according to the appropriate context and the nature of information required. Extended stays in the villages and participation in festivals and community activities within the villages also provided me first-hand knowledge of the cultural and social dynamics within the prospective ecotourism sites. I also interviewed willing women respondents who shared their experience of weaving, selling of small forest produce in local markets and other value additions. Interviews were recorded with a digital voice recorder (Panasonic) after obtaining permission from the interviewed people. This was then transcribed onto a word processing program where primary themes and issues were highlighted for detailed analysis. In the absence of audio recordings, conversations and observations were noted in a diary which was transcribed onto a word processing program later.

Ecological data on the fauna of the region was conducted through short survey walks along existing trails while opportunistic sightings of birds and butterflies were also recorded. Identification of birds were done with the help of binoculars and local field guides. On some occasions, when there were flocks, bird calls were recorded to identify the species based on calls later. Whenever possible, fauna were photographed with a digital SLR camera.

I also sourced secondary data from newspapers, magazines, reports and websites on recent developments in Arunachal Pradesh. Specifically, I looked for details on the impact of development and growth initiatives, their impact on local livelihoods and culture and the growth of ecotourism and other tourism related activities within the state.

Primary Data Collected:

- Ecological Data: Fauna of the region (Birds and butterflies) are presented in the form of tables in Annexure 1

- Qualitative Data: Household interviews and other forms of discussions were collected mostly in the form of audio recordings and then translated and transcribed

Details of Field Survey Arranged

Based on extensive discussions and a review of current literature and media reports, we identified biodiversity rich areas within the eastern Himalayas where rapid development threatens large scale changes among local communities. This formed the basis for the next stage of the work which comprise of a field survey in prospective field sites in northeast India. Within Arunachal Pradesh, we identified the north central region of the state to be an area of prime interest. These areas form part of the Siang valley, that is located on both sides of the Siang river, also known as the Tsangpo in Tibet which eventually forms the mighty Brahmaputra in the plains of Assam. Although preliminary reports from some surveys (Birand & Pawar, 2004; Newton, 2002; Singh, 1994) reveal an incredible diversity of birds and other flora and fauna in this region, it still does not have any representation among the 'Important Bird Areas' compiled by Birdlife International. This is also a region where the enormous Dihang Dibang Biosphere Reserve is located with the Mouling National Park as a part of it. Field visit was planned to central Arunachal Pradesh to the district of Upper Siang to ascertain possibility of finding long term field site for eco-tourism activities. A brief bird survey was conducted in Upper Siang to understand the biodiversity potential for implementing bird-based tourism in the future. Bird surveys were conducted outside Protected Areas within the village forest areas. During these surveys, we also recorded any opportunistic sighting of fauna along the roads.

After selection of intensive study area, regular field surveys were conducted along established trails in and around Bomdo village. Walks would last from early morning to afternoon and covered all different habitats available in the landscape. Field surveys also helped identify scenic areas that could be possible areas of interest for ecotourism.

Strategic Planning of Activities

Detailed planning is an essential part of working in northeast India although often plans need to be reevaluated based on the prevalent conditions which are highly dynamic. This is especially important for field work in remote mountains and valleys within the region which are not well connected by good roads, telephone and even electricity. Logistics is a primary issue of working here and needs to be seriously considered. Working in a state like Arunachal Pradesh also requires official documents like the Inner Line Permit to enter and remain in the state. These documents have to be renewed frequently and field plans need to factor this issue as it involves additional travel.

Travel within the rugged terrain of Arunachal Pradesh also requires access to good vehicles and logistical support without which it may be impossible to stick to timelines. The other important issue with regard to planning of fieldwork is the availability and selection of local field staff. Since the effectiveness of the work depends primarily on the field support from the local people, it is essential to have a good field team who are willing and able to carry out the planned work. It is therefore also important to maintain good relations with elders of the villages and the leaders of the local institutions. Their support is essential to being able to conduct surveys in their land, hire people and to get free and honest feedback regarding the objectives of the project. It is important to invest as much time as necessary to develop good relations and maintain it.

Activity-wise Time Frame followed using Gantt/PERT Chart

	Jun 2016	Dec 2016	Jun 2017	Dec 2017	Jun 2018	Dec 2018	Aug 2019

What are the potential areas across the eastern Himalayas where supplementary livelihood options could be implemented?							
What are the primary income generating eco-tourism related activities that can be implemented in these areas?							
Who are the primary stakeholders responsible for the implementation of such activities and what factors determine their support for the same?							
How do alternative livelihood options influence people's well-being in selected study sites?							

b. 3. Key Findings and Results

The primary findings from this research project are summarized below according to the nature of the results:

Ecological information: Results on the faunal diversity of this region was collected through bird surveys and butterfly walks to identify hooks for nature-based tourism. A list of birds for this region includes 160 species with most of them available in close proximity of the village. I also identified 50 butterfly species along with photo documentation. Various other species of small mammals are present in the mixed forests that surround the village. The collation of faunal data is an ongoing process and needs to be coninued through other visiting scientists who come into the region.

Best practices from successful nature based tourism sites: Visits to two successful ecotourism sites in north West Bengal and Sikkim provided important information on how nature-based tourism sites can be managed successfully. The bird tourism area of Latpanchar in northern West Bengal is situated at the border of the Mahananda Wildlife Sanctuary and has employed various local youth as guides. Specialist tourists such as bird watchers and wildlife photographers from Kolkata have become regular visitors to this place. My interviews with various stakeholders gave me important insights on the need to involve the entire community. The other ecotourism site of Yuksom in West Sikkim has been an important and popular area with mountaineers, trekkers, nature lovers and even Buddhist tourists. The issue here was more of controlling the flow of tourists and setting in place a system that filtered out all but the serious and discerning tourist who had an appreciation of the natural beauty and cultural harmony of the place. This was possible through the concerted efforts of local youth and a progressive NGO (KCC). KCC has managed to build excellent networks among the tourists across the world and involved the tourism and forest departments of the state to have a holistic system in place. An important lesson in this place was the need to involve all stakeholders and to let the benefits come to the local people. In fragile mountain areas it was also important to restrict the numbers of tourists and not get carried away by the success in a particular season.

Identification of environmentally benign alternative livelihoods involving tourism: In addition to nature-based tourism, I also investigated the possibility of introducing other opportunities for earning cash that would not be harmful to the environment or disrupt traditional livelihood practices. For this I explored various options and discussed them with the villagers followed by a personal evaluation of the logistical limitations, social and cultural context involved with each activity. As part of this exercise, I identified additional options - trekking, camping, angling, sale of organic produce and handicrafts. Apart from these, the setting up of homestays appears to be a prime opportunity for visiting tourists to learn about local Adi culture and also offer the home-owners a fine opportunity to earn cash by hosting guests in their spare rooms.

Consultations with village authorities to discuss limitations and problems: This is a crucial process and each of the different options for ecotourism are discussed with the village authorities to gain a better understanding of the practical problems and limitations involved with some of the potential plans. In my consultations, I involved both the government body of the Panchayat as well as elders of the Adi Kebang, the traditional local institution that has been responsible for all issues in the village from generations. I also involved the younger generation of unemployed educated youth who would be crucial to the success of nature based outdoor activities due to their ability to easily communicate with outsiders as well as their familiarity with technology. In general there is a great deal of support and excitement for such initiatives although there are underlying unresolved issues with regard to the handling of finances and the setting up of cooperative to handle the day-to-day functioning of the ecotourism activities. Women have also not been involved in these discussion and to ensure gender equity in the planned activities, their involvement has to increase.

Key Results

- **Existing Scenario and the need for alternative livelihoods:** Respondents described the existing economic and social scenario in light of the rapid changes occurring in the region. These changes have increased privatization of land and the importance of cash. This has led more households looking for opportunities to earn cash - whether in the form of small contracts for village works or labour employment with the GREF for road construction or even as permanent jobs with the government. With increasing reach and popularity of education, the younger generation is going to schools and even colleges all of which are far away from the village. In comparison to the existing number of only five graduates in the village, currently there are more than 14 students who are studying for their graduation. However, this has given rise to a new generation who are experiencing a sense of alienation from their traditional subsistence livelihoods of swidden (*jhum*). The educated younger generations are no longer interested in agriculture and are looking for opportunities to earn cash in the small towns of Arunachal Pradesh. The lack of industries and large commercial establishments in Arunachal Pradesh ensure that there are very few jobs available for the growing educated workforce in the cities that have migrated from the villages. A greater incorporation into the market economy and the recent availability of finished goods in these remote areas have further increased people's requirement for cash. People also stated that the transition to cash crops from swidden is not favourable to them due to the remote location of the village and consequent lack of transportation and communication facilities. There is a need to find gainful and yet environment friendly employment within the village that does not disrupt their traditional lifestyle and cultural practices. Ecotourism has the potential to provide earning opportunities to people in the village without forcing major changes to their lives.
- **Nature of tourist demands:** A major consideration before deciding on the activities to be included under ecotourism is to determine which activities are desirable for the tourists and are likely to attract people. In this regard, I identified certain activities based on talks with ecotourism operators, tourists and through the perusal of websites and discussion forums dealing with tourism in northeast India. Some of these have been successfully implemented in other ecotourism locations in the eastern Himalayas. My personal experience (during the current fieldwork as well as previous research engagements in northeast India) allowed me to interact with various tourists in this region who expressed their desire for various ecotourism activities such as bird-watching, photography and trekking.
- **Learnings from Ecotourism initiatives in West Bengal and Sikkim:** Visits to Latpanchar in West Bengal and Yuksom in Sikkim provided some key pointers that would be helpful in the implementation of successful ecotourism project.

Training of local youth - In both the locations, local educated youth who had been unemployed were trained in identifying birds, and other fauna and flora and learning the scientific names. This made them able to communicate well with photographers and amateur bird watchers who wanted specific information on the biodiversity of the region. The training was provided by experts in a comprehensive workshop in the initial stages of the project.

Involvement of the community - In Yuksom, the KCC played a major role in coordinating the activities with the Forest Department and kept a close watch on the type of visitors coming into the area. They ensured that the peace and culture of the area was given first priority and only responsible ecotourists were allowed. They work with the entire community and have complete support of the residents who benefit from tourist visits. In Latpanchar, there was some initial opposition from some members of the community who felt that the benefits of the ecotourism would be available only to the few houses which were providing homestays due to the better infrastructure. However, they were convinced to participate in the process and benefit from alternate means such as opening small shops or acting as local guides. This was successful and over time the entire community saw the benefits and supported the process.

Maintenance of homestays - Yuksom has an exceptional system of homestays in which residents give out one or two rooms of their houses and provide simple, hygienic food at reasonable prices. The presence of trekking trails, monasteries and other scenic landscapes in close proximity was an added incentive. However, with time Yuksom has also seen the emergence of some standard hotels which are on the outskirts. In Latpanchar there are no hotels and homestays are the only option. Bookings are done over phone as the area is remote. However, the homestays are very well maintained and professionally run by the owners. This has given rise to a loyal group of ecotourists and photographers who return here every year to see rare birds such as the Rufous-necked Hornbill. The homestay owners guarantee complete safety and take responsibility for the food and welfare of guests during their stay.

- **Identification of alternative livelihoods well suited to the study area:**

Birds and Butterfly watching:

The Upper Siang district is located in a biodiversity rich region that is yet to be fully investigated in terms of the biodiversity values present in this region. The presence of various rare birds that have limited distribution make this region a desirable destination for birdwatchers and wildlife photographers who wish to go off the beaten track. The faunal surveys during this project resulted in the generation of a list of birds and butterflies most of which have not been reported earlier for this region. These were all found in close proximity of the village and could be spotted within a day’s walk of the main village. The presence of such a diverse range of species within reach of the village is a positive development and provides convincing evidence of the potential for birds and butterfly based ecotourism. Local youngsters who know the forests and trails around the village intimately are able to act as guides and direct external visitors on the best routes as well as the timings to maximise sightings.

Homestays and local culture:

Homestays would not only allow the visitors to stay in close proximity to the villagers and experience their food, culture and lifestyle, it would also allow the hosts to earn some important cash income by letting out their spare rooms and providing basic services like clean, hygienic meals that promoted local organically grown food and ethnic cuisine. Staying with the villagers in their houses would also allow the guests to participate and understand the various festivals, rituals and cultural practices and see them through the eyes of the locals. This would also foster a greater understanding of mountain people and their problems among outsiders.

Trekking and other leisure activities:

Activities such as trekking, camping in mountains, angling and swimming in the Siang river can be promoted in Upper Siang due to the proximity of mountains as well as the mighty river. The scenic landscapes around the village promote panoramic views of the snow mountains to the north, the Siang river and the various hill ranges on all sides. The steep nature of the terrain can provide a challenge to trekkers who want to test their abilities. These routes are well known by the villagers and the trails are maintained to keep them suitable for walking throughout the year. The Siang river and its various tributaries also lie in close proximity to the village and the villagers often use these areas for fishing. Angling can therefore be a potential ecotourism activity that will also allow visitors to experience the majesty and power of the mighty Siang river from close proximity.

Handicrafts and organic items:

Ecotourism is also another opportunity to market locally made goods that do not have access to large markets and delivery systems. Value addition to locally grown food items and traditional handicrafts make them desirable to external visitors coming from cities. Nyaupane and Paudel (2011) identify various 'green options' available for the villagers such as locally produced food, beverages and handicrafts. Food items and handicrafts also provide opportunities for women to participate and contribute valuable services towards the success of ecotourism initiatives (Scheyvens, 2007).

The growing popularity of healthy organic food items provides a ready market for locally produced items in the villages. Villagers growing these items have been unable to sell them as the distance to the market and lack of roads and transportation facilities prevent them from doing so. With the presence of willing buyers in the villages in the form of ecotourists, this will benefit the people and motivate them to continue growing organic food items and avoid fertilisers and pesticides. The added advantage of watching the products being made in front of their eyes will motivate visitors to purchase them and provide a just price to the villagers.

There is a growing acknowledgement of the fact that the market-based development model may not be ideal for all regions and communities. In northeast India changes brought forth by rapid development threatens to impact both traditional livelihoods and well-being of the people as well the rich biodiversity. Ecotourism has shown great potential across the world and there are various successful models in Latin America, Africa and Asia. These success stories have shown that it is possible to balance socio-economic development of local communities through benefit sharing, while conserving the rich biodiversity that surround them. In the mountains of the eastern Himalayas, there is tremendous scope for utilising ecotourism to strike this balance between development of communities and the maintenance of biodiversity. Apart from this, ecotourism also allows urban middle class from across the country to experience and understand the lives of mountain communities and develop a greater appreciation for their culture and livelihoods.

However, ecotourism is vastly different from regular tourism because it needs to ensure that while visitors have new and unique experiences, this does not negatively affect the communities hosting them. Thus, a great deal of care is necessary before ecotourism projects can be launched. The research required to understand these finer details of the communities and their potential as ecotourism locations is lacking in India and this ultimately translates to very few successful projects. This project explored the potential ecotourism opportunities and discovered that there are many underlying factors that need to be considered.

The potential success of nature based outdoor activities such as trekking and bird/butterfly watching requires well-trained educated guides who are also able to communicate well with outsiders. Till a few generations ago this would have been a huge gap among the Adi of Upper Siang. However, today many children are leaving the village to go to towns for higher education. These youth often end up without jobs and unable to use their education and exposure in any way. Such youth would be ideal beneficiaries of outdoor ecotourism activities in which they can guide visitors. The lack of good roads and transportation has prevented the villagers from growing any major crops for the market. Ecotourism can ensure a market for various products even if they are grown in a small scale by eliminating the need for middlemen and transporting it to markets. This would also ensure a fair price for them by avoiding payment to middlemen who corner most of the profits.

On the other hand, there are many potential pitfalls that need to be identified. The success of the ecotourism venture also relies heavily on the quality of the homestay accommodations as the guests have no other option. Since there is a great difference in the lifestyles of hosts and visitors, the homestay needs to be comfortable enough with minimum hygiene, solar lights etc. Adi villages have also been dealing with dual power centers in the village in the form of the Adi Kebang and the Panchayat. Both need to be taken into confidence if a project needs to be successful. Projects also need to understand limitations within the village that cannot be changed - such as the period for agriculture during which all the residents are busy with their responsibilities. Agriculture is still the primary occupation in the village and tourism during that period may not be feasible.

Understanding these various factors can only contribute to a more informed and well prepared approach to implementing ecotourism in these remote mountains.

c. 4. Overall Achievements

Achievements under each of the objectives are listed below in a tabular format

Objectives	Achievements
What are the potential areas across the eastern Himalayas where supplementary livelihood options could be implemented?	Survey of literature followed by field survey in Upper Siang district and identification of study site village
What are the primary income generating eco-tourism related activities that can be implemented in these areas?	Field surveys and interviews to identify the primary income generating ecotourism related activities were conducted. The activities identified from this exercise were: – Bird/Butterfly watching – Trekking & photography of scenic landscapes – Angling and camping by the Siang river – Organic products and handicrafts

Who are the primary stakeholders responsible for the implementation of such activities and what factors determine their support for the same?	Extensive interviews, focus group discussions and meetings with elders and all concerned people in the village allowed for the identification of the major stakeholders and factors that influence their support for alternative livelihoods. These stakeholders are: – Adi *Kebang* (traditional institution) – Panchayat representatives – Teachers – Young people – Women's Groups
How do alternate livelihood options influence people's well-being in selected study sites?	Alternate livelihood options will provide much needed relief to farmers in a time of change when they are unable to decide whether to engage with the market completely or to retain their subsistence cultivation. It will be able to provide employment to educated youngsters from the village who are interested in earning cash and engaging with outsiders. Selling handicrafts and organic products to visitors will also allow them to avoid the problem of market availability, communication and transport that has prevented the sale of such goods earlier. Outdoor field based activities such as trekking and bird watching will provide more incentives for people to maintain their village forests.

In my review of previous studies on ecotourism and alternate livelihoods, I have identified the fact that there have been very few studies from the eastern Himalayas. My work and review of literature adds to that growing database that will allow future projects to make better decisions with regard to ecotourism and alternate livelihoods in the IHR. In addition to that, the ecological surveys have provided new information for this region on the avifauna and butterflies. This has been provided in the Annexure 1.

The main aim of the project was to develop the green skills among the villagers and to convert them into alternative livelihood opportunities. These alternative livelihood opportunities would help the villagers in earning revenue from ecotourism. Therefore, the project does not specifically develop new green skills but utilizes existing green skills among the local people and promotes it for improvement of livelihoods as well as the growth of ecotourism.

d. 5. Impacts of Fellowship in IHR

Socio-Economic Development

- Jobs provided to field assistants during the period of the study.

- The overall aim of the project was to improve the socio-economic development of the people through alternative livelihoods.
- The recommendations and findings of the project can help in improving the socio-economic development through environment friendly green jobs.

Scientific Management of Natural Resources

- The study was conducted in an area where the management of natural resources are done by the village authorities who were well aware of the need for managing it efficiently
- My project reiterated the need to maintain their natural wealth, including the wildlife and flora of the place since they would be directly important for bringing in nature based ecotourism to the region.

Conservation of Biodiversity

- Biodiversity conservation by local village authorities in the form of leaving some areas free from bird trapping and fishing to encourage the visibility and availability of rare species were discussed with the people.
- The project identified activities like bird watching, butterfly watching and walking on nature trails as important alternative livelihoods and which will directly influence local people to maintain the biodiversity of their region.

Protection of Environment

- The need to maintain their forests and natural resources in a healthy state for the success of the alternative livelihoods are a strong incentive for the people to protect their environment from large scale conversion to plantations.

Strengthening Networking in IHR

- I helped strengthen networking in the IHR by studying the best practices from one region and trying to apply those learnings in a different region. This allowed me the ability to interact with both sets of people.
- The project would have been able to organize a workshop to bring together successful practitioners from one part of the IHR to interact with others who are starting out if there were no restrictions on time and resources for this project. It is something that can be followed up by future researchers.

e. 6. Exit Strategy and Sustainability

The findings from this project contribute to raising awareness about the impact of developmental processes on mountain communities. The project has attempted to find alternative livelihood options for remote villages in the eastern Himalayas which are environmentally friendly and can also fulfil the needs of cash income that is growing.

These findings can contribute towards the sustainable development of the IHR in two different ways. Firstly, it is one of the few research projects that documents the impact of development policy on the well-being of mountain communities in the IHR. Through this study, it is apparent that not all forms of development that are being promoted by government agencies are appropriate for adoption by all communities in the region - especially those which forces farmers into the market economy with which they are largely unfamiliar. Such inappropriate livelihood diversions forced by government policies can cause great harm to their social and economic lives. Government agencies would be better advised to have flexible strategies that takes into account that local realities such as communication, familiarity with markets and fair prices. Remote communities might be better served by introducing them to markets in a gradual way when compared to other areas which are closer to cities and towns. A gradual and phase-wise introduction of market options with the onus being on the villagers to choose when they want to engage with the global economy would help in promoting sustainable livelihoods.

The second contribution to promoting sustainable development in the IHR is through the exploration of alternative livelihood practices that are environmentally friendly and also popular with a particular group of tourists. Alternative livelihood options have become imperative as the need for cash has ensured that subsistence-based communities had no other options apart from labour and engaging with a market that is loaded heavily against them. This research project has explored the role of 'green' and 'cultural' tourist activities that is non-extractive and non-destructive in nature. It also provides more incentives for village communities to safeguard their natural resource base and retain cultural practices like handicrafts, songs and dances. These findings provide hope to many similar communities across the remote parts of the IHR who are facing such similar challenges to their livelihoods and well-being from sudden developmental programs.

Each community and each region has different challenges and some of them are specific to the region. However, through this project I have come across some general learnings that would be beneficial for similar projects in other parts of the IHR.

Nature based ecotourism has been successful in various locations across the Eastern Himalayas and if it implemented properly, it has a lot of scope in other sites which have rich biodiversity, scenic landscapes and an amenable local community. During implementation of any ecotourism or other nature-based tourism project that requires the active participation from the community, a balance needs to be maintained between tourist needs and local customs and practices. For example, although winter is a favourable time for tourists to travel to the region, early winter period (September/October) is the time when harvesting of some crops are still being done by the villagers. This period can also clash with many cultural festivals that are important to the local people. During this period, they may not be able to provide enough time for the tourism activities. Thus, tourist schedules should be flexible and adapt to local livelihoods and priorities.

There also needs to be an appreciation of local culture and rules of the tribal communities by outsiders. Research in many other parts of the world have also demonstrated that with the entry of revenue-based livelihoods, egalitarian communities lose much of their intra group equality. Tribal communities in the IHR are all extremely egalitarian, but with their exposure to the external world, power imbalances have been created even within communities. Any intervention, even if it is ecotourism, needs to keep this in mind and avoid disturbing the social balance within local societies.

Any form of alternative livelihood such as ecotourism requires special skills among the hosting villagers and these skills can only be obtained through proper training. This training needs to be done by experienced practitioners who have been successfully running similar projects in other areas. Much of the success and the sustainability of such alternative livelihoods depends on the quality of training that is imparted to the hosts so that they are able to connect better with tourists and visitors from outside.

The most important factor that can contribute to the success or failure of similar projects is the support from the local institutions and elders of the communities. For this, there needs to be complete involvement of community institutions, elders and any other existing institutions that will not only ensure support for the project but also ensure a sustainable course of action. The focus should be on empowering local governance and people rather than relying on external NGO's or government bodies.

The current study was able to document only some of the faunal resources for the region. Such basic research on the biodiversity of community managed forests and mixed-use landscapes need to be done across other taxa such as fishes, amphibians, reptiles and even insects. This would help highlight the importance of mixed-use landscapes in northeast India as reservoirs of biodiversity separate from the protected area network.

There is also an urgent need to document conservation and management of natural resources by local institutions and groups. All mountain communities in the IHR already have various internal measures monitored and enforced through local institutions to safeguard and manage their natural resources effectively. These efforts of local governance to protect biodiversity need to be documented so that they can be supported and strengthened.

With regard to alternative sources of livelihoods and ecotourism, a much-needed study would be to monitor existing initiatives across the IHR in different states and to compare and contrast them to understand the best practices and common problems with them. A follow up study in areas where ecotourism is ongoing to understand the benefits to local people and problems would further help in defining appropriate strategies to implement them elsewhere. In my research I have tried to gather some learnings from sites in Sikkim and north West Bengal, and through reviewing existing published material but other studies could attempt a much broader comparison across a larger geographic and thematic areas. This would include physical visits to all sites and interviews and in-depth study of the project personnel and its functioning.

Recommendations for sustaining the fellowship in IHR are as follows:

f.

- **Support from relevant government departments:** Sustaining a project of this nature requires a great deal of support and interest from relevant government agencies. However, this was a prominent absence for the study region and even after repeated attempts it was difficult to involve the concerned government departments (Tourism, Forests and Wildlife, Agriculture). It is not possible for researchers to carry out their research and also spend endless amounts of time trying to gather support from official agencies. The motivation in such projects for the welfare and benefit of the local people have to be incorporated among all local level state departments and their staff. Without their support it is unlikely to work.
- **Outreach and publicity of ecotourism:** Ecotourism is still a form of tourism that is not preferred by a majority of tourists in India. Although the average income of the Indian middle class has risen substantially, they prefer to travel abroad rather than to locations within India. One reason for that is that they are unaware of many of the unique aspects of nature, culture and associated ecotourism that exists in various parts of the IHR. Awareness campaigns to educate and inform people about these options are required so that it reaches a greater number of people and interested people can come and experience it. This might require targeted approaches towards adventurous and outdoor focused travellers such as photographers, hikers, adventure sports enthusiasts as well as people who are interested in knowing more about diverse cultures within India.
- **Maintaining rapport with local people:** Projects of this nature can only succeed with the support of the local people and the existing institutions. During my work, I was able to establish good rapport with the villagers and able to communicate the need for their support. However, with time these relationships can weaken with the absence of researchers or facilitators. There needs to be regular workshops or outreach programs to involve existing areas of ecotourism and to understand and solve any problems being faced at these sites.
- **Safeguarding biodiversity as a priority:** While ecotourism and other associated activities are important alternative livelihoods, it is also important to remember that biodiversity conservation should be given top priority. Any activity that may impact the biodiversity of the region should be stopped. This could be indirect and unintentional too, such as the spread of invasive species by visitors from outside. There are also chances for wildlife trade to utilise these networks to further their goals. Village authorities need to be constantly educated about these potential threats and methods to effectively counter them.

g. 7. References/Bibliography

Alström, P., Rasmussen, P. C., Zhao, C., Xu, J., Dalvi, S., Cai, T., … Olsson, U. (2016). Integrative taxonomy of the Plain-backed Thrush (Zoothera mollissima) complex (Aves, Turdidae) reveals cryptic species, including a new species. *Avian Research*, *7*, 1. https://doi.org/10.1186/s40657-016-0037-2

Athreya, R. (2006). A new species of "'Liocichla'" (Aves:Timaliidae) from Eaglenest Wildlife Sanctuary, Arunachal Pradesh, India. *Indian Birds*, *2*(4), 82–94. Retrieved from http://www.birdlife.org/news/news/2006/09/indian_birds_liocichla.pdf

Birand, A., & Pawar, S. (2004). An ornithological survey in north-east India. *Forktail*, *20*(June 2001), 7–16.

Blamey, R. K. (2001). *Principles of Ecotourism*. *The encyclopedia of ecotourism*. https://doi.org/10.1007/s13398-014-0173-7.2

Boo, E. (1990). Ecotourism: the potentials and pitfalls, volume 1. *Ecotourism: The Potentials and Pitfalls, Volume 1.*

Devi, M. K., Devi, M. K., & College, S. D. (2012). Ecotourism in Assam : A Promising Opportunity for Development. *South Asian Journal of Tourism and Heritage*, *5*(1).

Fennell, D. (2015). *Ecotourism* (Fourth Edi). Routledge.

Hetzer, N. D. (1965). Environment, tourism, culture. *Links*, *1*(3).

Honey, M. (2008). *Ecotourism and sustainable development: Who owns paradise?* Island Press.

Lascurain, H. C. (1987). The future of ecotourism. *Mexico Journal*, *1*(987), 1.

Mertz, O., Wadley, R. L., & Christensen, A. E. (2005). Local land use strategies in a globalizing world: Subsistence farming, cash crops and income diversification. *Agricultural Systems*, *85*(3 SPEC. ISS.), 209–215. https://doi.org/10.1016/j.agsy.2005.06.007

Myers, N., Mittermeier, R. a, Mittermeier, C. G., da Fonseca, G. a, & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*(6772), 853–858. https://doi.org/10.1038/35002501

Newton, P. N. (2002). Bird records from the Siang River valley, Arunachal Pradesh, India. *Forktail*, *18*(January 2000), 156–157.

Nyaupane, G. P., & Poudel, S. (2011). Linkages among biodiversity, livelihood, and tourism. *Annals of Tourism Research*, *38*(4), 1344–1366. https://doi.org/10.1016/j.annals.2011.03.006

Puri, M., Karanth, K. K., & Thapa, B. (2018). Trends and pathways for ecotourism research in India. *Journal of Ecotourism*, *0*(0), 1–20. https://doi.org/10.1080/14724049.2018.1474885

Ramakrishnan, P. S., & Kushwaha, S. P. S. (2001). Secondary forests of the Himalaya with emphasis on the North-Eastern hill region of India. In *Journal of Tropical Forest Science* (Vol. 13, pp. 727–747).

Scheyvens, R. (2007). Ecotourism and gender issues. In J. Higham (Ed.), *Critical Issues in Ecotourism*. Elsevier.

Singh, P. (1994). Recent bird records from Arunachal Pradesh. *Forktail*, *10*(November 1992), 65–104.

Wadley, R. L. (2002). Coping with Crisis — Smoke , Drought , Flood and Currency : Iban Households in West Kalimantan , Indonesia, *24*(1).

Wight, P. (1993). Ecotourism: ethics or eco-sell? *Journal of Travel Research*, *31*(3), 3–9.

h. 8. Acknowledgements

I would like to thank my supervisor Dr. Nitin Rai whose guidance through this project was significant. I would like to thank the National Mission for Himalayan Studies whose funding has been instrumental in the pursuance and completion of this research. I would also like to thank the Ministry of Environment, Forest and Climate Change, Er. Kireet Kumar and Dr. Ravindra Verma, ATREE, Bangalore and people of the villages of Upper Siang, especially Bomdo village.

i. Appendices

Appendix 1a. List of birds in the study area

S. No.	FAMILY	ENGLISH NAME	LATIN NAME	STATUS
1	Pycnonotidae	Ashy Bulbul	*Hemixos flavala*	r
2	Corvidae	Ashy Drongo	*Dicrurus leucophaeus*	R
3	Strigidae	Asian Barred Owlet	*Glaucidium cuculoides*	r
4	Hirundinidae	Asian House-Martin	*Delichon dasypus*	r
5	Corvidae	Bar-winged Flycatcher-shrike	*Hemipus picatus*	R
6	Sittidae	Beautiful Nuthatch	*Sitta formosa*	r
7	Sylviidae	Beautiful Sibia	*Heterophasia pulchella*	r
8	Accipitridae	Black Baza	*Aviceda leuphotes*	r
9	Pycnonotidae	Black Bulbul	*Hypsipetes leucocephalus*	R
10	Corvidae	Black Drongo	*Dicrurus macrocercus*	R
11	Accipitridae	Black Eagle	*Ictinaetus malayensis*	R
12	Turdidae	Black Redstart	*Phoenicurus ochruros*	rW
13	Muscicapidae	Black-backed Forktail	*Enicurus immaculatus*	r
14	Sylviidae	Black-chinned Yuhina	*Yuhina nigrimenta*	r
15	Sylviidae	Black-eared Shrike-Babbler	*Pteruthius melanotis*	r
16	Sylviidae	Black-faced Laughingthrush	*Garrulax affinis*	r
17	Sylviidae	Black-faced Warbler	*Abroscopus schisticeps*	r
18	Sylviidae	Black-headed Shrike-Babbler	*Pteruthius rufiventer*	r
19	Nectariniidae	Black-throated Sunbird	*Aethopyga saturata*	r
20	Aegithalidae	Black-throated Tit	*Aegithalos concinnus*	r
21	Muscicapidae	Blue Whistling-Thrush	*Myiophonus caeruleus*	R
22	Alcedinidae	Blue-eared Kingfisher	*Alcedo meninting*	R
23	Turdidae	Blue-fronted Redstart	*Phoenicurus frontalis*	r
24	Pittidae	Blue-naped Pitta	*Pitta nipalensis*	r
25	Megalaimidae	Blue-throated Barbet	*Megalaima asiatica*	R
26	Sylviidae	Blue-winged Laughingthrush	*Garrulax squamatus*	r
27	Corvidae	Bronzed Drongo	*Dicrurus aeneus*	R
28	Cinclidae	Brown Dipper	*Cinclus pallasii*	r
29	Laniidae	Brown Shrike	*Lanius cristatus*	W
30	Strigidae	Brown Wood-Owl	*Strix leptogrammica*	R
31	Sittidae	Chestnut-bellied Nuthatch	*Sitta castanea*	R
32	Turdidae	Chestnut-bellied Rock-Thrush	*Monticola rufiventris*	r
33	Sylviidae	Chestnut-crowned Bush-Warbler	*Cettia major*	r
34	Sylviidae	Chestnut-headed Tesia	*Tesia castaneocoronata*	r

35	Sylviidae	Chestnut-tailed Minla	*Minla strigula*	r
36	Corvidae	Collared Treepie	*Dendrocitta frontalis*	r
37	Accipitridae	Common Buzzard	*Buteo buteo*	rW
38	Cuculidae	Common Hawk-Cuckoo	*Cuculus varius*	R
39	Falconidae	Common Kestrel	*Falco tinnunculus*	RW
40	Sylviidae	Common Tailorbird	*Orthotomus sutorius*	R
41	Fringillidae	Crested Bunting	*Melophus lathami*	R
42	Cerylidae	Crested Kingfisher	*Megaceryle lugubris*	R
43	Alaudidae	Crested Lark	*Galerida cristata*	R
44	Accipitridae	Crested Serpent-Eagle	*Spilornis cheela*	R
45	Sylviidae	Cutia	*Cutia nipalensis*	r
46	Turdidae	Daurian Redstart	*Phoenicurus auroreus*	rw
47	Columbidae	Emerald Dove	*Chalcophaps indica*	R
48	Cuculidae	Eurasian Cuckoo	*Cuculus canorus*	r
49	Upupidae	Eurasian Hoopoe	*Upupa epops*	RW
50	Accipitridae	Eurasian Sparrowhawk	*Accipiter nisus*	RW
51	Passeridae	Eurasian Tree Sparrow	*Passer montanus*	R
52	Nectariniidae	Fire-breasted Flowerpecker	*Dicaeum ignipectus*	r
53	Sylviidae	Golden Babbler	*Stachyris chrysaea*	r
54	Sylviidae	Golden-breasted Fulvetta	*Alcippe chrysotis*	r
55	Megalaimidae	Golden-throated Barbet	*Megalaima franklinii*	r
56	Megalaimidae	Great Barbet	*Megalaima virens*	r
57	Paridae	Great Tit	*Parus major*	R
58	Centropodidae	Greater Coucal	*Centropus sinensis*	R
59	Sylviidae	Greater Necklaced Laughingthrush	*Garrulax pectoralis*	r
60	Corvidae	Green Magpie	*Cissa chinensis*	r
61	Columbidae	Green Pigeon	*Treron sp.*	R
62	Paridae	Green-backed Tit	*Parus monticolus*	r
63	Nectariniidae	Green-tailed Sunbird	*Aethopyga nipalensis*	r
64	Turdidae	Grey Bushchat	*Saxicola ferrea*	R
65	Sylviidae	Grey Sibia	*Heterophasia gracilis*	r
66	Corvidae	Grey Treepie	*Dendrocitta formosae*	r
67	Passeridae	Grey Wagtail	*Motacilla cinerea*	rW
68	Laniidae	Grey-backed Shrike	*Lanius tephronotus*	rW
69	Corvidae	Grey-chinned Minivet	*Pericrocotus solaris*	r
70	Muscicapidae	Grey-headed Canary-Flycatcher	*Culicicapa ceylonensis*	r
71	Sylviidae	Grey-hooded Warbler	*Seicercus xanthoschistos*	r
72	Cisticolidae	Hill Prinia	*Prinia atrogularis*	r

73	Accipitridae	Himalayan Griffon	*Gyps himalayensis*	R
74	Phalacrocoracidae	Indian Cormorant	*Phalacrocorax fuscicollis*	R
75	Cuculidae	Indian Cuckoo	*Cuculus micropterus*	R
76	Coraciidae	Indian Roller	*Coracias benghalensis*	R
77	Phasianidae	Kalij Pheasant	*Lophura leucomelanos*	r
78	Corvidae	Large-billed Crow	*Corvus macrorhynchos*	r
79	Falconidae	Lesser Kestrel	*Falco naumanni*	w?p
80	Corvidae	Lesser Racket-tailed Drongo	*Dicrurus remifer*	r
81	Muscicapidae	Lesser Shortwing	*Brachypteryx leucophrys*	r
82	Picidae	Lesser Yellownape	*Picus chlorolophus*	R
83	Fringillidae	Little Bunting	*Emberiza pusilla*	w
84	Meropidae	Little Green Bee-eater	*Merops orientalis*	R
85	Muscicapidae	Little Pied Flycatcher	*Ficedula westermanni*	r
86	Eurylaimidae	Long-tailed Broadbill	*Psarisomus dalhousiae*	r
87	Corvidae	Long-tailed Minivet	*Pericrocotus ethologus*	r
88	Laniidae	Long-tailed Shrike	*Lanius schach*	R
89	Pycnonotidae	Mountain Bulbul	*Hypsipetes mcclellandii*	r
90	Columbidae	Mountain Imperial-Pigeon	*Ducula badia*	R
91	Strigidae	Mountain Scops-Owl	*Otus spilocephalus*	r
92	Sylviidae	Nepal Fulvetta	*Alcippe nipalensis*	r
93	Passeridae	Olive-backed Pipit	*Anthus hodgsoni*	RW
94	Irenidae	Orange-bellied Leafbird	*Chloropsis hardwickii*	R
95	Falconidae	Oriental Hobby	*Falco severus*	R
96	Muscicapidae	Oriental Magpie-Robin	*Copsychus saularis*	R
97	Alaudidae	Oriental Skylark	*Alauda gulgula*	R
98	Columbidae	Oriental Turtle-Dove	*Streptopelia orientalis*	RW
99	Zosteropidae	Oriental White-eye	*Zosterops palpebrosus*	R
100	Picidae	Pale-headed Woodpecker	*Gecinulus grantia*	r
101	Columbidae	Pin-tailed Green-Pigeon	*Treron apicauda*	r
102	Turdidae	Plain-backed Thrush	*Zoothera mollissima*	r
103	Turdidae	Plumbeous Water-Redstart	*Rhyacornis fuliginosus*	r
104	Phasianidae	Red Junglefowl	*Gallus gallus*	R
105	Sylviidae	Red-billed Leiothrix	*Leiothrix lutea*	r
106	Sylviidae	Red-billed Scimitar-Babbler	*Pomatorhinus ochraceiceps*	r
107	Muscicapidae	Red-breasted Flycatcher	*Ficedula parva*	W
108	Sylviidae	Red-faced Liocichla	*Liocichla phoenicea*	r
109	Trogonidae	Red-headed Trogon	*Harpactes erythrocephalus*	R
110	Pycnonotidae	Red-vented Bulbul	*Pycnonotus cafer*	R

111	Pycnonotidae	Red-whiskered Bulbul	*Pycnonotus jocosus*	R
112	Sylviidae	Rufous-backed Sibia	*Heterophasia annectens*	r
113	Accipitridae	Rufous-bellied Eagle	*Hieraaetus kienerii*	r
114	Sylviidae	Rufous-necked Laughingthrush	*Garrulax ruficollis*	r
115	Phasianidae	Rufous-throated Partridge	*Arborophila rufogularis*	r
116	Sylviidae	Rufous-vented Yuhina	*Yuhina occipitalis*	r
117	Sylviidae	Rufous-winged Fulvetta	*Alcippe castaneceps*	r
118	Passeridae	Russet Sparrow	*Passer rutilans*	r
119	Passeridae	Russet Sparrow	*Passer rutilans*	r
120	Muscicapidae	Sapphire Flycatcher	*Ficedula sapphira*	r
121	Corvidae	Scarlet Minivet	*Pericrocotus flammeus*	R
122	Sylviidae	Silver-eared Mesia	*Leiothrix argentauris*	r
123	Sylviidae	Slender-billed Scimitar-Babbler	*Xiphirhynchus superciliaris*	r
124	Muscicapidae	Small Niltava	*Niltava macgrigoriae*	r
125	Muscicapidae	Spotted Forktail	*Enicurus maculatus*	r
126	Nectariniidae	Streaked Spiderhunter	*Arachnothera magna*	r
127	Sylviidae	Streak-throated Barwing	*Actinodura waldeni*	r
128	Sylviidae	Striated Babbler	*Turdoides earlei*	r
129	Pycnonotidae	Striated Bulbul	*Pycnonotus striatus*	r
130	Sylviidae	Striated Laughingthrush	*Garrulax striatus*	r
131	Sylviidae	Stripe-throated Yuhina	*Yuhina gularis*	r
132	Paridae	Sultan Tit	*Melanochlora sultanea*	r
133	Accipitridae	Upland Buzzard	*Buteo hemilasius*	r?w
134	Sittidae	Velvet-fronted Nuthatch	*Sitta frontalis*	R
135	Muscicapidae	Verditer Flycatcher	*Eumyias thalassina*	r
136	Sittidae	Wallcreeper	*Tichodroma muraria*	rW
137	Sylviidae	Whiskered Yuhina	*Yuhina flavicollis*	r
138	Passeridae	White Wagtail	*Motacilla alba*	rW
139	Sylviidae	White-browed Shrike-Babbler	*Pteruthius flaviscapis*	r
140	Muscicapidae	White-capped Water-Redstart	*Chaimarrornis leucocephalus*	r
141	Turdidae	White-collared Blackbird	*Turdus albocinctus*	r
142	Sylviidae	White-crested Laughingthrush	*Garrulax leucolophus*	r
143	Sylviidae	White-naped Yuhina	*Yuhina bakeri*	r
144	Passeridae	White-rumped Munia	*Lonchura striata*	R
145	Apodidae	White-rumped Needletail	*Zoonavena sylvatica*	R
146	Sylviidae	White-spectacled Warbler	*Seicercus affinis*	r
147	Sittidae	White-tailed Nuthatch	*Sitta himalayensis*	r
148	Pycnonotidae	White-throated Bulbul	*Alophoixus flaveolus*	r

149	Corvidae	White-throated Fantail	*Rhipidura albicollis*	R
150	Dacelonidae	White-throated Kingfisher	*Halcyon smyrnensis*	R
151	Apodidae	White-throated Needletail	*Hirundapus caudacutus*	s
152	Troglodytidae	Winter Wren	*Troglodytes troglodytes*	r
153	Bucerotidae	Wreathed Hornbill	*Aceros undulatus*	R
154	Corvidae	Yellow-bellied Fantail	*Rhipidura hypoxantha*	r
155	Paridae	Yellow-browed Tit	*Sylviparus modestus*	r
156	Paridae	Yellow-cheeked Tit	*Parus spilonotus*	r
157	Passeridae	Yellow-hooded Wagtail	*Motacilla citreola*	rW

Appendix 1b. List of butterflies in the study area

S. No.	Common Name
1	Banded Treebrown
2	Blue Peacock
3	Chestnut Tiger
4	Chocolate Pansy
5	Common Banded Awl
6	Common Bluebottle
7	Common Fivering
8	Common Grass Yellow
9	Common Map
10	Common Maplet
11	Common Rose
12	Common Tiger
13	Cruiser
14	Dark Cerulean
15	Dark Velvet Bob
16	Dot Dash Sergeant
17	Four Bar Swordtail
18	Glassy Tiger
19	Golden Sapphire
20	Great Mormon
21	Great Nawab
22	Green Commodore
23	Hill Jezebel
24	Indian Cabbage White
25	Indian Fritillary
26	Indian Red Admiral
27	Large Cabbage White
28	Large Silverstripe
29	Large Yeoman
30	Long Banded Silverline
31	Orange Oakleaf
32	Orange Staff Sergeant
33	Plain Puffin
34	Popinjay
35	Punchinello
36	Purple Sapphire
37	Red Lacewing
38	Redbase Jezebel
39	Spot Puffin
40	Stately Nawab
41	Striped Blue Crow
42	Studded Sergeant
43	Tailed Sulphur
44	Tawny Rajah
45	White Commodore
46	White Dragontail
47	Yellow Jack Sailer
48	Yellow Orangetip
49	Yellow Rajah
50	Yerbury's Sailer

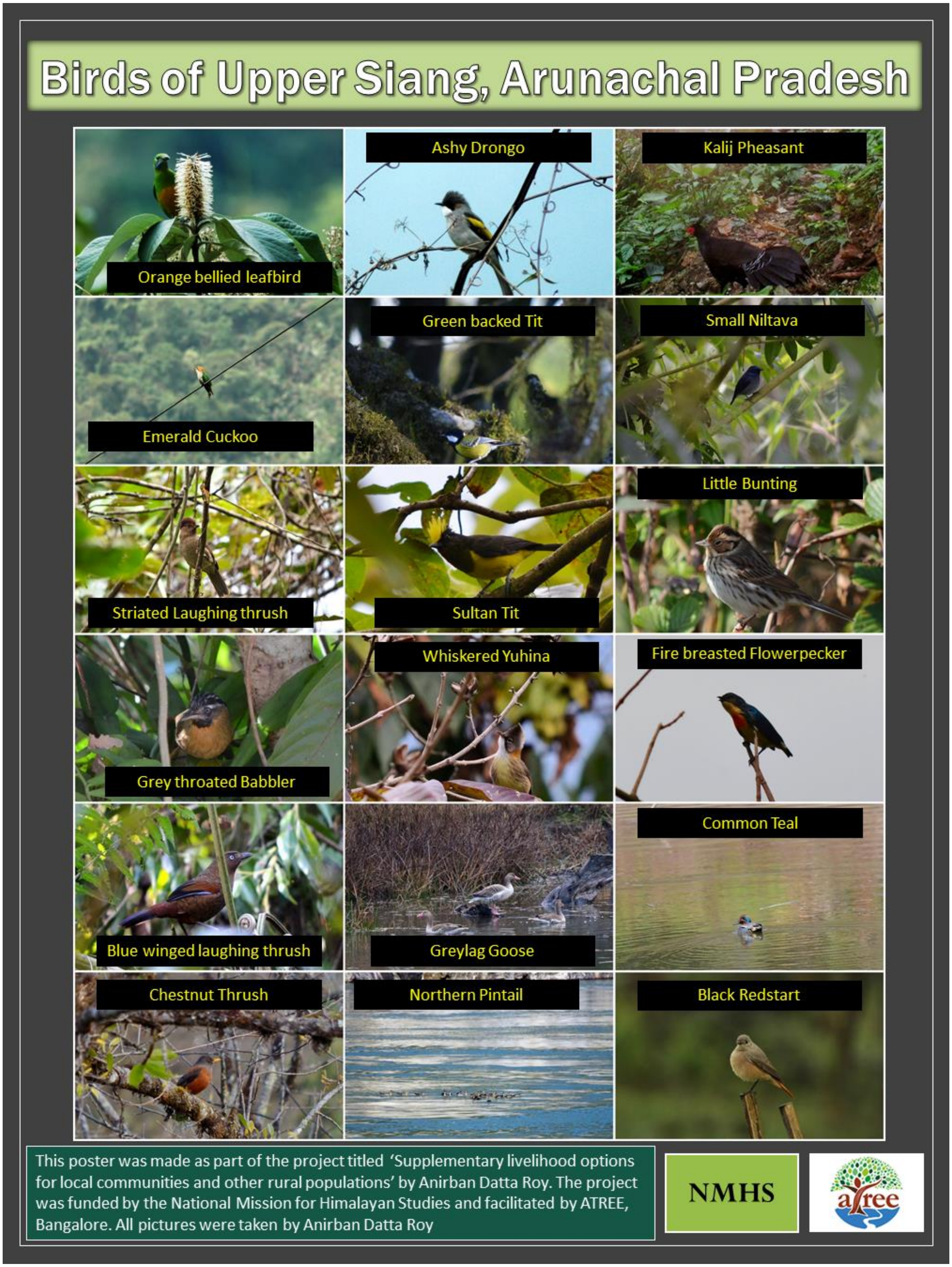


Figure 1: Birds of Upper Siang poster for dissemination for tourist visitors

Tabular listing of review of ecotourism literature with relevance to IHR

S. No.	Reference	Year	Major Objective	Method	Finding
1	Promoting ecotourism in the buffer zone areas of Nanda Devi Biosphere Reserve: An option to resolve people—policy conflict (Maikhuri et al. 2000)	2000	• History of tourism in NDBR • Impact of conservation policy on tourism and livelihoods • Selection of a model for ecotrekking • Appropriate strategies for sustainable ecotourism	Household surveys, interviews with local people, tourism operators, government agencies etc.	• Long history of trekking and mountaineering • Conservation policy banning tourism affected local livelihoods and created hostility between local people and authorities • Critical factors that are directly/indirectly affecting carrying capacity should be considered and limiting factors to be identified early on • Plan formulation should be a coordinated effort between all stakeholders
2	Willingness to pay for biodiversity conservation (Bhandari and Heshmati 2010)	2010	To investigate the factors that influence tourists' willingness to pay (WTP) for biodiversity conservation	Field survey with pretested structured questionnaire which had interviews of 375 domestic tourists	• 70% of tourists are willing to contribute for conservation • Education is a key predicting variable for tourists WTP • Higher socio-economic status is positively related with WTP responses
3	Tigers, tourists and wildlife: visitor demographics and experience in three Indian Tiger Reserves (Lyngdoh et al. 2017)	2017	• What categories of visitors choose to experience wildlife? • What drives visitors to experiencing wildlife? • Differences in the expectations	Open and closed ended questionnaires among tourist visitors to Tiger Reserves	• Large numbers of visitors in PAs are domestic, young and are initially attracted by a flagship species i.e. the tiger. • Ease of access, distance, hospitality

			and satisfaction of visitors? • Role of infrastructure in enrichment of visitor experiences		infrastructure and trained manpower are crucial for satisfying visits
4	Identification of potential ecotourism sites in West District, Sikkim using geospatial tools (Kumari et al. 2010)	2010	To assess the potential ecotourism sites in West District, Sikkim with an objective of income generation for local people and ecological restoration	Creation of various tourism suitability indicators through Remote Sensing and incorporation of primary and secondary data into maps	Identification of various potential ecotourism sites
5	Geographical analysis of tourism sites in Andaman Archipelago (India) and ecotourism development for Smith Island of North Andaman (Rengarajan et al. 2014)	2010	Use of the the nearest-neighbour analysis to understand the spatial distribution of tourism sites that are declared by A&N Administration for tourism development	Nearest neighbour analysis using ERDAS software	Tourism sites in Andaman exhibit a cluster distribution pattern with most sites concentrated more in Port Blair area than in Mayabunder and Diglipur areas
6	Explaining the status and scope of ecotourism development for livelihood security: Andaman and Nicobar Islands, India (Chand et al. 2015)	2015	Holistic investigation of various dimensions of ecotourism programme with special reference to the A&N Islands covering assessment of expenditure pattern by the Andaman administrations to promote ecotourism, perception of tourists on the various facilities existing in the islands and the factors determining the choice of	Primary and secondary data collected from various sources. Primary interview data collected through pre-tested questionnaires. Interviews were also used to collect data from key informants that included tourists, local people and government officials	Factors such as economy in travel and boarding, availability of tourist facilities and comfort, safety, etc. were major factors that determined the choice of the tourists that visited the islands. The weights given by the tourists to the natural sites in A&N Islands revealed that the landscape topped list followed by beaches, scenery, reserved forests, limestone caves and

			destination by tourists among various alternatives		coral sights. Historical sites, museums and heritage sites were also among top cites attraction. Recent initiatives by the Andaman administration gives due care to sustainably develop the tourism infrastructure of the islands to harness the potential of eco-friendly tourism
7	Assessment of ecotourism resources: An applied methodology to Nameri National Park of Assam-India (Das 2013)	2013	(i) To highlight how the biodiversity and cultural base can be an attraction for tourists; (ii) To study the tourist-flow pattern and their preferred destinations and needs; and (iii) To evaluate the status of existing facilities with the help of applied methodology for potentiality analysis of the ecotourism resources in the park	Primary and secondary data both utilized. Primary data on tourists were collected in the field through questionnaires to individuals as well as groups. Preparation of maps in relation to tourist interest	Potential sites within Nameri NP were assessed based on these multi-criteria stepwise analysis to identify areas of 'high tourist potential index'.
8	Ecotourism in Assam : A Promising Opportunity for Development (Devi et al. 2012)	2012	• The present status of tourism in Assam • The potentialities of ecotourism in Assam • The problems of tourism as well as ecotourism	Secondary data analysis	Assam has several ecotourism resources and is a centre of nature based tourism and especially ecotourism. Identification of these potential sites were done and problems identified at various sites
9	Ecotourism Benefits and Livelihood Improvement	2011	Description of the socio-economic characteristics of	Face-to-face interviews, supported by structured	Farmers were keen to take up ecotourism and wanted to

	for Sustainable Development in the Nature Conservation Areas of Bhutan (Gurung and Seeland 2011)		three rural communities living inside or close to protected areas in Bhutan and examining possible ways to improve their living standards through ecotourism for sustainable development	questionnaires, were conducted to determine 1) sources of livelihood; 2) the impact of tourism; and 3) the readiness of rural communities to participate in income-generating activities	use the proceeds to increase their livestock herds. However, this would increase pressure on natural resources, causing land degradation. Additionally, income from ecotourism may also lead, in the long run, to social inequality in remote communities. To prevent environmental stress in protected areas, social inequity and potential land degradation, newly generated wealth from ecotourism needs to be appropriately invested by the stakeholders.
10	Land use and natural resources planning for sustainable ecotourism using GIS in Surat Thani, Thailand (Bunruamkaew and Murayama 2012)	2012	To prepare ecotourism planning for sustainable development involving GIS as a tool for evaluating and monitoring the natural resources, especially potential ecotourism sites in Surat Thani.	Use of Remote Sensing to prepare LULC maps, classification of potential ecotourism areas checked for suitability through districtwise analysis	• Identification of priority areas for ecotourism and whether future land uses can be modified for future development within the province • This study further classified suitable areas for ecotourism at district level of Surat Thani where ecotourism sites should be promoted.
11	Rural Tourism in Nagaland, India: Exploring the	2011	To highlight the hidden resources of rural tourism in the state and suggests ways out of it by	Direct personal interviews as well as spot visits of the potential areas	The inflow of tourists in the state is meagre due to many different reasons,

	Potential (Ezung 2011)		undertaking a case study of Wokha district of the state inhibited by the Lotha Tribe		namely, government restriction policies, insufficient infrastructure and a sense of insecurity. To develop this industry in the state, it is suggested that the Inner Line Permit (ILP) and Restricted Area Permit (RAP), which are enforced in the state, should be lifted so that tourists do not find it difficult to enter the State

Fellowship Report No.: 2 of 10

Researcher Details

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HRA	Aniruddha Marathe	April 1, 2016	July 31, 2019	Understanding Patterns in Ant (Hymenoptera: Formicidae) Species Richness and Co-occurrence Across Elevation Gradients.	Dr. Priyadarsanan Dharmarajan, Senior Fellow

10. ANIRUDDHA MARATHE

1 Introduction

Ants (Hymenoptera: Formicidae) are highly diverse and widespread insects in most terrestrial ecosystems. More than 100 million years of evolution has distributed them over varied climates and habitats throughout the world (Lach *et al.* 2010). Today they dominate leaf litter communities of dense rainforests, extreme temperatures of deserts and colonize urban areas with equal success. Across these habitats, ants perform roles of decomposers, herbivores, seed dispersers and predators, making them important components of the ecosystem. As one moves across these habitats, climates and life histories, the species composition of ants changes rapidly. Therefore, questions such as 'How are different species of ants distributed across gradients of environmental variables?', 'How many ant species can coexist at a place?' are not only intuitively interesting but also ecologically important. This work aims to study species richness and distribution of ants along a large elevational gradient in the Eastern Himalayas. Sampling and analysis will be designed to facilitate multivariate understanding of the patterns in species richness and composition.

The question 'Why do some places have more species than others?' has been addressed for more than a century. A large number of mechanisms that maintain and regulate species richness have been hypothesized (Chesson 2000; Rosenzweig 1995) such as (1) higher rates of speciation due to higher mean temperature (Allen & Gillooly 2006; Brown *et al.* 2004) (2) biogeographic history of the landscape (Fløjgaard *et al.* 2011; Srinivasan *et al.* 2014) (3) reduced extinction rates due to higher abundance and greater immigration (Shmida & Wilson 1985) (4) greater co-existence of species by finer partitioning of niches (Janzen 1967), and (5) greater co-existence of species due to higher resource availability (Srivastava & Lawton 1998).

Gradients in species richness across elevations have been recognized since the days of Victorian natural history explorations (Lomolino 2001). The earliest reference to elevational gradients in modern ecological literature appears in work relating to the niche concept (Grinnell & Storer 1924) that laid the foundations for gradient analysis (Whittaker 1952, 1960, 1967).

Later, patterns of bird species richness documented across the Andes (Terborgh 1971, 1977) were widely cited as general trends that mimic the latitudinal gradient. However, today, elevational patterns are known from a large variety of gradients at multiple scales and for several different taxa. Global reviews of literature (Rahbek 1995; Szewczyk & McCain 2016) have questioned and refuted decrease in species richness across elevational gradients as the general pattern, a paradigm challenged by many cases of hump-shaped patterns. There have also been clearer analyses of predictor variables such as temperature, seasonal variation in climate and productivity, that limit ecological communities along these gradients (Körner 2007), which separate true elevational phenomena from contingent effects.

Ants are a good study system for ecological studies of this kind because of high species richness and rapid change in species composition across habitats and climates (Andersen & Sparling 1997). Since they are found in a large variety of climates and habitats (Hölldobler & Wilson 1990), a wide elevation range will be available to sample ants. This is confirmed by other studies, which have investigated elevational gradients in ant species richness (Bharti 2008; Bharti *et al.* 2016; Bharti & Sharma 2009; Samson *et al.* 1997). Being social insects maintaining perennial colonies, their responses to changes in climate and habitats are likely to be different from solitary insects. Therefore, ants deserve special attention in studies on gradients in species richness.

While there has been significant attention to taxonomy of Indian ant fauna, quantitative studies on ant communities from India are very few. After an extensive search of literature (See methods in (Marathe & Priyadarsanan 2018)), I could find only fifteen studies that used clearly defined methods for sampling ants. Some of this research focused on comparison of sampling methods (Gadagkar et al. 1993); comparison between natural tree-fall gaps and closed canopy forest (Basu 1997), and between natural and human impacted landscapes (Priyadarsanan D. R. et al. 2001). There are few studies on patterns of ant species richness across elevation gradient in the Western Ghats (Anu & Sabu 2007; Sabu et al. 2008; Vineesh et al. 2007) and in the Central Himalayas (Bharti & Sharma 2009; Bharti et al. 2013).

Bingham (1903) reported 268 ant species from Northeast India and Burma in his monograph. This information has been further updated by Chapman and Capco (1951) in their catalogue of ant species of Asia. In recent years, a few new records and descriptions of ants from Arunachal Pradesh have contributed to this knowledge (Tewari & Maity 1976; Tewary et al. 1977). The recently published state fauna of Arunachal Pradesh has listed out sixty-two ant species (Ghosh et al. 2006) but the updated checklist of Indian ants has reported a much higher number of 255 species (Bharti et al. 2016b). Dutta and Raychaudhuri (1983) studied the association between ants and aphids in Sikkim Himalaya. There are other studies that highlight the importance of ants as seed predators (Khan et al. 2005), and importance of ants in the diet of mammals (Seth et al. 2001). However, there are no structured inventories or, quantitative estimates of diversity, or studies on ant ecology from the entire Eastern Himalayan region.

This study is expected to address these knowledge gaps by quantifying the changes in ant communities across elevation gradient and offering ecological hypothesis for explaining the patterns. I proceed by analysing patterns in species richness of ant communities, where I contrast between effects of climate, habitat, and topography. Next, I situate patterns in beta diversity in the context of the gradients in species diversity to contrast between effects of reduction in species pool and ecological limits on individual density. Finally, I use functional group classification for ants, to discuss some additional biological limits on species distribution and therefore diversity.

a. 2 Methodologies, Strategy and Approach

Study Site

This study was conducted in the Eaglenest Wildlife Sanctuary (EWS) located in western Arunachal Pradesh, which is part of the Himalaya biodiversity hotspot (Myers 2003) . EWS covers a wide elevation range from 500m to 3250m (Fig 1). The temperature at the lowest elevations is as high as 30°C during summer (Apr - May) but drops sharply with elevation to about 15°C at 2400m during the same period. Winter temperatures range from 15°C to 3°C across the same elevation range according to 'WorldClim data' (Hijmans *et al.* 2005). Vegetation in the sanctuary is broadly tropical evergreen, sub-tropical and temperate broadleaved (Champion & Seth 1968). Rhododendron stands and small patches of coniferous forest are present near the highest elevations. However, site-specific vegetation data does not exist. Most of the sanctuary is free of any recent disturbance except some areas at the lowest elevations.

Sampling Design

All sampling locations were on the south facing slope of the EWS ridge. We classified the elevation gradient into nine broad classes of elevations or elevation bands between 600m and 2400m at 200m intervals, and sampled each of these bands during the summer (April - May) of 2013. Within each elevation band, four replicate transects of 100m length were established separated by 300m to 1000m.

Sufficient care was taken so that the difference in actual elevation between transects within an elevation band was less than 50m. All transects were sampled with 10 pitfall traps each. Plastic jars with 10 cm diameter mouth were used as pitfall traps. Each trap had a mixture of 90% alcohol as fixative. A few drops of glycerol were added to prevent evaporation of alcohol. The jars were buried in the ground such that the lip of the jar was in level with or slightly below the ground. Ten such pitfall traps (10 m apart) were placed on each transect. Pitfall traps were open for 48 hours. Two of the four transects in each were sampled with 20 Winklers each while the other two were sampled with 10 Winklers, made as per standard specifications (Bestelmeyer *et al.* 2000) Sampling among replicates within elevation s was uneven due to logistic constraints.

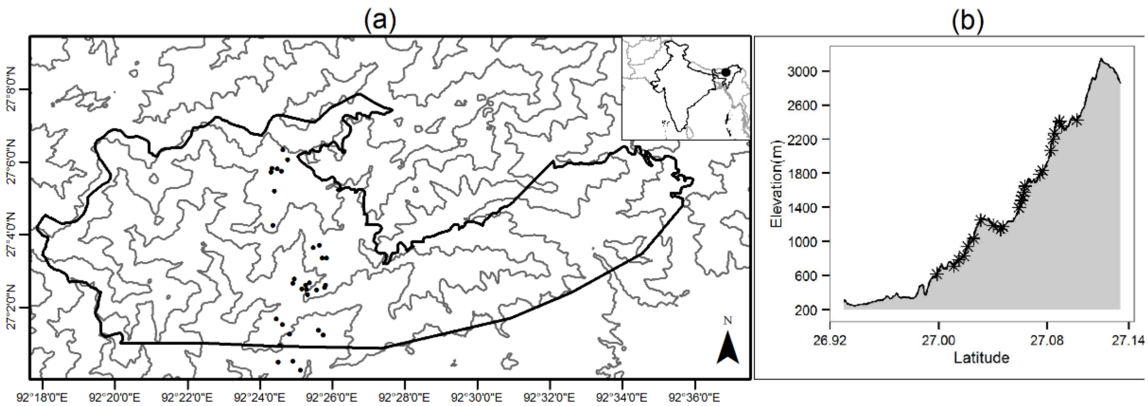


Fig 1. Map of study area. (a) Sampling locations within Eaglenest wildlife sanctuary (EWS) and (b) Elevation profile of the sampling locations.

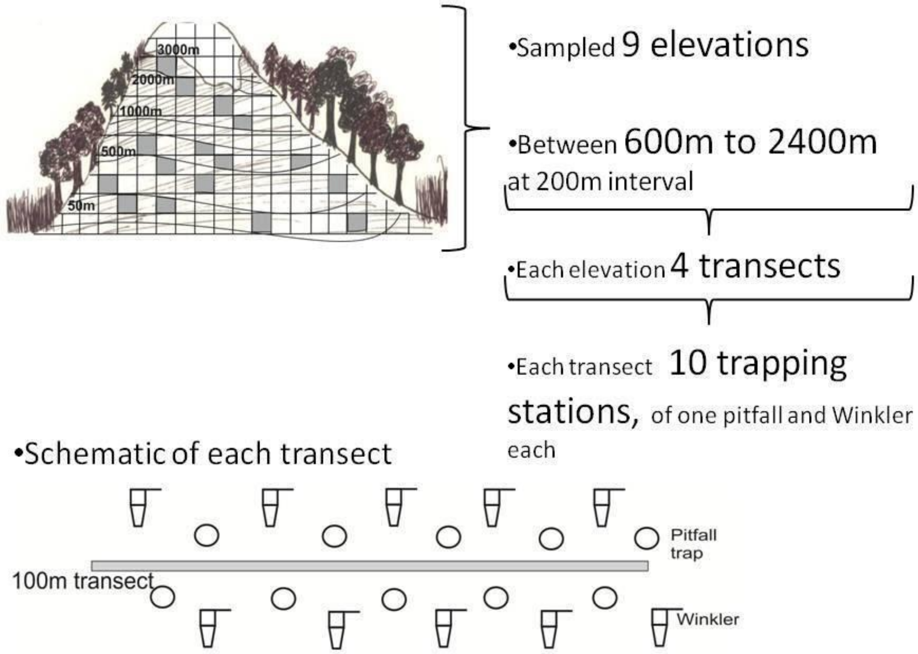


Figure 2. Schematic of sampling design

The present fellowship grant was written to support analysis of the data to identify mechanisms driving the patterns in ant communities across elevational gradients. For the analysis, species richness was compared across elevations where the four replicate samples were pooled to get species richness of an elevation band. Differences in species composition among local samples and across species pools were used to estimate beta diversity and its predictors. Details of the analyses for each component are presented in the respective sections.

Analytical methods

Regression analysis

Since transects are nested within elevation bands, we used hierarchical regression analysis using generalized linear mixed models with Poisson errors to identify the variables explaining the most variation in species richness. The regression models had different predictors at elevation bands and transects.

We used rarefied species richness at each transect as a response variable for regression analysis. Pitfall traps and Winkler collections differ in rates of species accumulation and collect nested assemblages (Fisher 1999). Therefore, using these different methods as replicates for estimating species richness is not meaningful. Hence, for regression analysis, we used data only from Winklers and rarefied the species richness to a common sample size of ten Winkler samples at each transect. We used the package 'INEXT v2.0' (Hsieh *et al.* 2014) for obtaining rarefied species richness.

We checked for spatial auto-correlation in species richness using Moran's I and by checking autocorrelation in the residuals from the regression model of species richness with elevation as the covariate. If the dependence of species richness on a possible explanatory variable across the elevational gradient is sufficient to account for most of the spatial dependence in species richness, then the regression residuals should not have any spatial autocorrelation (Bivand *et al.* 2008).

We used climatic variables obtained from 'WorldClim' (Hijmans *et al.* 2005) at 30 arc second resolution as predictors at the level of elevation bands. Because of high correlation among different climatic variables in the WorldClim data, we only used 'Mean Annual Temperature' (Bioclim variable1) to represent the variation in climate across elevation. In addition, we also estimated habitat variables that define structural complexity during field work.

We compared regression models that included effect of either climatic variables or habitat complexity and one model that included both variables. The models were compared using AICc. We used 'R v3.4' (RDevelopmentCoreTeam 2014) to carry out all analyses. We used package 'spdep v0.5-88' (Bivand *et al.* 2011) for spatial analysis and package 'lme4 v1.1' (Bates *et al.* 2014) for regression analysis.

Geometric constraints models

For testing the effect of geometric constraints on species richness, we used simulation models that randomly distribute species across elevations. We randomized the elevational extents of each species by randomly selecting mid-points from all possible values based on the nature of boundaries and geometric constraints. We used the observed range size frequency distribution so that the number of elevation bands occupied by a species was the same as the observed data but range locations were randomized (Wang & Fang 2012). Other studies have used species with small ranges, which are not affected by geometric constraints, to estimate effects of climatic predictors (Szewczyk & McCain 2016; Wang & Fang 2012). We did not use this method as species with small ranges (up to three elevation s) constitute more than 50% of the species pool.

Given that the spatial scale of the study area is relatively small compared to the entire elevational gradient in eastern Himalaya, elevational extents sampled during this study are likely to be smaller than the entire elevational range of the species, as at least some species may extend beyond the 600m to 2400m bounds of this study. Earlier studies have dealt with problems of truncated elevational or spatial extents by augmenting data from literature (Rana *et al.* 2019). However, since there is little distributional data available for ants, we considered the chance of occurring below or above the sampled elevational extent as uniform for all species. To account for this, we considered the domain as 200m to 2800m for all geometric constraints models. However, the proportion of elevational extent occupied by each species within the sampled elevational range is the same as in the data, and we compare the predicted richness within the sampled elevational range only. We did not include a completely random range scatter model, as there is little biological evidence for such distributions. Goodness of fit for competing geometric constraints models can be compared using the R^2 values (McCain 2003, 2004). We calculated residual deviations of all candidate models and considered We used package 'rangemodelR v1.0.4' (https://CRAN.R-project.org/package=rangemodelR) in 'R v3.4' (RDevelopmentCoreTeam 2014) for running geometric constraints models.
We define alpha diversity as mean species richness of all four local samples, and gamma diversity as total observed species richness of each elevation zone. We represent beta diversity as the multiplicative partition (beta = 1- mean alpha/gamma) within each elevation zone. To visualize the pattern in beta diversity, we used scatter plots for alpha and gamma diversity across elevation. The difference between slopes for alpha and gamma on a linear scale represent absolute turnover. When the y-axis is log transformed, the difference represents proportional turnover (Rodríguez & T Arita 2004).

In order to test if there are systematic changes in limits on alpha diversity that lead to beta diversity across elevational gradients, we used null models that randomly assembled local communities to generate expected values of beta diversity. Systematic variation in this difference indicates a gradient in the importance of random vs. deterministic processes on beta diversity. Earlier uses of such null models, each local community is assembled by sampling the observed number of individuals without replacement from the abundance distribution of the species pool (Kraft *et al.* 2011). However, this method may not be the most suitable for ants. The distribution of foraging worker ants is very likely aggregated, as ants are social insects and forage in trails or groups of workers. In addition, the proximity of traps to ant nests may cause greater number of captures in certain traps. This would lead to aggregated distribution among traps, which would reduce the number of traps occupied by each species compared to the random distribution of individuals. Therefore, an appropriate null expectation of beta diversity should account for small-scale aggregation at the trap level within transects. However, it is not straightforward to separate between biological and sampling related causes of aggregation. Therefore, in addition to simulations using abundances, we randomized occurrences, as this represents the number of traps occupied after completely accounting for aggregation in individuals of each species. During randomization, the total number of times a species is recorded at an elevation zone is the same as observed values but its distribution among local communities is randomized.

We used Standardized Effect Sizes (SES) as well as raw difference between mean and observed values as measure of deviation, as the two can have contrasting patterns. All analysis was carried out in R statistical software (RDevelopmentCoreTeam 2014).

Changes in species composition from one location to another can arise due to species loss, replacement, or combination of the two (Baselga 2010). We separated the species loss (nestedness), and replacement (turnover) components of total change in species composition (Baselga & Orme 2012) and examined patterns in pair wise dissimilarity across elevation. If the patterns are different, then the two components are analyzed separately. Relation between compositional distance and elevational distance between sites was expressed using the Mantel statistic.

We used the raw data approach that focuses on variation in community matrix (Legendre 2008; Legendre *et al.* 2005), to analyze changes in species composition. Measures of compositional change based on total variation in the community (total sums of squares of the community matrix) is the measure of extent of change in species composition and therefore is analogous to beta diversity (Legendre *et al.* 2005).

Environmental predictors represented a combination of local habitat variables and climatic gradients across elevation. Geographic distance or spatial coordinates were used to represent spatial variables. More sophisticated ways of representing geographic space are available such as the 'Principle Components of Neighbour Matrices' (PCNM) that can separate between large- and small-scale spatial effects (Borcard *et al.* 2004; Borcard & Legendre 2002). However, we did not use these methods due to small spatial scale of the study area, and almost linear relationship between elevation, geographic distance, and clamte. The response variable for redundancy analysis was the site by species matrix of total number of occurrences for each species at each elevation. The raw values in community data represent compositional differences analogous to the Euclidean distance, which is not ideal for ecological analysis (Legendre & Cáceres 2013). Therefore, we used 'Hellinger transformation' (all values in the matrix divided by square root of row totals) on the community data.

We used variation partitioning to separate the total variation into four components i) explained purely by environmental variables, ii) explained purely by spatial variables, iii) explained by spatially structured environment, and iv) unexplained variation.

Changes in functional group composition across elevation

Ant functional groups are classified based on habitat requirements and competitive dominance. We used the information available in literature to assign ant genera to previously identified functional groups. Following functional groups were represented in the species pool:

1. Generalized Myrmicinae (GM): These are some of the most diverse and widespread ant groups, which are typically habitat generalist and omnivorous.

2. Opportunists (OPP): This group contains species similar to the GM but have relatively poor competitive

ability. This group also includes genera of sub-family Dolichoderinae

3. Cryptic (CRY): These ants have very small workers and are predominantly found in the leaf litter. Because of the small body size of workers, direct competitive interactions with other species are thought to be minimal.

4. Specialist predators (SP): These are exclusively predatory and typically large bodied ants. Workers of most species in this group forage individually without forming foraging trails except for the group raiding genus *Leptogenys* that is known to form foraging trails.

5. Tropical climate specialist (TCS): This group includes genera with an affinity to tropical climate. Most species in this group are thought to have originated in moist tropical environments.

6. Cold Climate Specialists (CCS): This group includes genera that are well adapted to colder climate. These groups have ecological dominance at cold high elevation conditions where tropical specialists and generalist groups do not survive.

7. Subordinate Camponotini (SC): This group includes mostly arboreal species of genera *Camponotus* and *Polyrhachis* (Bharti *et al.* 2013)

We used exploratory analysis to represent variation in functional group composition across elevations. Variation in different components of diversity within each functional group including species richness, Shannon's index of diversity and total number of occurrences, are represented using scatter plots.

We constructed community data for functional groups using total occurrences recorded at each elevation band for all species within each group. The community data was transformed using 'Hellinger transformation' to analyze contribution of spatial and environmental variables using redundancy analysis and variation partitioning. The explanatory variables for this analysis were the same as the ones used for redundancy analysis with species data.

b. 3 Key Findings and Results

We collected 10,560 individuals belonging to 157 species and 51 genera. Observed species richness decreased with an increase in elevation, without any indication of a peak at mid elevations. The pattern was consistent for data specific to each of the two collection methods as well as for the pooled data (Fig 3a-c). The total number of species occurrences decreased with elevation and the occurrence-based rarefaction curves for each elevation did show decreases in slope but no clear asymptote (Fig 4a, b). Canopy cover, litter volume and understory height diversity showed weak patterns of increase with elevation while temperature showed a strong decrease (Fig 5a-d).

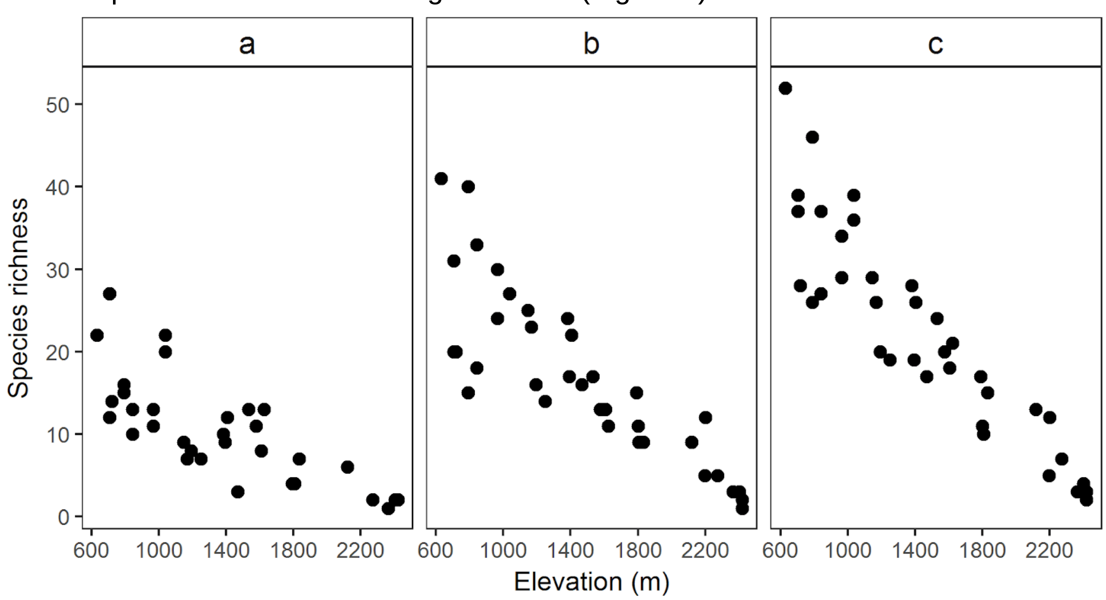


Figure 3. Observed species richness of ants across elevation. (a) pitfall trap, (b) Winklers, (c) pooled

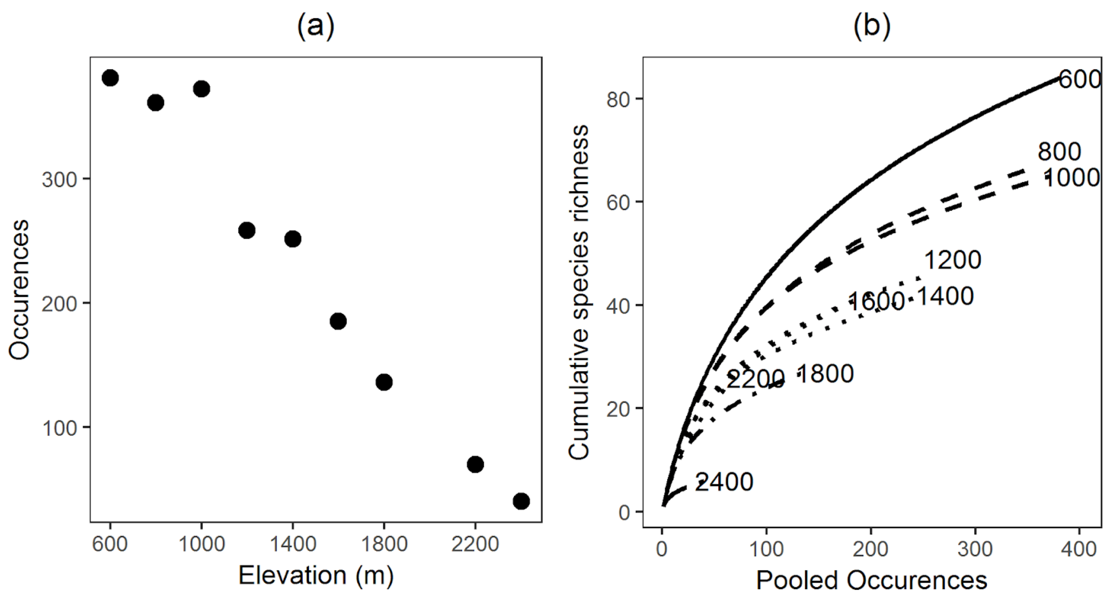


Figure 4. Rarefaction for ant communities at each elevation band. (a) Total number of occurrences recorded at each elevation, (b) rarefaction curves with cumulative species richness of ants and cumulative number of occurrences for each elevation

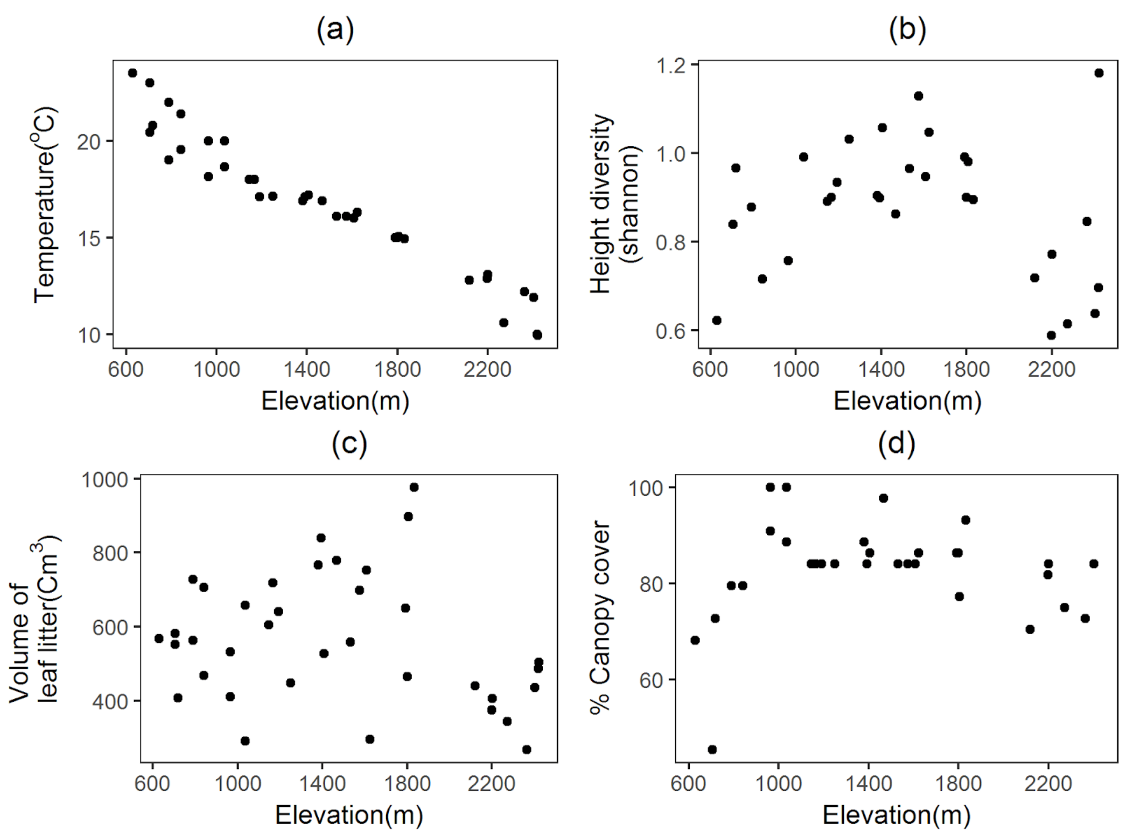


Figure 5. Pattern of predictor variables across elevation. (a) temperature, (b) canopy cover, (c) volume of leaf litter, and (d) vegetation complexity

Spatial patterns in species richness
Rarefied species richness for transects across the elevation gradient had strong spatial auto-correlation. However, after accounting for the trend across elevation, the strength of auto-correlation was much lower with lower standard deviates (Table 1). AICc values of regression models with effect of climatic gradient (models 1 and 2, Table 2) were much lower compared to models with habitat variables as the only predictor (Table 2). Temperature was an important predictor variable in regression analysis using other approaches as well (Table 1 – 4 in S1 Text).

Table 1. Moran's I value for observed species richness, Chao2 estimates at each transect and residuals of regression with elevation.

Variable	Moran's I	Standard deviate	p-value
Species richness	0.76	6.75	<0.01
Residuals - species richness	0.24	2.2	0.01

Table 2. Results of mixed effects regression models for rarefied species richness with random intercept at each elevation. (MAT = Mean Annual Temperature,)

No.	Variable	Estimate	Std. Error	Random effect	AICc	Deviance
1	Intercept MAT	2.49 0.61	0.07 0.08	0.01	196.26	189.5
2	Intercept MAT Volume of leaf litter Understory complexity	2.48 0.59 0.07 0.01	0.06 0.07 0.05 0.05	0.009	199.68	187.7
3	Intercept Volume of leaf litter Understory complexity	2.47 0.04 -0.01	0.23 0.06 0.06	0.48	218.34	209.04

Effect of geometric constraints on species richness

The model without range cohesion but constrained by temperature (model1) explained only 46% of the variation in species richness (Table 3). This means that species occur at adjacent elevations more often than expected by chance, and limits of temperature on species distribution cannot explain contiguity of ranges. Therefore, we interpolated species occurrences between minimum and maximum for the rest of the analysis.

The percentage of variation in total species richness explained by 'model3' - combined effect of geometric constraints and temperature - is less than the null model (Table 3). The other two models explained species richness better, with reduced geometric constraints at low elevations but not at high elevations. The best model ('model5') included temperature as a constraining variable and did not have a hard boundary at the lowest observed elevation (Table 3). These results show that species ranges are not limited by geometric constraints at lower elevations, and that distribution of species is limited by temperature (Table 3).

Table 3. Simulation models for species richness of elevations. The R^2 values are calculated as (1 - (deviance of candidate model / deviance of model 1). Model 1 is range scatter model weighted by temperature. Negative R^2 values indicate that candidate model is not better than the null model.

Models	Description	R2
Model 5	Model4 with upper domain boundary truncated at 2400m	0.78
Model 4	Model2 but midpoint adjustment only at low elevations	0.50
Model 3	Model2 with midpoint adjustment at both boundaries	0.19
Model 2	Hard boundaries, ranges contiguous, temperature weighted	-0.21

Pattern of beta diversity across elevation

The species richness of elevation zones or gamma diversity decreases across elevation with steeper slope than the species richness of transects or alpha diversity (Figure 6a). This represents the absolute turnover between transects within each elevation zone (gamma - alpha or additive partitioning), which decreases with elevation (Figure 6b). However, the two slopes are not different when the y-axis is log-transformed (Figure 6c) and the corresponding multiplicative beta diversity is mostly invariant across elevations (Figure 6d).

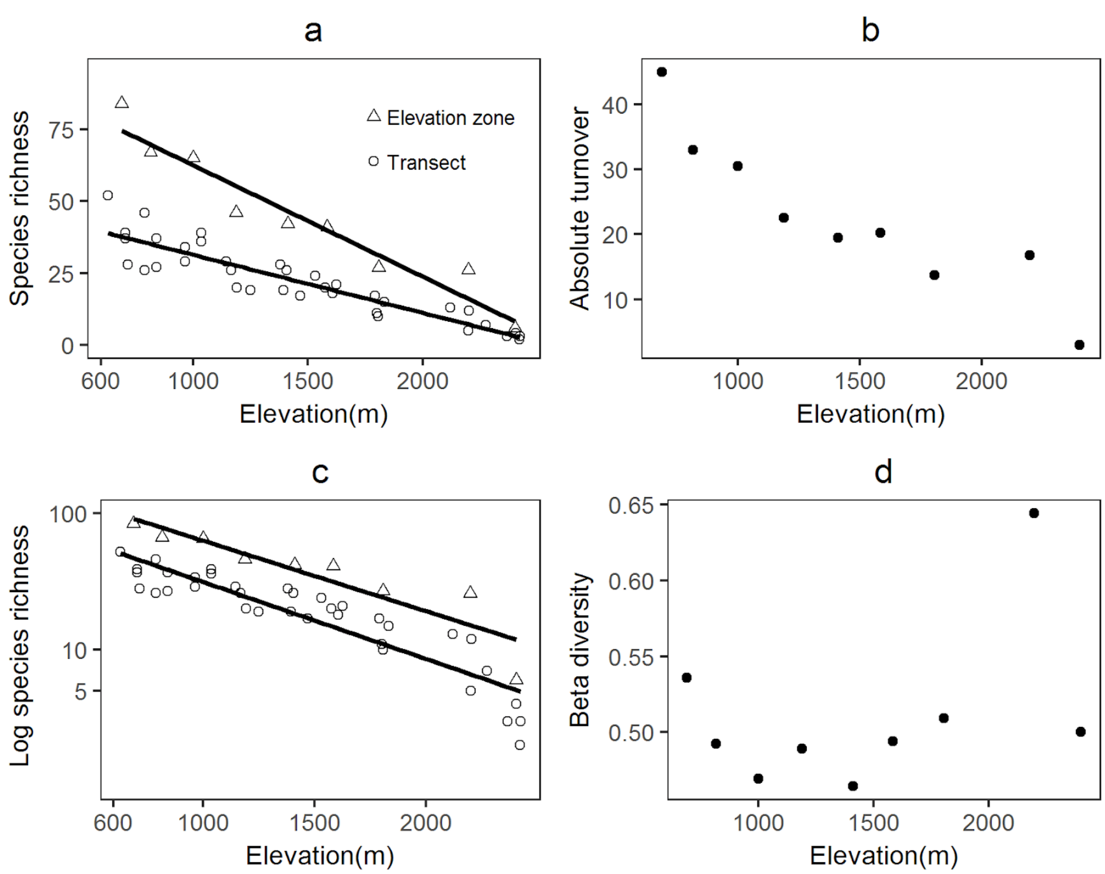


Figure 6. Patterns in alpha and gamma diversity relative to each other with the corresponding measure of beta diversity. (a) alpha and gamma diversity across elevation; (b) absolute turnover across elevation; (c) log transformed alpha and gamma diversity across elevation; (d) multiplicative beta-diversity across elevation gradient.

Null expectations of beta diversity

The aggregation corrected estimates of beta diversity, obtained by occurrence-based randomizations, were higher than the binomial or abundance based model as expected and its deviation from the observed values was much smaller (Figure 7a). Further, there was no pattern in the residuals of the aggregation expected beta diversity (Figure 7b)., while the difference between aggregation and binomial expectation decreased with elevation (Figure 7c).

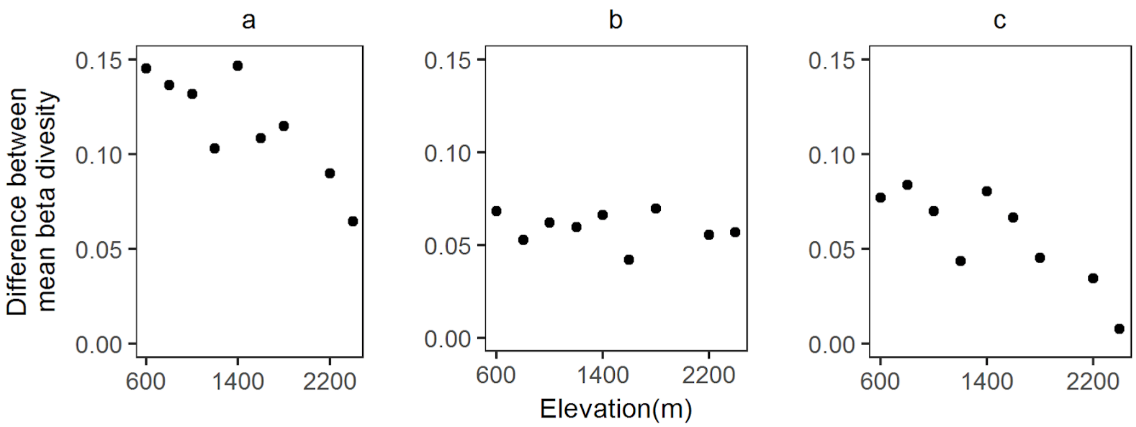


Figure 7. (a) Difference between observed and binomial estimates of beta diversity;

(b) Difference between observed and aggregation accounted estimates of beta diversity;

(c) Difference between aggregation accounted and binomial models for beta diversity

Pairwise differences in species composition

Changes in species composition of elevation bands were correlated with difference between elevations (Mantel statistic = 0.78, p-value = 0.001). Patterns in species loss and replacement across elevation gradient were similar to the total compositional change (Figure 8). Redundancy analysis showed that spatial and environmental variables together explained only 29% of variation in the community matrix. Most of the variation in species composition was attributed to spatially structured variation in environment (Table 4).

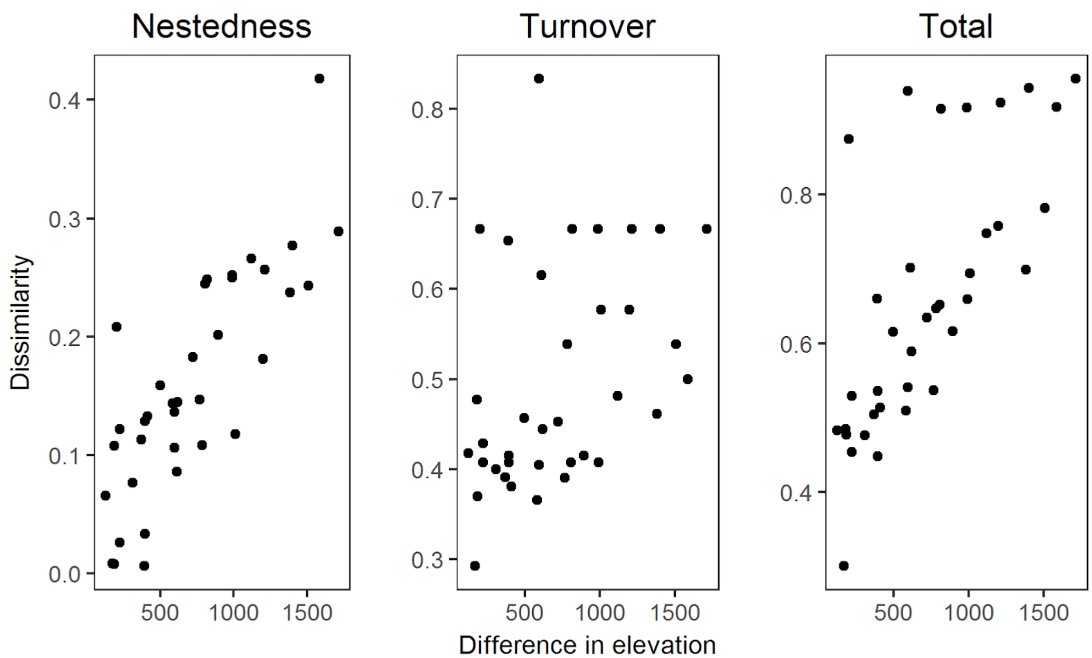


Figure 8. Pattern in pair wise species dissimilarity represented as species turnover, nestedness, and combination of the two.

Functional group composition

Most of the ant species collected were classified under the functional groups SP, GM, OPP, and CRY. Species belonging to the group SC did not occur beyond 1000m. Contribution to total change in functional group composition was not equal; SP, TCS, OPP, and CRY contributed most of the variation while other three groups showed much less variation (Figure 9). Species diversity, richness and total abundance of all functional groups decreased with increasing elevation, except for CCS (Figure 10).

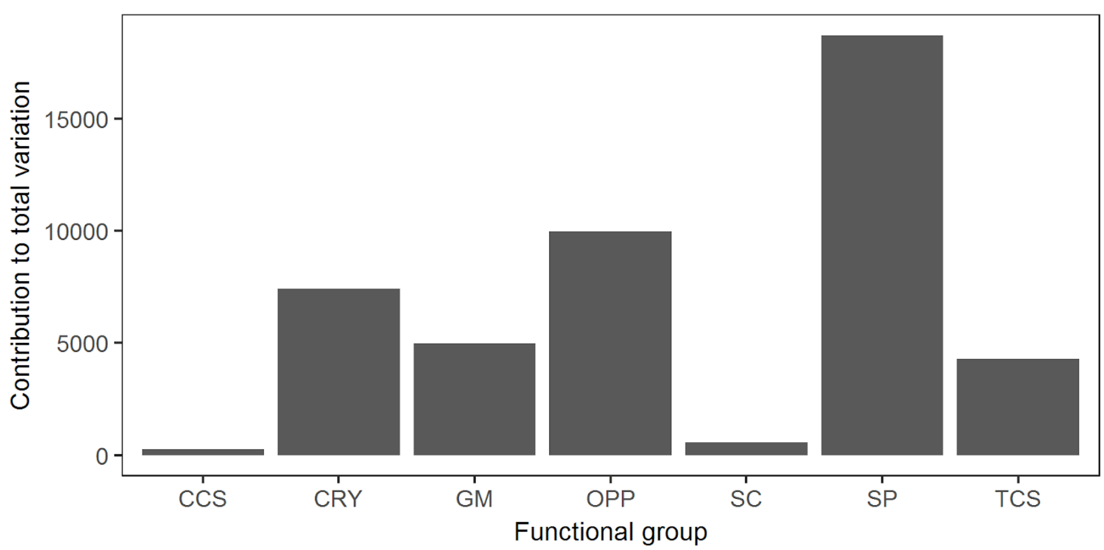


Figure 9. Contribution of functional groups to total variation in composition

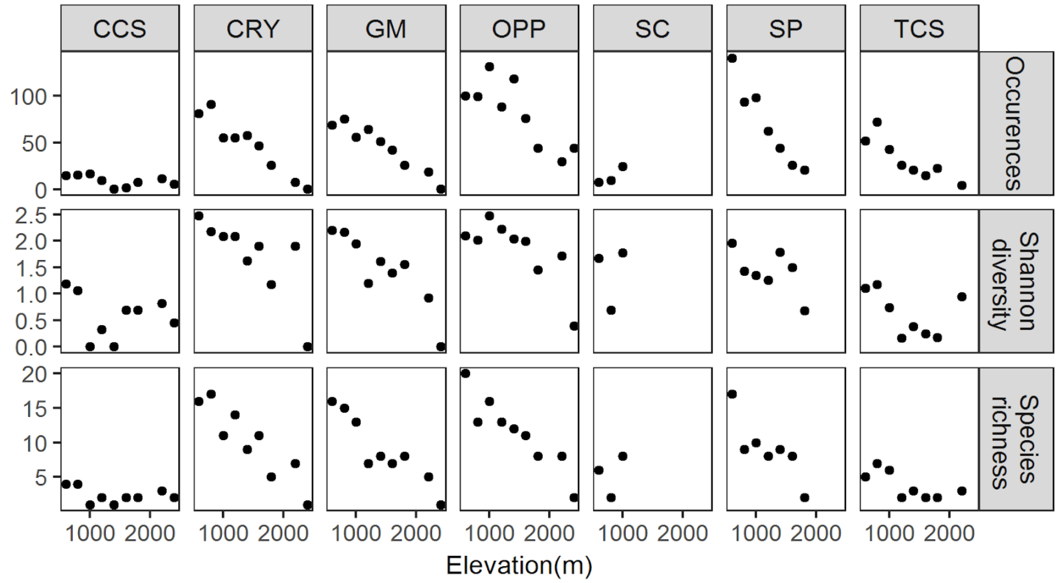


Figure 10. Variation in different components of diversity within elevation bands across elevation.

The relative contribution of different functional groups to species assemblages changed with elevation. While the overall proportion of CCS in the species pool was low, the relative contribution increased with elevation. The proportion of OPP was also greater at higher elevations (Figure 4). Redundancy analysis showed that a much greater percent of variation was explained after aggregating species into functional groups (R^2= 0.56 for functional groups, R^2 = 0.29 for species). However, most of the variation was explained by spatially structured variables as in the case of species composition (Table 2).

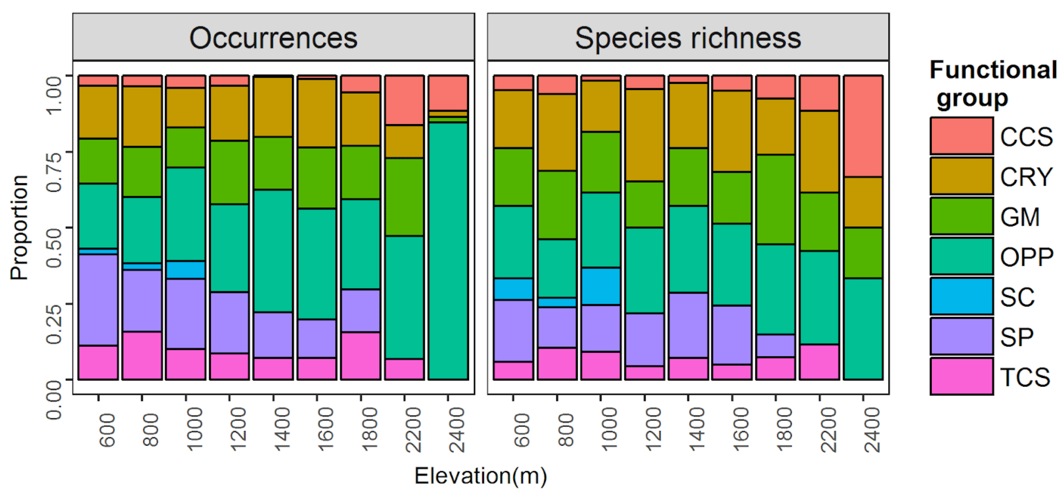


Figure 11 Proportional contribution of functional groups to species composition at elevation bands

Table 4. Variation partitioning using redundancy analysis for species composition

Components	Predictors	R^2	P-value
Total (T)	Geographic and environmental	0.29	<0.13
Environmental (E)	Environmental	0.24	0.01

Spatial (S)	Geographic distance	0.22	<0.05
Only Environmental (T-S)		0.07	0.4
Only spatial (T-E)		0.05	0.4
Spatially structured environmental ((S+E) – T)		0.17	
Unexplained (1-T)		0.43	

Table 5. **Variation partitioning using redundancy analysis for functional group composition**

Components	**Predictors**	**R^2**	**P-value**
Total (T)	Geographic and environmental	0.56	<0.13
Environmental (E)	Environmental	0.54	0.01
Spatial (S)	Geographic distance	0.47	<0.05
Only Environmental (T-S)		0.08	0.4
Only spatial (T-E)		0.01	0.4
Spatially structured environmental ((S+E) - T)		0.46	
Unexplained (1-T)		0.43	

c. 4 Overall Achievements

This work is the first quantitative ecological study using structured inventory of ants across an elevational gradient in the Eastern Himalayas. Although the inventory is from a relatively small area, the elevational sampling design facilitated capturing a large portion of the total regional species pool. The number of species recorded in this study is 61% of all species recorded from the state of Arunachal Pradesh so far. We used patterns in three properties of ecological communities: species richness, species composition, and elevational extents to test competing hypotheses for community assembly. The conclusions from this work build on general ecological principles to provide explanation of patterns in ant communities across elevational gradient. A key determinant of most patterns is the gradient in temperature but biological properties such as body size, resource specialization, and life history strategies interact with the underlying environmental gradient to produce the observed patterns.

Most of the changes in species composition appear to be driven by spatially structured environmental variation. Redundancy analysis could only explain about one third of the total variation in the species matrix. This could be largely because the occurrences of species do not have predictable patterns across elevations. When the species are aggregated into functional groups, the local abundances have linear decreasing trends across elevations, which explain the higher proportion of total variation explained.

Most studies involving ant functional groups are on disturbance gradients (Andersen 1991; Bestelmeyer & Wiens 1996; Hoffmann 2010; Nakamura *et al.* 2007; Stephens & Wagner 2006) or on recovery of communities post disturbance (Andersen *et al.* 2003; Andersen & Sparling 1997). Studies about compositional changes in ant communities across elevational gradients are relatively rare. However, environmental variation across elevational gradients has been used to validate the functional groups model in the Western Ghats (Vineesh *et al.* 2007), Western Himalayas (Bharti *et al.* 2013) and North America (Andersen 1997). The most abundant and species rich functional groups in this study were GM, and OPP while CCS were the least abundant (Figure 3). King and Andersen (1998) report similar patterns in variation in ant functional group compositions from Australian tropical forests. These patterns conform to the predictions of the original functional group model, where either GM or OPP groups are expected to be most diverse in closed canopy forest habitats. While the overall diversity in cold climate specialists was low, its relative contribution to the assemblage increased with elevation. Similar trends were also observed in ant assemblages from the Western Himalaya (Bharti et al. 2013) and the Western Ghats (Vineesh *et al.* 2007). This suggests the role of environmental variables in driving gradient in species composition across elevations.

d. 5 Impacts of Fellowship in IHR

The Eastern Himalaya, and Northeast India, are regarded as regions of global conservation priority. However, much scientific knowledge about the distribution of biodiversity in the region remains broad brushed at best. It is largely due to lack of location specific biodiversity inventories, and analysis of biodiversity patterns. The lack of fine grain biodiversity data, limits any on-ground conservation prioritization, or impact assessment of anthropogenic activities. The present study is a step towards bridging this long standing knowledge gap. It provides the first quantitative ecological analysis of data on an insect taxa from the Eastern Himalaya. It provides sampling strategies for rapid assessment of leaf-litter insect diversity, which could be useful in the future studies. We believe this work will be most valuable if it is the first of many such efforts that will help further existing knowledge about community assembly in Eastern Himalaya.

e. 6 EXIT STRATEGY AND SUSTAINABILITY

The data contributed and models developed will remain useful much beyond the scope of this study. The insect collections curated as part of the study will be useful, for taxonomic studies in future. We plan to continue using the data to understand processes regulating diversity of ecological communities.

One of the major limitations of the work is its small spatial scale, which ignores many processes that may be apparent only through data at larger scales, such as multiple river valleys, or longitudes. The small spatial scale of the study was a deliberate decision, as there was complete lack of any practical experience of conducting such a work in the region. However, ATREE has broader interests in the Eastern Himalaya, and we aim to build on this effort through continued inventory and biodiversity analysis.

f. 7 REFERENCES/BIBLIOGRAPHY

Allen, A. P., & Gillooly, J. F. (2006). Assessing latitudinal gradients in speciation rates and biodiversity at the global scale. *Ecology Letters*, **9**(8), 947–954.

Andersen, A. N. (1991). Responses of ground-foraging ant communities to three experimental fire regimes in a savanna forest of tropical Australia. *Biotropica*, 575–585.

Andersen, A. N. (1997). Functional groups and patterns of organization in North American ant communities: a comparison with Australia. *Journal of Biogeography*, **24**(4), 433–460.

Andersen, A. N., Hoffmann, B. D., & Somes, J. (2003). Ants as indicators of minesite restoration: community recovery at one of eight rehabilitation sites in central Queensland. *Ecological Management & Restoration*, **4**(s1).

Andersen, A. N., & Sparling, G. P. (1997). Ants as indicators of restoration success: relationship with soil microbial biomass in the Australian seasonal tropics. *Restoration Ecology*, **5**(2), 109–114.

Baselga, A. (2010). Partitioning the turnover and nestedness components of beta diversity. *Global Ecology and Biogeography*, **19**(1), 134–143.

Baselga, A., & Orme, C. D. L. (2012). betapart: an R package for the study of beta diversity. *Methods in Ecology and Evolution*, **3**(5), 808–812.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4. *R Package Version 1.0-4*, **http://CRAN.R-project.org/package=lme4.** Retrieved from http://CRAN.R-project.org/package=lme4.

Bestelmeyer, B. T., Agosti, D., Alonso, L. E., … Silvestre, R. (2000). Field techniques for the study of ground-dwelling ant: an overview, description, and evaluation. In D. Agosti, J. Majer, L. Alonso, & T. Schultz, eds., *Ants: standard methods for measuring and monitoring biodiversity*, Washington, D.C.: Smithsonian Institution Press, pp. 122–144.

Bestelmeyer, B. T., & Wiens, J. A. (1996). The effects of land use on the structure of ground-foraging ant communities in the Argentine Chaco. *Ecological Applications*, 1225–1240.

Bharti, H. (2008). Altitudinal diversity of ants in Himalayan regions (Hymenoptera: Formicidae). *Sociobiology*, **52**(2), 305–321.

Bharti, H., Bharti, M., & Pfeiffer, M. (2016). Ants as bioindicators of ecosystem health in Shivalik Mountains of Himalayas: assessment of species diversity and invasive species. *Asian Myrmecology*, **8**, 1–15.

Bharti, H., & Sharma, Y. P. (2009). Diversity and abundance of ants along an elevational gradient in Jammu-Kashmir Himalaya-I. *Halters*, **1**, 10–24.

Bharti, H., Sharma, Y. P., Bharti, M., & Pfeiffer, M. (2013). Ant species richness, endemicity and functional groups, along an elevational gradient in the Himalayas. *Asian Myrmecology*, **5**, 79–101.

Bivand, R., Anselin, L., Berke, O., … Lewin-Koh, N. (2011). spdep: Spatial dependence: weighting schemes, statistics and modelsID - 2978.

Bivand, R. S., Pebesma, E. J., Gomez-Rubio, V., & Pebesma, E. J. (2008). *Applied spatial data analysis with R*, Vol. 747248717, New York: Springer.

Borcard, D., & Legendre, P. (2002). All-scale spatial analysis of ecological data by means of principal coordinates of neighbour matrices. *Ecological Modelling*, **153**(1–2), 51–68.

Borcard, D., Legendre, P., Avois-Jacquet, C., & Tuomisto, H. (2004). Dissecting the spatial structure of ecological data at multiple scales. *Ecology*, **85**(7), 1826–1832.

Brown, J., Gillooly, J., Allen, A., Savage, V., & West, G. (2004). Toward a metabolic theory of ecology. *Ecology*, **85**(7), 1771–1789.

Champion, S. H., & Seth, S. K. (1968). A revised survey of the forest types of India. *Government of India, New Delhi*.

Chesson, P. (2000). Mechanisms of maintenance of species diversity. *Annual Review of Ecology and Systematics*, 343–366.

Colwell, R. K., Brehm, G., Cardelús, C. L., Gilman, A. C., & Longino, J. T. (2008). Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. *Science*, **322**(5899), 258–261.

Fisher, B. L. (1999). Improving inventory efficiency: a case study of leaf-litter ant diversity in Madagascar. *Ecological Applications*, **9**(2), 714–731.

Fløjgaard, C., Normand, S., Skov, F., & Svenning, J. (2011). Deconstructing the mammal species richness pattern in Europe–towards an understanding of the relative importance of climate, biogeographic history, habitat heterogeneity and humans. *Global Ecology and Biogeography*, **20**(2), 218–230.

Grinnell, J., & Storer, T. I. (1924). *Animal life in the Yosemite*, Berkeley: University of California Press.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, **25**(15), 1965–1978.

Hoffmann, B. D. (2010). Using ants for rangeland monitoring: global patterns in the responses of ant communities to grazing. *Ecological Indicators*, **10**(2), 105–111.
Hölldobler, B., & Wilson, E. (1990). *The ants*, Cambridge, Massachusetts: Harvard University Press.

Hsieh, T., Ma, K. H., & Chao, A. (2014). iNEXT: Interpolation and Extrapolation for Species Diversity. *R Package Version 2.0, URL: Https://Cran.r-Project.Org/Web/Packages/INEXT/Index.Html*. Retrieved from https://cran.r-project.org/web/packages/iNEXT/index.html

Janzen, D. H. (1967). Why mountain passes are higher in the tropics. *The American Naturalist*, **101**(919), 233–249.

King, J. R., & Andersen, A. N. (1998). Ants as bioindicators of habitat disturbance: validation of functional group model for Australias humid tropics. *Biodiveristy and Conservation*, **7**(12), 1627–1638.

Kraft, N. J., Comita, L. S., Chase, J. M., … Anderson, M. J. (2011). Disentangling the drivers of β diversity along latitudinal and elevational gradients. *Science*, **333**(6050), 1755–1758.

Lach, L., Parr, C. L., & Abbott, K. L. (2010). *Ant ecology*, New York: Oxford University Press.
Legendre, P. (2008). Studying beta diversity: ecological variation partitioning by multiple regression and canonical analysis. *Journal of Plant Ecology*, **1**(1), 3–8.

Legendre, P., Borcard, D., & Peres-Neto, P. R. (2005). Analyzing beta diversity: partitioning the spatial variation of community composition data. *Ecological Monographs*, **75**(4), 435–450.

Legendre, P., & Cáceres, M. (2013). Beta diversity as the variance of community data: dissimilarity coefficients and partitioning. *Ecology Letters*, **16**(8), 951–963.

Lomolino, M. V. (2001). Elevation gradients of species density: historical and prospective views. *Global Ecology and Biogeography*, **10**(1), 3–13.

McCain, C. M. (2003). North American desert rodents: a test of the mid-domain effect in species richness. *Journal of Mammalogy*, **84**(3), 967–980.

McCain, C. M. (2004). The mid-domain effect applied to elevational gradients: species richness of small mammals in Costa Rica. *Journal of Biogeography*, **31**(1), 19–31.
Myers, N. (2003). Biodiversity hotspots revisited. *Bioscience*, **53**(10), 916–917.

Nakamura, A., Catterall, C. P., House, A. P., Kitching, R. L., & Burwell, C. J. (2007). The use of ants and other soil and litter arthropods as bio-indicators of the impacts of rainforest clearing and subsequent land use. *Journal of Insect Conservation*, **11**(2), 177–186.

Rahbek, C. (1995). The elevational gradient of species richness: a uniform pattern? *Ecography*, **18**(2), 200–205.

Rana, S. K., Gross, K., & Price, T. D. (2019). Drivers of elevational richness peaks, evaluated for trees in the east Himalaya. *Ecology*, **100**(1), e02548.

RDevelopmentCoreTeam. (2014). R: A language and environment for statistical computing (Version 3.2), Vienna, Australia: R Foundation for Statistical Computing. Retrieved from URL http://www.R-project.org/

Rodríguez, P., & T Arita, H. (2004). Beta diversity and latitude in North American mammals: testing the hypothesis of covariation. *Ecography*, **27**(5), 547–556.

Rosenzweig, M. L. (1995). *Species diversity in space and time*, Cambridge: Cambridge Univ Press.

Samson, D. A., Rickart, E. A., & Gonzales, P. C. (1997). Ant Diversity and Abundance along an Elevational Gradient in the Philippines. *Biotropica*, **29**(3), 349–363.

Shmida, A., & Wilson, M. V. (1985). Biological determinants of species diversity. *Journal of Biogeography*, 1–20.

Srinivasan, U., Tamma, K., & Ramakrishnan, U. (2014). Past climate and species ecology drive nested species richness patterns along an east-west axis in the Himalaya. *Global Ecology and Biogeography*, **23**(1), 52–60.

Srivastava, D., & Lawton, J. (1998). Why more productive sites have more species: an experimental test of theory using tree-hole communities. *American Naturalist*, **152**(4), 510–529.

Stephens, S. S., & Wagner, M. R. (2006). Using Ground Foraging Ant (Hymenoptera: Formicidae) Functional Groups as Bioindicators of Forest Health in Northern Arizona Ponderosa Pine Forests. *Environmental Entomology*, **35**(4), 937–949.

Szewczyk, T., & McCain, C. M. (2016). A Systematic Review of Global Drivers of Ant Elevational Diversity. *PloS One*, **11**(5), e0155404.

Terborgh, J. (1971). Distribution on environmental gradients: theory and a preliminary interpretation of distributional patterns in the avifauna of the Cordillera Vilcabamba, Peru. *Ecology*, 23–40.

Terborgh, J. (1977). Bird species diversity on an Andean elevational gradient. *Ecology*, 1007–1019.

Vineesh, P., Sabu, T. K., & Karmaly, K. (2007). Community structure and functional group classification of litter ants in the montane evergreen and deciduous forests of Wayanad region of Western Ghats, Southern India. *Oriental Insects*, **41**(1), 427–442.

Wang, X., & Fang, J. (2012). Constraining null models with environmental gradients: a new method for evaluating the effects of environmental factors and geometric constraints on geographic diversity patterns. *Ecography*, **35**(12), 1147–1159.

Whittaker, R. H. (1952). A study of summer foliage insect communities in the Great Smoky Mountains. *Ecological Monographs*, 2–44.
Whittaker, R. H. (1960). Vegetation of the Siskiyou mountains, Oregon and California. *Ecological Monographs*, **30**(3), 279–338.

Whittaker, R. H. (1967). Gradient analysis of vegetation. *Biological Reviews*, **42**(2), 207–264.

g. 8 ACKNOWLEDGEMENTS

I would like to thank my supervisor Dr. Priyadarsanan and the National Mission for Himalayan Studies whose funding has been instrumental in the pursuance and completion of this research. I would also like to thank the Ministry of Environment, Forest and Climate Change and Er. Kireet Kumar.

h. APPENDICES

List of Ant Species (refer to attachment HRA-AM_insects.pdf)

Fellowship Report No.: 3 of 10

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HRA	Vidyadhar Atkore	April 1, 2016	March 31, 2019	Evaluating the role of anthropogenic and ecological factors on freshwater fish diversity in the Arunachal Pradesh: Implication for conservation	Dr.Jagdish Krishnaswamy, Senior Fellow

11.

12. VIDYADHAR ATKORE

1 INTRODUCTION

Natural flow regime maintains the integrity of river ecosystem since it provides wide arrays of river habitat on which many riverine lifeforms complete their life cycle (Arthington et al., 1992; Bunn, 2002; Jardine Timothy D., 2015; Sheldon, 1988). An ecologically important flow regime has five main characteristics: magnitude, frequency, duration, timing (predictability) and the rate of change (flashiness) (N. LeRoy Poff, 1997). A magnitude of flow (mean monthly discharge) may characterise habitat in a stream (Richter, Baumgartner, Powell, & Braun, 1996). The frequency of episodic flows (high or low pulse frequencies) may give a clue as to how and when drought or flood condition occur (Richter et al., 1996). This classification has been applied for many temperate and tropical rivers to understand the relationship between the flow regime and associated river biodiversity (Anderson, Freeman, & Pringle, 2006; King et al., 2015; Macnaughton et al., 2015; White, Ondračková, & Reichard, 2012; Zhang, Malmqvist, & Englund, 1998). Alteration in stream flow is thought to influence the river biota both positively and negatively (Dudgeon, 2000; Macnaughton et al., 2015; Sakaris, 2013) benefiting eurytopic species but affecting rheophilic species (Aarts, 2003). Dams alter streamflow drastically thereby influencing the distribution of many river dependent species (Dudgeon, 2000; Pringle, 2001). To understand the impacts of dams on aquatic life, researchers have categorized a dammed river into four segments 1) an upstream segment largely unaffected by the dam (fully upstream) 2) the segment inundated by the water behind the dam 3) and the remaining downstream portion of the river (Brown & Ford, 2002). A fully upstream section may harbour native fluvial specialist species whereas, section just behind may form an impoundment effect which benefit many generalist-eurytopic omnivore fish guilds (Aarts, 2003). The fully downstream section may be dominated with generalist, non-native rheophilic omnivore feeding guilds (Aarts, 2003). Apart from these effects, catchment history, topography and land use changes, water abstraction & construction of dams etc also influence hydrological processes which changes structure of fish communities (Jackson, Peres-Neto, & Olden, 2001; Schloseer, 1991).

The intensity of released water downstream the hydropower dam is usually high. This fluctuating water was considered as a form of disturbance and also known to altered natural river habitats (Travnichek, Bain, & Maceina, 1995). How much minimum flow is required to sustain ecological function below the dam is important aspect in river conservation (Smakhtin, 2006). A concept of recovery from the disturbance was implied that, the disturbed system (i.e. the system that has responded to a disturbance) will move towards some natural bounds within which it can persist (Connell & Sousa, 1983). Different ways were adopted in a comprehensive review on the recovery of an aquatic system in the temperate rivers (Niemi, 1990). Later researchers have adopted mainly three criteria to study the recovery: i) availability of pre-disturbance data as a reference ii) post-disturbance sampling that assured the recovery time iii) approximate time when the stressor ended (Detenbeck, DeVore, Niemi, & Lima, 1992). Broadly they agreed that, most of the species were resilient to the many forms of disturbances and they showed resilience within three years.

Health of a river can be assessed based on the structure of fish communities (Karr, 1981). For instance, availability of a good proportion of fluvial specialist (rheophilic) especially downstream was considered as part of recovery (Travnichek et al., 1995). For instance, researchers who have studied the effect of the enhanced (minimum) flow below the dam on the fish communities, have found a double increase in the richness and abundance of fish species and the presence of eurytopic species was more than rheophilic (fluvial specialist) species. Such minimum flow also reduces abundance of larval fishes in the highly regulated river in the USA (Scheidegger & Bain, 1995) to which authors have hypothesised that it could be due to the change or shift in the water depth and discharge (Kinsolving & Bain, 8 1993) and the distance downstream (Bain, 1989). In another study, researcher have studied an entry of a tributary to the main river but before the dam seems to have some amelioration effect to the fish communities (Alexandre, 2013; Brown & Ford, 2002). But, they realized that, the finding a recovery endpoint below the dam was difficult (Kinsolving & Bain, 1993).

Above studies came from temperate regions and largely tested for depauperate stream fauna, none from the tropical Asian rivers. I would like to explore this idea in biodiverse region of North Eastern Himalayas. I hypothesise that, an entry of undisturbed/unregulated stream especially below the dam would create an amelioration effect thereby leading to species recovery (species composition should match to the undisturbed stream reference composition). Pls see a conceptual diagram below.

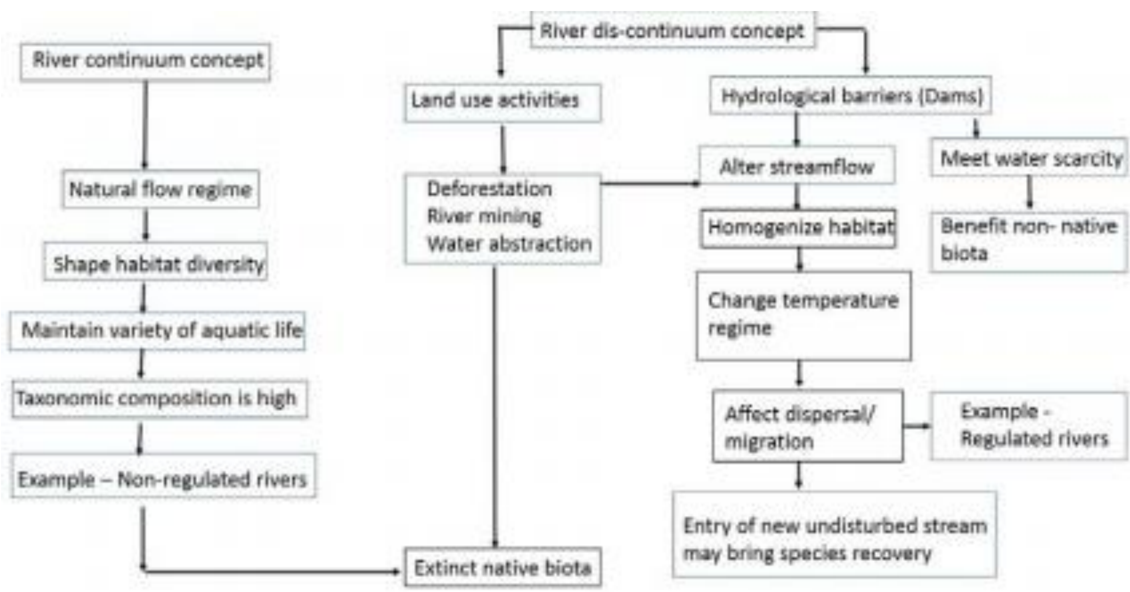


Figure 1. Shows the schematic diagram of species recovery below the dam with new stream joining below the main river channel bringing the amelioration effect

13.

a. 2 METHODOLOGIES, STRATEGY AND APPROACH

We identified undammed tributaries both above and below of hydropower dams. Segments of 100m were sampled in each of these tributaries. We also measured stream habitat and other important environmental characteristics (water temperature, alkalinity, conductivity and substrate composition).

b. 3 KEY FINDINGS AND RESULTS

At a distance of 20 km, total as well as endemic species recovery is evident in Ranganadi sub-basin (Fig 1 & 2). Fish abundances in pool was highest followed by riffle and run (Fig. 3). Other key life-history traits varied along the upstream-downstream gradient (Fig 4). With respect to habitat, main reproductive guilds such as lithophil was highest in riffle while lithopelagophils was highest in pool habitat (Fig 5). With increasing distance from a dam, we observed differences in water chemistry variables. Water temperature, conductivity declines while total alkalinity and total hardness values increased.

Undammed tributaries serve as refuge by providing substrate composition and maintain ecological functions for many mobile riverine species as opposed to dammed tributaries. Recognizing and conserving such undammed tributaries is the need of the hour within a hydrologically modified river basin.

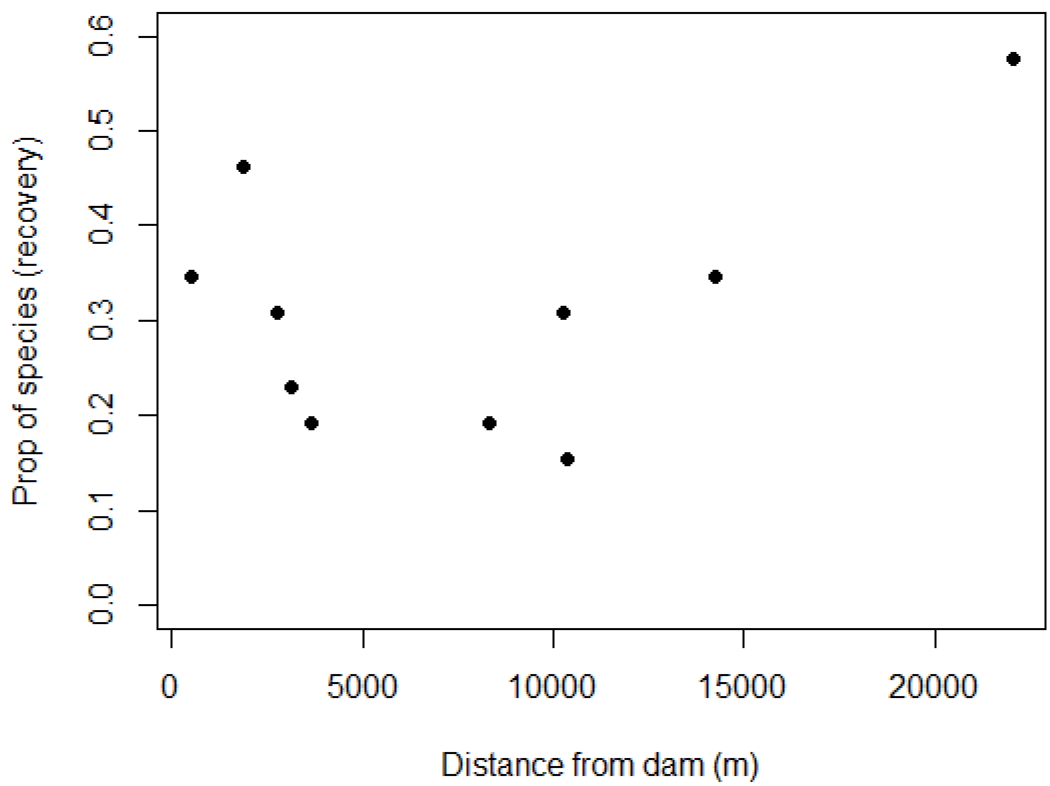


Figure 1. Graph showing total species recovery in Ranganadi sub-basin, Arunachal Pradesh.

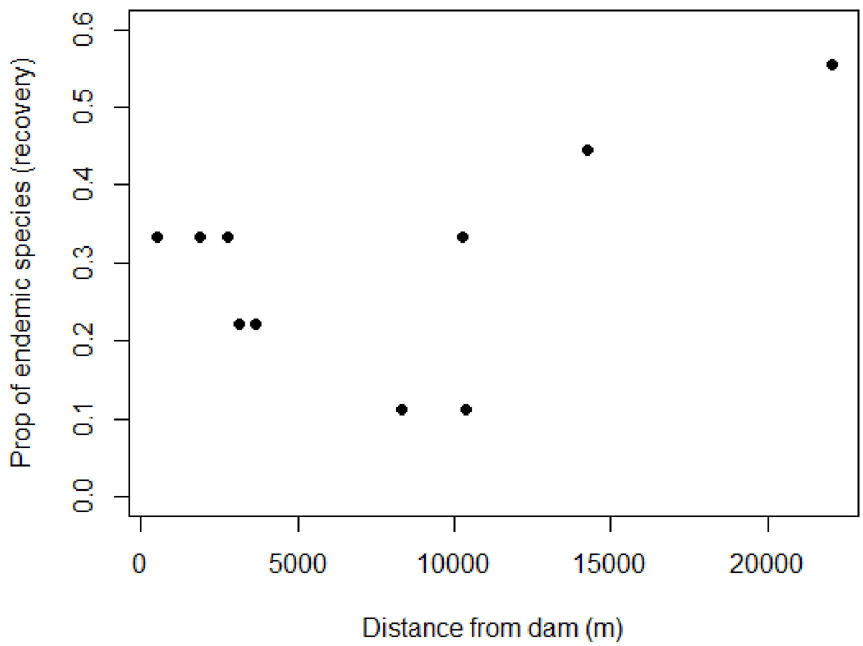


Figure 2. Endemic fish species recovery in Ranganadi sub-basin, Arunahcal Pradesh, India.

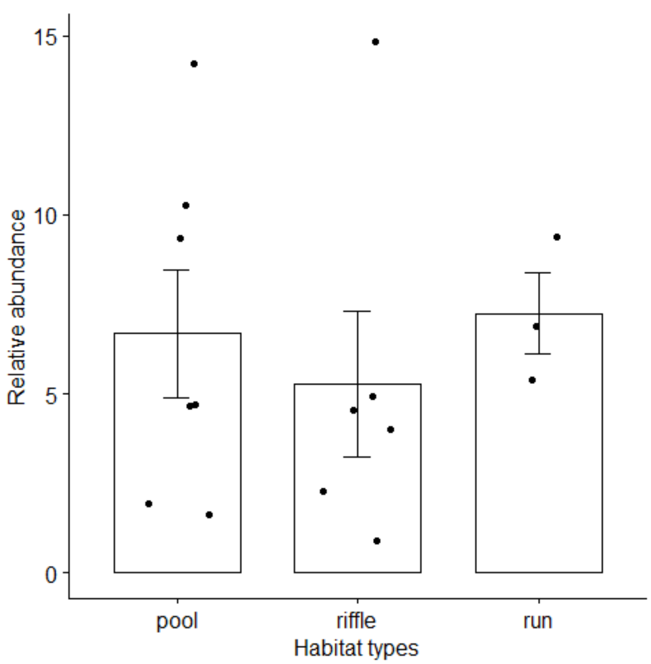


Figure 3. Relative abundance of fishes in three habitat types.

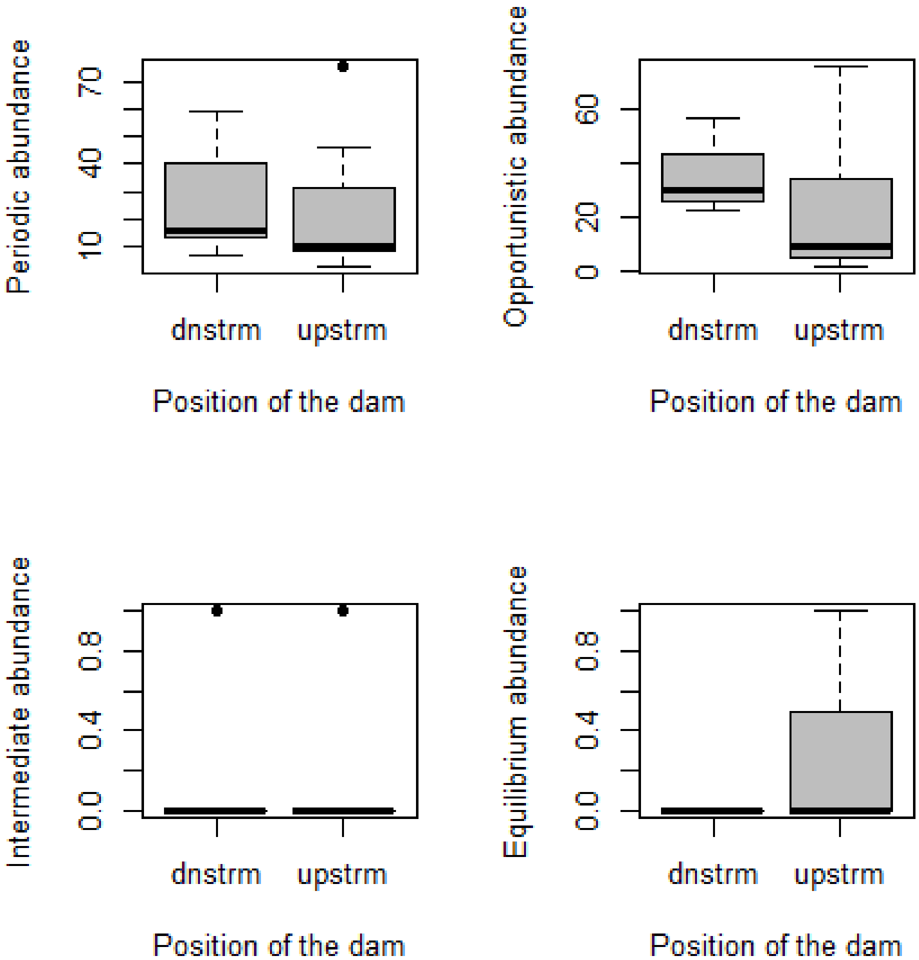


Figure 4. Distribution of key life-history traits along upstream-downstream gradient

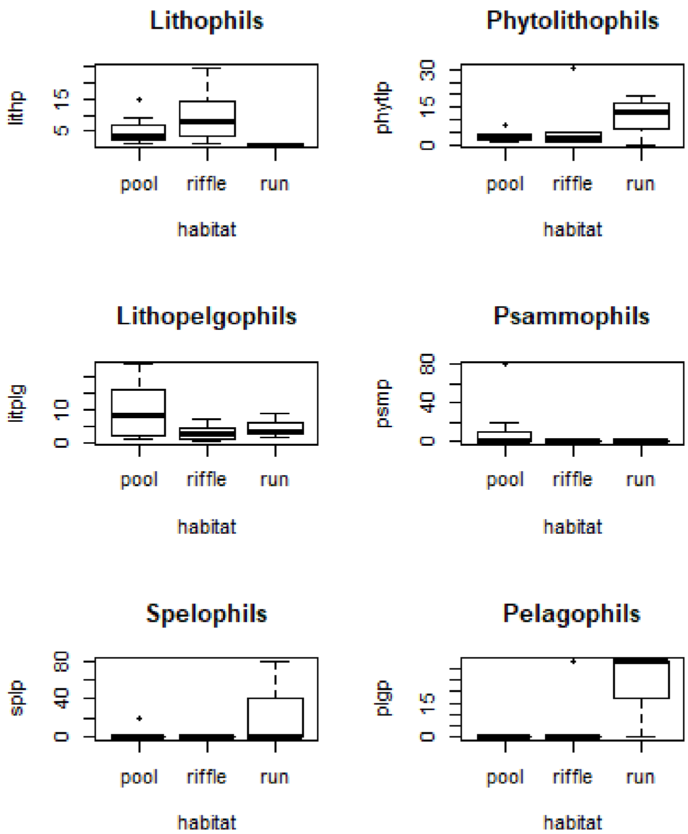


Figure 5. Distribution of key reproductive guilds across three habitat types.

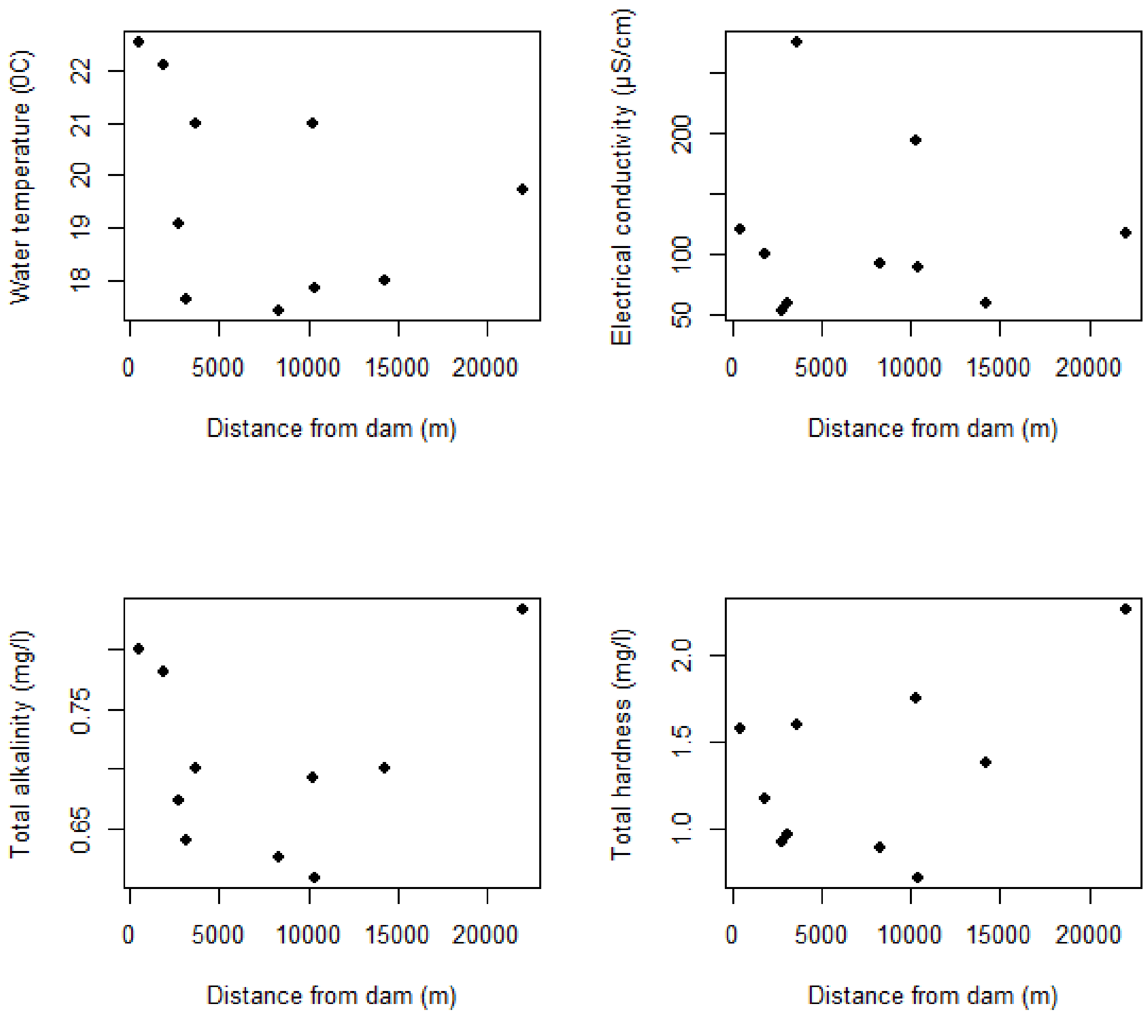


Figure 6. Relationship between key water chemistry variables with the distance from a dam.

c. 4 OVERALL ACHIEVEMENTS

- Fish diversity varied across habitat, season and with respect to dam position. Total alkalinity influenced species richness and relative abundance significantly; other variables did not.
- Three reproductive guilds declined downstream of the dam. Water temperature, conductivity, total alkalinity was higher downstream of the dam possibly due to limited riparian vegetation, stream-bed exposure, flow alteration and sub-surface geology.
- The impact of dams on genetic diversity of native fish could not be assessed but samples of selected species have been preserved at the ATREE Conservation & Genetics Lab.
- Species recovery is evident 20 km downstream of the dam possibly due to the refuge provided by undammed tributaries.

d. 5 IMPACTS OF FELLOWSHIP IN IHR

The influence of dams on native and endemic fish must be considered for sustainably meeting India's renewable energy goals (INDC target).

e. 6 EXIT STRATEGY AND SUSTAINABILITY

Undammed tributaries serve as refuge by providing substrate composition and maintain ecological functions for many mobile riverine species as opposed to dammed tributaries. Recognizing and conserving such undammed tributaries is the need of the hour within a hydrologically modified river basin.

f. 7 REFERENCES/BIBLIOGRAPHY

Aarts, BramG W., Nienhuis, Piet, H. (2003). Fish zonations and guilds as the basis for assessment of ec ological integrity of large rivers. *Hydrobiologia, 500*(1-3), 157-178. doi: 10.1023/A:1024638726162

Alexandre, C. M., Ferreira, T. F. Almeida, P. R. (2013). Fish assemblages in non-regulated and regulated rivers from permanent and temporary Iberian systems. *River Research an d Applications, 29*(8), 1042-1058. doi: 10.1002/rra.2591

Anderson, Elizabeth P., Freeman, Mary C., & Pringle, Catherine M. (2006). Ecologica consequences of hydropower development in Central America: impacts of small dams and water diversio n on neotropical stream fish assemblages. *River Research and Applications, 22*(4), 397-411. doi: 10.1002/rra.899

Arthington, Ah, King, Jm, O'Keefe, Jh, Se, Bunn, Ja, Day, Pusey, Bj, & Tharme, R. (1992). *Develpment of a holistic approach for assessing environmental flow requirements for riverine ecosystems.*

Bain, M. B., and J. M. Boltz. . (1989). Regulated streamflow and warmwater stream fish: a general hypoth esis and research agenda. (Vol. 89): U.S. Fish and Wildlife Service Biological Report. Brown, Larry R., & Ford, Tim. (2002).

Effects of flow on the fish communities of a regulated California river: implications for managing native fis hes. *River Research and Applications, 18*(4), 331- 342. doi: 10.1002/rra.673

Bunn, S.E., & A.A. Arthington. (2002). Basic principles and ecological consequences of altered flow re gimes for aquatic biodiversity. *Environmental Management, 30*(4), 492-507. doi: 10.1007/s00267-002-2737-0

Connell, Joseph H., & Sousa, Wayne P. (1983). On the Evidence Needed to Judge Ecological Stability o r Persistence. *The American Naturalist, 121*(6), 789-824.

Detenbeck, NaomiE, DeVore, PhilipW, Niemi, GeraldJ, & Lima, Ann. (1992). Recovery of temperate stream fish communities from disturbance: A review of case studies and synthesis of theory.*Environment al Management, 16*(1), 33-53. doi: 10.1007/BF02393907

Dudgeon, D. (2000). Largescale hydrological changes in Tropical Asia: Prospects for riverine biodiversity. *BioScience, 50*, 9.

Jackson, Donald A., Peres Neto, Pedro R., & Olden, Julian D. (2001).
What controls who is where in freshwater fish communities the roles of biotic,
abiotic, and spatial factors. *Canadian Journal of Fisheries and Aquatic Sciences, 58*(1), 157-
170. doi: 10.1139/f00-239

Jardine Timothy D., Nicholas R. Bond, Michele A. Burford, Mark J. Kennard,Douglas P. Ward, Peter Bayli
ss,Peter M. Davies, Michael M. Douglas,Stephen K. Hamilton, John M. Melack, Robert J. Naiman,Neil E.
Pettit,Bradley J. Pusey,Danielle M. Warfe, and Stuart E. Bunn. (2015).
Does flood rhythm drive ecosystem responses in tropical riverscapes? *Ecology, 96*(3), 684–692.

Karr, James. (1981). Assessment of Biotic integrity using fish communities. *Fisheries,
6*(6), 21-27.

King, Alison J., Gwinn, Daniel C., Tonkin, Zeb, Mahoney, John, Raymond, Scott, & Beesley, Leah. (20
15). Using abiotic drivers of fish spawning to inform environmental flow management. *Journal of Applie
d Ecology*, n/a-n/a. doi: 10.1111/1365-2664.12542

Kinsolving, Alan D., & Bain, Mark B. (1993). Fish Assemblage Recovery Along a Riverine Disturbance
Gradient. *Ecological Applications, 3*(3), 531-544. doi: 10.2307/1941921

Macnaughton, Camille J., McLaughlin, Fraser, Bourque, Guillaume, Senay, Caroline, Lanthier, Gabriel, H
arvey-Lavoie, Simonne, . . . Boisclair, Daniel. (2015).

The Effects of Regional Hydrologic Alteration on Fish Community Structure in Regulated Rivers*River Res
earch and Applications*, n/a-n/a. doi: 10.1002/rra.2991

N. LeRoy Poff, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, R
ichard E. Sparks, and Julie C. Stromberg (1997). The natural flow regime: a paradigm for river conser
vation and restoration. *BioScience, 47*(11), 769-784 doi: 10.2307/131309910

Niemi, Gerald J., DeVore, Philip, Detenbeck, Naomi, Taylor, Debra, Lima, Ann, Pastor, John, Yount, J. D
avid, Naiman, Robert J. (1990). Overview of case studies on recovery of aquatic systems from disturban
ce. *Environmental Management, 14*(5), 571-587. doi: 10.1007/bf02394710

Pringle, C. M. (2001). Hydrologic connectivity and the management of biological reserves: a global per
spective. *Ecological Application, 11*(4), 981-998.

Richter, Brian D., Baumgartner, Jeffrey V., Powell, Jennifer, & Braun, David P. (1996). A Method for As
sessing Hydrologic Alteration within Ecosystems

Un Métro para Evaluar Alteraciones Hidrológicas dentro de Ecosistemas. *Conservation Biology, 10*(
4), 1163-1174. doi: 10.1046/j.1523-1739.1996.10041163.x

Sakaris, P. C. (2013). *A review of the effects of hydrologic alteration on fisheries and biodiversity and the
management and conservation of natural resources in regulated river systems*. Scheidegger, Karl J., & B
ain, Mark B. (1995). Larval Fish Distribution and Microhabitat Use in Free-
Flowing and Regulated Rivers. *Copeia, 1995*(1), 125-135. doi: 10.2307/1446807

Schloseer, Issac J. (1991). Stream fish ecology: a landscape perspective. *BioScience, 41*(10), 704-712.

Sheldon, Andrew L. (1988). Conservation of Stream Fishes: Patterns of Diversity, Rarity, and Risk. *Cons ervation Biology, 2*(2), 149-156. doi: 10.2307/2386101

Smakhtin, V. and Anputhas, M. (2006). An Assessment of Environmental Flow Requirements of Indian Ri ver Basins. Colombo, Sri Lanka: International Water Management Institute Research.

Travnichek, Vincent H., Bain, Mark B., & Maceina, Michael J. (1995). Recovery of a Warmwater Fish As semblage after the Initiation of a Minimum-Flow Release Downstream from a Hydroelectric Dam. *Transactions of the American Fisheries Society, 124*(6), 836-844. doi: 10.1577/1548-8659(1995)124<0836:ROAWFA>2.3.CO;2

White, Seth M., Ondračková, Markéta, & Reichard, Martin. (2012). Hydrologic Connectivity Affects Fish A ssemblage Structure, Diversity, and Ecological Traits in the Unregulated Gambia River, West Africa. *Biot ropica, 44*(4), 521-530. doi: 10.1111/j.1744-7429.2011.00840.x

Zhang, Yixin, Malmqvist, Björn, & Englund, Göran. (1998). Ecological processes affecting community structure of blackfly larvae in regulated and unregulated rivers: a regional study.*Journal of Ap plied Ecology, 35*(5), 673-686. doi: 10.1046/j.1365-2664.1998.355345.x

g. 8 ACKNOWLEDGEMENTS

I would like to thank my supervisor Dr. Jagdish Krishnaswamy whose guidance through this project was significant. I would like to thank the National Mission for Himalayan Studies whose funding has been instrumental in the pursuance and completion of this research. I would also like to thank the Ministry of Environment, Forest and Climate Change, Er. Kireet Kumar.

h. APPENDICES

An updated list of fish species sampled in Ranganadi sub-basin

fish acronym	Fish species	Family
bar.bend	*Barilius bendelisis* (Hamilton 1807)	Cyprinidae
bar.sch	*Barilius shacra* (Hamilton 1822)	Cyprinidae
bar.vag	*Barilius vagra* (Hamilton 1822)	Cyprinidae
gar.got	*Garra gotyla* (Gray 1830)	Cyprinidae
gar.lis	*Garra lissorhynchus* (McClelland 1842)	Cyprinidae
gar.ann	*Garra annandalei* Hora 1921	Cyprinidae
gar.sp1	*Garra* sp1	Cyprinidae
gar.min	*Garra minima* Arunachalam, Nandagopal & Mayden 2013	Cyprinidae
gar.sp2	*Garra* sp2	Cyprinidae
gar.ran	*Garra* sp.nov	Cyprinidae
gar.bir	*Garra birostris* Nebeshwar & Vishwanath 2013	Cyprinidae
sch.sp1	*Schistura* sp1	Nemacheilidae

phy.sp1	*Physoschistura* sp1	Nemacheilidae
sch.sp4_tago	*Schistura* sp2	Nemacheilidae
bot.ros	*Botia rostrata* Günther 1868	Botiidae
tar.lat	*Tariqilabeo latius* (Hamilton 1822)	Cyprinidae
tor.put	*Tor putitora* (Hamilton 1822)	Cyprinidae
dan.aqu	*Devario aequipinnatus* (McClelland 1839)	Cyprinidae
neo.hex	*Neolissochilus hexagonolepis* (McClelland, 1839)	Cyprinidae
psi.aru	*Psilorhynchus arunachalensis* (Nebeshwar, Bagra & Das 2007)	Psilorhynchidae
sch.ric	*Schizothorax richardsonii* (Gray 1832)	Cyprinidae
cha.gac	*Channa gachua* (Hamilton 1822)	Cyprinidae
cha.str	*Channa striata* (Bloch 1793)	Cyprinidae
dan.rer	*Danio rerio* (Hamilton 1822)	Cyprinidae
pun.cho	*Puntius chola* (Hamilton 1822)	Cyprinidae
ore.pag	*Oreoglanis pangenensis* Sinha & Tamang 2015	Sisoridae
amb.aru	*Amblyceps arunachalense* Nath & Dey 1989	Amblycipitidae
pse.sul	*Pseudecheneis sulcata* (McClelland 1842)	Sisoridae
abo.bou	*Aborichthys boutanensis* (McClelland 1842)	Nemacheilidae
abo.ver	*Aborichthys verticauda* Arunachalam, Raja, Punniyam & Mayden 2014	Nemacheilidae
abo.sp1	*Aborichthys* sp1	Nemacheilidae
abo.sp2	*Aborichthys* sp2	Nemacheilidae
pet.tic	*Pethia ticto* (Hamilton 1822)	Cyprinidae
ban.der	*Bangana dero* (Hamilton 1822)	Cyprinidae
cyp.cap	*Cyprinus carpio* Linnaeus 1758	Cyprinidae
sch.sp_dam	*Schistura* sp3	Nemacheilidae

Fellowship Report No.: 4 of 10

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HJPF	Annesha Chowdhury	April, 2016	July 31, 2019	Biodiversity, Ecosystem Services and Human Wellbeing in the Darjeeling tea-forest	Dr. M Soubadra Devy, Senior Fellow

14. ANNESHA CHOUDHARY

1 INTRODUCTION

Forest-agricultural matrices are being converted to more intensive land-use in India, and a growing concern is the impact of land-use and land-cover change on the persistence of biodiversity as well as people's wellbeing. The tea-forest landscapes in the Darjeeling Himalayas remain interspersed between protected areas such as the Singhalila National Park and the Senchel and Mahananda Wildlife Sanctuaries and are known to exist as extensions of the forest frontier, by either facilitating movement between suitable habitats for both flora and fauna and sometimes by serving as refugia. Current approaches to biodiversity conservation emphasize focus on landscapes outside protected areas and therefore on aspects of human wellbeing such as livelihoods, health, in order to achieve such goals sustainably. With rise in tea tourism and a gradual change in management of tea estates my study asks whether the Darjeeling tea-forest landscape has the ability to support biodiversity and wellbeing of the people dependent on this landscape.

As part of the methodologies, we used a combination of natural science and social science methodologies. Activities began with conducting an exhaustive reconnaissance of the Darjeeling tea estates. There are 87 tea estates however, only those tea estates were selected that were in proximity to three different protected areas ie. Singhalila National Park, Senchel and Mahananda Wildlife Sanctuaries. Thereafter, methods were standardized and fieldwork continued by conducting biodiversity assessments as well as group and semi-structured interviews with various households of the tea landscape.

As part of the methodologies, we used a combination of natural science and social science methodologies. Activities began with conducting an exhaustive reconnaissance of the Darjeeling tea estates. There are 87 tea estates however, only those tea estates were selected that were in proximity to three different protected areas ie. Singhalila National Park, Senchel and Mahananda Wildlife Sanctuaries. Thereafter, methods were standardized and fieldwork continued by conducting biodiversity assessments as well as group and semi-structured interviews with various households of the tea landscape.

Site sampling strategy – The Darjeeling tea estates were selected based on a complex system of stratified random and systematic sampling. Based on ownership, management regime and the combination of certifications adopted or not adopted 13 sites were selected with a spatial and temporal replicate in year two of the assessments

Image 1. Biodiversity forest trails, Darjeeling

Image 2. Vegetation Plots

Image 3. Sign Survey

Image 4 and 5. Setting up camera traps

Sampling method - For every biodiversity assessment trails (Image 1) for identified within the tea-forest landscape. Vegetation assessments **–** This included laying 4 nested vegetation plots measuring 5m X 5m (Sutherland, 2006, Image 2) at an interval of 250m within the 1 km trail to enumerate all trees and shrubs. A 1m X 1m nested sub-plot, randomly placed inside each 5m X 5m plot was laid to enumerate all herb species, percentage grass cover. Faunal surveys – This included surveying (Sutherland, 2006) mammals through sign-survey (Image 3) and camera traps (Image 4 & 5), birds through point counts and soil arthropods via pitfall traps along the trails used for vegetation sampling. Each taxon was selected to represent different degrees of vagility and occupying a different stratum of the ecosystem.

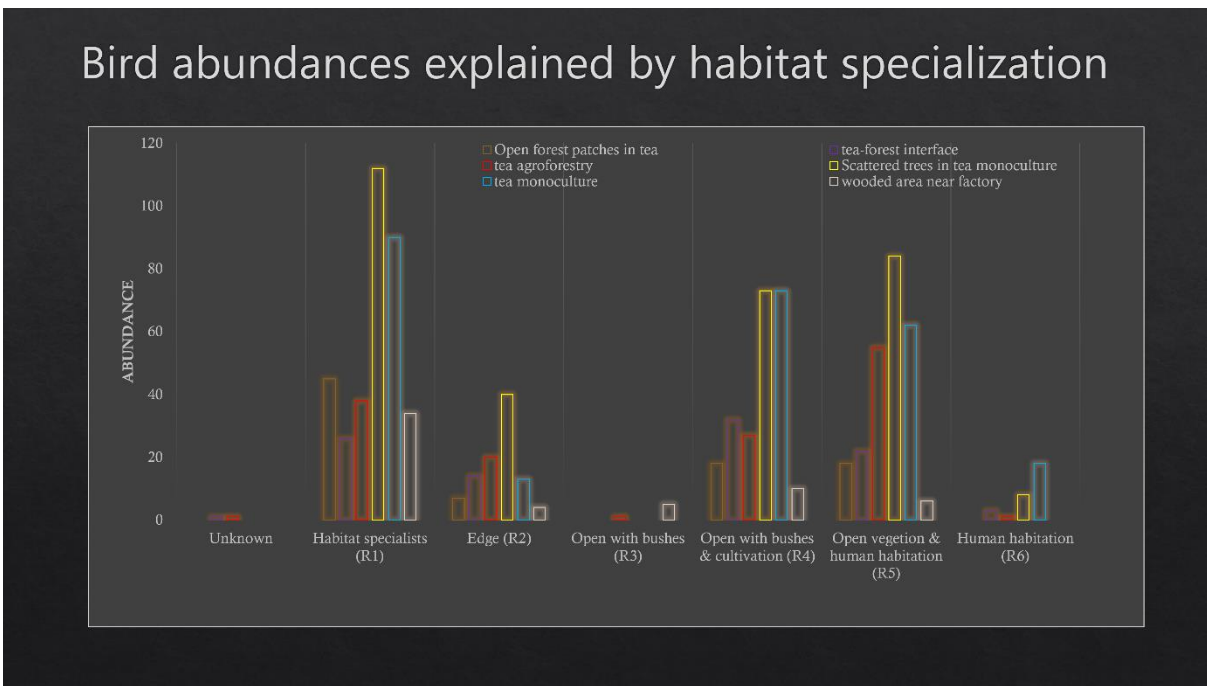


Image 6. Bird abundances

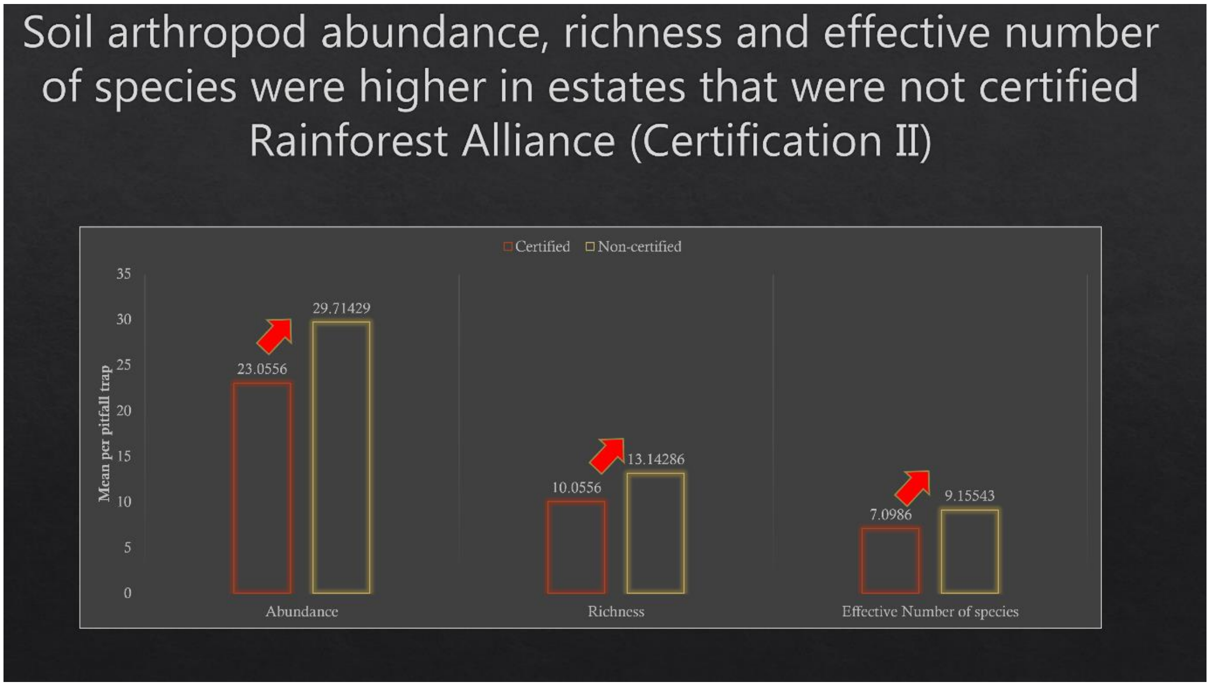


Image 7. Soil arthropod abundance, richness and effective no. of species

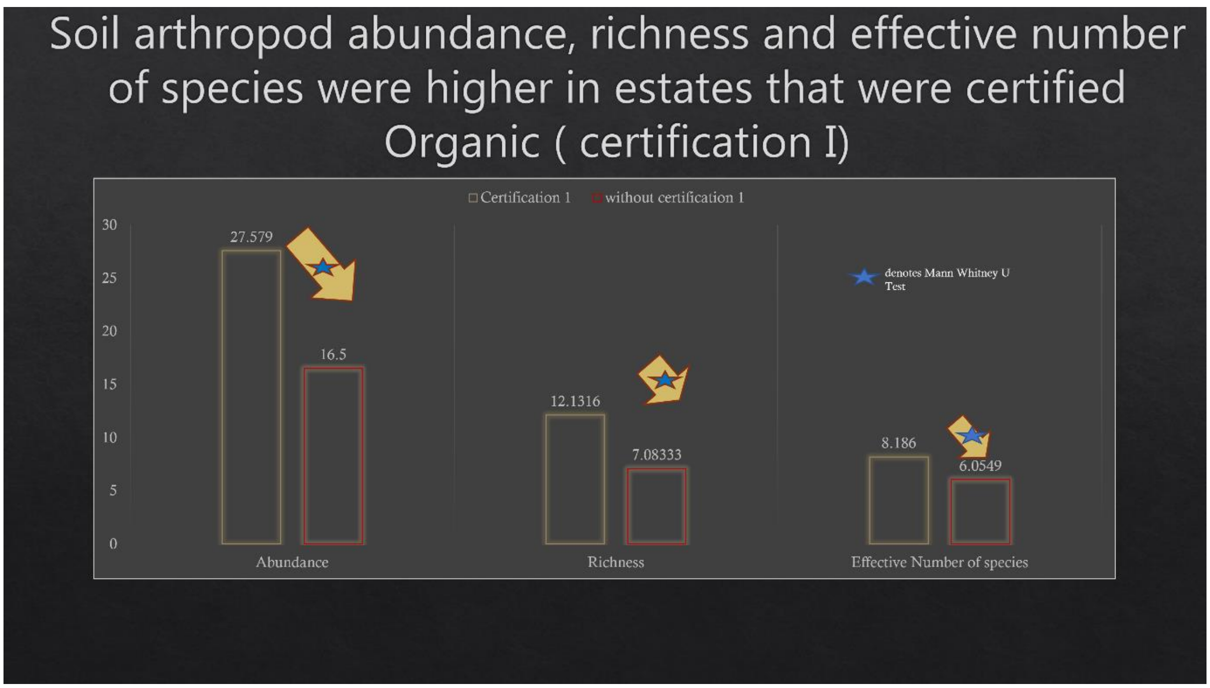


Image 8. Soil arthropod abundance, richness and effective no. of species

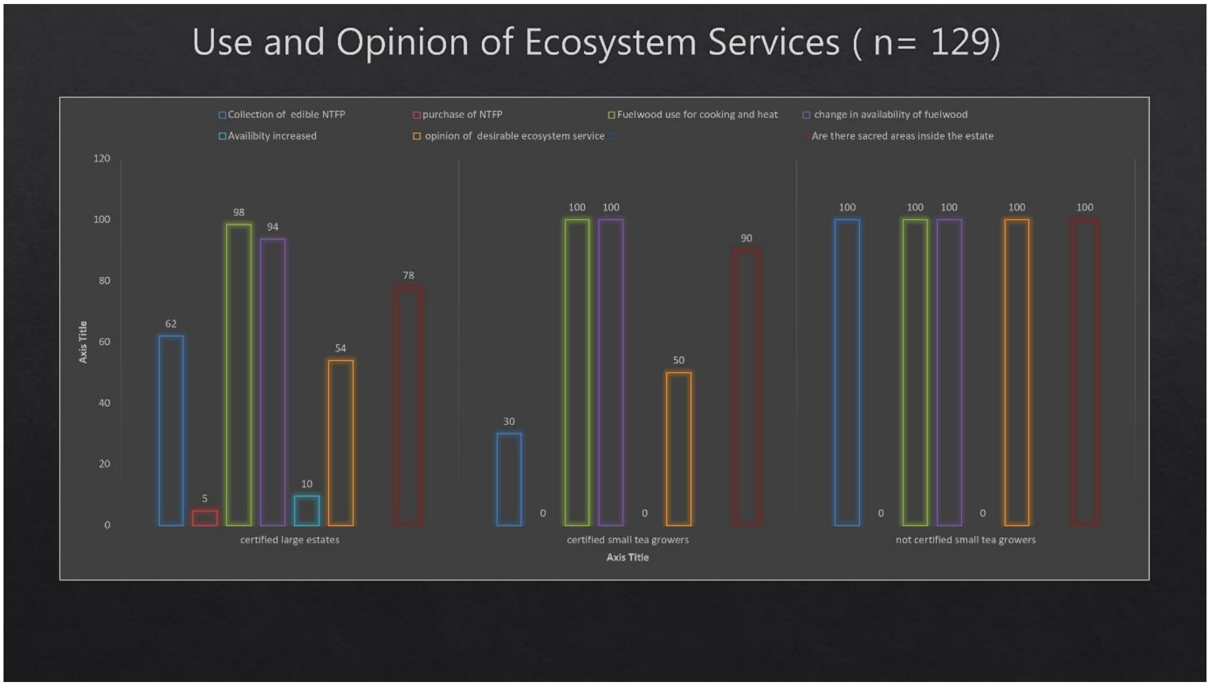


Image 9. Use and Opinion of Ecosystem Services

Mammal survey – The survey of mammals involved using camera traps and sign surveys (Lyra-Jorge et al., 2009) along trails. Bird survey – Bird surveys involved point counts every 250m along the 1 km transect. All bird s*pecies* along with activity within a 30m radius were *n*oted for 10m *and co*nducted between 6.00 am – 9.00am. Soil arthropod survey – Pitfall traps (McGavin et al., 1997; Jones *et. al.,* 2003) containing 70% alcohol will be placed every 250m along every 1 km trail. Focus group discussions and other participatory meetings were used to get data on community use and level of dependence on ecosystem goods and services. Results of faunal assessments such as abundance and species richness will be used to evaluate cultural service such as aesthetics and recreational opportunities from the tea-forest landscape (Sherrouse et al., 2011). Semi-structured questionnaire survey (Newing, 2011) was used to collect data at the household level in every village within tea-estates. Field work for biodiversity surveys was conducted in two seasons i.e. pre-monsoon and post-monsoon in 2016 and 2017. Household interviews were conducted in 2018 in months when tea estate management allowed multiple visits. Photographs are provided for reference.

Training local people – fieldwork required the support on field from many individuals. Many of the local youth were trained to handle equipment and conduct biodiversity assessments along with conducting group meetings with villagers.

a. 2 METHODOLOGIES, STRATEGY AND APPROACH

For every biodiversity assessment trail identified within the tea-forest landscape. Vegetation assessments **–** This included laying 4 nested vegetation plots measuring 5m X 5m (Sutherland, 2006) at an interval of 250m within the 1 km trail to enumerate all trees and shrubs. A 1m X 1m nested sub-plot, randomly placed inside each 5m X 5m plot was laid to enumerate all herb species, percentage grass cover. Faunal surveys – This included surveying (Sutherland, 2006) mammals through sign-survey and camera traps, birds through point counts and soil arthropods via pitfall traps along the trails used for vegetation sampling. Each taxon was selected to represent different degrees of vagility and occupying a different stratum of the ecosystem. Mammal survey – The survey of mammals will involve using camera traps and sign surveys (Lyra-Jorge et al., 2009) along trails. Bird survey – Bird surveys involved point counts every 250m along the 1 km transect. All bird s*pecies* along with activity within a 30m radius were *n*oted for 10m *and co*nducted between 6.00 am – 9.00am. Soil arthropod survey – Pitfall traps (McGavin et al., 1997; Jones *et. al.,* 2003) containing soap solution was placed every 250m along every 1 km trail. Focus group discussions and other participatory meetings were used to get data on community use and level of dependence on ecosystem goods and services. Results of faunal assessments such as diversity indices and species richness will be used to evaluate cultural service such as aesthetics and recreational opportunities from the tea-forest landscape (Sherrouse et al., 2011). Semi-structured questionnaire survey (Newing, 2011) was used to collect data at the household level in every village within tea-estates.

A Nikon Coolpix P900 Camera was used to document fieldwork, the landscape, the ecosystem and different aspects of being in the tea-forest mosaic.

Mammal sign survey was conducted by walking the pre-identified trails and noting any signs of mammal presence such as scats, pug marks, scratches on trees. The only equipment used was a Garmin GPS device that was used to geo-tag the location, in case the presence of any mammal was detected. Additionally, 5MP – 10M Digital Infrared Camera Traps were used to assess mammal presence within tea-forest areas through 336 hours of monitoring.

Birds were assessed using the point-count method. Two Nikon ACULON A211 -10-22 x 50 8252 Binoculars were used to observe and identify birds. The information was then noted in a notebook. A Garmin GPS device was used to geo-tag the location.

Regular Styrofoam cups measuring 3.5” in height and 3.2” at the diameter on top were used as traps for soil arthropods. 70% ethyl alcohol purchased from a local vendor in Siliguri to store trapped soil arthropods for sorting and identifications. The cups were filled with soap solution and placed in a depression at ground level and left overnight to allow maximum trapping of soil arthropods.

A metal, soil corer measuring approximately 10” in height and diameter of 4” was used to collect soil samples after removing debri and grass from top layer and stored in air-tight zip lock bags before air drying.

A rope, measuring 20m was used to delineate the 5m X 5m quadrat for the vegetation sampling. A SUNNTO tandem clinometer was used assess the bearings for the quadrat, measure the slope and aspect. A spherical crown densiometer was used to assess canopy cover. A Forestry Supplier’s DBH tape was used to measure girth of trees. A Hawke Sport Rangefinder was used to measure tree height.

Birds – A total of 5400 birds were recorded which includes 518 individuals in pre-monsoon 2016 season, 960 individuals in post monsoon season in 2016; 889 individuals in premonsoon season in 2017 and 1528 individuals in post-monsoon 2017 and finally 1505 individuals in winter 2018. This included 157 species across 33 families and 17 unidentified bird species.

Soil Arthropods – A total of 4231 individuals were sorted and identified from Darjeeling tea matrix, belonging to 674 morphospecies whereas 3 are unknown. The soil arthropods identified were then categorized found to belong to 28 families.

Mammals – A total 17 species of mammals were identified using the tea-forest landscape. These included common leopard, the melanistic leopard, civet cat, jungle cat, yellow throated martens, wildboars, and barking deer.

Vegetation – We have identified over 40 different endemic tree species across all sampling points. The most dominant form of exotic species is tea (*Camelia sinensis* and *Camelia assamensis*) and pine (*Cryptomeria japonica*).

Soil samples were collected from all sampling points. They were sieved, air dried and tested for N:P:K, Organic Carbon and pH.

Prior to fieldwork a reconnaissance survey was carried out to select the optimal sites for sampling. A pilot assessment was done to understand the logistic requirement based on which the number of sites were decided, given the seasonal variability and onset of monsoons as well as time taken to travel to and from different field sites. There was a constant challenge to get daily permission from estate management as sometimes they would reschedule, however, we were able to conduct field work with minimal issues.

A 2km X 2 km sampling grid was created to stratify the landscape into measurable units. Only those grids were selected that were in proximity to the three protected areas. Then pre-identified trails were determined inside the grids. The reconnaissance survey was also used to identify the pre-defined trails that were to be used as sampling trails throughout the study. Local residents and experts were consulted to decide which location inside a tea estate would be ideal for sampling.

Accommodation at the field site was arranged in proximity to the sampling location owing to the timing of our study. The team would leave the host's home at day break and begin bird sampling between 6.00 and 6.30 am depending on when bird activity would begin. Field assistants and locally hired assistants would assist us in then, conducting vegetation assessment at every sampling location. We would complete survey at one point, collect the soil, place the pitfall trap, take photographs of the landscape, or birds, mark the point using Garmin GPS device and silently move to the next sampling point. Given the multiple taxa it would take upto 4-6 hours to return to base after which, the soil sample would be immediately sieved, air dried and stored in labelled zip lock bags.

A prior permission from tea plantation management was required to conduct household interviews. The households were first stratified based on their ethnicity and caste and then 10% of households from each group were interviewed to maintain representation of all different groups residing inside the tea estates.

Fieldwork was conducted after procuring research permits from the West Bengal Forest Department. Although the study was not conducted inside any protected area, this was done to maintain goodwill of the FD and also have their knowledge about the various equipment to be used for faunal surveys in tea estate forests. Fieldwork was conducted every season, with prior permission from the Darjeeling Tea Association and Indian Tea Association, and respective tea management. Equipment had been purchased prior to going to the field.

Purchase of Equipment was done while in the head office in Bangalore mostly via Amazon and Forestry Suppliers along with some local vendors

Homes of tea estate employees/ workers were extended for stay for a reasonable amount of money on a per diem basis.

Two field assistants were hired to assist with equipment handling and fieldwork. Local boys were trained and their capacity built such that they could conduct vegetation, faunal assessment with precision and minimal supervision when replicates were being surveyed at the same time.

Local vehicles were used to reach field sites from Darjeeling town where the research team was originally located during every field season.

The research team was always in touch with the local Police Station, the local ATREE office and other partner organizations about the whereabouts of field workers.

b. 3 KEY FINDINGS AND RESULTS

There is a major difference between certification and practice in Darjeeling tea-plantations. A plantation may be certified but may not have all practices that adhere to sustainable agriculture standards and hence may not affect biodiversity in positive ways. Analysis of soil arthropod data revealed that soil arthropod abundance, richness and effective number of species was higher in estates that were Organic certified compared to those that were conventional. Practicing organic agriculture in tea estates, irrespective of their ownership ie small tea growers vs. large estates had an enhanced positive effect on soil arthropods. Soil arthropod species richness and abundance were significantly higher in pre-monsoon sampling period as compared to post-monsoon sampling. Certifications were not a good indicator of biodiversity friendly practices in tea plantations. This was evident from the results of our bird assessments where certification could not explain bird abundances and species richness differences between estates. 129 respondents were interviewed from the Darjeeling tea-forest landscape and they revealed a high dependence on the surrounding ecosystem for their needs of fuelwood, fodder, edible wild fruits and vegetables and medicinal plants. There is a difference in opinion regarding the status of their access to forests. The main difference is that while small tea growers have their own homestead gardens and land, from which they can draw a number of ecosystem goods and services, tea plantation workers mostly rely on the estate forests, which they do not own, for their ecosystem services needs.

Key Results:

- Darjeeling tea-forest landscape supports biodiversity such as large and small mammals, birds and soil arthropods.
- How biodiversity friendly a tea plantation is depending on their management practices and the type of habitat the estate has
- Darjeeling tea-forest landscape supports the wellbeing of the people dependent on the landscape by directly being a source of fuelwood and fodder
- Darjeeling tea-forest dependence is high for the residents because they largely belong to low-income and poor families owing to the number of members in every household
- Management decisions and access to key ecosystem goods and services has a bearing on what kind of tradeoff occurs between biodiversity conservation and human wellbeing.

Conclusions of study:

- We conclude that Darjeeling tea plantations are moving in a positive direction with maximum number of tea estates adopting Organic practices
- Worker income remains low, however, they are able to support themselves by growing vegetables such as leafy greens, trees and dried tea bushes for fuelwood and timber.
- Plantation management can improve conditions for biodiversity by keeping a record of bird and mammal biodiversity and provide income to newly trained individuals from the landscape for that purpose.
- Certifications require tea plantations to keep a large proportion of their estate as forested, these mandates help to support biodiversity by providing habitat and refuge and a source of critical ecosystem goods and services that communities living in the tea plantations depend on.

c. 4 OVERALL ACHIEVEMENTS

This study was successful in creating a positive relationship with the Forest Department and with members of the Darjeeling Tea Association, India Tea Association and local people within the landscape. This study enabled us to confirm that tea plantation plays a big role in fostering animal movement and provide refuge to a lot of wildlife. Many tea plantations currently have active mandates for supporting wildlife in the region. Local people have been trained while conducting fieldwork to assess conditions of the estate forests and maintain a record of wildlife and vegetation for future use.

Even though a lot of studies are conducted in the Darjeeling Himalayas it remains data deficient. This study adds to the database of few studies that document wildlife outside of protected areas in the region especially for the species that can be encountered in the tea estates of Darjeeling across different elevations.

The study also adds more information regarding the wellbeing of plantation workers. Much has been written about and studied regarding the plight of the workers with respect to their low wages. This study attempts to add to that database by providing new insights on what wellbeing means for people living in the tea plantation landscape

Given the exhaustive nature of fieldwork for this study many tea estate workers and local people were trained in handling and using forestry survey equipment such as GPS devices, tags, DBH tapes.

Additionally, they were also trained in entering such information into datasheets. For each of these, tea estate management, requested the research team to train the workers so that they may be able to monitor estate forest by themselves. Local workers were also trained in handling camera traps and monitoring them for the long periods that they were installed in the region. On-site demonstrations were held so that information dissemination and understanding was uniform.

The study also found the Green Skills Development in the region was in keeping with the value system and attitudes of people living in the region. The attitudes of management and workers seemed to exhibit a potential for creating a sustainable social, economic and environmental outcome for the tea industry.

d. 5 IMPACTS OF FELLOWSHIP IN IHR

- Through our training programs, we were able to impart knowledge and provide a scientific basis to sustainable and scientific management of the Natural Resources in the region which is mainly the forests, the tea ecosystem itself and rivers.
- Sustainable practices that have basis in scientific thought are already implemented in the way the plantations are managed.
- Additional effort and guidance for scientific management is provided by the standards or guidelines of the various certifications that are adopted. Even though many require improvements, tea plantation management has a history of scientific management since its inception, therefore, there is a tendency to monitor and control natural resource use with the help of the forest department and local NGOs.
- Darjeeling tea-forest landscape supports biodiversity such as large and small mammals, birds and soil arthropods.
- How biodiversity friendly a tea plantation is depending on their management practices and the type of habitat the estate has
- Additional conservation issues in the region remain tightly regulated by management. Conservation education and awareness is present, however, much more is required for more pro-active engagement of all stakeholders involved.
- Most study sites have a mandate for environmental protection and a protocol based on the needs of the certification.
- Activities mostly involve ban on hunting, ban on cutting trees and tree plantation activities.
- Additional activities such as garbage disposal and waste management do happen however, there is still scope for improvement.
- Although most tea plantations are converting to organic methods of agriculture, a few still remain conventional hence they use pesticides which can be harmful not just for the people, but also wildlife and biodiversity in the area.
- The most needed infrastructure in the Darjeeling tea forest region are well designed and built roads, drainage system and sanitation solutions. Although these are not within the scope of the study undertaken in this fellowship, field experience revealed the need for such infrastructure in order to achieve sustainable goals such as conservation and human wellbeing.
- The potential for strengthening networking in the region is very high.
- The region is well known for its ability to organize and work together.

- There is a need for every part of the local government institutions, local NGOs, the Darjeeling Tea Association and Indian Tea Association to work together. There have been instances in the past where these agencies have worked together for overall environmental and social benefits, however, more would result in better outcomes.

e. 6 EXIT STRATEGY AND SUSTAINABILITY

The findings would help design better management plans and decision with respect to tea plantation and plantation labour in the region. This study highlights the importance of plantation forests not just for wildlife conservation but for better outcomes for people in the region. More effort could be put in managing estate forests, even if they are strips for future needs of ecosystem services and movement pathway by wildlife.

This assessment could be scaled up to include more and more tea plantations in the region as well as in the neighbouring states. Such studies could be used as a repository for not just wildlife management outside of protected areas but also how it can be successful without impeding people's rights and wellbeing.

Given the limited scope of this study due to logistic and budget constraints as well as time constraints, more taxa could not be included. The study could be scaled up to include assessment of amphibians and orthopteran insects as well as canopy dwelling organisms to assess their responses to different management practices. Additionally, more forest types could be included given how heterogenous the landscape is, thus increasing the sampling effort to be able to make more nuanced decisions regarding the condition of these cover types and better management of these natural and semi-natural spaces.

We recommend a more matrix-oriented approach in implementing conservation measures. This means that the tea-forest landscape must be managed as a whole and only focus on natural areas should be avoided. Our study shows the presence and use of the tea growing areas by different types of taxa and thus we recommend managing and sustaining tea plantations with focus on wildlife and vegetation.

We also recommend estate management to continue efforts in increasing worker participation in managing the tea-forest ecosystem and allowing them to reap the benefits of the ecosystem that they have been maintaining for their own wellbeing.

Such landscapes are ideal for sustainable eco-tourism initiatives and can be used to improve conditions of people residing within tea plantation areas

f. 7 REFERENCES/BIBLIOGRAPHY

Tscharntke, Teja, et al. "Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management." *Ecology letters* 8.8 (2005): 857-874.

Tscharntke, Teja, et al. "Conserving biodiversity through certification of tropical agroforestry crops at local and landscape scales." *Conservation Letters* 8.1 (2015): 14-23.

Vatn A, "Institutions and the environment", Edward Elgar Publishing Ltd., Cheltanham, UK, 2005

Zhang, Wei, et al. "Ecosystem services and dis-services to agriculture." *Ecological economics* 64.2 (2007): 253-260.

Sutherland, William J., ed. *Ecological census techniques: a handbook*. Cambridge University Press, 2006.

Senanayake, R. " Analog forestry: an alternative to 'clear and simplify", LEISA Magazine, 16.3, 2000

Seale, Clive, et al., eds. *Qualitative research practice*. Sage, 2004.

Schlüter, M., J. Hinkel, P. W. G. Bots, and R. Arlinghaus, “Application of the SES framework for model-based analysis of the dynamics of social-ecological systems”. *Ecology and Society* 19(1): 36, 2014
http://dx.doi.org/10.5751/ES-05782-190136

Tea Board of India (TBI), (http://www.teaboard.gov.in/inner2.asp?param_link_id=410) , 2013

Sancha, Noé U., et al. "Metacommunity structure in a highly fragmented forest: has deforestation in the Atlantic Forest altered historic biogeographic patterns?." *Diversity and Distributions* 20.9 (2014): 1058-1070.

Schleyer, Christian, and Tobias Plieninger. "Obstacles and options for the design and implementation of payment schemes for ecosystem services provided through farm trees in Saxony, Germany." *Environmental Conservation* 38.04 (2011): 454-463.

Seastedt, Timothy R., Richard J. Hobbs, and Katharine N. Suding. "Management of novel ecosystems: are novel approaches required?." *Frontiers in Ecology and the Environment* 6.10 (2008): 547-553.

Sen, Amartya. "The ends and means of sustainability." *Journal of Human Development and Capabilities* 14.1 (2013): 6-20.

Shankar, T. R., and Divya Mudappa. "Bridging the gap: Sharing responsibility for ecological restoration and wildlife conservation on private lands in the Western Ghats." *Social Change* 33.2-3 (2003): 129-141.

Sherrouse, Benson C., Jessica M. Clement, and Darius J. Semmens. "A GIS application for assessing, mapping, and quantifying the social values of ecosystem services." *Applied Geography* 31.2 (2011): 748-760.

Shigeo, Y. and Loreau, M. "Biodiversity and ecosystem productivity in a fluctuating environment: the insurance hypothesis." *Proceedings of the National Academy of Sciences* 96.4 (1999): 1463-1468.

Raudsepp-Hearne, C., Garry D. Peterson, and E. M. Bennett. "Ecosystem service bundles for analyzing tradeoffs in diverse landscapes." *Proceedings of the National Academy of Sciences* 107.11 (2010): 5242-5247.

Raman, T. R., and Divya Mudappa. "Correlates of hornbill distribution and abundance in rainforest fragments in the southern Western Ghats, India." *Bird Conservation International* 13.03 : 199-212, 2003.

Perfecto I, Vendermeer J and Wright A, “ Nature’s Matrix- Linking Agriculture, Conservation and Food Soverignty”, *Earthscan* , London, UK, 2009

Millenium Ecosystem Assessment, 2005

Nagendra, Harini, and Madhav Gadgil. "Biodiversity assessment at multiple scales: linking remotely sensed data with field information." *Proceedings of the National Academy of Sciences* 96.16 (1999): 9154-9158.

Neilson, J. and Pritchard, B.. Value chain struggles: institutions and governance in the plantation districts of South India. John Wiley & Sons, 2009.

Newing, Helen. Conducting research in conservation: social science methods and practice. Routledge, 2010.

Norberg, Jon, and Graeme S. Cumming, eds. *Complexity theory for a sustainable future*. Columbia University Press, 2013.

Norgaard, Richard B. "Ecosystem services: From eye-opening metaphor to complexity blinder." *Ecological economics* 69.6 (2010): 1219-1227.

Liyanage, Wasantha KDD, et al. "An Assessment of the Contribution of an Analog Forest as a Sustainable Land-use Ecosystem for the Development of Rural Green Economy in Sri Lanka." *Journal of Tropical Forestry and Environment* 3.1, 2013.

Loconto, A. "Value Chains and Chains of Values: Tracing Tanzanian Tea." The 116th EAAE Seminar" Spatial Dynamics in Agri-food Systems: Implications for Sustainability and Consumer Welfare. 2010.

Loreau, Michel, et al. "Biodiversity and ecosystem functioning: current knowledge and future challenges." *science* 294.5543 (2001): 804-808.

Lyra-Jorge, Maria Carolina, et al. "Comparing methods for sampling large-and medium-sized mammals: camera traps and track plots." *European Journal of Wildlife Research* 54.4 (2008): 739-744.

Mace, Georgina M., Ken Norris, and Alastair H. Fitter. "Biodiversity and ecosystem services: a multilayered relationship." *Trends in ecology & evolution* 27.1 (2012): 19-26.

Jones, D. T., et al. "Termite assemblage collapse along a land- use intensification gradient in lowland central Sumatra, Indonesia." *Journal of Applied Ecology* 40.2 (2003): 380-391.

Huntsinger, Lynn, and José L. Oviedo. "Ecosystem services are social-ecological services in a traditional pastoral system: the case of California's Mediterranean rangelands." *Ecology and Society* 19.1 (2014): 8.

Indian Tea Association, (www.indiatea.org)

International Coffee Organization(ICO), "Sustainability Initiatives", (http://www.ico.org/sustaininit.asp)

ECONOMICS, CONSERVATION. "An Economic Analysis of the Benefits of Habitat Conservation on California Rangelands." (2010).

De Groot, Rudolf S., Matthew A. Wilson, and Roelof MJ Boumans. "A typology for the classification, description and valuation of ecosystem functions, goods and services." *Ecological economics* 41.3 (2002): 393-408.

Chetana, H. C., and T. Ganesh. "Importance of shade trees (Grevillea robusta) in the dispersal of forest tree species in managed tea plantations of southern Western Ghats, India." *Journal of Tropical Ecology* 28.02 : 187-197, 2012

g. 8 ACKNOWLEDGEMENTS

I extend my thanks to the National Mission on Himalayan Studies and The Ministry of Environment and Forests, Government of India for supporting this study. I extend gratitude to Dr. Soubadra Devy, Principal Investigator, for guiding me through this work. Additional thanks to Dr. Aravind Madhastha and Dr. Siddhartha Krishnan. I also thank our Academy at ATREE, for supporting me through this work. We extend thanks to the West Bengal Directorate of Forests, Darjeeling Tea Association, the Indian Tea Association and every single tea estate management for granting us permission to carry out this study and supporting us during fieldwork. I also thank our field assistants Samir Biswakarma and Gyabo Sherpa. Without their continuous efforts this extensive study would have been impossible. I thank, Dr Abhas Kr. Sinha and the Uttar Banga Krishi Viswavidyalaya for helping us analyse our soil samples. I would also like to thank Dr. T Ganesh, Dr. Aniruddha Marathe, Abhishek Samrat of the Ecoinformatics Lab, ATREE, Dr. P. Dharma Rajan and the Insect Laboratory at ATREE for their inputs and support. Finally, I thank the USAID and ATREE office in Darjeeling and Sikkim for their help whenever we needed them.

APPENDICES

List of Birds of the Darjeeling tea landscape

Bird Common Name	Bird Common Name	Bird Common Name	Bird Common Name	Bird Common Name
Ashy drongo	Common Redstart	Grey hooded warbler	Pale footed bush warbler	Siberian rubithroat
Ashy throat warbler	Common Stonechat	Grey Treepie	Pigeon	Silver eared Mesia
Indian paradise flycather	Common Tailor bird	Grey wagtail	Pipit	Slatey blue flycatcher
Babbler	Crimson sunbird	Hill Myna	Plum headed parakeet	Smokey warbler
Barn Swallow	Cuckoo	Himalayan Bulbul	Plumbeous water redstart	Some babbler 2
Besra	Dark breasted Rosefinch	Himalayan Cuckoo	Prinia	Spangled Drongo
Black Bulbul	Drongo	House Crow	Purple Sunbird	Spotted Dove
Black Drongo	Dusky Warbler	House Sparrow	Red breasted flycatcher	Striated Prinia
Black faced Warbler	Eagle/KIte	house swift	Red throated thrush	Striated Swallow
Black headed bulbul	Emerald Dove	Hume's leaf warbler 2	Red-billed Leiothrix	Stripe-breasted woodpecker
Black hooded Oriole	Fantail	Jungle babbler	Red-rumped swallow	Sunbird
Black kite	Fire capped tit	Jungle prinia	Redstart	Swallow

Black lored tit	Fire tailed sunbird	Kalij pheasant	Red-vented Bulbul	Tickell's leaf warbler
Blue fronted redstart female	Fire tailed sunbird female	Kingfisher	Rock thrush	Treecreeper
Blue throated Barbet	Flower Pecker	Leaf Warbler	Rosefinch	Ultra marine flycatcher
Blue throated blue flycatcher	Flycatcher	Little bunting	Rufous bellied niltava	20 Unknown birds
Blue whistling thrush	Forktail	Little forktail	Rufous caped Babler	Verditer Flycatcher
Blue winged laughingthrush	Fulvetta	Little pied Flycatcher Female	Rufous faced Warbler	Wagtail
Blue-capped Rock Thrush	Golden throated barbet	Long Tailed Shrike	Rufous fronted tit	Wallcreeper
Brown Shrike	Great Barbet	Long-tailed broadbill	Rufous gorgeted flycatcher	Warbler
Bulbul	Greater coucal	Maroon Oriole	Rufous necked laughingthrush	Wedge-tailed Green Pigeon
Chestnut bellied rockthrush	Greater Yellownape	Monal	Rufous sibia	Western Crowned warbler
Chestnut-crowned laughingthrush	Green Pigeon	Mountain Bulbul	Rufous vented yuhina	Whiskered Yuhinia
Chestnut-tailed Starling	Green tailed sunbird	Nepal fulvetta	Rufous woodpecker	Whistler's Warbler
Cockerel	Green-backed tit	Nuthatch	Rusty cheek Scimitar babbler	White browed fantail male
Common chiffchaff	Grey bird	Oriental Cuckoo	Rusty fronted barwing	White browed fulvetta
Common Green Magpie	Grey Bushchat	Oriental Magpie Robin	Rusty tailed flycatcher	White browed wagtail
Common Hawk Cuckoo	Grey head small white eye	Oriental Turtle Dove	Scarlet Minivet	White capped redstart
Common myna	Grey headed canary flycatcher	Owl	Scimitar Babbler	White crested laughingthrush
Yellow crowned woodpecker	Yellow breasted greenfinch	Woodpecker	White throatet Tit	White tailed robin
Yellow vented warbler	Yellow browed warbler	Yellow bellied bush warbler	White-rumped munia	

List of Mammals

Common Name	**Scientific Name**
Barking Deer/Indian Muntjac	*Muntiacus muntjak*
Chinese Pangolin	*Manis pentadactyla*
Field rat	*Rattus nitidus*
Fox	*Vulpes bengalensis*
Jungle Cat	*Felis chaus*
Civet	*Paguma larvata*
Leopard	*Panthera pardus*
Leopard cat	*Prionailuru bengalensis*
Monkey	*Rhesus macaque*
Porcupine	*Hystrix sp.*
Hare	*Lepus sp*
Wildboar	*Sus scrofa*
Binturong	*Arctictis binturong*
Yellow-throated Marten	*Martes flavigula*
Indian Mongoose	*Herpestes edwardsii*
Asian Golden cat	*Catopuma temminckii*

Fellowship Report No.: 5 of 10

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HJPF	Barkha Subba	April, 2016	March 31, 2019	Influence of environmental and spatial variables on the species richness and composition of stream frogs in Sikkim	Dr. Ravikanth Gudasalamani, Senior Fellow

15. BARKHA SUBBA

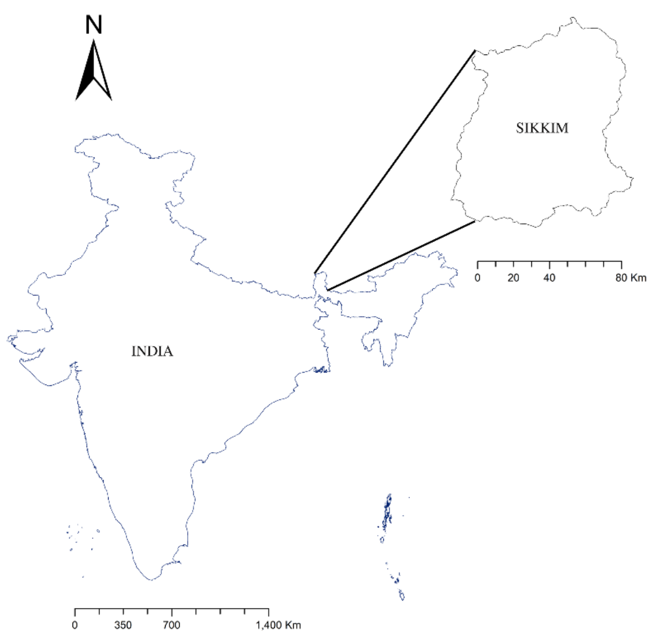
1 INTRODUCTION

Study area, Survey Sites and choice of predictors

The state of Sikkim (7,096 km2) lies between 27°05' N to 28°07' N and 087°59' N to 088°56' E and is part of the youngest and loftiest mountain systems of the world ‘the Himalayas’, which is also one of the Biogeographic Zones in India and a global biodiversity hotspot (Mittermeier et al. 2005). It presents a complex landscape as the geomorphic changes over time has played a significant role in the formation of the existing topography. Starting at the foot with an elevation of less than 300 meters it stretches up to more than 8550 m. a.s.l. Two important river systems characterize Sikkim Himalaya namely, Teesta and Rangeet River Systems. Teesta river originates from the Teesta Kangse glacier that lies above 7068 m a.s.l., and flows southward through gorges and rapids in the Sikkim Himalaya (Meetei *et al.* 2007). Rangeet river is the main tributary of Teesta which originates from the Himalayan mountains in West Sikkim and joins Teesta at a confluence called Triveni in South Sikkim. These great Himalayan Rivers have over the period created their own watersheds and sub watersheds. These rivers are not only fed by the glaciers but they also benefit from various natural springs and small streams locally called “jhoras”, that flow across their basins (Banerjee 1998). The study was carried out along the Teesta and Rangeet river valleys. These rivers flow through variegated vegetation along its route, from tropical semi deciduous and moist broad-leaved forests at lower elevations to alpine vegetation at higher elevations. The vegetation is determined chiefly by elevation and climatic conditions (Hooker, 1854). The climate, which is mainly determined by geographical location, relief and altitude, varies from hot tropical in the foothills to Arctic cold at the summits. Obstruction in movement of monsoon winds by high mountains has resulted in significant variation in climatic profiles across the state (Mani, 1974). Vegetation transition along an elevation roughly takes place at an interval of 900m and has given rise to six vegetation types. These are Tropical semi-deciduous forests (<900 m); Tropical moist and broad-leaved forests (900–1800 m); Temperate broad-leaved forests (1800–2800 m); Temperate coniferous and broad-leaved forests (2800–3800 m); Sub-alpine (3800–4500 m) and Alpine vegetation (>4500 m) (Haribal 1992).
I selected 54 sites at forest streams with 3 different stream orders (1,2 and 3) along Teesta - Rangeet river valleys (Fig. 1). and along an elevation gradient of 300m to 5400m. The study area was categorized into 9 bands with 500 m interval between 300m and 5400m (Table 3.1).

Table 1. Categorization of the study area in Sikkim based on elevation (500m intervals)

Elevation zone	Elevation (m)
Zone I	<500
ZoneII	500-1000
ZoneIII	1000-1500
ZoneIV	1500-2000
ZoneV	2000-2500
ZoneVI	2500-3000
Zone VII	3000-3500
ZoneVIII	3500-4000
Zone IX	>4000



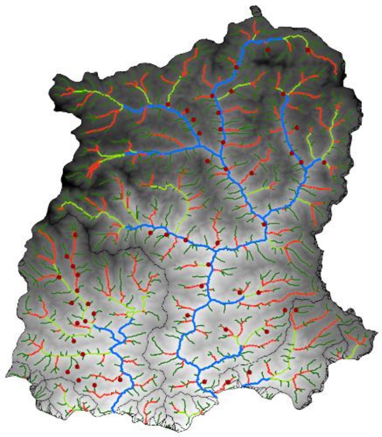


Figure 1 Location of the study area and sampling sites

a. 2 METHODOLOGIES, STRATEGY AND APPROACH

I selected 54 sites at forest streams to cover the range of mean temperature of the warmest months (MTWMs 4 °C to 30 °C), average precipitation of the warmest months (PWMs; 186mm to 2500mm) and different stream orders within the study area. Majority of the frog species in the area are most active, and thus most likely to respond directly to ambient temperature and moisture during the warmest quarter of the year (May to Sept). Both MTWMs and PWMs were calculated from long term climatic data using WorldClim, a bioclimatic prediction system.

Sites were surveyed for frogs 2 times each over 2 breeding seasons between June to September 2016 and 2017 using nocturnal stream searches. Nocturnal searches involved walking along a 200m stream transect, spotlighting for frogs with head lamps and counting and recording frog advertisement calls so that even well-camouflaged species were detected with fair certainty. When necessary for identification, frogs were caught, photographed, then released. A minimum of one-person hour was spent searching each site. Presence and number of individuals of all frog species encountered during the surveys was recorded.*Results*: I found 23 species of amphibians belonging to eleven genera and four families during the study. Among this,13 species of stream dwelling anurans exclusively required streams for breeding.

Field Survey

Sites were surveyed for frogs 2 times each over 2 breeding seasons between June to September 2016 and 2017 using nocturnal stream searches. Nocturnal searches involved walking along a 200m stream transect, spotlighting for frogs with head lamps and counting and recording frog advertisement calls so that even well-camouflaged species were detected with fair certainty. When necessary for identification, frogs were caught, photographed, then released. A minimum of one-person hour was spent searching each site. Presence and number of individuals of all frog species encountered during the surveys was recorded.

Data Collection

I selected 54 sites at forest streams to cover the range of mean temperature of the warmest months (MTWMs 4 °C to 30 °C), average precipitation of the warmest months (PWMs; 186mm to 2500mm) and different stream orders within the study area. Majority of the frog species in the area are most active, and thus most likely to respond directly to ambient temperature and moisture during the warmest quarter of the

year (May to Sept). Both MTWMs and PWMs were calculated from long term climatic data using WorldClim, a bioclimatic prediction system.
Canopy openness was determined using spherical Densiometer Model-A (Lemon, 1956) which was a gridded convex mirror reflecting a 180-degree view of the canopy. Water current within each site was categorized into slow, moderate and fast flowing based on visual assessment. Dissolved Oxygen and water temperature was measured in the field using a hand held Dissolved Oxygen meter with temperature readings (Sper Scientific 850045). pH and conductivity of the water was measured using handheld pH and conductivity meter (Hanna HI98107, conductivity tester DIST3) respectively. Riparian vegetation cover was visually assessed to estimate the vegetation cover on both sides of the stream. The ASTER Global Digital Elevation Model (GDEM) of 30 m resolution (METI and NASA 2011) for the study area were used to extract the following topographic predictors in ArcGIS using Spatial Analyst and Topography toolbox: elevation, slope, and cosine aspect (McCune and Dylan 2002), aspect was scaled to an index of 'southwestness' using a cosine transform (Table 3.2).

Table 2 List of predictors used in the regression and canonical ordination analysis of the anuran abundance data

Predictors	**Description**	**Units**	**Source**
Climate			
PWM	Average precipitation of the warmest months (May to September)	mm	WorldClim, Fick and Hijmans 2017
MTWM	Mean temperature of the warmest quarter (May to September)	°C	WorldClim, Fick and Hijmans 2017
Habitat			
pH	pH of stream water	pH units	Measured in the field using a hand-held pH meter with an accuracy of ±0.1 pH.
Water Temp	Temperature of the stream water	°C	Measured in the field using a hand held Dissolved Oxygen meter with temperature readings.
Cond	Conductivity of stream water	Siemens/m	Measured in the field using hand held conductivity tester
DO	Dissolved oxygen of stream water	mg/L	Measured in the field using hand held DO tester
Canopy	Measurement of canopy cover	%	Measured in the field using densiometer
Rip. Veg Cover	Riparian Vegetation cover	%	Measured in the field, visual estimate
Flow	Flow of stream water		Measured in the field using visual assessment
Topography			
Stream order	Extracted from DEM (30m res)		Used ArcMap(Ver10.1) to delineate stream orders using ASTER DEM
Slope		degrees	Measured in the field

Elevation	Measured in field using Garmin GPS eTrex vista H	m	Measured in the field
cosAsp	cosine transformation of aspect in radians using 30m DEM		ASTER GDEM, METI & NASA 2011

Data Analysis

Assessing species richness, compositional dissimilarity, and composition of species assemblages

Abundance data of frog species from 54 sites were used to investigate the relationship between the species richness of frog assemblages at the survey sites and environmental variables using Poisson regression. I used model selection based on pseudo R^2. A set of 10 competing models was developed using a combination of stepwise and subjective, iterative variable addition and subtraction methods taking broader scale predictors for climate and successively adding different combinations of finer scale predictors based on topography and local habitat. Variables were normalized. Intercorrelated variables having Pearson's correlation coefficient, $|r| >= 0.75$ were removed prior to model building following Dormann *et al.* (2013).

Compositional dissimilarity between survey sites in terms of their frog assemblages was calculated using the Bray -Curtis measure of compositional dissimilarity (Bray and Curtis 1957). Presence absence data of frog species at each site was used to calculate the dissimilarity index. The Bray-Curtis dissimilarity value (D) is bounded between 0 and 1, where 0 means two sites have identical composition, and 1 means the sites do not share any species. Dissimilarity matrix for the 38 survey sites was constructed using these dissimilarity values.

b. 3 KEY FINDINGS AND RESULTS

Species Occurrence

I found 23 species of amphibians belonging to eleven genera and four families during the study but for this analysis only 13 species of stream dwelling anurans which exclusively required streams for breeding were included. (Table 3.3)

Table 3. Species detected during the study and the number of sites at which they were detected

Species	Common Name	No. of sites
Amolops formosus	Assam Cascade frog	4
Amolops monticola	Mountain torrent frog	5
Amolops himalayanus	Himalayan cascade frog	8
Amolops marmoratus	Marbled cascade frog	11
Megophrys katabhako	-	6
Megophrys sanu	-	14
Megophrys robusta	White lipped horned toad	10
Nanorana gammii	Gammii frog	8

Nanorana blanfordii	Blanford's paa frog	7
Nanorana liebigii	Sikkim Paa frog	14
Nanorana annandalii	Annandale's paa frog	3
Scutiger boulengeri	Boulenger's lazy toad	9
Scutiger sikimmensis	Sikkim snow toad	13

Species Richness of frog occurrences and Dissimilarity Index

Thirteen species of stream breeding frogs were detected during the survey (Table 3.3), with the species richness at a site varying from 1 to 6. The variables for the best model (pseudo $R^2 = 0.72$) are MTWMs, PWMs, Con, pH, cosAspect, stream order and shrub cover. Poisson regression analysis showed a significant ($P< 0.01$) relationship between mean temperature of the warmest months (MTWMs), shrub cover and frog species richness (Table 3.4). Species richness revealed a hump- shaped or unimodal relationship with MTWMs (Fig. 3.2).

Table 4 Table showing estimate, standard error and P value from regression analysis of the best model with pseudoR^2=0.72 (Significant variables are in bold).

Variables	Estimate	Std. error	P value
pH	0.16	0.093	0.05 .
Cond	-0.15	0.109	0.168
Riparian Veg	**0.32**	**0.090**	**0.002****
MTWMs	**0.35**	**0.06**	**0.001****
Stream order	0.18	0.13	0.186
PWMs	0.31	0.286	0.138
cosAspect	-0.11	0.08	0.278

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(a)

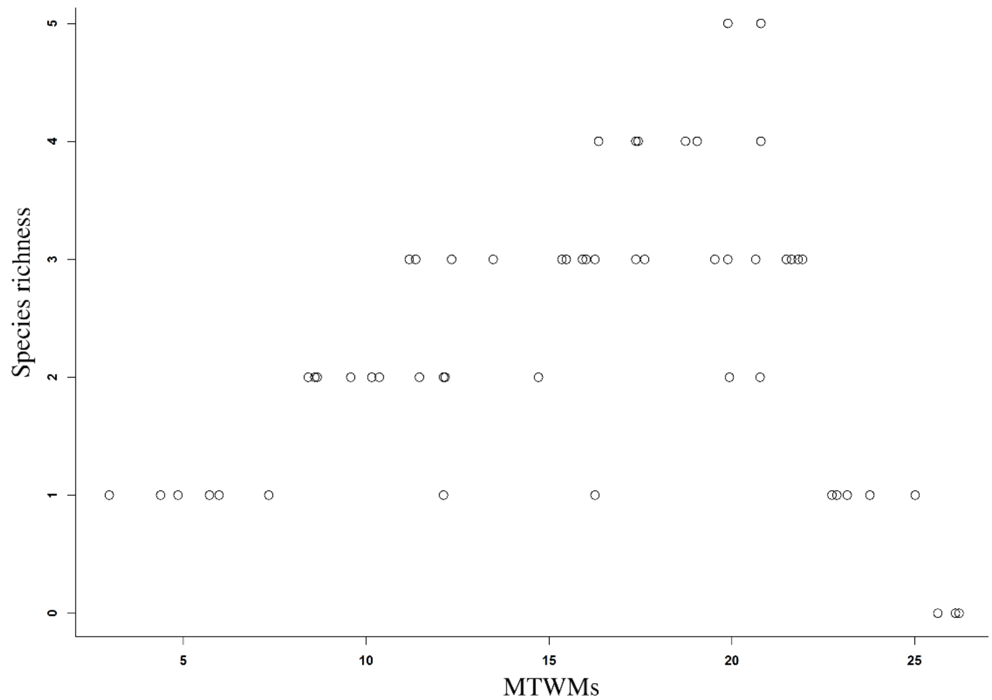


Figure 2 Result of the Poisson regression analysis of the relationship between species richness at survey sites and mean air temperature of the warmest months (MTWMs)

Cluster analysis of the 38 sites based on compositional dissimilarity of their frog assemblages produced three groups – A, B and C(Fig. 3.3). Sites with species richness of 1 and 0 were removed from the analysis in order to examine the community composition of frog assemblages.

Eight species were found at 11 sites in group A. This group contained all records of *Amolops marmoratus, Amolops formosus* and *Xenophrys katabhako*. Eight out of nine records of *X. robusta* was found in this group. Five species were found across the 15 sites in group B, with *Nanorana blanfordii, Scutiger sikimmensis* and *Scutiger boulengeri* restricted to sites in this group. We found eight species across 11 sites in group C with *N. annandalii* restricted to this group (Table 3.5).

Xenophrys sanu was the common species to all the groups. Eight out of fourteen records of this species was from group C. Group B has calm water species, with the exception of *N.liebigii*, and *X. sanu* which can also be found in moderate flow streams. Group A has species which can be found in fast flowing streams and, group C has mixed moderate to fast flowing stream species. Species found up to 2000 m in group A and C, group B has high elevation species found between 2500m to above 5000m except for *X. sanu* which has a large elevational range from 1600m to 2500m.

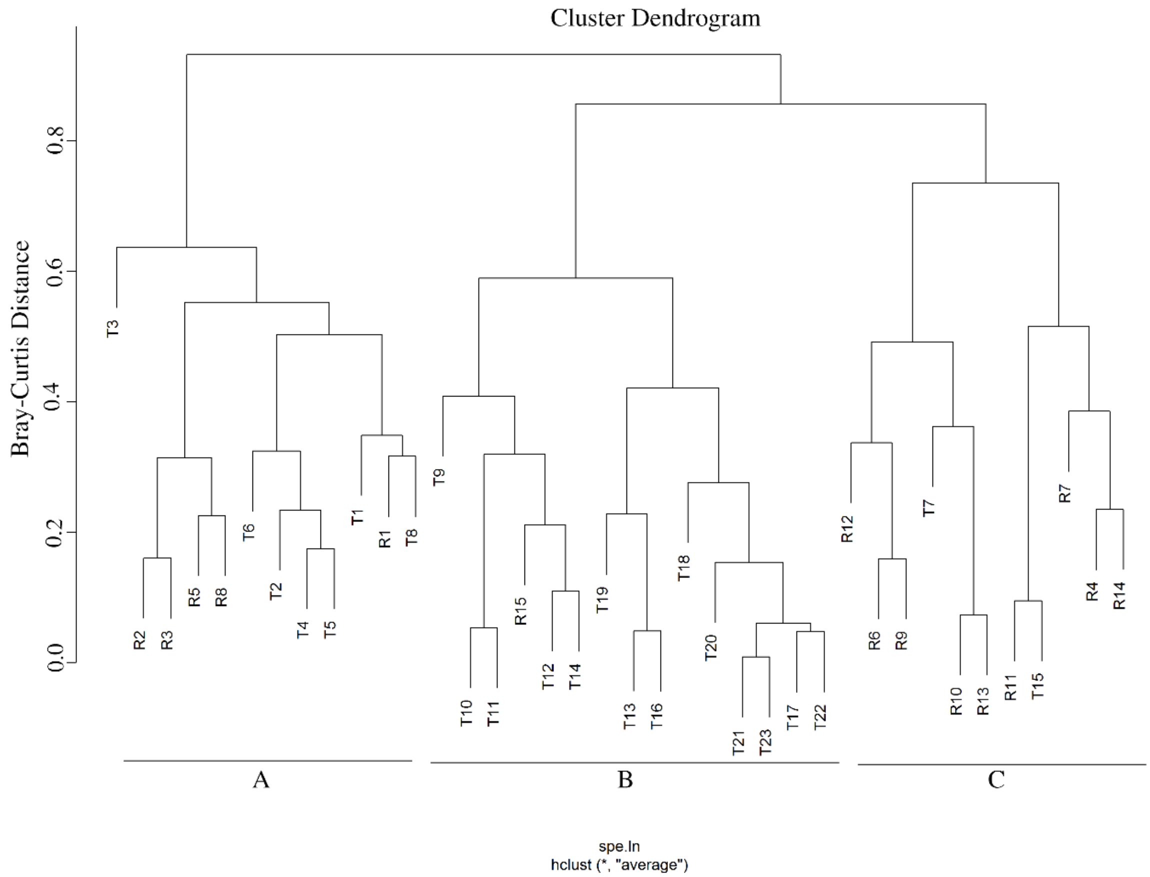


Figure 3 Cluster analysis of the 38 survey sites showing three groups A-C. Sites T1 to T23 are in the Teesta basin and R1 to R15 are in the Rangeet basin.

Choice of breeding sites by amphibians can be influenced by the characteristics of the surrounding terrestrial habitat as well as by quality of the water body (Alford 1999; Semlitsch and Bodie 2003). Understorey vegetation is generally assumed to be an important environmental characteristic for riparian frogs (Parris and McCarthy 1999). Riparian vegetation cover explained 24% of the variation in the assemblage composition when the effect of space was removed. Several frog species in the study use lower vegetation as calling and resting sites (e.g. *Xenophrys sanu, Xenophrys katabhako*) and hence constitutes an important structural component. The type of vegetation cover ranged from dense shrub in the tropical deciduous and temperate broad-leaved forests to alpine scrubs and grasslands. Species like *Amolops spp, Xenophrys spp.* are found in tropical to temperate forests whereas *Nanorana spp.* and *Scutiger spp.* occur in alpine scrubs, meadows, and grasslands.

The climatic variables contributed 37% of the explained variation in the composition of frog assemblages at hill streams when the spatial variable was removed. Frogs are sensitive to the changes in air temperature and moisture. Different species have different thermal and moisture requirement, for example some frogs like *Amolops marmoratus, A. monticola*, are found in relatively warmer and wetter areas whereas *Scutiger sikimmensis* and *S. boulengeri.*

Anuran assemblages at hill streams varies with the stream order (1st, 2nd and 3rd), which explained 8% variation. Low to medium elevation species like *Amolops himalayanus, A. monticola, Nanorana gammii* etc., was found in second to third order streams which are mostly fast to moderate flowing streams whereas high elevation species like *N. blanfordii, S. sikimmensis* and *S. boulengeri* were found mainly in first order streams which are mostly calm or slow flowing streams.

c. 4 OVERALL ACHIEVEMENTS

In conclusion, the biotic model (spatial structuring) was not able to explain the full variation of the composition in stream anuran assemblages nor was the environmental control model (environmental determinants). Both factors showed significant influences. Dispersal is one of the biotic process most likely to contribute to the spatial structure of assemblages at this scale, with competition, predation, and cannibalism operating at the level of an individual stream. Hence, riparian anurans of Sikkim are intriguing group for further studies of assemblage rules. Furthermore, keeping in mind the current striking decline of this group of vertebrates (Blaustein *et al.,* 1994; Stuart *et al*. 2004; Pounds *et al*. 2006), this study provides a baseline for future investigations with anthropogenically modified areas in Sikkim.

d. 5 IMPACTS OF FELLOWSHIP IN IHR

The results of the present study could be used to assess the adequacy of the current system of protected areas for stream breeding frogs in Sikkim, and to identify certain classes of habitat that may be at risk from urban development and hydel power projects. If characteristics of the riparian vegetation, climate and water quality prove to be important correlates of the composition of amphibian assemblages in general, conservation of all combinations of these variables would be a simple way of ensuring suitable habitat for most amphibians in a region.

e. 6 EXIT STRATEGY AND SUSTAINABILITY

f. The results of the present study could be used to assess the adequacy of the current system of protected areas for stream breeding frogs in Sikkim, and to identify certain classes of habitat that may be at risk from urban development and hydel power projects. If characteristics of the riparian vegetation, climate and water quality prove to be important correlates of the composition of amphibian assemblages in general, conservation of all combinations of these variables would be a simple way of ensuring suitable habitat for most amphibians in a region. Other parts of IHR where similar studies can be carried out are western himalayas and northern Arunachal Pradesh.

g. 7 REFERENCES/BIBLIOGRAPHY

Alford, R. A. 1999. Ecology: resource use, competition and predation. Pages 240 278, *in*: R. W. McDiarmid and R. Altig (editors). *Tadpoles: The Biology of Anuran Larvae*. University of Chicago Press.

Banerjee, B. 1998. *Use and Misuse of Water Resources in India.* Geographical Review of India, **3:** 248-260.

Beebee, T. J. C. and R.A. Griffiths. 2005. *The amphibian decline crisis. A watershed for conservation biology?* Biological Conservation **25:**271–285.

Bishop, P.J., A. Angulo, J.P. Lewis, R.D. Moore, G.B. Rabb, and G. Moreno. 2012. *The amphibian extinction crisis – what will it take to put the action into the amphibian conservation action plan?* SAPIEN 1–15.

Blaustein, A.R., D.B. Wake, and W.P. Sousa. 1994. *Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions*. Conservation Biology **8**: 60–71.

Borcard, D., P. Legendre and P. Drapeau. 1992. *Partialling out the spatial component of ecological variation.* Ecology **73:**1045 1055.

Borcard, D., F. Gillet, and P. Legendre. 2011. *Numerical ecology with R. Springer Science & Business Media.*

Bray, J.R. and J.T. Curtis. 1957. *An ordination of the upland forest communities of southern Wisconsin. Ecological monographs* **4:** 325-349.

Carey, A. B. and M.L. Johnson. 1995. *Small mammals in managed, naturally young, and old-growth forests.*Ecological Application **5:** 336 352.

Clements, F.E. 1916. *Plant Succession: An Analysis of the Development of Vegetation.* Vol. 242. Carnegie Institute of Washington Publication, Washington, DC.

Connell, J. H. 1983. *On the prevalence and relative importance of interspecific competition: evidence from experiments.* The American Naturalist **122:** 661 697.

Dias-Terceiro, R.G., L.I. Kaefer, R. de Fraga, M.C. de Araujo, P.I. Simoes, A.L. Lima. 2015. *A matter of scale: historical and environmental factors structure anuran assemblages from the Upper Madeira River, Amazonia.* Biotropica **47:** 259-266.

Dormann, C.F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carré, J.R.G. Marquéz, B. Gruber, B. Lafourcade, P.J. Leitão and T. Münkemüller. 2013. *Collinearity: a review of methods to deal with it and a simulation study evaluating their performance.* Ecography **36:** 27-46.

Ernst, R. and M.O. Rödel. 2005. *Anthropogenically induced changes of predictability in tropical anuran assemblages.* Ecology **86**: 3111–3118.

Ernst, R. and M.O. Rödel. 2006. *Community assembly and structure of tropical leaf-litter anurans*. Ecotropica **12**:113–129.

Ernst, R. & M.O. Rödel. 2008. *Patterns of community composition in two tropical tree frog assemblages: separating spatial structure and environmental effects in disturbed and undisturbed forests.* Journal of Tropical Ecology **24**:111–120.

Fick, S.E. and R.J. Hijmans. 2017. *Worldclim 2:New 1-km spatial resolution climate surfaces for global land areas.* International Journal of Climatology.

Finegan, B. 1984. *Forest succession*. Nature 312:109-114. Gauch, H. G., Jr. 1982. Multivariate analysis in community ecology. Cambridge University Press, New York, New York, USA.

Gardner, T.A., E.B. Fitzherbert, R.C. Drewes, K.M. Howell and T. Caro. 2007a. *Spatial and temporal patterns of abundance and diversity of an east African leaf litter amphibian fauna.* Biotropica **39**:105–113.

Gardner, T.A., M.A. Ribeiro-Junior, J.O.S. Barlow, T.C.S. Avila-Pires, M.S. Hoogmoed and C.A. Peres. 2007b. *The value of primary, secondary, and plantation forests for neotropical herpetofauna*. Conservation Biology **21**: 775–787.

Githaiga-Mwicigi, J. M. W., D.H.K. Fairbanks, and G. Midgley. 2002. *Hierarchical processes define spatial pattern of avian assemblages restricted and endemic to the arid Karoo, South Africa.* Journal of Biogeography **29:** 1067 1087.

Haribal, M. 1992. *The Butterflies of Sikkim Himalaya*. Sikkim Nature Conservation Foundation, Gangtok, India.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis. 2005. *Very high resolution interpolated climate surfaces for global land areas.* International Journal of Climatology 25:1965–1978. http://www.worldclim.org/bioclim, data.

Hooker, J.D., 1854. Himalayan Journals, vols. I. & II. Natraj Publishers, Dehradun, India.

Keller, A., M.O. Rödel, K.E. Linsenmair and T.U. Grafe. 2009. *The importance of environmental heterogeneity for species diversity and assemblage structure in Bornean stream frogs*. Journal of Animal Ecology **78:** 305-314.

Legendre, P. and M.J. Fortin. 1989. *Spatial pattern and ecological analysis*. Vegetatio **80:** 107-138.

Legendre, P. and L. Legendre. 1998. *Numerical ecology.* Elsevier.

Legendre, P., D. Borcard, and P. R. Peres-Neto. 2005. *Analyzing beta diversity: partitioning the spatial variation of community composition data.* Ecological Monographs **75:**435– 450.

Legendre, P. and M. Cáceres. 2013. *Beta diversity as the variance of community data: dissimilarity coefficients and partitioning.* Ecology letters **16**: 951-963.

Lemon, P.E. 1956. *Spherical densiometer for estimating forest overstory density.* Forest Science **2**: 314–320.

Li, Y., J.M. Cohen and J.R. Rohr. 2013. *Review and synthesis of the effects of climate change on amphibians.* Integrative Zoology **8:**145-161.

MacArthur, H. Robert and E.O. Wilson. 2015. *Theory of Island Biogeography*. Princeton University Press.

Mani, M.S. 1974. *Ecology and Biogeography in India*. Dr. W Junk Publishers, The Hague.

McCune, B., and K. Dylan. 2002. *Equations for potential annual direct solar radiation and heat load.* Journal of Vegetation Science **13:**603–606.

McCarthy, M.A. 1997. *Competition and dispersal from multiple nests*. Ecology **78:** 873–883.

McCarthy, M.A. and D.B. Lindenmayer 2000. *Spatially-correlated extinction in metapopulation model of Leadbeater's Possum*. Biodiversity and Conservation **9**: 47–63.

Meetei, L. I., S.K. Pattanayak, A. Bhaskar. M.K. Pandit and S.K.Tandon, S. K. 2007. *Climatic imprints in Quaternary valley fill deposits of the middle Teesta valley, Sikkim Himalaya.* Quaternary International **159:** 32-46.

Menin, M., A.P. Lima, W.E. Magnusson and F. Waldez. 2007. *Topographic and edaphic effects on the distribution of terrestrially reproducing anurans in Central Amazonia: mesoscale spatial patterns.* Journal of Tropical Ecology **23**:539–547.

METI, and NASA. 2011. ASTER Global DEM version 2. downloaded on July 12th 2013 from http://gdem.ersdac.jspacesystems.or.jp.

Mittermeier, R.A., P.R. Gill, M. Hoffman, J. Pilgrim, T. Brooks, C.G. Mittermeier, J. Lamoreux, G.A.B. da Fonseca. 2005. *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. CEMEX, Mexico.

Neave, H.M., R.B. Cunningham, T.W. Norton and H.A. Nix. 1996. Biological inventory for conservation evaluation III. Relationships between birds, vegetation and environmental attributes in southern Australia. Forest Ecology and management **85:**197-218.

Pearman P. B. 1997. *Correlates of amphibian diversity in an altered landscape of Amazonian Ecuador*. Conservation Biology **11:**1211–25.

Peres-Neto, P. R., P. Legendre, S. Dray, and D. Borcard. 2006. *Variation partitioning of species data matrices: estimaion and comparison of fractions.* Ecology **87:**2614–2625.

Pounds, J., Bustamente, M.R., Coloma, L.A., Consuegra, J., Fogden, M., Foster, P., LaMarca, E., Masters, K.L., Merino-Viteri, A., Puschendorf, R., Ron, S.R., Sanchez-Azofeifa, G.A., Still, C. and B. Young. 2006. *Widespread amphibian extinctions from epidemic disease driven by global warming.* Nature **439**: 161–167.

Rao, C. R. 1964. *The use and interpretation of principal component analysis in applied research. Sankhyā*: The Indian Journal of Statistics, Series A:329–358.

Rao, C. R. 1995. *A review of canonical coordinates and an alternative to correspondence analysis using Hellinger distance.* Qu ¨estiio ´ **19:** 23 63.

Ricklefs, R.E. and D. Schluter 1993. *Species Diversity in Ecological Communities: Historical and Geographical Perspectives.* University of Chicago Press, Chicago, Illinois.

Ricklefs, R.E. and I.J. Lovette.1999. *The roles of island area per se and habitat diversity in the species–area relationships of four Lesser Antillean faunal groups*. Journal of Animal Ecology **68:**1142-1160.

Ratchford, J. S., S.E. Wittman, E.S. Jules, A.M. Ellison, N.J. Gotelli and N.J. Sanders. 2005. *The effects of fire, local environment and time on ant assemblages in fens and forests.* Diversity and Distributions **11:**487-497.

Schoener, T.W. 1983. *Field experiments on interspecific competition.* American Naturalist **122:**240-285.

Semlitsch, R. D. and J.R. Bodie. 2003. *Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles.* Conservation Biology **17:** 1219 1228.

Stuart, S.N., J.S. Chanson, N.A. Cox, B.E. Young, A.S.L. Rodrigues, D.L. Fischman and R.W. Waller. 2004. *Status and trends of amphibian declines and extinctions.* worldwide. Science **306**: 1783–1786.

Ter Braak, C. J. F. 1986. *Canonical Correspondence Analysis: A New Eigenvector Technique for Multivariate Direct Gradient Analysis*. Ecology **67:**1167.

Townsend, C.R. 1989. *The patch dynamics concept of stream community ecology. Journal of the North American Benthological Society*. **8:** 36–50.

Whittaker, R. H. 1956. *Vegetation of the Great Smoky Mountains*. Ecological Monographs. **26:** 1- 80.

Watling, J.I. 2005. *Edaphically-biased distributions of amphibians and reptiles in a lowland tropical rainforest.* Studies in Neotropical fauna and Environment. **40** :15-21.

Woodward, B.D. 1983. *Predator-prey interactions and breeding-pond use of temporary-pond species in desert anuran community*. Ecology **64:** 1549–1555.

Zimmerman, B.L. and R.O. Bierregaard. 1986. *Relevance of the equilibrium theory of island biogeography and species-area relations to conservation with a case from Amazonia.* Journal of biogeography. **1:**133-143.

16. 8 ACKNOWLEDGEMENTS

I would like to thank my supervisor Dr. Ravikanth G. without whose guidance the project would not be possible. I would like to thank the National Mission for Himalayan Studies whose funding has been instrumental in the pursuance and completion of this research. I would also like to thank the Ministry of Environment, Forest and Climate Change and ATREE Academy for Conservation and Sustainability Studies.

APPENDICES

Please refer to the attachment HJRF-BS-01 for the amphibian list.

Fellowship Report No.: 6 of 10

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HJPF	Manish Kumar	April 1, 2016	July 31, 2019	Ecohydrology of Sikkim Himalaya in the context of climate change and climate variability	Dr. Jagdish Krishnaswamy, Senior Fellow

17. Manish Kumar

1 INTRODUCTION

Climate change in Sikkim Himalaya is poorly understood, the main reason being lack of long-term data for the region and regionally focused studies on understanding patterns in climate. Sikkim Himalaya, as part of the Eastern Himalaya, are characterised by one of the highest rainfall regions in the Himalayan region. Yet, there is considerable variability in rainfall within the small region, where parts of the state are experiencing considerable water shortage (Tambe et al., 2012). However, very few studies have tried to model the variability in rainfall and temperature at finer resolutions in the Himalayan region. The available studies work at coarser scales and their predictions for future changes in rainfall and temperature have limited applicability in terms of informing local climate mitigation and adaptation efforts.

In a study on spatial correlation in rainfall and elevation over the Teesta river basin, which drains the state of Sikkim, Seetharam (2003) reported higher variability in rainfall at stations in lower altitudes than for stations at higher altitudes. Seetharam (2008) has looked at changes in rainfall and temperature for the capital town of Gangtok in Sikkim from 1957-2005. He observed increasing trends in minimum temperature (+0.2°C/decade) and decreasing trends (-0.3°C/decade) in maximum temperatures in Gangtok. He also reported an increase in mean annual rainfall (+46.9 mm/decade), pre-monsoon rainfall (+20.3 mm/decade) and declining winter rainfall (-0.7 mm/decade). Updating the same work, Seetharam (2012) attempted future predictions in rainfall and temperature over Gangtok using synthetic climate scenario modeling approach. He predicted further drop in maximum temperature, indicating cooler days, increase in minimum temperature, indicating warmer nights, and 1 % increase in annual rainfall of Gangtok in the next few decades. At the scale of Eastern Himalaya, a bunch of studies have tried to model climate change impacts. Using high resolution regional climatic models, Sanjay et al. (2017) have predicted increase in summer rainfall by a maximum of 19.1 %, summer temperature by 4.3°C and winter temperature by 6°C. Ren et al. (2017) report increasing rate of warming (+0.3°C/decade) and decreasing rainfall (-25%/decade) over a period of 1901-2014 in the larger Eastern Himalayan region. Similarly, Kulkarni et al. (2013) used a high resolution PRECIS model to predict increase in temperature (up to +5°C) and rainfall (+40%) by the year 2098. How such increased rainfall variability is likely to interact with smaller-scale processes such as deforestation and degradation to influence the spring and streams of Sikkim Himalayas remains unclear.

The proposed research work focussed on developing predictive models for understanding the relative role of different Himalayan ecosystems in mitigating the hydrological responses, particularly in relation to extreme rainfall events**.** The proposed study will try to address the knowledge gap by achieving following **objectives:**

- Assess spatial and temporal variability in precipitation patterns across Sikkim Himalayas
- Predict hydrological responses of springs and streams in the context of climate variability and climate change in the Sikkim Himalayas

a. 2 METHODOLOGIES, STRATEGY AND APPROACH

The study uses a modelling framework for mapping and predicting the overall effects of the climate change on ecohydrological systems, combining ecosystem responses to changing climatic parameters using ecohydrological models (Asbjornsen et al., 2011). We are working on developing an ecohydrological model combines process-based ecological models with physical models used in hydrology, which allows for developing dynamic interactions between principal hydrologic components like precipitation, groundwater, soil moisture and stream flow; key eco-physiological processes like transpiration (Loinaz et al., 2012). The relative role of each components and processes in influencing the response variables vary with the spatial and temporal scales. We maintained five long-term monitoring sites and two Automatic weather stations for springs and streams and each site has one automatic discharge measuring station, automatic rain gauges and soil moisture sensors were installed. Data cleaning, processing and management tools and protocols have been developed and being carried over for the same. Monthly secondary precipitation and temperature data from Indian Meteorological Department were used to analyze long-term trends in rainfall and temperature across Sikkim Himalaya. Satellite based gridded temperature (MODIS- Land surface temperature) and for precipitation (CHIRPS) were used for assessing spatial patterns across Sikkim at fine resolution (0.05°). The results were presented at the NMHS-HRC, Gangtok. A manuscript detailing the same has been submitted to NMHS-HRC.

b. 3 KEY FINDINGS AND RESULTS

- Rainfall in Sikkim Himalaya seems to be primarily driven by orographic and monsoonal patterns.
- Strong multi-decadal cyclic patterns are observed in rainfall.
- Annual rainfall and number of rainy days have declined at lower elevations and have increased in summer and at higher elevations in Sikkim.
- Light rainfall (< 25 mm day-1) has increased over west, central and north Sikkim.
- The frequency of high-intensity precipitation events and large storms have increased in the recent decades over the south and east Sikkim, and are most vulnerable to climate change impacts like landslides and flash floods.
- Vegetation exerts significant controls on the streamflow, especially in dry seasons.
- The extent and timing of hydrological controls vary with the forest type.
- Springs under forested catchments have steadier low-flow discharges than springs under agricultural catchments, providing empirical evidences of the existing community knowledge structures that springs from forested areas seem to be more perennial than others.
- Changes in vegetation productivity and rainfall regimes will have strong influences on springs and first order streams, especially in the dry south Sikkim regions.

c. 4 OVERALL ACHIEVEMENTS

We maintained five long-term monitoring sites and two Automatic weather stations for springs and streams and each site has one automatic discharge measuring station, automatic rain gauges and soil moisture sensors were installed. Data cleaning, processing and management tools and protocols have been developed and being carried over for the same. Monthly secondary precipitation and temperature data from Indian Meteorological Department were used to analyse long-term trends in rainfall and temperature across Sikkim Himalaya.

d. 5 IMPACTS OF FELLOWSHIP IN IHR

The fellowship has provided crucial support to my PhD and the ongoing long-term sites in Sikkim. The sites are first of its kind in the Eastern Himalaya providing a physical monitoring framework to guide future work by other agencies in the region including the government. Inspired by our work, the Sikkim government has just initiated a project on monitoring 10 springs using the same monitoring design with technical help of our research group. The remaining work is focused on submitting the final manuscripts which will provide the first reports of plant-water use and regional hydro-meteorology from the eastern Himalaya. The research papers will acknowledge the crucial support provided by NMHS in enabling the research.

e. 6 EXIT STRATEGY AND SUSTAINABILITY

We demonstrate the need to develop similar long-term monitoring sites across Himalaya to develop comprehensive understanding of springs and streams in Himalaya and cover the variability for better modelling of short-scale processes.

18. 7 REFERENCES/BIBLIOGRAPHY

Kulkarni, A., Patwardhan, S., Kumar, K.K., Ashok, K., Krishnan, R., 2013. *High-resolution Regional Climate Model PRECIS Projected Climate Change in the Hindu Kush – Himalayan Region By Using the High-resolution Regional Climate Model* PRECIS. Mt. Res. Dev. 33, 142–151. https://doi.org/http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00027.1

Ren, Y.Y., Ren, G.Y., Sun, X.B., Shrestha, A.B., You, Q.L., Zhan, Y.J., Rajbhandari, R., Zhang, P.F., Wen, K.M., 2017. *Observed changes in surface air temperature and precipitation in the Hindu Kush Himalayan region over the last 100-plus years.* Adv. Clim. Chang. Res. 8, 148–156. https://doi.org/10.1016/j.accre.2017.08.001

Sanjay, J., Krishnan, R., Shrestha, A.B., Rajbhandari, R., Ren, G.Y., 2017. *Downscaled climate change projections for the Hindu Kush Himalayan region using CORDEX South Asia regional climate models.* Adv. Clim. Chang. Res. 8, 185–198. https://doi.org/10.1016/j.accre.2017.08.003

Seetharam, K., 2012. *Climate change synthetic scenario over gangtok, in: Climate Change in Sikkim.* Patterns, Impacts and Initiatives. pp. 1–18.

Seetharam, K., 2008. *Climate change scenario over Gangtok*. Mausam 59, 361–366.

Seetharam, K., 2003. *Correlation structure of daily rainfall over Teesta catchment.* Mausam 2, 2003.

Tambe, S., Kharel, G., Arrawatia, M.L., Kulkarni, H., Mahamuni, K., Ganeriwala, A.K., 2012. Reviving Dying Springs: *Climate Change Adaptation Experiments From the Sikkim Himalaya.* Mt. Res. Dev. 32, 62–72. https://doi.org/10.1659/MRD-JOURNAL-D-11-00079.1

a. 8 ACKNOWLEDGEMENTS

I would like to thank my supervisor Dr. Jagdish Krishnaswamy for his guidance and mentorship.I would like to thank the National Mission for Himalayan Studies whose funding has been instrumental in the pursuance and completion of this research. I would also like to thank the Ministry of Environment, Forest and Climate Change and ATREE Academy for Conservation and Sustainability Studies.

Fellowship Report No.: 7 of 10

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HJPF	Shweta Basnett	April 1, 2016	July 31, 2019	Conservation of Rhododendrons and its pollinators in Subalpine and Alpine regions of Sikkim Himalaya.	Dr. M Soubadra Devy, Senior Fellow

19. SHWETA BASNETT

1 INTRODUCTION

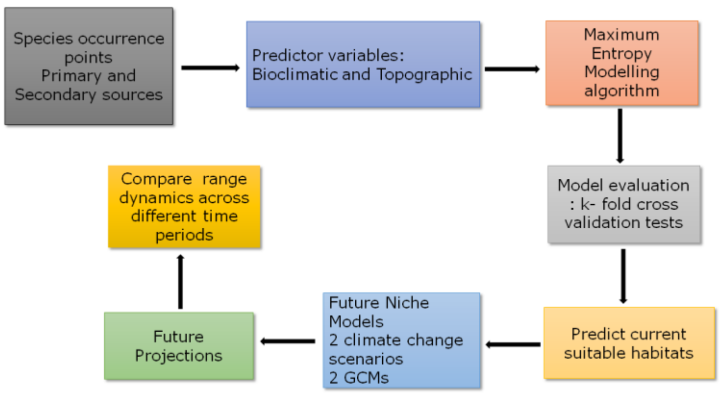
Rhododendrons are inhabitants of high altitude and cover a vast region of south-eastern Asia between the north-western Himalaya through Nepal, Sikkim, Eastern Tibet, Bhutan, Arunachal Pradesh, upper Burma and central China (Kumar P 2012). Across the globe, *Rhododendrons* are known for its high ornamental value Basnett and Devy (2013). However, apart from having attractive flowers *Rhododendron* also have high ecological importance (Singh et al. 2009). They form a dominant part of the important forests types as they are distributed all along the temperate, subalpine and alpine region supporting a wide range of animals and plants. They play a significant role in sustaining a wide range of insect and bird pollinator populations due to its profuse flowering and nectar provisioning from early spring to early summer (Ranjitkar et al. 2013; Singh et al. 2009). Especially in the Himalayan context, the major threats to *Rhododendrons* are deforestations and unsustainable extraction for firewood and incense by local communities. Due to the presence of polyphenols and flavonoids, *Rhododendrons* also make excellent fuel that burns even in the cold weather. *Rhododendron* also attracts lots of tourists during its flowering time. However, we still have very less information on its recreational services and neither the impact of high tourism on *Rhododendrons* habitat is evaluated.

Another important threat to *Rhododendron* is the climate change. The phenology of Rhododendron is highly sensitive to temperature (Rangitkar et al. 2013), and any shifts in its phenology can have a detrimental effect on its reproductive success further affecting the species functioning and its distribution. One way of understanding the effect of climate change is using ENMS. For, example Kumar P (2012) demonstrates the possible impact of climate change on *Rhododendrons* niches and its distributions using a Maximum entropy approach (known as MaxEnt, Phillips et al. 2006) the study suggests that the suitable bioclimatic envelope for *Rhododendrons* will be shrunk considerably under the envisaged climate change scenario. Furthermore, (Ranjitkar et al. 2014) used an ENM ensemble method to map the suitable climatic space for two tree *Rhododendrons*. The wide range of occurrence highlighted the adaptive capacity of these species and their distribution limits were associated with Isothermality, temperature ranges, the temperature of the wettest quarter, and precipitation of the warmest quarter of the year. The recent study on distributional overlaps of closely related *Rhododendron* sister species across the current and future climates highlights that precipitation variables are associated with *R.lowndesii* distribution, whereas temperature variables are associated with distributions of *R.lepidotum* and *R.cowanianum*. These research findings till present make it evident that it is difficult to generalize the effect of climatic factors across *Rhododendron* species.

Rhododendron forms the dominant component of the high-altitude plants distributed across the wide elevation range of 1800m to 5000m which makes them a model species for the climate change related study. The subalpine to alpine transition zone that includes timberline is the most fragile ecosystem in the Himalaya. *Rhododendron* is the only plant group that has a continuum in the ecotone as mentioned above. Therefore, it is imperative to understand the vulnerability of the keystone species such as *Rhododendron* (Singh et al.2009) in the Himalayas in response to climate change.

Against this backdrop, ecological niche models (hereafter ENM) of a narrowly and widely distributed *Rhododendron* species I explore 1) the areas of climatically suitable conditions in the present scenario and 2) and the role of global climate change in determining the distribution of these species in Himalayas and adjacent areas by projecting it to two scenarios for the year 2050s. Furthermore, we discuss future direction for research and conservation management in the wake of global change.

a. 2 METHODOLOGIES, STRATEGY AND APPROACH



This study was carried out within the distribution range of *R.lepidotum* and *R.setosum* which covered the Himalayan belt. *R.lepidotum* is widely distributed ranging from 72.0012°E to 103.8015°E and 25.4962°N to 34.8700°N whereas *R.setosum* is narrowly distributed and ranges from 83.9380°E to 91.9030°E and 27.3870°N to 28.3002°N. *R.lepidotum* covers an elevation gradient of 3000 to 4000m and *R.setosum* from 3500 to 4800m. These species occur as short shrub of about 1 to 2 feet height and are highly aromatic. I compiled occurrence data from field sampling and secondary sources which includes the Global Biodiversity Information Facility. I recorded 28 presence data for *R.setosum* and 80 for *R.lepidotum*. Ifiltered out the initial set of occurrence points after checking for spatial autocorrelation using package spThin in R.19 bioclim variables and one topographic variable-altitude were downloaded from global climate data (http://www.worldclim.org). I used Maximum Entropy (MaxEnt) approach estimate to develop the ecological niche models. The maximum entropy (MaxEnt) approach estimates a species environmental niche by finding a probability distribution of a species occurrence that is based on a distribution of maximum entropy. Jackknife test was performed to evaluate the variable importance and model performances were assessed using Area under the curve (AUC) statistic.

Vegetation plots:

I compiled occurrence data from from secondary sources which includes the Global Biodiversity Information Facility. I collected primary data in Kyongnosla Alpine Sanctuary by laying belt using stratified random sampling method. At every 200m belt transects of 50 x 20m were laid, and distance of 20m were maintained between each transect. The abundance of each Rhododendron species occurring inside the belt was measured.

Pollinator's dependence:

Data were collected by observing the visitors on flowers from a 3m distance to avoid disturbance to the visitors. Each plant was observed for about 10mins every visitor and the number of flowers it visits in that particular branch were recorded; visiting insects were captured in nets and photographed for its identification. To avoid any biases introduced by time-dependent changes in insect behaviour no one tree were surveyed twice at the same hour of the day.

Maxent modeling:
Maximum Entropy (MaxEnt) method was used to estimates a species environmental niche by finding a probability distribution of a species occurrence that is based on a distribution of maximum entropy (concerning a set of environmental variables). It was used to understand the probable distribution and the impact of anthropogenic climate change on selected *Rhododendrons* species and its pollinators. The occurrence points of the Rhododendron species and its pollinator were collected from secondary data, herbarium samples, and a field survey. A set of environmental variables were downloaded from global climate data (www.worldclim.org)

I collected primary data in Kyongnosla Alpine Sanctuary by laying belt using stratified random sampling method. At every 200m belt transects of 50 x 20m were laid, and distance of 20m were maintained between each transect. The abundance of each *Rhododendron* species occurring inside the belt was measured. Primary pollinator's data were also collected by observing the visitors on Rhododendron flowers using standard pollinator visitation study methodology. I made observation from 3m distance to avoid disturbance to the visitors. Each plant was observed for about 10mins every visitor and the number of flowers it visits in that particular branch were recorded; visiting insects were captured in nets and photographed for its identification. To avoid any biases introduced by time-dependent changes in insect behaviour no one trees were surveyed twice at the same hour of the day.

Review of literature and other secondary information helped in study design. Field trips gave lots of information on landscape, species distribution and overall ecology of Rhododendron species. Collaboration with other institute such as Botanical survey of India, Punjab university and University of Agricultural Sciences,GKVK, Bengaluru also helped in species identification of plants and insects.

Activity-wise Time Frame followed using Gantt/ PERT Chart (max. 1000 words)

	2016	2017	2018	2019
Review of literature	✔			
Designing study	✔	✔		
Data collecton		✔	✔	
Analysis		✔	✔	
Writing Manuscript			✔	✔

b. 3 KEY FINDINGS AND RESULTS

Jackknife tests illustrate that among the topographic variable altitude has a major contribution to the models of both the species. All the model performed better than random with AUC values >0.5 with *R.lepidotum* having an AUCcv=0.92 and *R.setosum* AUCcv=0.95.

The habitat suitability is highest between elevation gradient of 2200m to 4200m for *R.lepidotum*, and I noticed a sharp increase in its habitat suitability up to almost 6600m for *R.setoum*. The habitat suitability was found higher towards lower values of annual temperature (Bio_7) and lesser with the increase in temperature. Similarly, probability values for *R.setosum* also peaked around lower values of temperature seasonality (BIO_4) and the higher values of isothermality (BIO_3)

Under current climatic conditions, the model predicted a total suitable area of 901176 km^2 for wide-ranging *R.lepidotum*, and I observed a decrease in its overall suitability area in both the future scenarios. Whereas in case of narrow ranging *R.setosum* the present scenario model predicted a total area of 687338 km^2 for *R.setosum* and I observed an increase in the overall suitability area in both the future scenarios for the year 2050.

For R.lepidotum the 2050 rcp (representative concentration pathway) 4.5 predicted 122,494 km^2 (reduction of 778,682 km^2 in the total area from the present) and 2050 rcp8.5 scenario predicted 1,276,52 km^2 (reduction of 773,524 km^2 in the total area from present). In case of *R.setosum* 2050 rcp 4.5 predicted 907011km^2 (increase of 219,673 km^2 in the total area from present) and 865838 km^2 (increase in 178,500 km^2 in the total area from the present.
R. thomsonii which occurred below the treeline had the longest mean corolla length, highest nectar volume and was visited relatively more by birds. Other species occurring in this elevational gradient with similar floral characteristics in which birds were the dominant visitors were *R. hodgsonii* followed by *R. cinnabarinum* and *R. campanulatum*.

In contrast, among species growing mainly above the treeline, *R. anthopogon, R. setosum* and *R. lepidotum* were visited by insects such as bumblebees and flies. These three *Rhododendron* species also had the highest concentrations of nectar, shortest corolla length and displayed a shorter distance between the stamen and stigma.

R. wightii and *R. aeruginosum* which occurred between 3900 to 4000 m were largely visited by flies, followed by bumblebees, and were occasionally visited by birds.

Key Results

- Identified *Rhododendron* species distribution, with the help of vegetation plots and secondary literature.
- Identified the current and future distribution of narrow (*R.setosum*) and wide ranging (*R.lepidotum*) *Rhododendron* species.
- Collected database on Pollinators of Himalayan *Rhododendron*

This work, broadly describes the trajectory of change in *Rhododendron* species distribution in the phase of climate change. The projects outcome has identified the climatically suitable areas for the present and future scenario (2050) for two *Rhododendron* species.
The model also suggests that altitude is the primary factor that determines the ecological niches of these species. Different species occur along the altitude therefore, it provides information for the conservation planners to adopt a strategy at a species level in the face of climate change.

Overall, this result will help develop strategies for conservation of suitable areas for alpine and subalpine *Rhododendrons* of the Himalaya region.

For the first time this work also highlights bumblebees, birds and flies as a dominant pollinator of the high elevation Himalayan *Rhododendrons.*

c. 4 OVERALL ACHIEVEMENTS

Mountain top plant species are vulnerable to rapid climate change and climate is considered to be a primary determinant in the distribution of plant species. Our study aimed to estimate the future and present distribution of two high altitude *Rhododendron* species. We projected them to current and future climate conditions for the year 2050 under the moderate (rcp 4.5) and extreme (2050 rcp 8.5) climate change scenario. We considered a widely distributed (*R.lepidoptum*) and a narrowly distributed (*R.setosum*) species to quantify the effect of climate change. Our model suggests that the future climate change will alter the distribution of these species. The projected future model predicted a decrease in the habitat of *R.lepidotum* and an increase in *R.setosums* habitat. This study provides information for the conservation planners to adopt a strategy at a species level for conserving *Rhododendrons* in the face of climate change.

Through my published article titled "Floral traits determine pollinator visitation in *Rhododendron* species across an elevation gradient in the Sikkim Himalaya" in Journal Alpine Botany, I share the information on pollinators of Rhododendrons for the first time from the Eastern Himalayan region.

d. 5 IMPACTS OF FELLOWSHIP IN IHR

The project has helped document the higher elevation Rhododendron species and pollinators of Kyongnosla Alpine sanctuary. The study has also estimated the future and present distribution of a widely distributed (*R.lepidoptum*) and a narrowly distributed (*R.setosum*) species. Overall, the result suggests that future climate change will alter the distribution of these species. And for the conservation of *Rhododendrons* in the face of climate change, a conservation strategy needs to be adopted at a species level.

e. 6 EXIT STRATEGY AND SUSTAINABILITY

This work broadly describes the trajectory of change in *Rhododendron* species distribution in the phase of climate change. The project's outcome has identified the climatically suitable areas for the present and future scenario (2050) for two *Rhododendron* species.
My model also suggests that altitude is the primary factor that determines the ecological niches of these species. Different species occur along the altitude therefore, it provides information for the conservation planners to adopt a strategy at a species level in the face of climate change.

Overall this result will help develop strategies for conservation of suitable areas for alpine and subalpine *Rhododendrons* of the Himalaya region. For the first time this work also highlights bumblebees, birds and flies as a dominant pollinator of the high elevation Himalayan *Rhododendrons.*

This work can be easily replicated in other parts of the Himalayan region by adopting the same methodology. More primary data points need to be generated by carrying out more rigorous fieldwork covering larger geographical area by considering different mountains and large elevation gradient. Large sampling points will enable us to build more rigorous models and help better predict the distribution of species in the face of changing climate.

Earlier studies have rarely looked at future distributions of plants and their pollinators across multiple species along the altitudinal gradient. Therefore it is difficult to determine if the trend observed in *Rhododendron* species represent a wider pattern in high altitude plants. Studies which span multiple genera and inter- and intra-specific variations in species distributions and floral traits are necessary to be able to comment on the generality of these observed patterns in high altitude plant species.

Major recommendations for sustaining the outcomes of the fellowship in future

- Organize more workshops and conference among institutes who has received Nmhs grants
- Provide contingency to attend workshops and conferences in India and also abroad.
- Come up with a NMHS journal to publish any kinds of works funded by NMHS.
- More initiative is required in order to build a strong collaboration across different institutions and organizations.

20.

a. 7 REFERENCES/BIBLIOGRAPHY

Basnett S and Devy S (2013) *Rhododendrons* Beyond just beautiful flowers. www.sanctuaryasia.com.

Kumar P (2012). Assessment of impact of climate change on *Rhododendrons* in Sikkim Himalayas using Maxent modelling: limitations and challenges. *Biodiversity and Conservation* 21(5): 1251-1266.

Ranjitkar Sailesh, Eike Luedeling, Krishna Kumar Shrestha, Kaiyun Guan, and Jianchu Xu (2013) Flowering phenology of tree *Rhododendron* along an elevation gradient in two sites in the Eastern Himalayas. *International journal of biometeorology* 2: 225-240.

Ranjitkar Sailesh, Roeland Kindt, Nani Maiya Sujakhu, Robbie Hart, Wen Guo, Xuefei Yang, Krishna Kumar Shrestha, Jianchu Xu, and Eike Luedeling (2014) Separation of the bioclimatic spaces of Himalayan tree *Rhododendron* species predicted by ensemble suitability models. *Global Ecology and Conservation* 1:2-12.

Singh K K, L K Rai, and B Gurung (2009) Conservation of rhododendrons in Sikkim Himalaya: an overview. *World Journal of Agricultural Sciences* 5.3: 284-296.

b. 8 ACKNOWLEDGEMENTS

This research was funded by the National Mission on Himalayan Studies, and implemented by the Ministry of Environment, Forest & Climate Change of India (Grant No. GBPI/NMHS/HF/RA/2015-2016). We thank the Sikkim State Department of Forests and Wildlife, Sikkim Police Department and Indian Army for research permits and logistical support. We thank Saini Mallikat, Aaarti Pannure, Yeshwanth H, Vasuki Belavadi, Kumar Ghorpade and Seena Narayanan for insect identifications. Sonam Bhutia provided assistance for the data collection throughout the field work.

c. APPENDICES

Insect and bird pollinators of 10 *Rhododendron* species in Kyongnosla Alpine Sanctuary. The blank space (-) represents the unidentified specimens.

Elevation	*Rhododendron* Species	Time (hrs)	Pollinators			
			(Common name)	Family	Genus	Species
3400-3500	*R. campanulatum*	75.6	Blow flies	Calliphoridae	-	-
	R. cinnabarinum		Black-faced Laughingthrush	Leiothrichidae	*Trochalopteron*	*affine*
	R. thomsonii			Fringillidae	*Carpodacus*	*thura*
			Fire-tailed sunbird	Nectariniidae	*Aethopyga*	*gouldiae*
			Leaf warbler	Phylloscopidae	*Phylloscopus*	*affinis*

3500-	*R. campanulatum*	99	Fire-tailed sunbird	Nectariniidae	*Aethopyga*	*gouldiae*
3600	*R. cinnabarinum*		Leaf warbler	Phylloscopidae	*Phylloscopus*	*affinis*
	R. hodgsonii		Black-faced	Leiothrichidae	*Trochalopteron*	*affine*
	R. thomsonii		Laughingthrush		*arpodacus*	
			Himalayan white-browed rosefinch	Fringillidae		*thura*
3600-	*R. campanulatum*	100.8	March flies	Bibionidae	*Bibio*	-
3700	*R. campylocarpum*		Housefly	Muscidae	-	-
	R. hodgsonii		Blow flies	Calliphoridae	-	-
	R. thomsonii		Bumblebee	Apidae	*Bombus*	*pyrosoma*
			Fire-tailed sunbird	Nectariniidae	*Aethopyga*	*gouldiae*
			Leaf warbler	Phylloscopidae	*Phylloscopus*	*affinis*
			Black-faced	Leiothrichidae	*Trochalopteron*	*affine*
			Laughingthrush			
			Himalayan white-browed rosefinch	Fringillidae	*Carpodacus*	*thura*
3700-	*R. campanulatum*	93	March flies	Bibionidae	*Bibio*	-
3800	*R.*		Sawflies	Tenthredinoidae	*Tenthredo*	*rugiceps*
	campylocarpum		Hoverflies	Syrphidae	*Platycheirus*	*himalayensis*
	R. hodgsonii		Hoverflies	Syrphidae	*Meliscaeva*	*tribeni*
	R. thomsonii		Hoverflies	Syrphidae	*Criorhina*	*bomboides*
			Shore fly	Ephydridae	-	-
			Housefly	Muscidae	-	-
			Blow flies	Calliphoridae	-	-
			Bumblebee	Apidae	*Bombus*	*pyrosoma*
			Bumblebee	Apidae	*Bombus*	*tunicatus*
			Bumblebee	Apidae	*Bombus*	*rufofasciatus*
			Bumblebee	Apidae	*Bombus*	*keriensis*
			Fire-tailed sunbird	Nectariniidae	*Aethopyga*	*gouldiae*
			Leaf warbler	Phylloscopidae	*Phylloscopus*	*affinis*
			Black-faced	Leiothrichidae	*Trochalopteron*	*affine*
			Laughingthrush			
			Himalayan white-browed rosefinch	Fringillidae	*Carpodacus*	*thura*
3800-	*R. lepidotum*	38.9	Blow flies	Calliphoridae	-	-
3900	*R. campanulatum*		Sawflies	Tenthredinoidae	*Tenthredo*	-
	R. anthpogon		Shore fly	Ephydridae	-	-
			Housefly	Muscidae	-	-
			Dung flies	Scathophagidae	*Scathophaga*	-
			Hoverflies	Syrphidae	*Platycheirus*	*himalayensis*
			March flies	Bibionidae	*Bibio*	-
			Leaf warbler	Phylloscopidae	*Phylloscopus*	*affinis*
3900-	*R. aeruginosum*	92	Blow flies	Calliphoridae	-	-
4000	*R. anthpogon*		Shore fly	Ephydridae	-	-
	R. lepidotum		Housefly	Muscidae	-	-
	R. setosum		Leaf hoppers	Aphrodinae	-	-
			Bumblebee	Apidae	*Bombus*	*pyrosoma*
			Bumblebee	Apidae	*Bombus*	*keriensis*
			Bumblebee	Apidae	*Bombus*	*tunicatus*
			Leaf warbler	Phylloscopidae	*Phylloscopus*	*affinis*
			Fire-tailed sunbird	Nectariniidae	*Aethopyga*	*gouldiae*
4000-	*R. aeruginosum*	97.7	Shore fly	Ephydridae	-	-
4100	*R. anthpogon*		March flies	Bibionidae	*Bibio*	-
	R. lepidotum		Hoverflies	Syrphidae	*Platycheirus*	*himalayensis*
	R. setosum		Hoverflies	Syrphidae	*Epistrophe*	*griseocincta*
	R. wightii		Blow flies	Calliphoridae	-	-
			Bumblebee	Apidae	*Bombus*	*tunicatus*
			Bumblebee	Apidae	*Bombus*	*rufofasciatus*
			Bumblebee	Apidae	*Bombus*	*pyrosoma*
			Black-faced Laughingthrush	Leiothrichidae	*Trochalopteron*	*affine*
			Leaf warbler	Phylloscopidae	*Phylloscopus*	*affinis*

4100-4200	*R. anthpogon*	88.2	Blow flies	Calliphoridae	-	-
	R. aeruginosum		March flies	Bibionidae	*Bibio*	-
	R. setosum		Dung flies	Scathophagidae	-	-
	R. wightii		March flies	Bibionidae	*Bibio*	-
			Bumblebee	Apidae	*Bombus*	*rufofasciatus*
			Bumblebee	Apidae	*Bombus*	*keriensis*
			Bumblebee	Apidae	*Bombus*	*tunicatus*
			Leaf warbler	Phylloscopidae	*Phylloscopus*	*affinis*
4200-4230	*R. anthpogon*	50.4	Sawflies	Tenthredinoidae	*Tenthredo*	-
	R. setosum		Hoverflies	Syrphidae	*Epistrophe*	*griseocincta*
	R. aeruginosum		Housefly	Muscidae	-	-
	R. wightii		Blow flies	Calliphoridae	-	-
			Bumblebee	Apidae	*Bombus*	*tunicatus*
			Leaf warbler	Phylloscopidae	*Phylloscopus*	*affinis*

Fellowship Report No.: 8 of 10

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HJPF	Yangchenla Bhutia	April 1, 2016	July 31, 2019	Understanding the regeneration status of Oaks and its related species in the forest of Sikkim Himalaya	Dr. Ravikanth Gudasalamani, Senior Fellow

21. Yangchenla Bhutia

1 INTRODUCTION

The study explored the regeneration status of Oaks and its related species in the forests of Sikkim Himalaya. The study was carried out in mid elevation forests covering 900m to 2700m a.s.l. The result showed poor regeneration, with very few seedlings . The Oak and its related species (Fagaceae) are significant for the Himalayan region. They are reported as the dominant forest trees of the mid-elevation forests. Besides, they are highly valued by people in the Himalayas for its diverse use in agricultural practices. Their value goes well beyond the enormous trunk and massive canopies: their acorns form the major food source for wildlife, protect watersheds and ensures underground recharge for continuous flow of springs and rivers. Additionally, they are an important source of fodder, fuelwood, charcoal, etc. However, these forests are in major threat globally and the Himalayas. Sikkim reported major forest loss and degradation in the last three decades of the 20th century, which was primarily concentrated in the Temperate Oak forest. Out of the total degraded area of the 317km^2, Oak forest contributed chiefly, with 62%. Despite the ongoing threat of scientific records on the current scenario of Oak forest is null.

2 METHODOLOGIES, STRATEGY AND APPROACH

The present study was conducted along the mid elevation forest of Sikkim Himalaya, ranging from 900m to 2700m a.s.l. These elevations were selected, because it represents the potential distribution range of Oaks and their related species. Stratified random sampling was conducted after demarcating the forest between 900m to 2700m. Thirty plots of 0.1 ha (100m ×10m) with six 1m ×1m subplots were installed. Within each plot diameter of trees >3cm DBH (diameter at breast height at 1.3m) were measured and recorded, whereas seedlings (individuals with 2 to 5 leaves, Figure 2) were counted from the subplot. Parameters like geographic coordinates (Latitude and Longitude) were recorded from the field.

The approach was Stratified random sampling and Seed viability test. The acorn (cupule and seed together) were manually collected from 2016 to 2017 in September to December when acorns matured and started to fall. Acorn was collected from fourteen sites, covering 1000m to 2700m elevation. Minimum of 50 acorns was collected from individual trees representing different species. In the laboratory, 30 acorns were randomly selected for seed testing. The cupules were separated from the seed before seed measurement. Seed length and weights were also measured and recorded. The same seed was used to test seed viability, after soaking in water for 10 minutes. The ratio of floated and sunken seed was recorded. Lastly, the volume of each seed was estimated assuming the ellipsoid shape of seed.

a. 3 KEY FINDINGS AND RESULTS

The study recorded eight species of Oak and its related, represented by three genera: *Castanopsis, Lithocarpus*, and *Quercus,* within the family Fagaceae*.* The size class distribution showed an inverse "J" shaped distribution, with a large number of trees in the lower girth class which decreased with an increasing diameter. However, between different genera, the size class varied: *Quercus* and *Lithocarpus* represented the least number of size classes, whereas the genus *Castanopsis* showed the maximum number size class, with the highest number of trees in the lowest size class. The regeneration of Oak and its related species are very poor in the Himalayan region of Sikkim. The genus *Castanopsis* was the dominant tree species. The genera *Quercus* and *Lithocaprus* have extremely low seedling frequency. The Castanopsis species has high seed viability, whereas the seed volume was higher for most *Querucs* and *Lithocarpus* species.

b. 4 OVERALL ACHIEVEMENTS

In general, oaks in the Sikkim Himalayas are characterised by poor regeneration. Two genera, *Quercus* and *Lithocarpus* have low seedling frequency despite having higher seed volume. The study sites were dominated by *Castanopsis*, which has high seed viability.The genus Castanopsis is the dominant forest's trees with relatively higher stem density occurring between forests ranging from 900m to 2700m a.s.l. in the Sikkim Himalaya.

22.

a. 5 IMPACTS OF FELLOWSHIP IN IHR

The current study is the first to provide a quantitative investigation of the regeneration status of oaks and related species in the Sikkim Himalaya.

b. 6 EXIT STRATEGY AND SUSTAINABILITY

The study recommends an urgent restoration program, for instance setting up a nursery, protection of established seedlings in the forest using shelter tubes to improve seedling establishment, and the overall functioning of the forest ecosystem**.**

c. 7 REFERENCES/BIBLIOGRAPHY

Krishna, A. P. (2005). Snow and glacier cover assessment in the high mountains of Sikkim Himalaya. *Hydrological Processes*, *19*(12), 2375-2383.

Reich, P. B., Wright, I. J., Cavender- Bares, J., Craine, J. M., Oleksyn, J., Westoby, M., & Walters, M. B. (2003). The evolution of plant functional variation: traits, spectra, and strategies. *International Journal of Plant Sciences*, *164*(S3), S143-S164.

Singh, S. P., & Singh, J. S. (1986). Structure and function of the Central Himalayan oak forests. *Proceedings: Plant Sciences*, *96*(3), 159-189.

Singh, G., Rai, I. D., & Rawat, G. S. (2012). The mortality of banj oak(Quercus leucotrichophora A. Camus) trees in Mussoorie, Uttarakhand: is it an alarming call for rapid degradation?. *Current Science(Bangalore)*, *102*(12), 1622-1623.

Thadani, R., & Ashton, P. M. S. (1995). Regeneration of banj oak (Quercus leucotrichophora A. Camus) in the central Himalaya. *Forest Ecology and Management*

Tashi, S. (2004). *Regeneration of Quercus semecarpifolia Sm. in an old growth oak forest under Gidakom FMU-Bhutan* (Doctoral dissertation, M. Sc. Thesis. Wageningen University and Research Centrum, Wageningen).

Tambe, S., Arrawatia, M. L., & Sharma, N. (2011). Assessing the Priorities for Sustainable Forest Management in the Sikkim Himalaya, India: A Remote Sensing Based Approach. *Journal of the Indian Society of Remote Sensing*, *39*(4), 555-564.

d. 8 ACKNOWLEDGEMENTS

I would like to thank my supervisor Dr. Ravikanth G. without whose guidance the project would not be possible. I would like to thank the National Mission for Himalayan Studies whose funding has been instrumental in the pursuance and completion of this research. I would also like to thank the Ministry of Environment, Forest and Climate Change, Er. Kireet Kumar and ATREE Academy for Conservation and Sustainability Studies.

Fellowship Report No.: 9 of 10

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HJPF	Rinan Shah	April, 2016	July 31, 2019	Climatic and Non-Climatic Drivers of Environmental Change and Human Well-Being – Domestic Water Scarcity in the Eastern Himalaya	Dr.Shrinivas Badiger, Fellow

23. Rinan Shah

1 INTRODUCTION

In the current times, water scarcity has the world in grips. 2018 saw Cape Town in South Africa and Shimla in India undergo a water crisis which was widely reported by the international and national media. The water crisis now is said to have been solved in these two places but it should not put the emerging water issues on the back burner. Additionally, instead of looking at the cities and metropolises, attention should also be paid to areas which are undergoing urbanization and have to handle a large influx of people. Due to the multifaceted nature of water and the complexities of geographies and urbanization, the water crisis cannot be simply looked at the volumetric availability of water but also how the communities in any region are able to access water.

There are many regions in the world which receive a high amount of rainfall but experience water crises. This paradoxical situation of being water poor in a volumetrically water-rich region is manifested through biophysical factors as well as the political economy and the development trajectory of the region. These factors place the communities at a disadvantage where they are not able to acquire basic water requirements for their daily uses. The economic and socio-political statuses of the communities enable or disable them further. Additionally, the variety of water resources and the institutions around it create a multi-layered system which the communities need to navigate with whatever resources they have. The communities hence depend on a combination of the various water resources depending on the seasons, the availability of those and other resources to create a water bundle. One of the primary sources that make up this bundle in case of rural and urban settings is springs. The property regime surrounding springs makes it an interesting resource, with the literature largely looking at it as a common property resource. This aspect puts the springs away from state institutions and into the lap of the communities who use it who manage and use it of their own accord. Until now, particularly in the Darjeeling region, there has been no attempt into the understanding of springs by the state bodies and if there would be any advantages or disadvantages with the state being the flag bearer. This study looks at the manifestation of water scarcity in the Eastern Himalayan Region (EHR) of India, what the various water sources are and the kinds of changes which these resources are going through.

Water scarcity is not a function of reduced precipitation alone. Water cycles if interrupted can turn water which is a copious renewable resource to a disappearing non-renewable resource. For greater development and well-being of people, any plans for water resources will need to address the ecological issues as well as issues of equal access. It was speculated that by 2025, 92% of the 104 million-hectare meters of maximum utilizable annual freshwater resource of India would be utilized. This exponential increase in water scarcity cannot be linked only to variations in precipitation (Bandyopadhyay 1989). Projections of future water availability have displayed a decline in per capita availability over the next two decades to come. Shifts in water demand also depend on regional specificities, but Climate variability affects water resources especially the runoff. The availability, accessibility and quality of water resources are affected by climate change. Climate variability occurs at a sub-regional level but cannot be detected by global scale models. There are very few instances of water management sectors who have tried to assimilate inter-annual climate condition data in a methodical fashion in developing countries. Climate change scenarios hint at shifts in seasonality and intensity of rainfall which will impact runoffs, groundwater recharge, storage of water in soil, dams and reservoirs; increase in temperatures and transpiration rate from plants. These changes coupled with land use changes will aggravate the availability and accessibility of water. Any decrease in precipitation will be amplified by the hydrological system in the case of runoffs and groundwater recharge especially in arid and semi-arid regions (Ziervogel, Johnston, Matthew, & Mukheibir, 2012) the earlier statement would likely hold true for most cases. (Beniston, 2003).

Water scarcity is apparent in various regions of the world, be it arid regions which receive extremely less rainfall or wet regions which receive a high amount of rainfall. Water has moved from being an abundant resource to a scarce resource (Bandyopadhyay 1989). Indicators to ascertain water scarcity primarily use biophysical factors like rainfall and other climatic factors (Falkenmark and Lundqvist 1998; Government of West Bengal 2012; Hoekstra and Mekonnen 2012; Seckler, Molden, and Barker 1999). These methods create a notion of uniformity across a country overlooking the geographic and socio-economic differences and also the temporal and spatial nature of water flows. Quantifying natural resources fails to look at the processes involved in converting availability of resources into its accessibility for people. Hence a more nuanced way of understanding scarcity is needed (Anand 2004; Mehta 2006) because water scarcity is not a function of reduced precipitation alone. Water scarcity can be attributed to the biophysical changes, the political economy of the region and the urban planning and infrastructural changes among many others. The extent of utilization can also be a cause.

Water from its form in rain, ice, or snow is harnessed through reservoirs, supply tanks, rainwater harvesting systems, and others and supplied through pipeline distribution networks. The setup of water infrastructure is driven by the political economy of the region and the institutions which ascertain ownership over water sources. Presence of infrastructure does not imply access to all; hence we need to understand the rules of access and the story behind these rules. The absence of infrastructure throws in questions about the inefficiency or the lack of interest of the formal and informal institutions. The presence or absence of accessible water infrastructure also becomes dependent on the socio-economic status of the communities and their location. So, whenever a household needs to acquire water, they need to navigate through all these factors before they can acquire water for basic consumption. Due to the multiple institutions associated with the water resources and also the seasonality of water availability, communities need to create a water bundle of various sources.

The Himalaya is one of the most fragile ecosystems of the planet and also the most threatened. These areas are less touched by development and this is exhibited as the frequent occurrences and impacts of landslides, soil erosion, climate change and loss of biodiversity. Landslides and soil erosion are global phenomena but they are manifested in extreme forms in the Himalayas and its watershed. The natural and man-made elements responsible in the study area are environmental degradation on the virgin slopes, heavy precipitation, anthropogenic activities, over exploitation of natural resources and overshoot of tourism infrastructure (Verma and Mushtaq 2013). Water scarcity in mountain towns is unique due to its topography, the presence of springs, the nature of urbanization, and the seasonal influx of population. Mountainous regions are usually wetter and are called water towers of the world as they feed a majority of the rivers in the world. However, mountain regions which receive a high amount of rainfall face a water paradox, a water crisis not only in the dry months but also during the rainy season. The topography makes water harnessing an energy-intensive task on the one hand, and on the other allows for the prevalence of springs which are important water sources for rural as well as urban population. There has been rapid urbanization (Madan and Rawat 2000; Mell and Sturzaker 2014) in mountainous regions too which brings in a conflict of land, water, and other natural resources. Lastly, mountain towns are visited by tourists throughout the year with high seasonal numbers which overlap with the dry seasons making water crisis worse. Matters get worse for mountainous tracts because of the uncertain impacts of environmental hazards and disasters.

Of the various water sources, springs hold an important part in addressing water access of mountain communities. Springs do not fall under any formal institution hence the management, if any, is taken up by the communities who reside in their vicinity. Currently, there have been reports and studies which hint at the reduction in the number of springs as well as the quantity of water it provides. There are minimal records of springs and they are being taken up by various agencies. It has been observed that the more varied a water bundle, the less vulnerable are a group to water scarcity. The presence of a spring in a region enhances the water accessibility of a group.

The current study will take place in the Eastern Himalayan Region (EHR) of India. The EHR receives rainfall from the south-west (summer) monsoons as well as the north-east (winter) monsoons bringing the annual rainfall to 2000-4000 mm making it one of the regions which receive the highest rainfall in the country. However, there are numerous studies which have reported water crisis in this region (Chhetri and Tamang 2013; Drew and Rai 2016; Khawas 2002; Lepcha 2013; Rasaily 2014) – a paradox of water poverty in a 'water-rich' region (Sharma et al., 2010). The water crisis is attributed to the seasonality of rainfall and inaccessibility complications due to difficult terrain.

The study is focused in the urban mountain cities of Eastern Himalayan Region of India. The primary study site is the Darjeeling Municipal Town (Figure 1) in West Bengal. The water sources for the town are the Municipal supply (private household connection and public standpipes), springs and private water supply (tankers or households selling/sharing their excess water). The frequency of supply is very low – once a week during the lean months and twice to thrice a week during the monsoon months. The town has 32 wards which are spread across an area of 10.57 sq. km. The Municipal supply acquires its supply from the reservoirs in the Senchal Wildlife Sanctuary. The Municipality has no stakes in any kind of springs-related activity. They are entirely managed by the residents living in the vicinity of the springs. There is a wide gap between the demand and supply which varies across the seasons due to the monsoons and the floating population. There have been augmentations to the water sources, but the increase in the demand does little to close the gap. The municipality infrastructure for harnessing the precipitation is not able to accommodate the excessive rainfall and have to cut off more than half the streams which feed the reservoirs. Within the municipality region of 32 wards, the differences in the presence of springs, density of infrastructure, density of population and distance from the core of the town placed them at an advantage or a disadvantage.

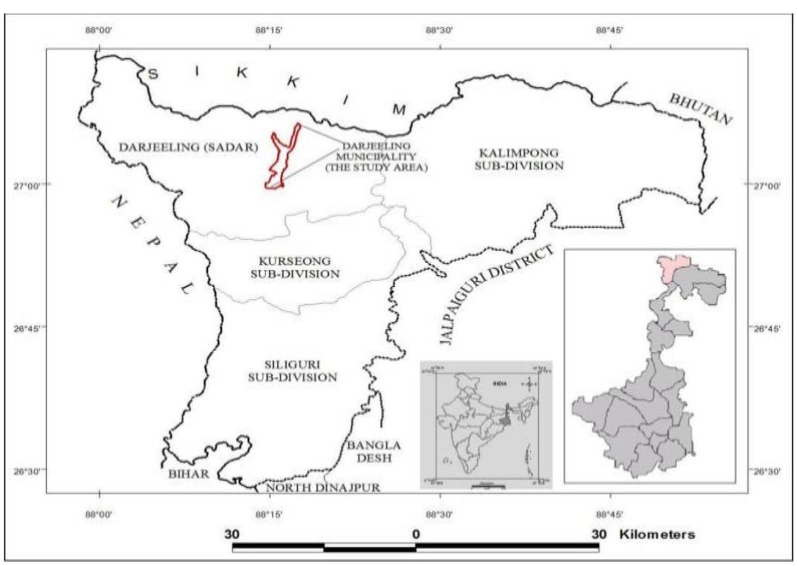


Figure 1 Location of the Darjeeling Municipality town (Chhetri and Tamang 2013)

The second site Gangtok (Figure 2) is the capital city of Sikkim and is a glacier dependent one for its water source. The development trajectory, as well as the political history, is very different from that of Darjeeling. These are some of the factors that would be used to carry out a comparison. Ratey chu, is the only source of formal water supply which caters to the domestic water needs of the city with a population of more than 1.6 lakhs without including the influx of tourists and other floating population. The inability to meet the water demands by the government has led to the formation of informal water markets which in return has affected the availability and accessibility of domestic water for the citizens of Gangtok.The study is done using mixed methods of qualitative and quantitative data. Focus group discussion, stakeholders interview and house to house survey was conducted to break into the existing water markets which may or may not be a part of the formal institution. This paper looks into the institutional, governance and water supply challenges which are exacerbating the situation by creating uncertainty of future water availability and driving the city towards water insecurity.

The power dynamics among various households vary between wards, accessibility, quality and quantity, hence creating a skewed relationship amongst different stakeholders within the same community. Water loss in pipes is a common phenomenon in the city as the water pipelines are laid down in public spaces making them easily vulnerable to damage both by manmade and natural calamities. It is important that policies are made taking a holistic approach and see water insecurity not only from the standpoint of "availability or quality" but also comprehend the dynamics of social,cultural, local politics, etc. In hilly regions, the undulating terrain plays a challenging role thus the distribution system should be strategically laid out to ensure pressure is equally or at least sufficiently distributed especially in a city like Gangtok which is fed by gravity system pipelines.

The study area is purposely chosen as Gangtok keeping in mind that it is the capital city of Sikkim which falls under the east district and estimated that 55.5 % of the state population lives in the city. Being an urban town/city, the issue of water scarcity has been slowly blanketing if not more, it is still an issue equal to that in rural areas.

Over the last few years, water scarcity has been frequently reported with its causes being stated as rapid population growth,urbanisation and other natural/manmade disasters or paralysis of institution/ governance and other related causes.Gangtok city is estimated with a population of 1.7 lakhs(source:2019) and is administered by the Gangtok Municipal Corporation(GMC). The city has 17 wards with about 24,000 households (Government of Sikkim, 2018) covering an area of 1902 hectares. The urban households in the city are supplied with water from the Public health and engineering department and quenches its thirst from Ratey chu which is located about 16 km away from the city at an altitude of 2621m. The water is then treated at Selep tank and distributed across different wards at separate intervals.

The case of Gangtok states that there exists a formal institution that supply sufficient/ adequate amount of water to houses at designated hours of the day or few times in a week. But, whether or not there is a consensus between the government and the general public with regard to sufficient supply of water demand to meet their daily requirements is yet to come to a consensus. Hence, this study will focus on the issue of domestic water scarcity in the Gangtok town and investigate the existing gap/s in demand and supply and the challenges people face in meeting the gap. The study will also entail a broader understanding of the issue at hand, address the research questions, methodology of the proposed research and expected outcomes of the study.

Figure 2. Map of Sikkim with the location of its capital Gangtok which is also the headquarters of East District of Sikkim (https://www.mapsofindia.com/maps/sikkim/sikkim-district.htm#).

The objectives for this study are as follows -

- To understand the causes and effects of the domestic water scarcity in the eastern Himalayan towns.
- The causes entail the biophysical and human induced changes in and around the water sources as well as the region to which the water is supplied and the extent of water utilization.
- The effects will be assessed in terms of the availability and accessibility of water and the definition of well-being and sufficiency for the communities.
- The political and economic drivers for the manifestation of scarcity will be investigated.

A pilot visit was done with the supervisor to the primary field site i.e. Darjeeling and the probable field site for comparison, Gangtok (24th to 28th June 2016). During this visit, we met and interviewed the various stakeholders in both the cities. We paid a visit to St. Paul's and Rockville supply tanks which supply water to the Darjeeling Municipal town where we had a discussion with the employees. We also visited the two springs within the town called Vineeta Gram Dhara and Lal Dhiki to understand the nature of springs and the kind of rules of access. We also interviewed the Water Works Department, Darjeeling Municipality. We visited the supply sources of Darjeeling Municipality – North and South Lakes, Sindhap Lake and Khong Khola pumping station in the Senchal Wildlife Sanctuary and the filter house at Jorebungalow. In Gangtok, we interviewed the Water Service and Public Health and Engineering Department as well as a Geologist. Through this visit we were able to gather information and further contacts. Rainfall data analysis is in place

We had planned for another visit in 2017 but the 104-days strike in Darjeeling hill region disabled the fieldwork from June-September 2017. During this time, I was working on my PhD research proposal. I also got the opportunity to visit the Department of International Environment and Development Studies (NORAGRIC) at the Norwegian University of Life Sciences (NMBU) under the Royal Norwegian Embassy Grant for Student Exchange (Nov - Dec 2017).

Since the beginning of the NMHS fellowship in 2016 I attended coursework at Ashoka Trust for Research in Ecology and the Environment and one course at National Institute of Advanced Studies to fulfil my credit requirements for a PhD registration. I completed the credits and successfully defended my research proposal and registered for a PhD at Manipal Academy of Higher Education on 10th February 2018. I carried out interviews with key informants. I carried out transect walks with mapping of springs, public utilities and tanker sources, an exploratory survey of water usage, and discussions with people using these water resources.

I did an exploratory survey of the various sources of tankers outside the town area and tagged the sources and had brief interviews with the tanker drivers/owners who were present there. Another visit of the supervisor to the field site took place in April-May 2018. I also wrote and submitted a manuscript for the Himalayan Researchers Consortium under NMHS titled 'Examining Water Accessibility in Urban Mountain Towns of the Eastern Himalayan Region'. The various public and private water institutions were identified which made up the water bundle of households. The clusters of households with similar access types were identified and I conducted interviews with key informants. My supervisor and I carried out discussions with staff of ATREE project office in Darjeeling where I presented my research proposal and sought their inputs and feedback on carrying out my field work. The themes of the interviews were the history of Darjeeling town and water infrastructure, current water scenario, functioning of water tanker systems, springs, and new water projects. I created a household level questionnaire and a sampling framework to take up household surveys. I worked on a journal article for a special issue in the Water Policy titled 'Conundrum or Paradox : Deconstructing the Spurious Case of Water Scarcity in the Himalayan Region through an Institutional Economics Narrative.' I wrote three popular articles where one in the ATREE Young Researchers Network was a photo story. I also presented the same photo story at ATREE and also wrote for the ATREE Eastern Himalayan Quarterly. My learnings were also shared in an article titled 'Decoding the Darjeeling Dilemma: Why there is rain but no water'.

Interviews and household surveys were carried out in Gangtok, the second site. An intern from TERI University helped with this fieldwork.

I worked on another journal article for a special issue on the post-water economy in the International Journal of Water Resources Development.

a. 2 METHODOLOGIES, STRATEGY AND APPROACH

In order to answer the research questions for the deliverables, the following set of information is being collected through this phase of the fieldwork (Tables 1 and 2). Corresponding to the 1st objective, interviews – structured and topic-guided will be taken up followed by household surveys. Sampling for the household surveys will be done using the data gathered prior as well as the ward demarcation maps. For the 2nd objective rainfall, water supply, and population data will be collected and analysed to understand any biophysical changes. The 3rd and 4th objectives will be achieved through interviews, literature review and some archival work.

Table 1. The collection method and probable sources for primary data

Primary Data	
Collection method	**Sources**
GPS logging	Augmented water sources (for formal supply) Springs (for informal supply) Tanker supply sources (for informal supply)
Interviews	Tanker systems (informal supply) – owners Community members
Topic guided interviews	Municipality employees Ward councillors *Samaj* heads Government officials Community members
Household surveys*	Community members

*Stratified random sampling – distance from supply and administrative centre and socio-economic conditions

Table 2. Secondary data to be used

Secondary Data
Rainfall records
Supply data (formal supply)
Census
Ward maps
National Sample Survey 69th Round Drinking Water, Sanitation, Hygiene and Housing Condition in India

Rainfall analysis was done using IMD data. The analysis was done in R programming language. The demand-supply curve was also created using supply and demand data and this was also done in R programming language.

Transect walks were done along the following routes

1. Capitol – Ava Art Gallery – Victoria Falls – Murda Hatti – Botanical Garden – Chandmari – Chowk Bazaar (Wards 16 and 17)
2. Happy Valley Tea Estate – Gaushala
3. Below Darjeeling Government College – Frymal Village – Bhotey Dhara
4. Jawahar Busty
5. Tungsung – Ganesh Gram – Alubari – Jorebungalow (through Tenzing Norgay Road)
6. Town Centre – Circuit House – Mary Villa - Jorebungalow (Hill Cart Road – Jalapahar Road)
7. Ward 31
8. Giri Dhara

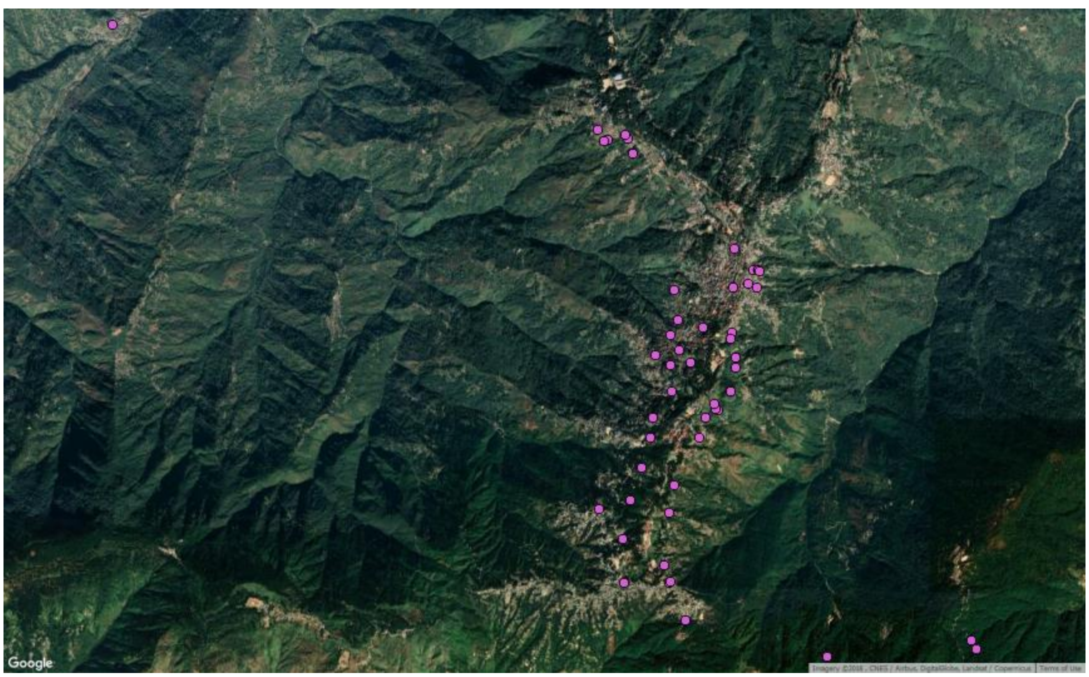


Figure 3. GPS Locations along transect walks

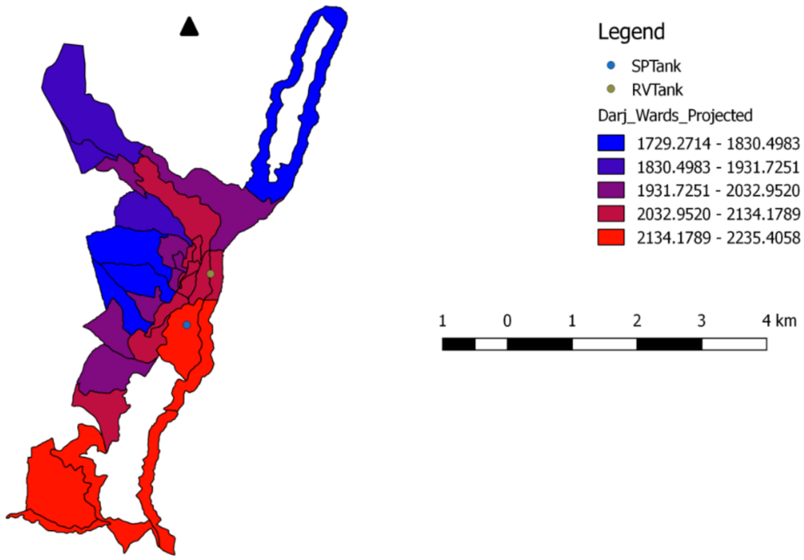


Figure 4. Ward-wise altitudinal map of Darjeeling Town. SPTank (St. Paul's Tank) and RVTank (Rockville Tank) are the two main supply tanks within the town.

In the paper titled 'Examining Water Accessibility in Urban Mountain Towns of the Eastern Himalayan Region' mentioned above I have used the NSSO 69th Round on Drinking Water, Sanitation, Hygiene and Housing Condition Data to study the domestic water issues in the district of Darjeeling. The variables used by the NSSO to ascertain the accessibility and quality of drinking water were analysed in SPSS to get an idea of the macro-level scenario.

All this information helped in creating surveys to be carried out at household levels from 2018 - 2019. I created a sampling framework to undertake household surveys. Using the ward map image and georeferencing it I was able to produce ward level map for Darjeeling town.

This enabled stratified random sampling by dividing the wards according to two spatial variables (1) average altitude of the ward and (2) distance from the main supply tanks within the town.

The data collection method for Gangtok was as follows –

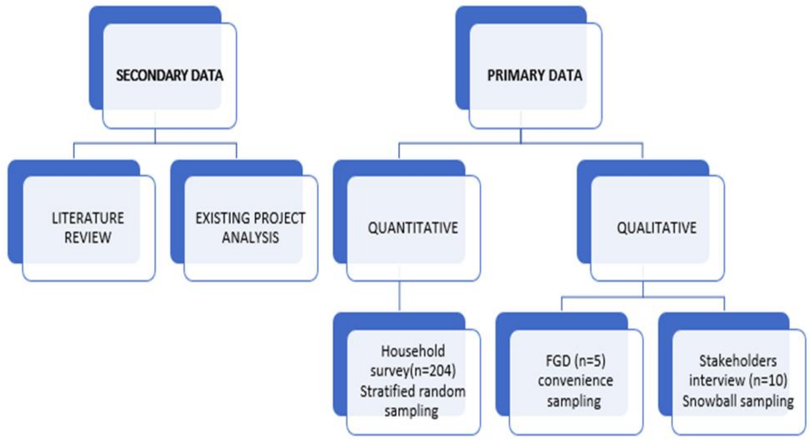


Figure 5. Schematic representation of data collection method

A target of 200 households was taken into account given the paucity of time and the size of the households across 17 wards under Gangtok Municipal Corporation, Sikkim. A total of 12 houses from each ward were taken for the household survey. Snowball sampling method was used to identify various stakeholders including government officials and experts from the field in the state and a semi-structured questionnaire was used in order to understand the existing structure of distribution and supply system in Gangtok.

GPS logging of water sources, springs and tanker supply sources (for informal supply) was done using an eTrex30 GPS logging device. I used a voice recorder for recording interviews after taking the interviewees consent. With the help of existing literature, we were able to record the springs within the Darjeeling Municipal town. We worked on interviews with stakeholders and people who had been associated with the Darjeeling water associations. We did household surveys.

The initial pilot visit and meeting with the various state bodies were an important start. Then we carried out interviews and transect walks around the town. The interviews were through snow-balling method and it was highly contingent on the getting in touch with the interviewee, followed by their availability and willingness to give an interview. I would like to mention that I have been successful in getting saturation with the information being shared. The transect walks were intense as it was done mainly on foot, since there are many regions within the town that are inaccessible by road. The last mile walk to a household is always on foot. Most transect walks took a day and many were done in parts over a couple of days. During the transect walks, we located the various villages, ward, springs, and other water sources. We also carried out discussions with the community members who we came across. All these information collection and the work done for the research proposal for my PhD helped in creating household level questionnaires. These household level questionnaires were pilot tested in the different clusters which had been identified as getting the same kind of water access. Once the pilot testing was done, using the sampling framework described above, I took up household level interviews. I did stratified sampling to select the wards. Within the wards, I carried out snowballing to get the households who would provide me with information.

b. Activity-wise Timeframe followed using Gantt/ PERT Chart

Research Activity	Time in Months					
	2016-2017		2017-2018		2018-2019	
	6	12	18	24	30	36
Course Work	■	■				
Literature Survey	■	■	■	■	■	■
Pilot Visit, Stakeholder Consultations and Identify Study Sites	■			■	■	■
Data Collection (HH Surveys, FGDs and Official Records)		■	■	■	■	■
Mapping of Study Sites and Water Resources	■			■	■	■
Compilation of Data	■	■	■	■	■	■
Analysis of Data			■	■	■	■
Half Yearly Reports						
Preparation of Final Report						■

c. 3 KEY FINDINGS AND RESULTS

	Monsoon rain fall (mm)	Non monsoon rainfall (mm)	Surface water (BCM)	Ground water (BCM)	Trans boundary water (BCM)	Per capita water availability as of 2001 CM/ capita
Darjeeling	2224.0	527.8	5.78	0.52	16.25	3945.32
Jalpaiguri	2471.3	604.8	11.30	2.64	32.56	4130.27
Koch Bihar	2604.0	667.6	6.42	2.32	44.18	3552.65
Uttar Dinajpur	1902.3	504.6	3.31	1.68	16.86	2059.38
Dakshin Dinajpur	1469.9	458.4	1.55	0.95	18.64	1676.0
Maldah	1307.7	407.1	2.14	1.40	553.21	1084.15
Murshidabad	1167.4	385.6	0.54	2.52	561.88	525.63
Birbhum	1143.0	384.3	1.46	1.67	4.50	1047.02
Nadia	1175.3	432.2	-0.27	2.17	48.25	415.8
Bardhaman	1174.0	425.6	1.84	3.34	45.54	757.02
Bankura	1159.7	387.5	2.06	2.09	13.35	1309.8
Purulia	1163.0	344.3	3.68	0.77	9.69	1767.9
Paschim Medinipur	1218.9	441.9	2.36	3.82	3.61	1199.1
Purba Medinipur	1240.3	457.6	3.27	0.83	76.68	820.5
Haora	1240.5	451.2	0.96	0.37	67.36	313.6
Hugli	1208.2	441.4	0.59	1.70	65.28	457.6
Kolkata	1245.9	454.7	0.25	0.00	50.07	55.0
North 24 Parganas	1231.0	452.3	1.91	1.58	50.33	393.6
South 24 Parganas	1266.7	461.9	1.86	3.84	81.03	831.6
TOTAL[9]			51.01	34.21	1759.27	

Key:

Water sufficient : >1600 cum/capita	Water Stress: 1000-1600 cum/capita	Water scarcity: 500-1000 cum/capita	Severe scarcity: <500 cu m/capita	Districts experiencing annual water deficit with respect to total average receipt of rain fall

Figure 6. Water sources in different districts of West Bengal (Government of West Bengal 2012)

The Government of West Bengal in their West Bengal State Action Plan on Climate Change (Government of West Bengal 2012) have defined water sufficiency, water stress, water scarcity, severe scarcity, annual water deficit as above (Figure 5). Here, the per capita availability of water is calculated using rainfall and the population data and this value define the level of water scarcity. Such categorizations do not reflect the creation of the scarcity for the communities and mislead the creation of policies. Hence, there is a need to recognize the physical aspect of water availability and identify discrepancies and also to understand scarcity in a larger context to determine how the physical availability of water gets translated into accessibility for the dependent communities.

Manifestation of water scarcity in the mountain towns is unique due to their biophysical and social characteristics such as the topography of the mountains, nature of springs supply, pattern of urbanization and seasonal water demand.

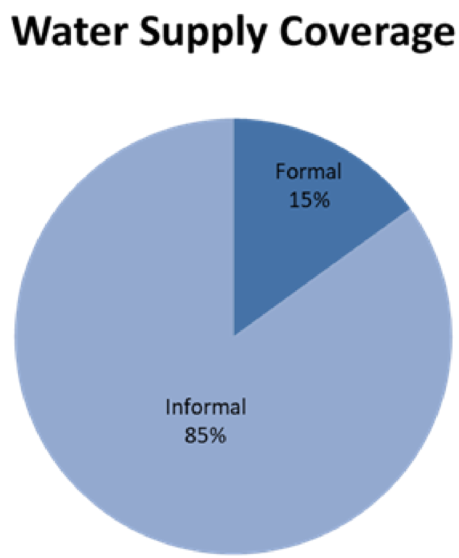


Figure 7. Water Coverage by Darjeeling Municipality

Darjeeling Town receives its water supplies from the municipal supply (public taps and private connections), springs and private suppliers. There are many kinds of private suppliers like tankers, hand-drawn carts, and water porters. The number of households covered by the Darjeeling Municipality Water Works Department is only 15%, the rest of the 85% households and also some from the 15% receive water from non-municipal sources.

Within Darjeeling town, there are around 90 springs under different property regimes. This means that some springs are public where everyone can access. There are some private springs where landowning households do not allow access to everyone and even sell it to other households. In addition to the larger water tankers of 6000 litres there are smaller “pick-up” trucks (2000 litres) for water supply too. There are a large number of households that have self-drawn lines (PVC pipes) in the Gandhi Road region where the pipes are drawn directly from the water sources or from the private suppliers. The Jalapahar Cantonment supplies water at a fee to the residents living around it. The tankers (6000 litres) and smaller trucks (2000 litres) get their water from sources which lie outside the municipality boundaries. These sources have temporary water storage and supply units. A fee is imposed on the water tankers if they fill water at certain sources and it is a recent phenomenon. The duration it takes to fill a 6000 litres tanker is 7 mins during monsoons or if the storage is full otherwise it takes 1-1.5 hours. This water selling business is for 4 months of the year. The tankers trucks without inbuilt compartments transport other materials during the rest of the year. These tankers mainly supply to public, hotels, and police.

Since the coverage of the municipality is very low it is important to look at the other sources where the 85% of the households in Darjeeling receive their water from.

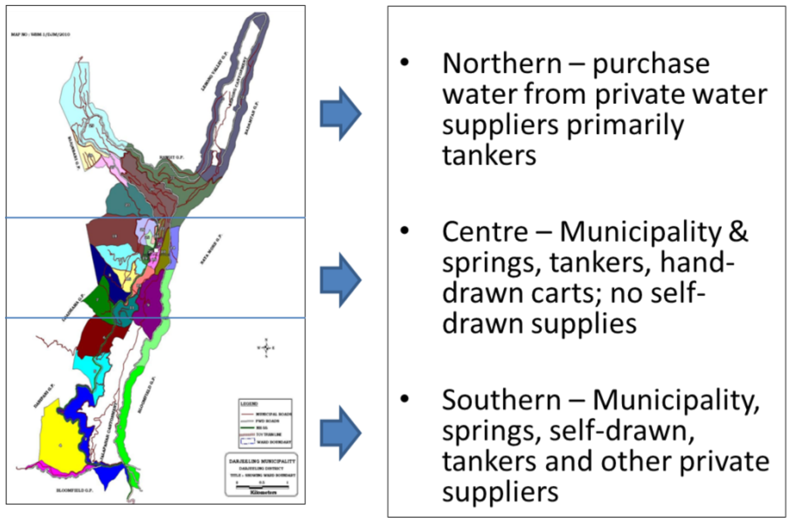


Figure 8. Clusters of water access within Darjeeling town

The communities residing in the northern cluster purchase water from private water suppliers primarily tankers and some springs. This region has a low presence of municipality sources. Most households depend on tanker water throughout the year. The ones residing around the town centre depend on municipality supplies & a few springs, tankers, and hand-drawn carts. This region is said to face the most water scarcity since they do not have sources to draw supply from like the southern part of the town. The southern part has a mix of municipality supplies, springs, self-drawn supplies, tankers and other private suppliers. The communities take supply from the tankers only when they do not have supplies from other sources.

The paper titled 'Examining Water Accessibility in Urban Mountain Towns of the Eastern Himalayan Region' macro data analysis of the NSSO 69th Round Survey for Darjeeling district is done to understand the domestic water issues. Some of the results are mentioned here. 26.3% of the sampled households used public tap/standpipe as the principal source of water followed by unprotected wells (24.8%) and tube wells and boreholes (14.2%). 95.3% of the surveyed households were found to have sufficient water throughout the year. However, this is quite contrary to what various studies and my surveys have shown. Water insufficiency is faced by the communities mostly in the months of April and May, followed by June, and January and February. The maximum travel time to and from the source of water is 30 minutes and the wait time at the source of water varies from 1 to 60 minutes. Around 88.1% of the surveyed households agree that there is no defect in the quality of water. All the indications from NSSO results show absence of issues pertaining to water supply, yet the literature hints at existing issues. This discrepancy was investigated by looking at the sampling methods employed by NSSO which is driven by population densities.

Table 3. Subdivisions of Darjeeling District (2005)

Name of the sub-division	Area in sq.km	Population
Darjeeling Sadar	921.68	429381
Kalimpong	1053.12	251642
Kurseong	503.03	194680

Siliguri	802.01	971120
Total	3149*	1842034

**The total of the rural and urban area may not conform to the district area.* (Bureau of Applied Economics and Statistics, 2005)

As Siliguri subdivision has the largest population density the case of Darjeeling district is skewed towards Siliguri, a geographically different region with a higher population density. Since the sampling is biased, this gets reflected in the results as well. As the analysis shows the top three principal water sources being used are public tap/standpipe, unprotected wells, tube wells and boreholes. These public taps in Darjeeling town are close to non-existent. Well, tube wells and boreholes are a feature which is absent in the hill regions of Darjeeling because of its geography and high seismicity.

The manifestation of scarcity in this region is driven by multiple factors. Mountain towns are mostly located at high altitudes and have high urban population density. So on the one hand they have fewer water sources compared to the mid or low altitudinal sections of the mountainous regions. And on the other since these towns are the centres of administrative and financial functions with better facilities than all other mountainous settlements there is an in migration of people to avail these facilities. The population density is also affected by the floating population of tourists during peak seasons which is double and sometimes triple the fixed population. These towns face issues of water harnessing which is highly energy intensive. At the household level, one's spatial location which most times is determined by a household's socio-economic conditions affects access to resources. If a household does not have legal documents and approximately Rs.1 lakh rupees at one's disposal, they will not be able to get a municipal supply. The wait time to get a water connection ranges from anywhere between 6 months to 5 years. If a household is close to a spring, the members feel more secure as they can go and access it but there will be a wait time there. The spatial location differences were also discussed above (Figure 7). There is a low presence of formal water supply systems which could be due to the requirements to get a connection which most households are unable to acquire. Darjeeling is primarily dependent on monsoons which have to last through the rest of the year, with the decrease in winter rain and snow, the temporality of monsoons will be felt more.

The rainfall data analysis highlights some results especially regarding the winter rain which is an important source to create a buffer and bridge the non-rainfall months to the months when the rainfall starts.

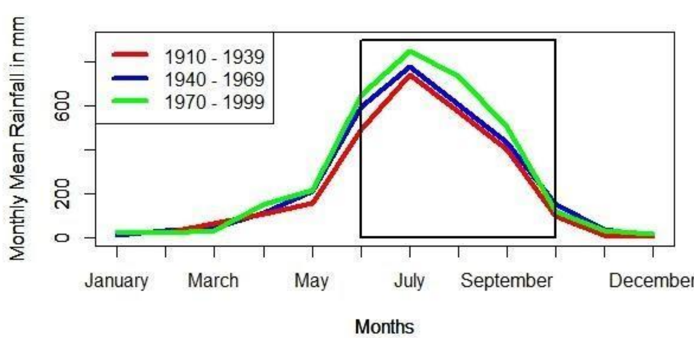


Figure 9. 30-year mean monthly rainfall (http://www.imd.gov.in/section/nhac/mean/Darjeeling.htm, Indian Meteorological Department, 2015)

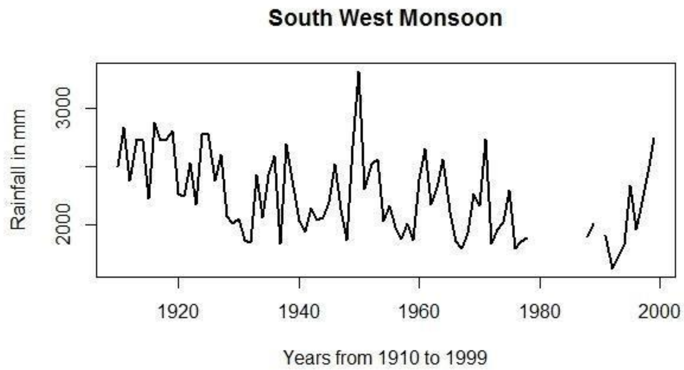


Figure 10. South-west (summer) monsoon trend for 100 years

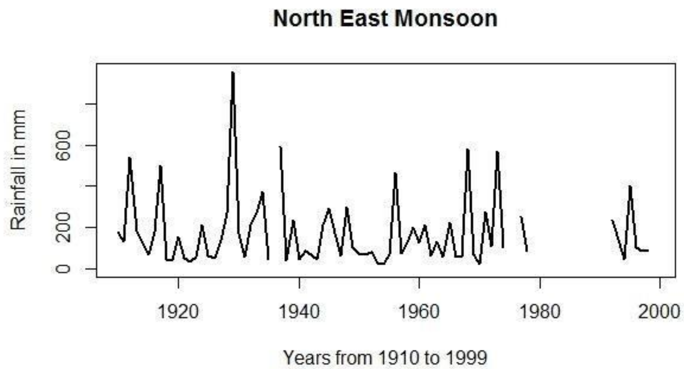


Figure 11. North-east (winter) monsoon trend for 100 years

The rainfall data analysis provides some important insights. Figure 8 shows three 30-year monthly mean rainfalls. There is an increase in the recent south-west monsoon. There is a slight decrease in the annual south-west monsoon across the long term analysis for the same duration – this does not include those years that had at least missing data for one month. The long term analysis done using IMD data for monsoon and winter precipitation showed a negative trend for both but it wasn't very significant. The two analyses in conjunction do not show any significant change in the availability for the south-west monsoon but the existence of an increased erratic pattern. From the analyses done so far availability of water is quite good for the region. However, there might be issues with long term availability as the non-monsoon indicators are not good. In the work done by Barua, et al. (2012) of similar geography, in Namthang Block of South Sikkim, most of the respondents remarked about the changing rainfall pattern which has led to reduced recharge of aquifers resulting in the drying up of springs. Thus, cause difficulties in access compelling people to travel longer distances (2 to 3 km) to collect water. Extrapolating this for our study area, there seems to be a dire need for storage infrastructure.

To understand the interplay of population, demand and supply on a month wise scale, the analysis was done in R. The following plot was arrived at (Figure 11).

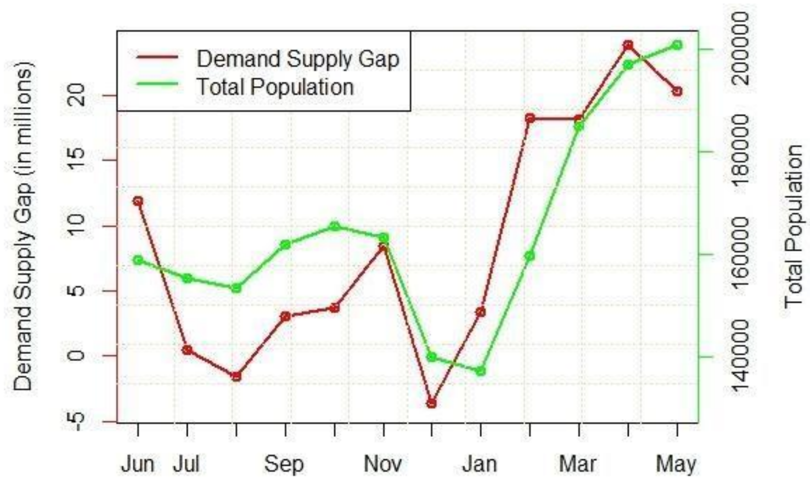


Figure 12. Demand and Supply Gap. Demand considering only the Municipality supply

The analysis has been done for the duration starting June to May. The plot presents a demand-supply gap on the left axis and total population on the right axis from June to May. The demand supply gap is subtracting the total demand of the population (fixed and floating) from the total supply available. The supply is not able to fulfil demands in any month except August and December. The phenomenon observed in August is because it is one of the months with the highest monsoon rainfall but the same observation cannot be applied to the month of December as it is one of the months with the lowest rainfall. However, for the present time scale December is the month with the second highest supply. This question will be answered using the following argument.

Drawing from this observation, we can say that the demand-supply gap is driven by an externality which makes the supply more vulnerable. The next plot has a similar comparison, but between the floating population of the 12 months, their respective demands and the total supply available.

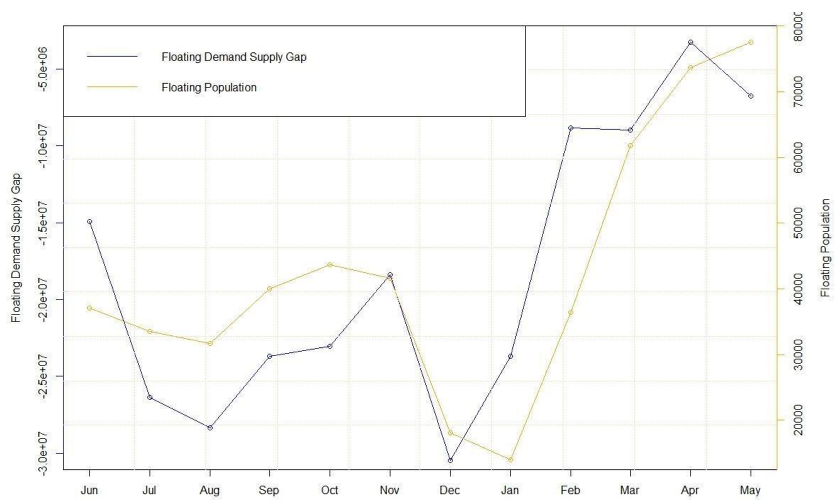


Figure 13. Floating demand supply gap versus floating population on a month-wise scale from June to May

The gap is persistent throughout the year but is widest in December and it is also the month where the floating population drops to half since November, which indicates that the supply is sufficient. The most demand from the floating population is during the months of February, March, April and May as these are the months with the lowest supplies and when the floating population in the form of students and tourists visit the place. There is evidence of the peaks in population, especially the floating population driving up the demand which puts forward the need for dealing with this artificial stress.

- Rainfall pattern shows no significant climate variability detected but the spread of rainfall shows an increase across months
- The NSSO data analysis doesn't provide a clear understanding of the granular scale at the sub-division or town level
- The primary disaggregated data that was lacking was collected this through topic-guided interviews and household questionnaires
- Existing demand supply gap is exacerbated due to the seasonal variation in rainfall and with the increase in the floating population (students, tourists, seasonal migration)
- Every household creates a water bundle for household and commercial purposes using a combination of the resources below -
    - Formal water systems – private individual, public taps
    - Springs – 60% of rural and urban population depend on them
    - "Private" suppliers
        - Tankers (6000 litres)
        - Water trucks (2000 litres)
        - Hand drawn carts
        - Water porters
        - Private springs
        - Cantonment area
        - Water sellers
        - Water sharers
- Springs are the main source for all state and non-state supplies. They do not come under the ambit of any state agency. Springs are always managed by villages through self-help groups which could have arisen due to the absence/negligence of state agencies. Some springs are also private in nature. The mapping of urban springs has begun in recent times and we have also been successful in creating a repository. The perennial springs are famous and a large population are dependent on them
- Since Darjeeling Hill Region falls under Gorkha Territorial Administration, an autonomous hill council so there are two PHEs in the region called State PHE and GTA PHE under the Government of West Bengal and Gorkha Territorial Administration (GTA) respectively.

1 OVERALL ACHIEVEMENTS

The objectives for this study are as follows -

- To understand the causes and effects of the domestic water scarcity in the eastern Himalayan towns.
- The causes entail the biophysical and human induced changes in and around the water sources as well as the region to which the water is supplied and the extent of water utilization.
- The effects will be assessed in terms of the availability and accessibility of water and the definition of well-being and sufficiency for the communities.
- The political and economic drivers for the manifestation of scarcity will be investigated.

Addressed deliverables

- Long term and 30-year rainfall trends were analysed.
- An understanding of the institutional structure and economics of Darjeeling and Gangtok which provides safe drinking water.
- A review of literature is in place and a PhD research proposal was written and research designed for carrying out the field studies was reviewed at the institute and the University.
- Macro analysis of NSSO data was done.
- A study of the sources making up the water bundle of households other than those under the ambit of the formal institutions and the clusters of access type identified.
- Interviews with key informants, transect walks with mapping of springs and public utilities, exploratory survey of water usage has been done.
- An insight into the possibility of using the spring water to address the water sufficiency issue.
- Demand supply gap of a fixed and floating population was done.

- All these observations point to the kind of choices the formal institutions can make – whether to forward with brand new augmentation sources or study the existing system and refurbish it.
- The creation of a data repository of the water sources for the region.
- Articles for journals as well as popular articles.
- Springs and tanker sources located and information gathered and the water institutions identified.
- Household interviews were carried out in both Darjeeling and Gangtok.
- The information of springs and various other water sources were collated. Household level surveys regarding domestic water usage were done.

d. 5 IMPACTS OF FELLOWSHIP IN IHR

I had the opportunity of being a part of many lectures to school and college students. Additionally, I was a part of I attended a Multi-Stakeholder Dialogue on Improving Tea Productivity, Addressing Land Degradation, and Driving Sustainable in Darjeeling hosted by ATREE, UNEP, GEF under UNEP, and Rainforest Alliance in Darjeeling. I also assisted in the Himalaya Clean-Up in Darjeeling and the Environment Day Event at Darjeeling Government College. I was invited to be a part of the World Water Day celebration at Little Rangit English School where I addressed the school on the scarcity of water and the need for our involvement. I trained students to take household surveys which would be a part of their Environmental Studies project. I designed, facilitated and taught a 7-day course Youth, Environment and Sustainability for 14-18 year old children (2nd – 8th June 2019) at Mahindra United World College (UWC) India (MUWCI).

Throughout my term of the fellowship, I have been fortunate to meet people from all walks of life and talk about water and the concerns surrounding it. I attended a workshop on Managing and Governing Resource in the “Anthropocene”: Political Ecological Explorations from South Asia at Indian Institute of Technology Kharagpur and presented at the 2nd Himalayan Researchers’ Consortium, National Mission on Himalayan Studies (NMHS), Gangtok, Sikkim, India. I also presented a paper “Ascertaining Access to Water Provisioning Systems in the Urban Mountain Town of Darjeeling, India” at Graduate Research Meet 2018, Emerging Trends in Humanities and Social Sciences at Department of Humanities and Social Sciences, Indian Institute of Technology Guwahati, and was part of the Authors Meet Critics 2018 organized by International Journal of Urban and Regional Research. I supervised a Masters intern from TERI University who worked on domestic water issues in Gangtok and she has submitted her thesis.

e. 6 EXIT STRATEGY AND SUSTAINABILITY

The findings of the fellowship throw light on the persistent problem of water scarcity at household level. Even in the case of climate change or not, water scarcity is a persistent issue. Hence the focus of sustainable development in the IHR needs to consider some chronic problems which have been there for decades together. Domestic water access is just one of the many problems, others include lack of sanitation, waste disposal, lack of physical space, educational opportunities, employment opportunities, haphazard construction and many others. All such problems need to be understood from a systemic perspective before we align their causation with for example climate change.

Domestic water scarcity is a problem across IHR, and it gets severe where the settlements are more urbanized. Hence when sustainable urban development is being considered for such regions, the uniqueness of urbanization in the landscape must be considered. The urban mountain towns are unlike the majority of the other towns in the lowlands and Great Plains of India. They have a unique pattern of urbanization, sometimes along a ridge in the case of Darjeeling, sometimes along the slope like Gangtok and many others. They have a large number of springs, which are now on the verge of being lost, exacerbating the water crisis further for such regions. The towns face a huge seasonal flux in population as they primarily depend on tourism for their economy. All these factors need to be considered whenever urban sustainable development of mountain cities is the agenda.

Since the government now has taken springs into consideration while looking at water issues in the mountain towns, the ways in which these springs are used should also be considered. In addition to the state supplies that harness these springs there are a plethora of water suppliers who harness them and supply water at exorbitant costs. The state agencies should also create a method where the poorest can also access the state systems through private connections. The situation in the mountain towns is similar to those across the world where the poor pay more per litre of water in terms of a proportion of their income or absolute income. The results from this fellowship and the methods can be replicated across "urban" IHR settlements. This would provide an interesting comparison across the length and breadth of the India Himalaya. Additionally, similar studies can also be done across the rural-urban spectrum to see the gravity of water issues in mountain regions.

One important aspect that could not be covered was the pollution aspect. This would help address if there are any pollution related issues with the water the communities receive. Most springs that the communities use are adjacent to natural drainage bodies which are now used as drains and dumping sites. Majority of the communities are of the view that the spring water is pure and clean but they have not been tested yet. Another aspect is the property regimes around springs and how they have been created around springs.

There should be provision where the fellowship outcomes could be brought back to the communities. Since the outcomes of the fellowship is directly related to ongoing issues in the region, it would be beneficial if the fellows were enabled by the fellowship providers to bring this to the attention of the authorities and the various state agencies involved.

f. 7 REFERENCES/BIBLIOGRAPHY

Anand, P. B. 2004. "The Political Economy of Water Scarcity and Issues of Inequality, Entitlements and Identities: A Tale of Two Cases from Southern India." *International Journal of Technology Management and Sustainable Development* 3 (2): 115–32. https://doi.org/10.1386/ijtm.3.2.115/0.

Bandyopadhyay, Jayanta. 1989. "Riskful Confusion of Drought and Man-Induced Water Scarcity." *Ambio* 18 (5): 284–92.

Bureau of Applied Economics and Statistics. (2005). *District Statistical Handbook, 2004, Darjeeling.* Kolkata: Government of West Bengal.

Chhetri, Bishal, and Lakpa Tamang. 2013. "Population Growth and Associated Problems : A Case Study Of Darjeeling Town." *International Journal of Humanities and Social Science Invention* 2 (5): 63–67.

Drew, Georgina, and Roshan P. Rai. 2016. "Water Management in Post-Colonial Darjeeling: The Promise and Limits of Decentralised Resource Provision." *Asian Studies Review* 40 (3): 321–39. https://doi.org/10.1080/10357823.2016.1192580.

Falkenmark, Malin, and Jan Lundqvist. 1998. "Towards Water Security: Political Determination and Human Adaptation Crucial." *Natural Resources Forum* 22 (1): 37–51. https://doi.org/10.1111/j.1477-8947.1998.tb00708.x.

Government of West Bengal. 2012. "West Bengal State Action Plan on Climate Change."

Hoekstra, Arjen Y, and Mesfin Mekonnen. 2012. "The Water Footprint of Food." *Proceedings of the National Academy of Sciences* 109 (9): 3232–37. https://doi.org/10.1016/B978-0-12-799968-5.00007-5.

Khawas, Vimal. 2002. "Environment and Rural Development in Darjeeling Himalaya: Issues and Concern." Ahmedabad.

Lepcha, Neelee K C. 2013. "Problems And Prospects Of Water Resource Of Kurseong Municipality , Darjeeling District , West Bengal." *Science Park Research Journal* 1 (19): 1–11.

Madan, Sapna, and Laxmi Rawat. 2000. “The Impacts of Tourism on the Environment of Mussoorie, Garhwal Himalaya, India.” *The Environmentalist*, 249–55.

Mehta, Lyla. 2006. “Water and Human Development: Capabilities, Entitlements and Power.” New York: United Nations Development Programme.

Mell, Ian C., and John Sturzaker. 2014. “Sustainable Urban Development in Tightly Constrained Areas: A Case Study of Darjeeling, India.” *International Journal of Urban Sustainable Development* 6 (1): 65–88. https://doi.org/10.1080/19463138.2014.883994.

Rasaily, D.S. 2014. *Darjeeling Pahadka Nagarpalika Kshetra Ko Vikas Ra Khane Paani Ko Itihaas Sanchipta Ma, San. 1835-2012*. New Delhi.

Seckler, David, David Molden, and Randolph Barker. 1999. “Water Scarcity in the Twenty-First Century.”

Verma, Anil K, and Raheela Mushtaq. 2013. “Landslides: An Environmental Hazard in the Pir-Panjal Himalayan Range in Poonch District of J&K State, India.” *Indian Journal of Scientific Research* 4 (1): 143–48.

Ziervogel, G., Johnston, P., Matthew, M., & Mukheibir, P. (2012). Using Climate Information for Supporting Climate Change Adaptation in Water Resource Management in South Africa. *Climatic Change*, 537-554.

g. 8 ACKNOWLEDGEMENTS

I am thankful for the institutional support provided by the Ashoka Trust for Research in Ecology and the Environment, and by the Manipal Academy of Higher Education (formerly, Manipal University), and for the financial support provided by the Government of India’s National Mission on Himalayan Studies Grant. I am also grateful to the many respondents in the Darjeeling region who provided valuable time and insights. The first author thanks her faculty at Tata Institute of Social Sciences who guided her masters’ dissertation which laid groundwork for this study.

Fellowship Report No.: 10 of 10

Type of Fellowship (HRA/HJRF/ HJPF)	Name of Himalayan Researcher	Date of Joining	Date of Resignation**	Research Title	Name of the PI & Designation
HJPF	Urbashi Pradhan	April 1, 2016	July 31, 2019	Fragmented Landscape and Biodiversity: A study of pollinators and dispersers outside protected area network in Sikkim	Dr. M Soubadra Devy, Senior Fellow

24. Urbashi Pradhan

1 INTRODUCTION

Landscape modifications for various human uses such as agricultural, industrial, human settlement and roads have dramatically altered the composition, structure and ecological characteristics of the environment (Laurance and Bierregaard 1997). These modifications leaves smaller and more isolated fragments of natural habitat which can be seen embedded in a growing sea of agriculture, pasture, managed forests, and urbanized areas[1](Laurance and Bierregaard 1997; Polasky et al. 2005). These smaller patches of forest may not support large charismatic animals, but some studies in tropics have showed that forest fragments support a good population of bees, butterflies, birds and small mammals and also provision ecosystem services like pollination, dispersal, clean air, water (Steffan-Dewenter and Tscharntke 2002a; Klein et al. 2003; Ricketts 2004; Ghazoul 2005)

In a study Bodin et al. (2006), demonstrated small habitat patches, well distributed over the landscape were found to be the best predictor for wild bee richness and also of great importance for the provisioning of pollination and seed dispersal services as well. In the same study, through application of a model they demonstrated the substantial decrease in the crop pollination on the removal of smallest forest patches. Studies have shown that the pollinators straddle the zone between fragments and farms/orchards and help in providing pollination service (Klein et al. 2003; Ricketts 2004; Bodin et al. 2006). Proximity to native habitat

[1] the process of breaking down of contiguous forest patch is termed as habitat fragmentation (Wilcove et.al.)

has been shown to increase the diversity and abundance of bees visiting target plant species in a wide range of geographic and ecological settings(Ricketts 2004; Kremen et al. 2007; Krishnan et al. 2012).

Boreux et al. (2013) explored the effect of habitat size on pollination service in the Indian setting. They studied the combined effect of distance from forest and its size on pollination service to *Coffea canephora* in Kodagu district of Karnataka in Southern India. Their study showed that the abundance of three dominant pollinators—*Apis dorsata, Apis cerana and Tetragonula iridipennis*—decreased with increasing distance from forest fragments in rain-fed plots. In the same study, Krishnan et al. (2012) demonstrated that cross pollination yielded highest fruit sets, thereby emphasizing the importance of pollination service from forest fragments to *C. canephora*. While the abundances of *A. dorsata* and *T. iridipennis* responded positively to size, it was negative in response to distance from forest fragments. However, the third pollinator species *A. cerana* did not respond to both area and distance.

Around the world, the conservation community is increasingly recognizing ecosystem services like pollination as natural capital assets that supply life-support services of tremendous value Daily and Matson (2008) not only to plants and animals but also to people. The fundamental challenge of natural resource management now is to understand the relationship between these goods and services and quality of natural habitats (Costanza et al. 1997; Daily and Matson 2008). These goods and services that we obtain from natural ecosystems can be a strong economic justification for the conservation of biological diversity (Daily and Matson 2008). Of many goods and services that we obtain from nature, pollination provisioning is one which can be quantified. For instance, in a study carried out by Ricketts (2004), approximately $62,000 (U.S.) per year was calculated to be the value of pollination service provisioned by two tropical forests to one Costa Rican coffee farm.

There is evidence of the global and local decline of pollinators including wild species, which is becoming a threat to wild plants as well as economically important crops (Biesmeijer et al. 2006). Decline in pollinators has affected many communities directly linked to pollination service through reduced availability of food and other resources. Ghazoul (2005) also highlighted that the presence of natural/semi-natural areas around agricultural matrices can serve as insurance through flow of wild pollinators at times when managed pollination service fails. One of the major challenges of natural resource management now is to understand the relationship between the quality of these fragmented natural habitats and the goods and services provisioned by them (Haines-Young and Potschin 2010). The International Pollinators Initiative, established by the Fifth Conference of Parties to the Convention on Biological Diversity in 2000, declared an “urgent need to address the issue of worldwide decline of pollinator diversity”(Ghazoul 2005). Although the value of ecosystem services to sustain society is immense, their vulnerability to environmental change is still poorly understood (MEA 2005). Diminishment of favourable interaction such as pollination, seed dispersal in forest fragments may affect local dependent human communities through reduced availability of food and other resources(Steffan-Dewenter and Tscharntke 2002b). This paper will explore the *current distribution and status of pollinators and their food plant in fragment habitats outside the protected area network of Sikkim.* The main objective of the study is to understand the role of fragmented habitats outside protected areas in supporting biodiversity through higher order interaction such as pollination and to estimate major pollinator food plants in fragmented forest.

a. 2 METHODOLOGIES, STRATEGY AND APPROACH

Assessing the biodiversity of pollinators

Forest fragments situated between 700 – 1500 amsl were surveyed and a random sampling method was used to capture pollinators visiting flowering plants. Insects which were seen collecting/feeding on nectar with pollen load on their body were considered as pollinators and collected in plastic bags (70% ethanol) for taxonomic identification in the laboratory.

Vegetation sampling

Vegetation sampling was carried out with an aim to assess the status of food plants of bees. Nine forest fragments which were visited by people for their daily requirements were selected covering an altitudinal gradient of 700-1500 m above msl from East, West and South districts in Sikkim. Ten plots of 10 m × 10 m dimension were laid in each of the selected forest fragments at an interval of 100 m. In total, 90 plots were selected across the study area. Diameter at Breast Height (DBH) of all trees with more than 10 cm was enumerated. Information on the bee food plants from the area was collated from farmers' interviews and literature.

Assessment of perception and knowledge

A questionnaire survey is being carried out to assess the perception of people on pollinators in the landscape and the role of forest fragments in supporting pollinators.

b. 3 KEY FINDINGS AND RESULTS

Vegetation structure in forest fragments

A total of 671 individuals representing 48 tree species were recorded in 90 plots across nine sites. *Schima wallichii* (42%), *Alnus nepalensis*(8.49%) were the dominant plant species in the fragments outside PAs. Species such as *Castanopsis indica, Macaranga pustulata, Ostodes paniculata, Terminalia myriocarpa* and *Exbucklandia populnea* were constituted 3-5%. *Albizia lebbeck, Acer cambelli* and *Erythrina indica* (1.49%) were even sparser with 10 to 35 individuals which occurred in 8 to 21 plots. List of pollinator food plants present in the fragmented forest of Sikkim between 700-1500 masl are listed below (Table 1). A total of 45 species belonging to 26 different families were recorded in the vegetation plots spread across the southern part of Sikkim. Shannon's diversity index(SDI- Figure 1) for vegetation plot was highest in Kokaley plot with SDI value of 1.04 followed by Suntaley(SDI 0.92) and Najitam(0.80) and lowest was in Pachek plot (SDI 0.66) with marginally higher in Tirikhola(SDI 0.67) and Kabirthang(SDI 0.72). Figure 2 represents the species richness in each plot. Pendam has the highest species richness of 20 followed by Suntaley(17) while Kokaley and Zoom has 16 species each. Amongst all Kabirthang has the lowest richness of species(9) in the plot, followed by Pachek(10), Rumbuk, Najitam which has 11 species each and Tirikhola which has 15 species recorded in the vegetation plot.

Table 2: Pollinator food plant of Sikkim

Sl. No.	Scientific name	Family
1	Acer cambelli	Sapindaceae
2	Acer oblongum	Sapindaceae
3	Alangium begoniaelifolium	Alangiaceae
4	Albizza lebbeck	Leguminosae
5	Albizza procera	Leguminosae
6	Alnus nepalensis	Betulaceae
7	Bauhinia purpurea	Caesalpiniaceae
8	Bischofia javanica Bl.	Euphorbiaceae
9	Bombax ceiba	Malvaceae
10	Brassatopsis mitis	Araliaceae
11	Callicarpa arborea	Verbenaceae
12	Callicarpa arborea	Verbenaceae
13	Castanopsis hystrix	Fagaceae
14	Castanopsis indica	Fagaceae
15	Castanopsis tribuloides	Fagaceae
16	Choerospondias axillaris	Anacardiaceae
17	Ecbucklandia populnea	Hamamelidaceae
18	Engelhardtia spicata	Juglandaceae
19	Erythrina indica	Leguminosae
20	Eucalyptus sp	Myrtaceae
21	Eurya acuminate	Theaceae
22	Ficus bengalensis	Moraceae
23	Ficus hispida	Moraceae
24	Ficus hookeri	Moraceae
25	Glochidion spp	Phyllanthaceae
26	Gynocordia odorata	Flacourtiaceae

27	Hovenia dulcis	Rhamnaceae
28	Juglans regia	Juglandaceae
29	Litsaea polyantha	Lauraceae
30	Macaranga denticulata	Euphorbiaceae
31	Macaranga pustulata	Euphorbiaceae
32	Maesa Cheria	Myrsinaceae
33	Michelia lanuginose	Magnoliaceae
34	Morus laevigata	Moraceae
35	Ostodes paniculatus	Euphorbiaceae
36	Prunus cerasoides/ p. ellipticus	Rosaceae
37	Pyrus pashia	Rosaceae
38	Rhododendron sp	Ericaceae
39	Rhus semialata/R. chinensis	Anacardiaceae
40	Rhus succedanea	Anacardiaceae
41	Schima wallichii	Theaceae
42	Syzygium cumini	Theaceae
43	Terminalia chebula	Combretaceae
44	Terminalia myriocarpa	Combretaceae
45	Viburnum cordifolium	Caprifoliaceae

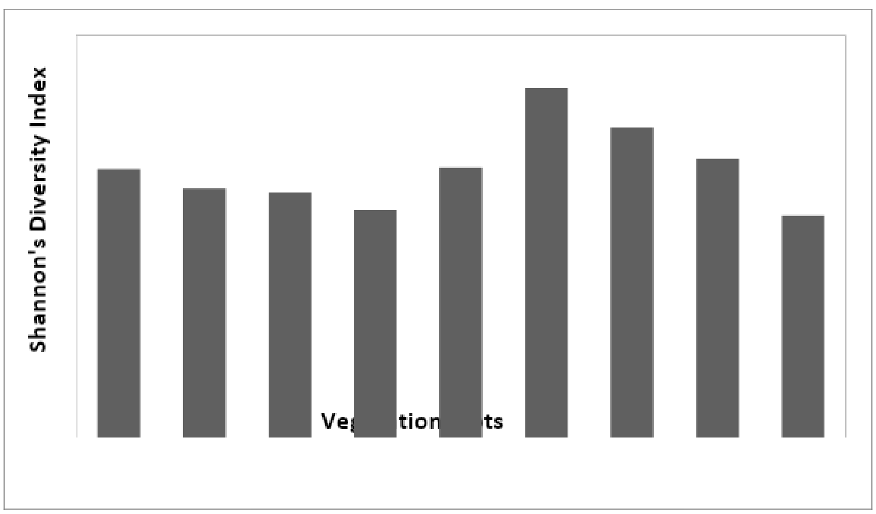


Figure 1: Shannon's Diversity index across vegetation plots.

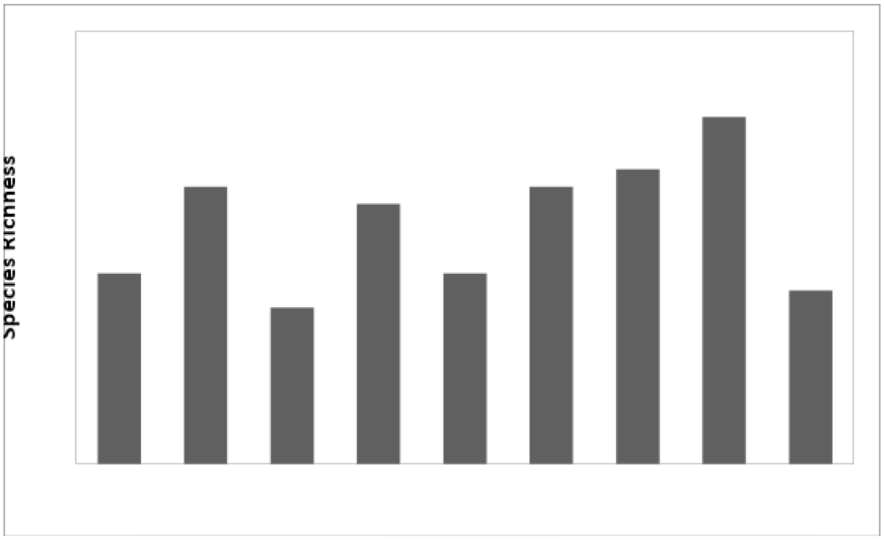


Figure 2: Species richness across vegetation plots

Pollinator diversity

Insect sampling results highlighted 25 species of insects belonging to four classes Hymenoptera, Diptera, Hemiptera and Coleoptera were collected and identified in the laboratory(Table 1).

Table 1. List of pollinators

Pollinators			
sl no	**Order**	**Family**	**Species**
1	Coleoptera	Scarabaeidae	*Anomola* sp.
2	Coleoptera	Chrysomelidae	*Chrysonopa* sp.
3	Coleoptera	Scarabaeidae	*Clinteria* sp.
4	Coleoptera	Chrysomelidae	Galerucinae
5	Coleoptera	Coccinellidae	*Oenopia kirbyi* Mulsant
6	Coleoptera	Cantharidae	Unidentified
7	Diptera	Sarcophagidae	*Wohlfartia* sp.

8	Diptera	Calliphoridae	*Chrysomya* sp.
9	Diptera	Syrphidae	*Episyrphus* sp.
10	Diptera	Syrphidae	*Eristalinus taeniops* (Wiedemann)
11	Diptera	Syrphidae	*Eristalis tenax* (Linnaeus)
12	Diptera	Syrphidae	*Eupeodes confrater* (Wiedemann)
13	Diptera	Syrphidae	*Ischiodon scutellaris* (Fabricius)
14	Diptera	Syrphidae	*Melanostoma* sp.
15	Diptera	Rhiniidae	*Rhinia* sp.
16	Diptera	Syrphidae	*Scaeva pyrastri* (Linnaeus)
17	Diptera	Syrphidae	episyrphus viridaureus
18	Diptera	Syrphidae	*Eristalis* sp.nr. *basifemorata* Brunetti
19	Hemiptera	Lygaeidae	*Graptostethus incertus* (Walker)
20	Hemiptera	Largidae	*Physopelta gutta gutta* (Burmeister)
21	Hemiptera	Lygaeidae	*Spilostethus pandurus* (Scopoli)
22	Hymenoptera	Apidae	*Apis cerana*
23	Hymenoptera	Halictidae	*Lasioglossum sp*
24	Hymenoptera	Scoliidae	Phalarimeris
25	Hymenoptera	Halictidae	*Seladonia sp*

Farmers' perception of pollinator, pollination service forest conservation

Results of interviews with 80 farmers highlighted that they identify common honey bees as pollinators but do not have much idea about pollination service. Pollinators other than honey bees such as flies were not acknowledged much by the local community. However, farmers felt that the abundance and diversity of bees and other insects have decreased in the landscape. A comprehensive list of pollinator food plants was prepared which was used as a baseline to carry vegetation sampling later. Farmers acknowledged the importance of fragmented forest in sustaining the bee/pollinator population in the landscape and were willing to participate for its conservation.

c. 4 OVERALL ACHIEVEMENTS

- List of pollinators of Sikkim mandarin orange published.
- List of pollinator food plants in the fragmented forest.
- Perception of local community on pollinator diversity, pollination service, threat to pollinators and farmers willingness to conserve forest which sustain pollinators.

25.

a. 5 IMPACTS OF FELLOWSHIP IN IHR

The contribution of pollinators in sustaining socio-economic wellbeing of the human race cannot be ruled out. However, our knowledge about pollinators in IHR is very limited. Specifically, Sikkim has witnessed a drastic decline in the production of large cardamom, the major cash crop of Sikkim due to decline of its pollinators (*Bombus haemmoraoidalis*) along with pests and diseases. Yet we know very little about the pollinators across Sikkim. Information on pollinators, their food plants and people’s perception on pollinators with NMHS fellowship will act as an important baseline for the future research.

b. 6 EXIT STRATEGY AND SUSTAINABILITY

Understanding of pollinators and their requirements will help not only scientific audiences but also agriculture/horticulture/floriculture departments along with farmers to enhance yield of cash crops in Sikkim and IHR area. Similar studies should be encouraged in other parts of IHR to better understand pollinators specific to certain areas.

c. REFERENCES/BIBLIOGRAPHY

Acharya BK, Vijayan L. 2015. Butterfly diversity along the elevation gradient of Eastern Himalaya, India. Ecol Res. 30(5):909–919.

Biesmeijer JC, Roberts SPM, Reemer M, Ohlemüller R, Edwards M, Peeters T, Schaffers AP, Potts SG, Kleukers R, Thomas CD, et al. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science. 313(5785):351–354.

Bodin Ö, Tengö M, Norman A, Lundberg J, Elmqvist T. 2006. The Value Of Small Size: Loss Of Forest Patches And Ecological Thresholds In Southern Madagascar. Ecol Appl. 16(2):440–451. doi:10.1890/1051-0761(2006)016[0440:TVOSSL]2.0.CO;2.

Boreux V, Krishnan S, Cheppudira KG, Ghazoul J. 2013. Impact of forest fragments on bee visits and fruit set in rain-fed and irrigated coffee agro-forests. Agric Ecosyst Environ. 172:42–48.

Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'neill RV, Paruelo J. 1997. The value of the world's ecosystem services and natural capital. nature. 387(6630):253–260.

Daily GC, Matson PA. 2008. Ecosystem services: From theory to implementation. Proc Natl Acad Sci. 105(28):9455–9456.

Garibaldi LA, Steffan-Dewenter I, Winfree R, Aizen MA, Bommarco R, Cunningham SA, Kremen C, Carvalheiro LG, Harder LD, Afik O, et al. 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science. 339(6127):1608–1611.

Ghazoul J. 2005. Buzziness as usual? Questioning the global pollination crisis. Trends Ecol Evol. 20(7):367–373.

Haines-Young R, Potschin M. 2010. The links between biodiversity, ecosystem services and human well-being. Ecosyst Ecol New Synth.:110–139.

Hazra N, Saha GK, Chaudhuri PK. 2002. Records of Orthoclad species from the Darjeeling–Sikkim Himalayas of India (Diptera: Chironomidae), with notes on their ecology. Hydrobiologia. 474(1–3):41–55.

Keitt TH, Urban DL, Milne BT. 1997. Detecting critical scales in fragmented landscapes. Conserv Ecol. 1(1).

Klein A-M, Steffan-Dewenter I, Tscharntke T. 2003. Bee pollination and fruit set of Coffea arabica and C. canephora (Rubiaceae). Am J Bot. 90(1):153–157.

Kremen C, Williams NM, Aizen MA, Gemmill-Herren B, LeBuhn G, Minckley R, Packer L, Potts SG, Roulston T, Steffan-Dewenter I. 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecol Lett. 10(4):299–314.

Krishnan S, Kushalappa CG, Shaanker RU, Ghazoul J. 2012. Status of pollinators and their efficiency in coffee fruit set in a fragmented landscape mosaic in South India. Basic Appl Ecol. 13(3):277–285.

Kumar A, Gupta JP. 1990. Four new species of Drosophilidae (Diptera: Insecta) from Sikkim, India. Proc Zool Soc Calcutta. 43:25–30.

Laurance WF, Bierregaard RO. 1997. Tropical forest remnants: ecology, management, and conservation of fragmented communities. University of Chicago Press. [accessed 2015 Sep 24]. https://books.google.co.in/books?hl=en&lr=&id=mJSZNQrO8PoC&oi=fnd&pg=PR9&dq=laurance+tropical+firest+remanant&ots=qjBKvP8Klw&sig=Pb2jpQzlBXooqZ6_IyGGXPKSatM.

MEA. 2005. Millennium ecosystem assessment. Ecosyst Hum Wellbeing Framew Assess Wash DC Isl Press. [accessed 2017 Aug 1]. http://chapter.ser.org/europe/files/2012/08/Harris.pdf.

Polasky S, Nelson E, Lonsdorf E, Fackler P, Starfield A. 2005. Conserving species in a working landscape: land use with biological and economic objectives. Ecol Appl. 15(4):1387–1401.

Ricketts TH. 2004. Tropical forest fragments enhance pollinator activity in nearby coffee crops. Conserv Biol. 18(5):1262–1271.

Salles J-M. 2011. Valuing biodiversity and ecosystem services: Why put economic values on Nature? C R Biol. 334(5):469–482.

Steffan-Dewenter I, Tscharntke T. 2002a. Insect communities and biotic interactions on fragmented calcareous grasslands—a mini review. Biol Conserv. 104(3):275–284.

Steffan-Dewenter I, Tscharntke T. 2002b. Insect communities and biotic interactions on fragmented calcareous grasslands—a mini review. Biol Conserv. 104(3):275–284.

d. 8 ACKNOWLEDGEMENTS

I would like to thank Dr Soubadra Devy M who guided me throughout this project. I would like to thank Dr Belavadi, Dr Yashwanth and Dr Arathi at GKVK, Bangalore and Dr Kumar Ghorpade, at University of Agricultural Science, Dharwad for helping us identify our pollinator samples. We would like to thank the Forest Department officials, PCCF Mr S.T.Lachungpa and PCCF Dr Thomas Chandy, Mrs Usha Lachungpa (Ex- Scientific officer) for giving the necessary permission to work in Sikkim. I would like to thank National Mission on Himalayan Studies(NMHS), The Ministry of Environment, Forest & Climate Change (MoEF&CC)-—who generously funded this research.

NMHS FELLOWSHIP COORDINATOR
(Signed and Stamped)

Place:
Date:

HEAD OF THE INSTITUTION
(Signed and Stamped)

Annexure-II

Consolidated Interest Earned Certificate

Please provide the detailed interest earned certificate on the letterhead of the grantee/ Institution and duly signed.

Annexure-IV

Details and Declaration of Refund of Any Unspent Balance

Please provide the details of refund of any unspent balance and transfer the balance amount through RTGS (Real-Time Gross System) in favor of **NMHS GIA General** and declaration on the official letterhead duly signed by the Head of the Institution.

Kindly note the further Bank A/c Details as follows:

Name of NMHS A/c:	NMHS GIA General
Bank Name & Branch:	Central Bank of India (CBI), Kosi Bazar, Almora, Uttarakhand 263643
IFSC Code:	CBIN0281528
Account No.:	3530505520 (Saving A/c)

In case of any queries/ clarifications, please contact the NMHS-PMU at e-mail: nmhspmu2016@gmail.com e.

f. # Technology Transfer and/ or Intellectual Property Rights Certificate

With a view to encourage the institutions to file patent applications on their innovations, motivate them to transfer their technologies for commercialization, and facilitate them to reward their inventions, the following instructions are issued.

1. In these instructions:

(a) **"Institution"** means any technical, scientific or academic establishment where research work is carried out through funding by the Central / State Government.

(b) **"Intellectual Property Rights"** include patents, registered designs, copyrights and layout design of integrated circuits.

(c) **"Inventor"** means an employee of the institution whose duties involve carrying out of scientific or technical research.

2. Scope: These instructions apply to those institutions receiving funds for research projects/ fellowships from NMHS, the Ministry of Environment, Forest and Climate Change (MoEF&CC).

3. Inventions by institutions: Institutions shall be encouraged to seek protection of Intellectual Property Rights (IPR) to the results of research through R&D projects/ fellowships. While the patent may be taken in the name(s) of inventor(s), the institutions shall ensure that the patent is assigned to it & DBT, GOI. The institution shall take necessary steps for commercial exploitation of the patent on non-exclusive basis. The institution is permitted to retain the benefits and earnings arising out of the IPR. However, the institution may determine the share of the inventor(s) and other persons from such actual earnings. Such share(s) shall be limited to 1/3rd of the actual earnings.

4. Inventions by institutions and industrial concerns: IPR generated through joint research by institution(s) and industrial concern(s) through joint efforts can be owned jointly by them as may be mutually agreed to by them and accepted by the Department through a written agreement. The institution and industrial concern may transfer the technology to a third party for commercialization on exclusive/non-exclusive basis. The third party, exclusively licensed to market the innovation in India, must manufacture the product in India. The joint owners may share the benefits and earnings arising out of commercial exploitation of the IPR. The institution may determine the share of the inventor(s) and other persons from such actual earnings. Such share(s) shall not exceed 1/3rd of the actual earnings.

5. Patent Facilitating Fund: The institution shall set apart not less than 25 per cent of such earnings for crediting into a fund called Patent Facilitating Fund. This Fund shall be utilized by the institution for updating the innovation, for filing new patent applications, protecting their rights against infringements, for creating awareness and building competency on IPR and related issues.

6. Information: The institutions shall submit information relating to the details of the patents obtained, the benefits and earnings arising out of IPR and the turnover of the products periodically to the Department/Ministry, which has provided funds.

7. Royalty-free license: The Government shall have a royalty-free license for the use of the intellectual property for the purposes of the Government of India.

(HEAD OF THE INSTITUTION)
(Signed and Stamped)