

*Landscape-level Assessment of Select Group of Pollinators and Factors
Influencing their Diversity and Distribution in Kullu Valley, Himachal Pradesh*

THESIS
SUBMITTED TO THE
FOREST RESEARCH INSTITUTE DEEMED to be UNIVERSITY
DEHRADUN, UTTARAKHAND

For
THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY IN FORESTRY
(Wildlife Science)



by
Susmita Khan

Under the Supervision of

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2024

“If all mankind were to disappear, the world would regenerate back to the rich state of equilibrium that existed ten thousand years ago. If insects were to vanish, the environment would collapse into chaos.”

– E. O. Wilson.

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सेवा में,

सुश्री सुसिमता खान,
द्वारा डॉ. बितापी सी. सिन्हा,
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विषय: वानिकी में डॉक्टर ऑफ फिलॉसफी डिग्री के लिए पंजीकरण।

प्रिय महोदया,

आपको अवगत करना है कि इस संस्थान में वानिकी में डॉक्टर ऑफ फिलॉसफी की डिग्री के लिए शोध छात्र (रिसर्च स्कॉलर) के रूप में आपके नामांकन हेतु निम्नलिखित निर्णय लिए गए हैं:


1. आपको डॉक्टर ऑफ फिलॉसफी के लिए दिनांक 01.03.2020 से 31.08.2025 तक पीएचडी शोध छात्र के रूप में पंजीकृत किया गया है।
2. आपका नामांकन संख्या है : **19PHD586**
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4. वन अनुसंधान संस्थान सम विश्वविद्यालय द्वारा स्वीकृत विषय "Landscape-level assessment of select group of pollinators and factors influencing their diversity and distribution in Kullu valley, Himachal Pradesh."
5. शाखा का नाम: **Wildlife Science**
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6. (i) पर्यवेक्षक का नाम: **Dr. Bitapi C. Sinha**
(ii) सह पर्यवेक्षक का नाम: **Dr. V.P. Uniyal**
Dr. K. Ramesh
7. आपको निम्न शुल्क जमा करने की सलाह दी जाती है:-
 - (अ) प्रयोगशाला शुल्क की अगली किस्त संबंधित एफआरआई सम विश्वविद्यालय/अनुसंधान केंद्र पर बैंक ड्राफ्ट के जरिए देय है।
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 - (इ) शोधप्रबंध जमा करने तक प्रत्येक वर्ष के लिए एफआरआई सम विश्वविद्यालय में पंजीकरण अवधि दौरान मार्च महीने में देय वार्षिक शुल्क देय होगा।
 - (ई) उपरोक्त शुल्क नियत महीने के दौरान अर्थात् प्रत्येक वर्ष मार्च माह में इस कार्यालय में जमा करना होगा अन्यथा विलंब होने पर रु. 1000/- (बैंक ड्राफ्ट) विलंब शुल्क भी जमा करना होगा।
 - (उ) आपको विश्वविद्यालय में शोधप्रबंध शुल्क और मौखिक परीक्षा शुल्क भी क्रमशः शोधप्रबंध प्रस्तुत करने और मौखिक परीक्षा के समय जमा करना होगा।

8. The research scholar is required to submit the six monthly progress report till the work presented in the pre-thesis submission seminar and is approved by the Research Advisory Committee for submission of thesis.
9. The research scholar shall appear before the Research Advisory Committee to make a presentation of the progress of his/her work for evaluation and further guidance.
10. Ph.D. Scholar shall be required to be present in the research center concerned for a minimum period of two years from the date of registration. Their presence shall be duly recorded and maintained in the research center concerned.
11. **Registration of a Ph.D. Scholar is liable to be cancelled by the Director at any time if:-**
 - i. Two consecutive six monthly progress reports are not submitted at all or are not satisfactory as per recommendations/comments of RAC.
However, the research scholar is required to submit the 1st six monthly progress report through his/her Supervisor & Chairman of RAC and 2nd and 3rd six monthly progress reports duly reviewed by RAC. The candidate will make six monthly presentation of 2nd & 3rd six monthly Progress report before RAC. After that all the 6 monthly Progress Reports shall be submitted through supervisor & Chairman, RAC while annual presentation would be held before RAC.
The six monthly progress reports are to be submitted till pre-thesis submission seminar.
 - ii. The attendance of Research Scholar is less than 75% in any term.
 - iii. The scholar violates the clause 5.1.4 of the PhD ordinance regarding compulsion of 2 years Study leave for pursuing PhD in case of In-service candidates (except the employees of ICFRE and Research Centers of FRI Deemed to be University).
12. No Ph.D. Scholar (except in-service candidates availing study leave) shall accept during the period of research any paid assignment apart from Research Fellowships, Research Assistantship etc. (in the same institute) unless in the opinion of the RAC such an assignment will not interfere with his/her research work.
13. A Ph.D. Scholar shall not be permitted to take any other degree course, but may be permitted by the RAC to take part-time Diploma or Certificate course(s) not affecting the scholars research work adversely.
14. A Research Scholar is required to pursue research in the Institute/Research Centre under the Supervisor on the approved subject for not less than twenty-four months commencing from the date of his/her registration.
15. The Research Scholar may not later than three months from the date of issue of registration letter, modify the scheme of the research work or nature or scope of the subject, on the recommendation of the Supervisor and RAC, with the approval of Director.
16. In case a Research Scholar does not submit his/her thesis within a period of 6 years from the date of his/her admission unless the term is extended by the Research Degree Committee on the specific recommendation of the Research Advisory Committee for a period of upto 1 calendar year, his/her registration shall lapse.

The recommendations of the R.A.Cs for extension of term of registration must reach this office before expiry of the term of registration.

The women candidates and Persons with Disability (more than 40% disability) may be allowed a relaxation of two years in the maximum duration of registration i.e. 5 years and six months. In addition, during the entire period of registration the women candidates may be provided Maternity Leave/Child Care Leave once in the entire duration of Ph.D. for up to 240 days with the approval of Vice Chancellor on the recommendation of Supervisor/Head of Division/Nodal Officer of the Research Centre concerned.

17. Prior to the submission of the thesis but at least 3 months before the expiry of term of registration, the scholar shall make a presentation in the Department before the Research Advisory Committee of the Institution concerned in Pre-thesis Submission Seminar. The minutes of RAC meeting for pre-thesis submission seminars to be send to the Registrar, FRI Deemed University with full comments alongwith a panel of examiners duly signed by R.A.C.
18. Ph.D. scholars must publish at least one (1) research paper in refereed journal and make two paper presentations in conferences/seminars before the submission of the thesis for adjudication, and produce evidence for the same in the form of presentation certificates and/or reprints. While submitting for evaluation, the thesis shall have an undertaking from the research scholar and a certificate from the Research Supervisor attesting to the originality of the work, vouching that there is no plagiarism and that the work has not been submitted for the award of any other degree/diploma of the same Institution where the work was carried out, or to any other Institution..
19. Please ensure that the clause 13 of the Ph.D. Ordinance is fully complied with before submission of the thesis to University.
20. Please note that your Registration as Research Scholar is to be governed as per rules, regulation, and ordinances of FRI Deemed to be University, with applicable amendments made by the University from time to time. For all further correspondence, please quote your enrolment number.


(ए.के. त्रिपाठी)

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Wildlife Institute of India

DECLARATION

I hereby declare that the thesis titled "**Landscape-level Assessment of Select Group of Pollinators and Factors Influencing their Diversity and Distribution in Kullu Valley, Himachal Pradesh**", submitted by myself, Ms. Susmita Khan (Registration No. 19PHD586) to Forest Research Institute (Deemed to be) University (FRI), Dehradun for the award of the degree of Doctor of Philosophy in Forestry (Wildlife Science) is a record of original research work carried out by me under the supervision of Dr. Bitapi C. Sinha (Retired Scientist-G), and co-supervision of Dr. V. P. Uniyal (Retired Scientist-G) and Dr. K. Ramesh (Scientist-F) of Wildlife Institute of India, Dehradun. The doctoral research has not formed the basis for an award of any other degree or diploma in other university or organization. I also declare that the thesis embodies my own work, observations, and analysis, and in that respect, the investigation appears to advance knowledge in the subject. The materials obtained from different sources has been duly acknowledged in the thesis. The thesis has been duly checked through DrillBit, a plagiarism detection tool approved by FRI (Deemed to be) University, and has plagiarism to acceptable limits.

Dehradun,

23/04/2024

Susmita Khan

Countersigned:

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[Co-supervisor]

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CERTIFICATE

This is to certify that the thesis titled "**Landscape-level Assessment of Select Group of Pollinators and Factors Influencing their Diversity and Distribution in Kullu Valley, Himachal Pradesh**" submitted by Ms. Susmita Khan (Registration No. 19PHD586) to Forest Research Institute (Deemed to be) University (FRI), Dehradun, for the award of the degree of Doctor of Philosophy in Forestry (Wildlife Science) is a record of bonafide research work carried out by her, under my supervision. The thesis has been duly checked through DrillBit, a plagiarism detection tool approved by FRI (Deemed to be) University, and the thesis has plagiarism to acceptable limits. No part of this thesis has been submitted for any other degree/diploma of the same institution where the work is carried out or to any other institution. It fulfils all the requirements of the ordinance governing the award of a Ph.D. Degree of FRI, Deemed to be University, Dehradun. Ms. Susmita Khan has adequate attendance during her thesis work and she was not engaged in any paid assignment.

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Dr. Bitapi C. Sinha
[Supervisor]



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This is to certify that the work incorporated into the thesis titled, "**Landscape-level Assessment of Select Group of Pollinators and Factors Influencing their Diversity and Distribution in Kullu Valley, Himachal Pradesh**" submitted to the Forest Research Institute (Deemed to be) University (FRI), Dehradun, for the fulfilment of the award of Doctor of Philosophy in Forestry (Wildlife Science), is a record of original research work conducted by Ms. Susmita Khan (Registration No. 19PHD586) under my guidance as her co-supervisor. The thesis has been duly checked through DrillBit, a plagiarism detection tool approved by FRI (Deemed to be) University, and the thesis has plagiarism to acceptable limits. No part of this thesis has been submitted for any other degree/diploma of the same institution where the work is carried out or to any other institution. It fulfils all the requirements of the ordinance governing the award of a Ph.D. Degree of FRI (Deemed to be) University, Dehradun.

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Dehradun,
23/04/2024

Dr. K. Ramesh
[Co-supervisor]



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CERTIFICATE OF PRE-THESIS PRESENTATION

This is to certify that Ms. Susmita Khan (Registration No. 19PHD586), carried out her research work under Supervision of Dr. Bitapi C. Sinha (Retired Scientist-G), and co-supervision of Dr. V. P. Uniyal (Retired Scientist-G) and Dr. K. Ramesh (Scientist-F) of Wildlife Institute of India, Dehradun. The topic of the research registered with Forest Research Institute (Deemed to be) University was "**Landscape-level Assessment of Select Group of Pollinators and Factors Influencing their Diversity and Distribution in Kullu Valley, Himachal Pradesh**". The research scholar presented her work in the pre-thesis submission seminar held on 3rd April 2024, and the RAC found the work to be satisfactory and approved the work to be submitted in the form of a thesis for evaluation by examiners for the "Award of Ph.D. Degree" by FRI, Dehradun.

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Name of the research scholar	Susmita Khan
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Name of the supervisor	Dr. Bitapi C. Sinha
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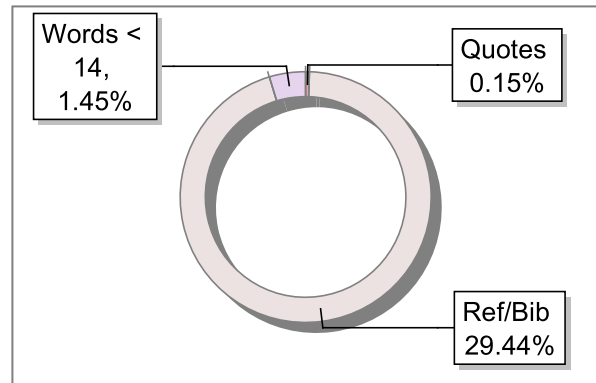
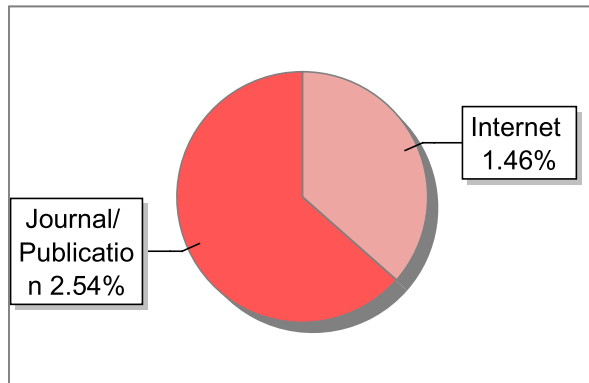
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Susmita Khan

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EXECUTIVE SUMMARY

□ Introduction

Pollination acts as a crucial process for biodiversity preservation and agricultural productivity, with various insect pollinators, especially bees, playing significant roles. Beyond bees, non-bee pollinators also contribute substantially to global crop pollination. These services stabilize over time with increasing pollinator diversity, offering resilience against environmental challenges. However, despite their importance, detailed studies on crop pollination systems remain outdated or inadequate, emphasizing the need for further research to safeguard these essential ecosystem services and mitigate the risks associated with pollinator declines.

The decline of wild and managed insect pollinators presents a global threat with profound economic and environmental implications. Assessments indicate alarming rates of endangerment among pollinator species, driven by various factors, including climate variability, landscape simplification, and habitat loss. Global pollinator decline not only jeopardizes agricultural productivity but also poses risks to biodiversity conservation and securing food availability. Furthermore, invasive plant species and habitat alterations exacerbate the situation, reducing pollinator visitation rates and impacting ecosystem stability. Climate change further exacerbates the vulnerability of pollinators, affecting their behavior and distribution. Urgent action is required to understand and mitigate the influences of landscape alterations and climate variability on pollinator communities to safeguard essential ecosystem services and protect global food systems.

Despite conservation efforts, including initiatives like the establishment of World Bee Day and national pollinator strategies, challenges persist, particularly in regions like India, where pollinator conservation receives less attention than charismatic megafauna. While some efforts have focused on conserving pollinators within agricultural ecosystems, attention to forest pollinators, especially non-bee species, remains inadequate. Additionally, the potential of Protected Areas to conserve pollinators is limited, highlighting the need for comprehensive transboundary or biogeographical pollinator conservation policies.

Insects represent a significant and diverse group of animals globally, with India hosting a substantial portion of this diversity, particularly within the Indian Himalayan Region (IHR). Within the IHR, insect diversity is recorded over 24,000 species/subspecies across various orders. Among these orders, Hymenoptera, Diptera, Lepidoptera, and Coleoptera stand out for their diversity and ecological significance as pollinators. Hymenoptera, encompassing bees,

wasps, and ants, plays crucial roles as pollinators, with over 3,000 species documented in the IHR. Diptera, known as true flies, constitute a diverse group with around 1,700 species in the region, contributing significantly to ecosystem functions. Lepidoptera, represented by moths and butterflies, are vital pollinators and exhibit substantial diversity, with over 1,000 species recorded in the Indian Himalayas, comprising a significant portion of India's butterfly diversity. Coleoptera, including beetles, constitute the largest insect order and boast over 10,000 species in the IHR, highlighting their ecological importance and remarkable diversity within the region.

However, various anthropogenic threats coupled with climate shifts, have caused a decline in the pollinator populations across the Hindu Kush Himalayan (HKH) region. Himachal Pradesh, part of HKH, known for its varied agro-climatic zones and horticultural crops, is experiencing a shift to high-value horticultural crops from traditional agriculture, such as apples, which primarily depend on insect pollinators for improved yields and fruit quality. However, habitat loss, changing climate, and increased anthropogenic disturbance in the state pose significant challenges to pollinator diversity and apple productivity. While past studies have shed light on insect pollinators in Himachal Pradesh, there remains a need for comprehensive research to document and quantify the services provided by these pollinators, especially in different landscape compositions, amidst the ongoing global decline of pollinators.

Change detection analysis using satellite data in a remote sensing platform is a crucial tool for understanding shifts in land use and land cover (LULC) over time, allowing for the identification of environmental and human-induced changes across various spatial and temporal scales. This method aids in assessing the impact of factors like urban expansion, agricultural practices, deforestation, and climate change on biodiversity and ecosystems. Climate change, particularly in vulnerable regions like the Himalayas, poses significant threats to ecosystem services and biodiversity. Projections indicate potential alterations in the distribution ranges of species, population dynamics, and phenology due to climate-induced changes. Species Distribution Models (SDMs) offer robust tools for the prediction of future spatial ranges of species based on environmental variables, enabling effective conservation planning and management strategies in the face of climate change-induced biodiversity shifts. Together LULC change analysis and predicting species distribution in climate change scenarios can aid in planning long-term conservation strategy on a landscape level.

This study explores the impact of LULC and climate change on pollinator diversity and distributional patterns in the Kullu and Tirthan valleys of Himachal Pradesh. By compiling a comprehensive list of entomofauna pollinators across various orchards in different landscape

configurations, the research aims to emphasize the need of conserving pollinator species in this ecologically sensitive region. Additionally, the study predicts potential shifts in pollinator distribution under future climate scenarios, providing valuable insights for conservation strategies. Through systematic analysis, the research contributes to a deeper understanding of pollinator communities and their interactions within the mountain horticultural belt of the Indian Himalayan Region. Ultimately, the findings aim to inform targeted conservation efforts to preserve the rich biodiversity of pollinators in this area.

With the aforesaid aim in focus, I have tried to address the following three objectives in my thesis:

- **Objective 1:** To assess the change in landscape composition of the study area over time.
- **Objective 2:** To assess the effect of change in landscape configuration and horticultural practices on pollinator communities (diversity and abundance) and their services.
- **Objective 3:** To model the distribution of major pollinators of economic importance belonging to different groups (Hymenoptera, Lepidoptera, Coleoptera, Diptera) in the study area.

To address the objectives, I have compiled my thesis into seven chapters and each chapter contributes to the overall structure and content of the thesis:

Chapter I (Introduction), contextualizes the study, outlines objectives, and defines scope.

Chapter II (Study area), describes geographical details and biodiversity of the study area.

Chapter III (Study design and methodologies), details sampling design, data collection, and analysis methods.

Chapter IV (Assessment of spatio-temporal changes in landscape composition over time), tracks landscape evolution from 2000 to 2022 using GIS and Remote Sensing.

Chapter V (Effect of change in landscape configuration and horticultural practices on pollinator community), examines pollinator diversity, richness, and abundance across landscape configurations.

Chapter VI (Modeling the distribution of major pollinators of different orders), evaluates spatial distribution patterns and vulnerability to climate change.

Chapter VII (Syntheses and recommendations), summarizes key findings, and provides recommendations for future research and protection efforts.

❑ **Study Area**

The Indian Himalayan Region (IHR) is a magnificent testament to the geological, ecological, and cultural diversity of the northern part of India. Stretching over 2,400 kilometers, the Himalayas serve as a natural boundary and play a vital role in shaping India's climate and hydrological sources, while also harboring rich biodiversity and cultural heritage. Within this region, the Kullu district of Himachal Pradesh stands out as a pristine haven of ecological richness and biodiversity, encompassing lush forests and diverse wildlife, including iconic species like the Himalayan brown bear and snow leopard. The district's ecological significance extends beyond its borders, contributing to the overall health and resilience of the Himalayan ecosystem. Apart from this, this district is also a very important commercial horticultural and agricultural belt with diverse crop production and supporting a diverse array of pollinators.

The research focuses on two major valleys within the Kullu district, each presenting contrasting landscapes and ecological contexts. The Kullu valley, a 76 kms long stretch situated along the Beas river, is characterized by diverse land use patterns and heightened anthropogenic activity, particularly in horticulture and tourism. In contrast, the Tirthan valley, nestled along the Tirthan river for a 45 kms long stretch, is designated as a conservation area with minimal disturbance and dense forest cover. It serves as a habitat for various wild and rare pollinator species. By focusing on these contrasting landscapes, the research aims to explore the effect of land use and landscape composition on pollinator communities, offering valuable insights into conservation strategies and biodiversity management within the region.

Sampling was conducted in 42 plum and apple orchards in Kullu and Tirthan valley. Major Plum varieties included Centa Rosa, Mariposa, and Red Beaut, while apple varieties encompassed Royal delicious, Golden delicious, and Scarlet Spur, among others in the sampling orchards.

❑ **Study design and methodologies**

The study meticulously investigated pollinator diversity dynamics in the Kullu and Tirthan valleys through a carefully designed research approach and methodologies.

▪ **Study design**

The study meticulously investigated pollinator diversity dynamics in the Kullu and Tirthan valleys through a carefully designed research approach. Beginning with a reconnaissance survey in January 2021 to understand ground conditions, the study spanned across 42 apple and plum orchards over two years, with 28 locations in Kullu valley and 14 in Tirthan valley.

Field sampling during the blooming period between February and May was strategically planned to coincide with optimal weather conditions, avoiding windy, rainy, or snowy days. A combination of active and passive sample collection methods, along with primary and secondary data, was employed for analysis. In Kullu valley, a stratified random sampling method based on landscape configurations was utilized, considering factors like distance from forest patches, elevational gradients, proximity to settlements, and orchard management practices. In Tirthan valley, landscape configurations were less applicable due to its conservation status and less disturbed nature, sampling was conducted randomly across the valley at regular intervals. Questionnaire surveys with orchard owners supplemented the data collection process, providing insights into pesticide usage, management practices, yield, and beekeeping practices. Overall, the study's comprehensive methodology ensured a thorough examination of pollinator diversity in these distinct Himalayan valleys.

- **Methodologies**

- Assessment of spatiotemporal changes in landscape composition over time**

The study conducted in the Kullu Valley aimed to analyze land use changes over time using Landsat satellite imagery from 2000 and 2022. High-quality images with minimal cloud cover were obtained for both years, ensuring accurate analysis. Image processing involved geometric and atmospheric correction, followed by supervised classification using the Random Forest technique in Google Earth Engine. Training samples for various land use classes were evenly distributed across the study area, and visual and spatial characteristics were utilized for classification. Additional resources such as Google Earth images were employed for difficult-to-distinguish land use types. Accuracy assessment using the Kappa coefficient index involved reference data from field surveys and Google Earth imagery. Misclassified pixels were rectified through recoding, and overall classification accuracy and kappa coefficient values were obtained. Change matrix generation using ERDAS Imagine allowed for the quantification and visualization of land use changes between 2000 and 2022. Final maps were prepared using ArcGIS software, with post-processing techniques applied to enhance clarity and precision.

- Effect of change in landscape configuration and horticultural practices on pollinator community**

Sampling was carried out during daylight hours from 9 am to 5 pm in each of the sampling sites in the Kullu and Tirthan valleys. Active methods such as hand picking, sweep netting, and aerial netting, as well as passive methods like pan traps colored in UV-bright yellow, white,

and blue, and filled with soapy water, were utilized to ensure a diverse collection of insect specimens.

Pan traps were arranged in clusters with 15 clusters randomly placed in each sampling site. Focal observations of pollinators were conducted within 1m x 1m plots along flowering branches of selected trees at three different time frames during the day. Specimens collected were processed differently based on the method of collection, either washed with plain water and preserved in 75% ethanol or euthanized using ethyl acetate in a killing jar and preserved in dry pouches. In the laboratory, specimens underwent further processing, including washing, drying, pinning, labeling, and identification using standard identification keys.

The collected samples were collectively analyzed to determine species diversity, richness, and abundance, involving Shannon and Simpson's diversity indices, Shannon evenness index, species richness, Chao-1, and rank abundance curve. Regression analysis (Generalized Linear Model), t-tests, and ANOVA were performed to explore the association between pollinator richness and abundance with different landscape configurations and whether there is any significant difference in pollinator diversity among these categories.

Data analysis was conducted using Excel, Past, and R, utilizing biodiversityR, vegan, ggplot2, and iNEXT packages. Observations were made on warm, sunny days to ensure active pollinator presence and to minimize bias.

Modeling the distribution of major pollinators belonging to different orders

The study conducted species distribution modeling (SDM) to identify the potential impact of climate change on pollinator species in the Kullu and Tirthan valleys of Himachal Pradesh. Primary data on species occurrence were collected through field surveys, supplemented by secondary occurrence records from literature surveys and databases like The Global Biodiversity Information Facility (GBIF). A total of 26 pollinator species belonging to Hymenoptera, Diptera, and Lepidoptera were selected for distribution modeling.

Spatial data preparation involved obtaining bioclimatic variables for current as well as for future scenarios from Worldclim V2.1 and digital elevation model (DEM) data. 12 Bioclimatic variables representing extreme environmental factors, annual trends, and seasonality were selected for analysis alongside DEM data. MaxEnt model was employed for SDM, utilizing 80% of the occurrence data for model creation and 20% for testing. Default settings were retained for model parameters, with the regularization multiplier set at 1. Contribution of each variable was estimated using the Jackknife test, and performance of the model was assessed using the Area under the curve (AUC) values of the Receiver Operating Characteristic (ROC)

method. The models were projected into two future scenarios (SSP126 and SSP585) for mid-century (2041–2060), and the predicted models were masked for the state of Himachal Pradesh. Binary maps were generated to depict species' presence or absence under present and future scenarios. The "Distribution change between binary SDM" tool was utilized to compute alterations in species' distribution, and the "Centroid change estimation" tool was used to assess directional shifts of suitable climatic niches for each species in the future. Additionally, the "Species richness estimation" tool was employed to determine species richness hotspots and richness shifts under present and future scenarios.

❑ Results and Discussion

Assessment of spatiotemporal changes in landscape composition over time

The study conducted a comprehensive assessment of land use and land cover changes in the Kullu and Tirthan valleys from 2000 to 2022. Utilizing high-quality data, the classification process achieved a high level of accuracy, with overall accuracies of 92% for 2022 and 87.5% for 2000, supported by strong Kappa coefficients of 90.31% and 84.65%, respectively.

In the Kullu Valley, significant increases in built-up areas (>14%) were observed, indicating rapid urbanization, particularly around Bhuntar airport, Kullu city, and Manali town, majorly due to improved communication, easy access to resources, and increased tourism business. This expansion was accompanied by a moderate increase in dense forest cover (>9%) but decreases in open forest/barren lands, orchards/agricultural land, and water bodies. Similar trends were noted in the Tirthan Valley, though less pronounced, with increases in built-up areas (1.99%) near Banjar town. However, given the Tirthan Valley's status as part of the Great Himalayan National Park Conservation Area (GHNPCA), such changes pose significant threats to its delicate ecosystem.

The change matrix revealed notable transformations between land use and land cover classes, including the alteration of orchard land into built-up areas, expansion of cultivation onto open lands, and natural succession processes leading to denser forest cover. Reversals of urbanization were also observed, with built-up areas converted back into agricultural land. These dynamic shifts underscore the complex interplay between urbanization, agricultural practices, and natural ecological processes shaping the landscape over time. Detailed insights provided by the analysis offer valuable information for informed decision-making regarding land conservation and management efforts in the region.

Effect of change in landscape configuration and horticultural practices on pollinator community

The study conducted in the Kullu and Tirthan valleys provides a detailed assessment of insect pollinator diversity, abundance, and the factors influencing their distribution within these ecosystems. Utilizing a combination of sampling methods and biodiversity analysis techniques, the study reveals valuable insights into the richness, evenness, and potential threats to pollinator communities in these regions.

With sampling coverage of over 95% in both the valleys, Kullu valley accounted for a total of 108 insect species encompassing 66 genera and 27 families and Tirthan valley accounted for 76 insect pollinators under 49 genera and 18 families, across five orders viz., Hymenoptera, Lepidoptera, Diptera, Coleoptera, and Thysanoptera.

Diversity indices such as Shannon's diversity index, Simpson's diversity index, Fisher's alpha, Shannon evenness index, and Chao-1 estimate indicate high species diversity, balanced distributions, and potentially rich pollinator communities in both valleys. However, despite high diversity, certain species dominate, suggesting skewed distributions possibly influenced by competitive interactions or environmental preferences. Hymenoptera and Diptera emerge as the most effective pollinators, supported by previous studies highlighting their significance in pollination services for fruit crops in the Himalayan region. Notable species include solitary bees like *Xylocopa sp.*, *Ceratina sp.*, *Bombus sp.*, *Amegilla sp.*, as well as syrphid flies and drone flies.

The proximity to natural forests significantly impacts pollinator richness and diversity, with orchards near forests exhibiting higher diversity. In the case of the elevational gradient, the highest diversity and richness were observed in the lower elevational belt. Management utilizing both modern technology and traditional practices with minimal chemical use, and presence of natural habitat surrounding the orchards, emerge as essential strategies for preserving pollinator populations and the pollination services they provide natural nesting and foraging sites to the pollinators. However, presence of large settlements and high tourism pressure negatively affects pollinator populations, indicating the importance of landscape management strategies to preserve biodiversity and ecosystem functionality. Presence of agricultural practices has also a negative effect on hymenopteran lepidopteran diversity.

In conclusion, the study underscores the importance of implementing sustainable land management practices to prioritize biodiversity conservation and support insect pollinators in

the Kullu and Tirthan valleys. These efforts are critical for maintaining ecosystem health, ensuring food security, and sustaining the well-being of human community in the region.

Modeling the distribution of major pollinators belonging to different orders

The study predicted the present as well as the future distribution of key insect pollinators to comprehend the potential impacts of climate change on key pollinator species in the state of Himachal Pradesh. The models demonstrated robust performance, with consistent area under the ROC curve (AUC) values of over 90% across different species, indicating reliable predictions. The predictor variable importance of different bioclimatic variables and DEM differed across species, highlighting the complex relationships between species and environmental factors.

Habitat suitability analysis under current and future climatic scenarios revealed potential habitat loss for many hymenopteran species, under SSP126 and SSP585. Vulnerable species such as *Bombus haemorrhoidalis* and *Osmia caerulescence* are projected to face significant habitat reduction. Conversely, some species like *Xylocopa latipes* and *Megachillae lanata* may experience increased suitable habitat. Dipteran species are also expected to undergo habitat loss, with notable reductions for *Chrysomya megacephala* and *Eristalis arbustorum* under SSP126. However, *Eristalis tenax* might expand its range. Lepidopteran species are anticipated to witness expanded habitat under both scenarios, though some, like *Colias fieldii* and *Aglais caschmirensis*, and particularly *Kanisk canace* are expected to face significant habitat loss under the future climatic scenarios. Species richness maps indicate changes in distribution hotspots with overall reduced richness in case of Hymenoptera and Diptera and both the future climate scenario and contrasting results for Lepidoptera with increased overall richness hotspots. Results also suggest that hymenopteran pollinators are expected to shift their distribution towards north to northwest, however, dipteran and lepidopteran pollinators might shift their distribution towards north and northeast. In summary, the result indicates, that habitat generalists show increased adaptability to changing climates, while more specialized species may face habitat loss. The study emphasizes the need for scientific and policy-based approaches to preserve natural habitats and develop a comprehensive mitigation strategy to decrease the impacts of climate alterations on Himalayan pollinators.

□ Syntheses and recommendations

The research emphasizes the importance of understanding the dynamics of pollinator diversity and ecosystem functioning in the setting of climate change and human-induced disturbances in

the Kullu and Tirthan valleys of Himachal Pradesh. The study reports the rich diversity of insect pollinators in orchards, crucial for sustaining both natural ecosystems and the local economy through crop pollination services. However, threats such as land use change and climate shifts pose significant risks to pollinator populations and ecosystem health.

The findings underscore the need for comprehensive conservation efforts that consider the complex connections between anthropogenic activities, agricultural practices, and natural habitats in the region. Conservation strategies should aim to preserve pollinator diversity and ecosystem functioning by prioritizing biodiversity conservation, promoting sustainable agriculture, and engaging local groups in conservation measures.

The analysis of land use and land cover changes over the past two decades reveals dynamic shifts driven by urbanization and infrastructure development. Sustainable land management practices and conservation efforts are essential to mitigate the adverse effects of the changing climate and preserve the unique ecological heritage of the region.

Furthermore, the study evaluates the future suitability of the habitats of pollinator species under varied climate scenarios using MaxEnt species distribution models. The heterogeneous responses among insect orders highlight the importance of considering species-specific ecological requirements and adaptive capacities in predictive modeling. Targeted conservation efforts are needed to protect vulnerable species, particularly specialized ones like Himalayan bumble bees.

Overall, the research contributes valuable insights into pollinator diversity and distribution in the Himalayan region, highlighting the importance of continued monitoring and research to develop effective conservation strategies in the context of climate change and anthropogenic pressures.

The study aligns with global policies emphasizing the significance of pollinators and their contributions to biodiversity conservation, sustainable development, and food security. It supports targets outlined in the Convention on Biological Diversity (CBD) and Sustainable Development Goals (SDGs), particularly Target 2 of the CBD focusing on pollination services, SDG 15 on terrestrial life conservation, SDG 2 on zero hunger through food security, and SDG 8 on economic growth and decent work through beekeeping and selling of honey and wax.

In the Himalayas, pollinators play a crucial role in sustaining mountain agriculture and horticulture, which are often practiced at subsistence levels. However, these ecosystems face various threats such as loss of pollinators due to pesticide use, encroachment, unregulated tourism, habitat loss, land fragmentation, climate change, and altered land use and land cover.

Drawing from the doctoral research, key management strategies and recommendations for future interventions on a landscape level include:

1. Public Awareness and Community Engagement

- Implementation of pollinator-friendly practices and educational programs.
- Establishment of pollinator conservation and information resource center.
- Advocacy for balanced agrochemical usage through governmental policies.

2. Habitat Improvement

- Prioritization of resilient management strategies to preserve natural habitats.
- Increase in floral diversity around orchards to support pollinator foraging.

3. Consideration of Zone of Influence

- Expansion of conservation initiatives out of agricultural lands to include forested landscapes.
- Focusing on the conservation of non-bee pollinators in addition to the honeybees.

4. PA Network and Conservation Status

- Formulation of comprehensive pollinator conservation policies aligned with international agreements.
- Evaluation of population status and list out the key pollinators in IUCN's Red List or Red Data Book.

5. Landscape Management Approach with Focus on Migratory Routes and Stepping Stones

- Assessment of migration patterns and stay-over sites of pollinators to develop targeted conservation pathways.
- Application of remote sensing and geoinformatics to inform landscape-level management strategies.
- Development of collaborative policies among Himalayan countries to protect transboundary habitats.



Chapter 1: Introduction

1.1. Pollinators and their importance: an overview

Pollination stands out as a critical process essential for preserving and enhancing biodiversity on Earth. Numerous ecosystems, including agroecosystems, rely directly or indirectly on the diversity of pollinators to maintain overall biological richness within the system. Additionally, pollination significantly benefits human populations by bolstering food security and enhancing livelihoods (Khan & Khan, 2004; Sharma et al., 2016). The realm of insect pollinators encompasses a vast array of species, with over 16,000 bee species (Hymenoptera: Apidae) identified globally (Kevan, 2003). The primary modes of plant pollination by insects encompass Mellitophily (bee pollination), Phalaenophily (moth pollination), Psychophily (butterfly pollination), Myophily (fly pollination), Cantharophily (beetle pollination), and Myrmecophily (ant pollination). Among these, bees are predominantly significant for the pollination of most plant species (Awasthi, 2001). In addition to social and managed honeybee pollinators, the pollination of major crops receives significant contributions from various wild and non-apis domesticated bees. This includes eusocial bumblebees, solitary bees such as *Nomia sp.* and *Osmia sp.* (Batra, 1998), *Megachile sp.* (Richards, 1997), and social stingless bees, which play crucial roles in pollinating tomatoes, horticultural crops, coffee, fodder, and other agricultural produce. Stingless bees are equally vital pollinators as honeybees, as they offer advantages over honeybees due to their smaller size, shorter foraging range, and resistance to various diseases and parasites (Abrol, 2009). Studies indicate that in apple orchards, 600 solitary bees can effectively pollinate as much as 30,000 honeybees (Delaplane & Mayer, 2000), and they may work synergistically with other managed bees to enhance crop yields. However, the increasing use of hybrid crop varieties and the introduction of exotic bee species for managed pollination have led to a lack of data on pollination biology and the specific pollinators required for certain crops (Klein et al., 2007). Beyond bees, various other non-bee pollinators such as flies (Diptera: predominantly represented by Syrphidae, Calliphoridae, Tachinidae, Empididae, and Muscidae), moths and butterflies (Lepidoptera), beetles (Coleoptera), hymenopterans including ants (Formicidae) and wasps, birds, and bats, also play pivotal roles in pollinating global crops and fostering economic growth. However, research on their contributions remains limited (Rader et al., 2016).

Ecosystem services are natural functions such as biological, and geochemical processes, water and gas regulation, nutrient recycling, genetic resources, biological control, pollination as well as the scenic beauty discovered in ecotourism, which is secondarily useful for human assistance (Costanza et al., 1997; Kearns et al., 1998; Garwin & Masood, 1998; Altieri, 1999; Fearnside,

1999; Daily, 2000, Palmer et al., 2004). Pollination service is classified as a regulating ecosystem service, which is necessary for the functioning of many other ecosystem services. Animal pollinators play a vital role in maintaining ecosystem service in landscapes of mixed agricultural and natural habitats (McGregor, 1976; Crane & Walker, 1984; Free, 1993; Williams, 1994; Burd, 1994; Nabhan & Buchmann, 1997; Allen-Wardell et al., 1998; Kearns et al., 1998; Westerkamp & Gottsberger, 2000; Larson & Barrett, 2000; Ashman et al., 2004). Almost 87.5% (approximately 308,000 species) of wild flowering plants of the world depend on biotic pollination for their sexual reproduction fully or in some part, and the number ranges from 94% in tropical areas to 78% in temperate zones (Ollerton & Tarrant, 2011). Pollinators contribute to the stability of terrestrial food webs by supporting wild plants, which offer diverse resources like food and shelter for a variety of other organisms, including invertebrates, mammals, birds, and other taxa (IPBES, 2016). Around 1/3 of the food consumed by human-domesticated animals relies directly or indirectly on pollination. (Costanza et al., 1997). Pollinators are essential for productive and healthy agricultural practices as they safeguard the production of fertile seed sets and full-bodied fruit in many crops (Klein et al., 2007) and Their annual economic contribution to global agriculture has been estimated to be approximately 153 billion pounds (€) (Gallai et al., 2009). Without pollination, the ecosystem's capacity to provide many essential supplies would be greatly diminished. Therefore, pollination acts as a regulating service that underpins the ecosystem functioning and the provisioning of other services critical for human well-being. Studies comparing the relative contributions of various taxa in crop pollination from five continents showed that crop pollination services provided by non-bees are 25–50% of the total number of flower visits. When examining the fruit set, it was observed that the fruit set increased with visits from non-bee insects regardless of bee visitation rates. This suggests that non-bee insects provide certain unique benefits not provided by bees. Non-bee pollinators exhibit less dependence on the existence of remnant natural or semi-natural habitats in the surrounding landscape compared to bees. Consequently, these pollinators play a crucial role in global crop production and respond differently than bees to landscape structure, potentially enhancing the resilience of their crop pollination services to changes in land use. Non-bee insects offer a valuable service and serve as potential insurance against declines in bee populations (Rader et al., 2016). Moreover, wild bee richness can increase the scale and temporal stability of pollination (Kremen et al., 2002; Klein et al., 2009; Garibaldi et al., 2011). Pollination services of an area stabilize over time proportionately with the pollinator diversity, as with increasing diversity, the chances increase that there will be species more tolerant to varied climatic conditions, like a cold and wet spring. Similarly, when there is high diversity

among pollinators, the presence of multiple species ensures that even if one species is impacted by factors such as disease, parasites, pesticides, or habitat loss, other species are still available to thrive and fulfill pollination roles. Native insect pollinators play an important role in crop pollination but are often underappreciated. Various recent studies in agricultural ecosystems have stated that native bees provide a vital role in crop pollination (Kremen et al., 2002; Winfree et al., 2007; Ganie et al., 2014). Decline in pollinating species can lead to a sharp decline in wild as well as cultivated plant species (Biesmeijer et al., 2006). While crop pollination is commonly referred as an endangered ecosystem service (Corbet, 1991; Williams, 1994; Ingram et al., 1996; Matheson et al., 1996; Allen- Wardell et al., 1998; Kearns et al., 1998; Kevan & Phillips, 2001; Steffan-Dewenter et al., 2005; Ghazoul, 2005), detailed studies of the crop pollination systems are mostly out of date or insufficient.

1.2. Major threats to the pollinators

Insect pollinators of both wild plants and crops are facing global threats, and their decrease could lead to significant economic and environmental repercussions. According to assessments by the IUCN's Red List, approximately 16.5% of land pollinator species and 30% of island pollinator species worldwide are considered endangered with heightened risks of extinction. Pollinators, whether wild or managed, play an important role in crop pollination on a global scale. They are often regarded as a vital link between forestry, agriculture, biodiversity, nutrition, and food security. The assessment report by IPBES (2016) highlighted several key drivers of change impacting the richness, diversity, and well-being of pollinators. Climate variability has had significant effects on biodiversity, including shifts in geographical distributions (Pounds et al., 1999), changes in community species composition (Easterling et al., 2000), fluctuations in phenological timings (Fitter and Fitter, 2002), and species extinction. Simplification of the landscape can also cause threats to the potential of pollinators' services. Some studies show a negative impact of changes in landscape configuration, intensification of agriculture, and loss of natural habitats on both species richness and abundance of wild bees in agroecosystems and identified as one of the major factors of pollinator declines (Steffan-Dewenter et al., 2002; Goulson et al., 2008; Kleijn & Raemakers, 2008; Ricketts et al., 2008; Williams & Osborne, 2009; Winfree et al., 2009; Fürst et al., 2014; Kennedy et al., 2013; Vanbergen et al., 2013; Schmid Hempel et al., 2014). In the past few years, many crucial pollinators, particularly honeybees, are experiencing unprecedented declines worldwide, with experts struggling to identify the exact reasons for this alarming trend (Ghazoul, 2005; Steffan-

Dewenter et al., 2005; Biesmeijer et al., 2006; Williams & Osborne, 2009). While there is much focus on managed honeybee (*Apis mellifera* L.) decline, a condition called Colony Collapse Disorder (Oldroyd, 2007), various species of wild bees have also experienced sharp decline (Biesmeijer et al., 2006; Potts et al., 2010) and in many cases have vanished from their natural historical ranges (National Research Council, 2007; Cameron et al., 2011). Aguilar et al., (2006) discovered a link between the decline of local pollinator abundance and diversity and reductions in wild plant pollination and seed production. Invasive plant species exert a notable negative impact on pollinator visitation and the fertilization of co-flowering species (Morales & Traveset, 2009). Montero-Castao & Vil (2012) revealed that habitat alterations and invasions by alien species have decreased pollinator visitation rates. The decline of pollinator populations represents a form of global change capable of influencing the layout and structure of terrestrial ecosystems as a whole. In numerous regions worldwide, the decline in pollinator populations and diversity represents a significant threat to agricultural productivity, biodiversity conservation, and maintenance. Decreases in pollinator numbers can result in a loss of pollination services, leading to severe ecological and economic consequences that could endanger the diversity of wild plants, destabilize ecosystems, reduce crop yields, jeopardize food security, and impact human well-being (Abrol, 2009). Insects are particularly vulnerable to climate change due to their limited temperature tolerance (Connor, 2008). Cold temperatures and excessive humidity have a dual effect on bee activity and pollen release, reducing bee activity and slowing down pollen release (Joshi & Joshi, 2010). Temperature, relative humidity, and wind influence the quantity and concentration of nectar, as well as a flower's attractiveness to bees (Somerville, 1999). For example, in case of extremely cold temperatures, honeybees need to allocate a significant amount of energy to heating the comb and brood (Kleinhenz et al., 2003), thereby diminishing their efficiency as pollinators. In response to the changes in environmental conditions, certain pollinator species have adjusted their migratory routes, shifted their habitats, and altered their seasonal behaviors, resulting in impacts on their populations and overall distribution. Pollinators that have evolved over extended periods are experiencing rapid declines. This persistent decrease in pollinator populations will ultimately lead to significant ecological and economic consequences, given their vital role in the pollination of nearly all agricultural, horticultural, and economically valuable crops worldwide (Gallai et al., 2009; Mattu & Mattu, 2007, 2010). Understanding the impact of changes in landscape structure and climate change on the pollinator community is crucial for the deterrence of further pollinator loss and for designing useful strategies to protect pollinators in human-dominated landscapes (Viana et al., 2012).

1.3. Conservation status

Animal-mediated pollination is a vital ecosystem service that helps regulate natural processes. Both wild and managed pollinators play significant roles in pollinating crops worldwide, although their specific contributions can vary depending on the crop type and location. Understanding pollinators and the ecology of pollination at a fundamental level, as highlighted by Heinrich & Raven in 1972, is essential for devising effective conservation and management strategies to ensure the sustainable utilization of biodiversity. Over the past decade, various research has revealed concerning trends in declining pollinator populations, observed throughout the globe. The discovery prompted increased awareness among Americans about the threatened status of *Apis mellifera*, which is now regarded alongside other significant fauna (Bhuyan, 2019). According to assessments by the IUCN Red List, 16.5% of vertebrate pollinators are endangered globally (rising to 30% for island species). Although insect pollinators have not been globally assessed, regional and national analyses indicate severe threats to certain butterfly and bee species. In Europe, 9% of bee and butterfly species are endangered, with declining populations observed in 37% of bees and 31% of butterflies. National Red List assessments revealed that over 40% of bee species are endangered. The Red List provides comprehensive information on the conservation status of each listed species, highlighting the declining populations of native bees. A pollinator management program was established with signing members from 168 countries in 1993 to address conservation issues of pollinators. The IUCN established the Bumblebee Specialist Group in 2011 to assess the global threat levels of all bumblebee species using the Red List criteria. However, conservation discussions often prioritize large mammals like big cats, elephants, and rhinos, particularly in regions like India, with little emphasis on pollinators. Since 2018, the United Nations has recognized these efforts by designating May 20th as World Bee Day. The FAO has urged countries to enhance their efforts in protecting bees, crucial allies in the fight against hunger. Direct threats to pollinators, including changes in land use, intensive agricultural practices, pesticide usage, pollution, invasive species, diseases, and climate change, endanger their abundance, diversity, health, and the pollination services they provide. The European Red List of Bees (Nieto et al., 2014) offers comprehensive data on the status of nearly 2,000 European bee species, which highlights agricultural intensification, urbanization, increased fire occurrences, and climate change as significant contributors to the extinction of 9% of European bees. Subsequently, member states of the Convention on Biological Diversity (CBD) committed to supporting pollinator conservation, leading some countries to develop national

pollinator strategies and action plans by 2019 (IPBES, 2019). However, research on trends and the impact of pollinator decline is predominantly focused on high-income countries in North America and Europe, with limited attention given to regions believed to be most vulnerable to pollinator diversity loss (Dicks et al., 2021). Since 1981, the Government of India has been executing the "All India Coordinated Research Project on Honeybees and Pollinators" under the Indian Council of Agricultural Research (ICAR). This project is designed to conserve pollinators while also aiming to enhance farmers' livelihoods and bolster ecosystem services. However, the initiative has primarily focused on conserving pollinators within agricultural ecosystems, with insufficient attention given to forest pollinators, especially non-bee species. It is also important to note that Protected Areas (PAs) can also offer undisturbed habitat for insects (Chowdhury et al., 2023). Despite this potential, approximately 76% of insect species documented in the GBIF with at least three occurrence records globally do not benefit from conservation efforts within PAs. This is largely because their habitats often lie beyond the jurisdiction of PAs (Chowdhury et al., 2023). Nevertheless, despite these challenges, there is currently no comprehensive pollinator conservation policy at a transboundary or biogeographical level.

1.4. Insect pollinator diversity in the Indian Himalayan Region

Insects are not only the most significant group of animals globally, comprising approximately 10,53,578 species, but also exhibit remarkable diversity within India, with approximately 65,047 (6.17%) species (Chandra, 2011, 2011a; Chandra et al., 2018). The Indian Himalayan Region (IHR) spans across three distinct bio-geographic zones: the trans-Himalaya, encompassing the cold deserts of Ladakh, Kargil in Jammu & Kashmir, and Lahaul & Spiti in Himachal Pradesh; the Himalaya, covering the northwest regions of Jammu & Kashmir and Himachal Pradesh, as well as Uttarakhand to the west; and Eastern & North-east India, including Sikkim, Arunachal Pradesh, Darjeeling district of West Bengal, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura. Within the IHR, the insect fauna comprises about 24,784 species/subspecies belonging to 26 orders, representing 38.1% of India's known diversity. The Central Himalaya exhibits the highest insect diversity with 12,053 species/subspecies, followed by the West Himalaya (10,002), North-West Himalaya (6,445), East Himalaya (3,819), Ladakh Mountains (1,031), Trans Himalaya-Sikkim (833), and Tibetan Plateau (811) (Chandra et al., 2018). Previous studies have identified various primary pollinators in the Oriental (Indomalayan) region including the Indian Himalaya region, which

incorporates a diverse array of honeybees, flies, wasps, beetles, ants, moths, and butterflies that fall under four major insect orders viz., Hymenoptera, Lepidoptera, Diptera, and Coleoptera (Corlett, 2004). Among the orders, Coleoptera (beetles) stands out with 10,533 species/subspecies under 107 families, representing 43% of the total insect diversity of IHR followed by Lepidoptera (5,356 species), Hymenoptera (3,054 species), and Diptera (1,698 species).

- **Order Hymenoptera:** Among all insect orders, Hymenoptera stands out as one of the most diverse and ecologically significant groups. Its members play crucial roles in various aspects beneficial to humans, serving as pollinators of flowering plants, producers of wax and honey, parasites of harmful insects, and prominent representatives of social insects such as ants, bees, and wasps. According to Aguiar et al. (2013), the global diversity of hymenopteran fauna stands at 1,50,659 species, with approximately 12,605 species documented in India (Chandra, 2011). In the Indian Himalaya, published data indicates the identification of 3,054 species of Hymenoptera, distributed across 816 genera, 52 families, and 16 superfamilies. Hymenoptera is estimated to encompass around 1,60,000 species (Marshall, 2012), classified into 188 families (Brake, 2017).

- **Order Diptera:** Diptera, commonly referred to as true "flies," constitute one of the most diverse insect groups globally, comprising over 8.05% of known biodiversity and 15.3% of global insect diversity (Chapman, 2009). In India, there are 87 families of Diptera, each with approximately 6,000 species (Alfred et al., 1998). Within the Indian Himalayas, a total of 1,698 species have been reported, spanning 427 genera and 64 families, with 329 species and 64 genera endemic to the region.

- **Order Lepidoptera:** The Lepidoptera community (moths and butterflies) represents approximately 1,58,423 species globally, categorized into 126 families and 46 superfamilies (Capinera, 2008). Lepidoptera stands out as one of the most extensively studied taxa worldwide, comprising 10% of all living organisms (Mallet, 2007). In India, there are around 12,500 species distributed across all biogeographic zones of the country. Butterflies and moths occupy distinct niches, with butterflies being active during the day (diurnal) and moths predominantly active at night (nocturnal). Both groups play significant roles as pollinators of flowering plants in both natural and managed ecosystems. According to Van Nieuwerkerken et al., (2011), the global butterfly species count stands at approximately 18,732, excluding the Hedyllidae family. India is home to about 1,501 butterfly species on the mainland (Kehimkar, 2008). In the Indian Himalaya region, the butterfly diversity is approximately 1,013 species, and when including subspecies, this diversity expands to 1,249 members, categorized into 343 genera across six families. The butterfly diversity of the Indian Himalayas accounts for approximately 67% of the butterfly diversity known from the country.

- **Order Coleoptera:** Coleoptera, which includes hard-bodied beetles and weevils, constitutes the largest order within the class Insecta and boasts the highest number of known insect species. These insects hold significant economic importance and exhibit a remarkable diversity in size, abundance, appearance, and behaviors, thriving in nearly all climates and latitudes. The IHR is home to a rich diversity of beetle fauna, with approximately 10,533 species identified across 2,684 genera and 107 families. This represents about 47.3% of the total beetle diversity found in India, which amounts to 22,299 species.

Table 1.1. Major insect pollinator diversity as reported from world, India and IHR at a glance.

Class/Order	World			India			IHR		
	Family	Genus	Species /Subspecies	Family	Genus	Species /Subspecies	Family	Genus	Species /Subspecies
Insecta	-	-	10,53,578	-	-	65,047	-	-	24,784
Hymenoptera	116	7738	1,50,659	68	-	12,605	52	816	3054
Lepidoptera	126	-	1,58,423	-	-	12,500	68	2,069	5,356
Diptera	188	-	1,60,000	87	-	>6000	64	437	1698
Coleoptera	176	29,500	3,89,487	-	-	22,299	107	2684	10,533

1.5. Importance of studying pollinators of the Himalayas

The Himalayan biogeography sustains a rich array of species, facing increasing threats from a rapidly deteriorating environment. Loss of pollinators is exacerbated by urban and industrial development, mining activities, hydropower projects, unsustainable timber extraction, unregulated tourism, parasites and diseases, invasive alien species, monoculture, and intensive farming methods. While the Himalayas have shown resilience to these pressures, the escalating effects of global warming and rising temperatures jeopardize the habitats of some charismatic, keystone, and beneficial pollinator species. Overgrazing has led to the depletion of numerous endemic plant species in alpine forests, compromising their migratory and nectar corridors, thereby endangering wildlife, and disrupting the food chain. This has prompted a response to what is being termed as the "pollinator crisis," particularly among conservationists and policymakers (IPBES, 2016). Research in Asia has revealed a link between declining insect populations and reduced crop yields, leading to efforts to regulate pollinator biodiversity and preserve their populations to ensure crop productivity. Many farmers worldwide are resorting to importing and breeding indigenous bee species and even hiring paid pollination services to

ensure reliable crop yields. This growing recognition of pollination as a critical ecosystem service for food security and ecosystem resilience has generated significant support for its conservation and management (Poppy et al., 2014).

However, in the past few years, a disturbance in crop pollination services due to the decline in the number and diversity of pollinators has been noticed throughout the Hindu Kush Himalayan (HKH) region (Partap & Partap, 1997, 2001, 2002; Ahmad et al., 2003; Partap, 2010 a,b). Researchers have found that a range of human activities, primarily anthropogenic practices, are the main contributors to the loss of pollinator habitats, resulting in diminished food sources for these vital organisms. Key factors exacerbating the decline of pollinators include the expansion of monoculture-dominated agriculture and the widespread use of pesticides (Verma & Partap, 1993; Aizen & Feinsinger, 1994; Allen-Wardell et al., 1998; Partap & Partap, 1997, 2002; Ahmad et al., 2003; Partap, 2010 a,b; 2011). Forests play a crucial role in providing habitats for food resources, nesting, and hibernation for various pollinator species. Studies have revealed that insect pollinators are more in numbers in orchards that are situated near forested areas than those that are far away from forests (Sharma & Gupta, 2010; Rajesh & Gupta, 2010). Therefore, a decrease in forest area either by destruction through natural calamities such as forest fires or by alteration to crop fields has a negative impact on pollinator abundance (IPBES, 2016). Climate change can also affect insect diversity as alterations in local weather conditions, such as gradual drops in rainfall and temperature, affect the lifecycle of natural pollinators (Partap & Partap, 2001, 2002).

In India, Himachal Pradesh is renowned as the horticultural state of the country, boasting diverse agro-climatic zones that span from subtropical regions to high-altitude cold deserts. This vast range of climates offers huge potential for cultivating a wide variety of horticultural crops effectively. Consequently, there has been a notable shift in cropping patterns within the state, with traditional agriculture giving way to the cultivation of high-value horticultural crops. Among the commonly grown temperate fruit crops are apple, plum, peach, cherry, pear, and apricot, collectively occupying around 35 percent of the total land area in the hilly state (Sharma & Rana, 2015) (table 1.2). Most of the blooms of these crops are self-incompatible and need cross-pollination by different insects to increase crop yield and improve seed and fruit quality (Sharma & Rana, 2015). Apple stands out as the predominant temperate fruit crop in India, accounting for approximately 2.8% of the country's total fruit production, and in Himachal Pradesh, apple productivity ranges from 6 to 7 tonnes per hectare. Within Himachal Pradesh, the economic impact of pollination was assessed across a variety of crops, including 13 fruit crops, 5 oilseeds, 1 pulse crop, 2 spices, 2 tree nuts, and 9 vegetables. The Total Variable

Cost (TVC) for all selected crops amounts to USD 815.1 million. Additionally, the Economic Value of Insect Pollination (EVIP) is estimated at USD 365 million, with a Relatable Value (RV) of 44.8% (Partap, 2011). The forest cover of this state is shrinking rapidly to provide cultivable land which in turn is destroying the nesting habitat and shelter locations of various pollinators and consequently threatening the diversity and distribution of flora and fauna of this region (Sharma & Rana, 2015). Changing climate is also another crucial factor in pollinator decline resulting in decreased apple productivity in this state in the last few decades causing serious alarm for the fruit growers of the country. Approximately 75% of Old Delicious apple orchards are facing issues with insufficient pollinizer proportions, with less than 20% being observed, resulting in pollination challenges (Gautam et al., 2003). Farmers in Himachal Pradesh employ honeybees for the pollination of their apple orchards. (Partap, 1999; Mattu and Mattu, 2010). There have been past studies on different insect pollinators in Himachal Pradesh by many authors like Sharma & Gupta, 2010; Bhattacharya et al., 2013; Partap, 2011; Sharma, 2012; Thakur & Mattu, 2014; Kumar et al., 2018; Nayak et al., 2019; Jamwal et al., 2020. However, studies on pollinator diversity in different land-use features, documentation, and quantification of the services provided by them are still lacking which needs to be addressed due to the current global decline of pollinators.

Table 1.2. Horticulture zones in Himachal Pradesh (source: hpenvis.nic.in/Database, 2016).

Zone description	Elevation range (m. asl.)	Suitable fruit crops
Low Hill and Valley areas near the plains	365-914	Mango, Litchi, Guava, Loquat, Citrus Fig, Ber, Papaya, Early varieties of Grapes, Jack Fruit, Banana, low chilling varieties of Peach, Plum and Pear, and Strawberry.
Mid Hills (Sub Temperate)	915-1523	Stone Fruits (Peach, Plum, Apricot, Almond), Persimmon, Pear, Pomegranate, Pecan nut, Walnut, Kiwi Fruit, Strawberry.
High Hills and Valleys in the interiors (Temperate)	1524-2742	Apple, Pear (Soft), Cherry, Almond, Walnut, Chestnut, Hazelnut, Strawberry.
Cold and Dry Zone (Dry Temperate)	2743-3656	Apples, Prunes, drying types of Apricot, Almond, Chilgoza, Pistachio nut, Walnut, Hazelnut, Grapes, and Hops.

1.6. Research gaps

The research areas regarding insect pollinators in the IHR predominantly comprise random surveys carried out across different states within the region. Despite surveys, certain

high-altitude insect pollinator taxa have remained relatively under-investigated from a taxonomic perspective. However, recent technological advancements have catalyzed a notable surge in research-based studies focusing on insect diversity in the Himalayan region. Among all insect groups, butterflies and beetles have garnered significant attention and research efforts. Butterflies, in particular, have been the subject of systematic research dating back to the early 18th century resulting in the documentation of 19,238 butterfly species globally (Heppner, 1998). In parallel, beetles have also been the subject of considerable study within the context of insect pollinators in the Himalayan region. While butterflies and beetles have received significant attention, there remains ample scope for further exploration and investigation, particularly concerning lesser-studied insect taxa and their roles in pollination networks within this ecologically rich and biodiverse region. A considerable portion of research conducted on the fauna and invertebrates of the Indian Himalayan Region (IHR) has focused on ecology, behavior, distribution, and taxonomy, however, there remains a notable gap in studies exploring themes such as molecular biology, conservation, and climate change. Additionally, efforts have been made to identify the lepidopterans and odonates of the IHR. However, scientific studies addressing the impact of pollinators on mountain agriculture productivity are limited. There is also a limitation in study on other important pollinators such as wild bees, bumblebees, flies, and wasps. To address this gap, there is a pressing need for detailed studies focusing on these less-studied pollinator groups, including investigations into their ecology, behavior, and evolutionary relationships within the unique ecosystems of the Himalayan region. By gaining a deeper understanding of the ecological roles and requirements of these pollinators, researchers can better assess their contributions to mountain agriculture productivity and develop more effective conservation strategies to safeguard their populations and the vital ecosystem services they provide. Despite the rich diversity of entomofauna pollinators in the IHR, conservation challenges persist due to several factors. Firstly, there is an insufficient level of taxonomic knowledge regarding many insect pollinator species in the region. Taxonomic identification is essential for understanding species diversity, distribution patterns, and ecological roles. Additionally, the lack of comprehensive distribution maps hinders conservation efforts by impeding the identification of priority areas for protection and management interventions. Moreover, the dearth of studies on the evolution and morphometry of pollinator species further complicates conservation efforts. Understanding the evolutionary history and morphological traits of pollinators is crucial for assessing their adaptive potential in the face of environmental changes and for informing conservation strategies aimed at preserving their genetic diversity. One urgent conservation priority is the establishment of an

IUCN Red List for declining pollinator populations in the IHR, particularly bees and butterflies. These iconic pollinator groups are experiencing alarming declines worldwide, driven by various factors including habitat loss, pesticide use, climate change, and disease. By formally assessing their conservation status and identifying species at risk of extinction, the IUCN Red List can inform targeted conservation actions and policy decisions aimed at mitigating their decline and safeguarding their vital ecological roles. Although some comprehensive research projects on pollinators have been undertaken in areas such as Jammu & Kashmir, Himachal Pradesh, and Uttarakhand in the Western Himalayas (ZSI, 1995), further concerted efforts are needed to safeguard the entomofauna at a regional level. Subsequent investigations in the Western Himalayas should concentrate on addressing research gaps, including the development of distribution maps for primary pollinators, conducting more taxonomy-oriented studies, studies on evolution and morphometry, exploring isolation and speciation at the molecular level, and undertaking genetic profiling of key pollinators. Further studies are necessary to elucidate how phenomena like climate change, seasonal fluctuations in crop resources, landscape characteristics (such as wild strips and vegetation cover), environmental variables (such as snowfall and precipitation), and human-induced disturbances impact the overall presence of primary pollinators in this region.

In summary, addressing the conservation challenges facing entomofauna pollinators in the IHR requires integrated research and conservation initiatives to effectively protect and conserve the diverse pollinator species that are essential for ecosystem functioning and human well-being in this region.

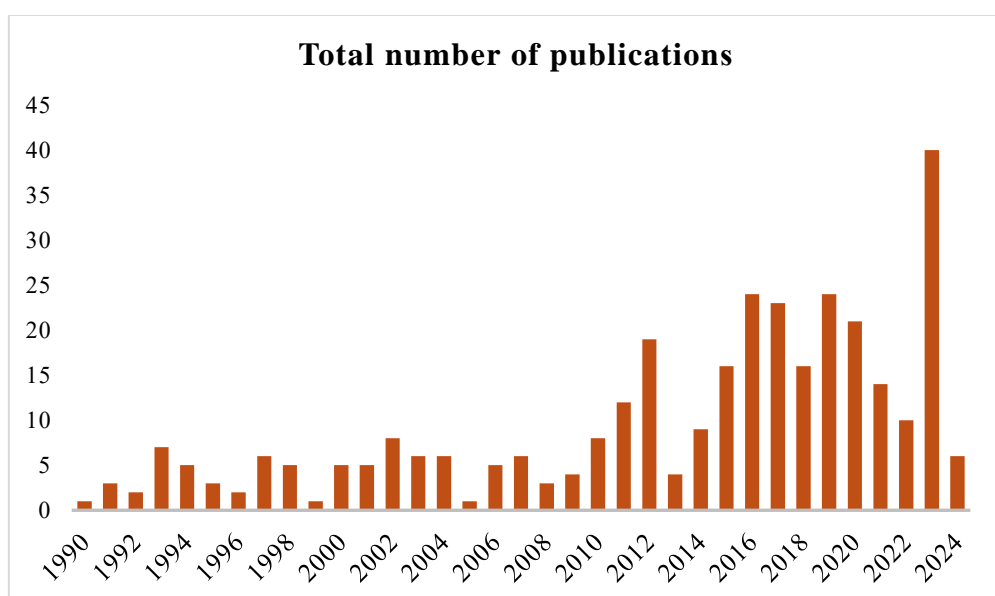


Figure 1.1. Year wise trend in publications related to insect pollinators in IHR

1.7. Importance of LULC change analysis and Species Distribution Modelling

Change detection analysis entails identifying alterations in the condition of an object or phenomenon by observing it at various time intervals (Singh, 1998). Utilizing remotely sensed data enables the acquisition of repeated observations of the Earth's surface across various temporal scales (NAP, 2008), facilitating the analysis of diverse planetary characteristics through the extraction of satellite imagery (Lillis & Kiefer, 1993). One primary application of such remotely accessed data obtained from Earth-orbiting satellites is in Land Use Land Cover (LULC) change detection. This method provides repetitive data at short intervals and maintains consistent image quality in digital format, making it suitable for computer processing and precise georeferencing (Anderson, 1977; Ingram et al., 1981; Nelson, 1983; Singh, 1984; Jensen, 1996; Lu et al., 2004; Chen et al., 2005). LULC change detection serves as a valuable tool in identifying significant forms of global change, whether originating from natural processes or human activities, across various temporal and spatial scales. This analysis enables drawing conclusions about the impact of environmental and human dynamics on change based on scientific evidence (CCSP, 2003; Lambin et al., 2003; Zheng et al., 2008). Numerous practical applications associated with LULC changes include assessing shifts in cultivation practices and landscape patterns, land degradation and desertification, alterations in coastal areas and urban expansion, fragmentation of landscapes and habitats, deforestation, mining activities, and more (Imbernon, 1999; Munroe et al., 2005; Adamo & Crews Meyer, 2006; Nagendra et al., 2006; Shalaby & Tateishi, 2007; Mouflis et al., 2008; Serra et al., 2008; Gao & Liu, 2010; Schulz et al., 2010; Wyman & Stein, 2010). The effective utilization of satellite remote sensing for LULC change detection hinges upon a thorough comprehension of landscape characteristics, the imaging process, and the methodologies employed to achieve the analysis of objectives (Yang & Lo, 2002). Precise knowledge of LULC changes in a given area is crucial for any sustainable management practice. Therefore, analyzing and mapping both the current LULC state and changes over time are deemed essential for gaining a better understanding of the situation and identifying solutions to socioeconomic and environmental challenges (Das, 2009; Lu et al., 2004; Pelorosso, 2009).

Due to human-induced climate change, there is a likelihood of alterations in ecosystem services and functioning (IPCC, 2021; Mooney et al., 2009). Projections from the IPCC suggest a minimum temperature increase of 1°C between 2030 and 2050 compared to preindustrial levels (IPCC, 2021). Climate change can manifest various impacts on biodiversity, including population fluctuations (Graae et al., 2018), shifts in species phenology

(Visser & Both, 2005), changes in species distribution ranges (Lenoir & Svenning, 2015), rapid shifts in species composition and diversity (Steinbauer et al., 2018), and localized extinctions (Bosso et al., 2022; Panetta et al., 2018). Following the assessment by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2016, it was acknowledged that certain wild pollinator species have experienced changes in their ranges, abundances, and seasonal activities due to observed climate change in recent decades. The Himalayas exemplify one such vulnerable region where factors such as cryosphere shrinkage, land use changes, vegetation alterations, and biodiversity loss have negatively impacted ecosystem services (Rani et al., 2022). While highly abundant and widely distributed species could extend their ranges, potentially displacing habitat-specialized species to narrower habitats. Endangered species might become confined to specific landscape patches due to difficulties in adapting latitudinally or altitudinally (Freeman et al., 2018). Understanding the repercussions of climate change on species diversity is crucial for devising effective long-term conservation strategies (Ali et al., 2021; Jenkins et al., 2021; Jones et al., 2013; Range et al., 2019).

Ecological Niche Modeling (ENM) assists in elucidating the relationship between species occurrence and environmental factors (Jose and Nameer, 2020), as well as predicting previously unidentified habitats for species (Elith et al., 2011; Paul et al., 2020).

Assessing potential habitats and species distribution is a critical aspect of ecological, wildlife conservation, and environmental studies, as well as evaluating changes across various scales. Species distribution prediction models serve as essential tools in generating potential maps that illustrate the relationships between environmental variables and species occurrence (presence/absence). These models play a crucial role in studying climate change scenarios and their potential impact on the geographic distribution of species. To gain a better understanding of the future effects of climate change, it is essential to comprehend both the current and projected distribution of species, for which various models and methodologies have been developed (Guisan & Zimmermann, 2000; Beaumont et al., 2005). In general, the ecological niche modeling approach integrates species occurrence data with environmental variables selected based on the species' biology. These combined data produce a model representing the species' requirements for the chosen variables (Guisan and Zimmermann, 2000; Rushton et al., 2004). This model is then utilized to generate a map of the study area by projecting it onto a Geographic Information System (GIS) platform, illustrating the potential geographic distribution of the species. Species Distribution Models (SDMs) are invaluable tools for predicting these spatial patterns from geographically and temporally sparse biodiversity data

(Guisan & Zimmermann, 2000; Elith et al., 2006). Species Distribution Models primarily differ in the types of requirements of species records (such as presence only, presence and true absence or presence and background) and the algorithms employed to delineate the species niche using predictors (like regression methods, Bayesian statistics, or machine learning techniques) (Peterson et al., 2011). The maximum entropy (MaxENT) model represents a versatile machine-learning approach that employs the probability distribution of maximum entropy, tailored to the constraints imposed by available occurrence data, to estimate the potential species distribution (Phillips et al., 2006). The underlying concept is that the distribution maximizing information entropy is statistically the most likely to occur (Phillips et al., 2006; Elith et al., 2011).

1.8. Aim and objectives

The primary aim of this study is to examine the impact of different land use practices and landscape composition on the diversity and distributional range of pollinators in the Kullu and Tirthan valleys of Himachal Pradesh.

Both natural phenomena and human activities significantly influence the formation of landscapes across varying spatial and temporal scales, resulting in noticeable changes across different landscape categories. These interventions leave distinct marks on the landscape, reflecting alterations over time and space and impacting the associated living communities. The extensive and diverse landscape, characterized by various agroclimatic zones, LULC types, and elevational gradients, is expected to play a crucial role in shaping the composition and dynamics of pollinator populations across different regions. Observations also suggest that climate change can greatly alter the distribution ranges and patterns of animals and plants, including insect communities, in diverse ways. These changes are particularly evident in heterogeneous landscapes like the Himalayas, where the effects can be notably pronounced. The complex topography and diverse ecosystems of the Himalayas amplify the effects of climate change on species distributions and interactions.

The research seeks to compile a comprehensive list of entomofauna pollinators found in apple and plum orchards across various LULC categories and elevational gradients within the study area, a western Himalayan landscape. Furthermore, the study also aims to underscore the importance of conserving the entomofauna pollinators of the IHR by elucidating species diversity and highlighting the distribution range of key pollinators under current climatic conditions, as well as predicting potential shifts in distributional range in future climate

scenarios. This systematic approach will contribute to a deeper understanding of pollinators and their interactions within the mountain horticultural belt of the IHR. By analyzing the influence of land use practices and landscape composition on pollinator diversity and distribution in this study I have tried to provide valuable insights into the factors shaping pollinator communities in this ecologically sensitive region. Additionally, by assessing the potential impacts of climate change on pollinator distribution, the research aims to inform conservation strategies for preserving the rich biodiversity of entomofauna pollinators in the Kullu and Tirthan valleys of Himachal Pradesh.

With the aforesaid aim in focus, I have tried to address three major research questions under the following three objectives in my thesis:

- **Objective 1:** To assess the change in landscape composition of the study area over time.

Research question: How has the landscape evolved over time in response to diverse natural and anthropogenic interventions?

Hypothesis: There will be significant alterations among various LULC categories of this area over the decades.
- **Objective 2:** To assess the effect of change in landscape configuration and horticultural practices on pollinator community (diversity and abundance) and their services.

Research question: Does the diversity of pollinators vary across different landscape configurations within the mosaic landscape of Kullu district?

Hypothesis: There will be a significant difference in diversity of different insect pollinators along different landscape configurations of the area.
- **Objective 3:** To model the distribution of major pollinators of economic importance belonging to different groups (Hymenoptera, Lepidoptera, Coleoptera, Diptera) in the study area.

Research question: What are the distribution patterns of major insect pollinators within the landscape, and are there anticipated shifts in response to future climate scenarios?

Hypothesis: There will be a significant difference between the present and future distribution patterns of insect pollinators in different future climatic scenarios with varied responses in this landscape.

1.9. Thesis organization

The thesis comprises seven chapters arranged in the following sequence and each chapter contributes to the overall structure and content of the thesis,

Chapter I (Introduction): This chapter serves as an introductory framework for the study, elucidating the rationale behind undertaking the study and clearly delineating its objectives and scope, laying out the groundwork for the subsequent chapters. Additionally, it establishes the specific goals that the research aims to achieve. By delineating the scope, the chapter sets clear parameters ensuring focused and coherent research. Overall, this chapter plays a crucial role in contextualizing the study and guiding the reader's understanding of its purpose and direction.

Chapter II (Study area): In this chapter, the primary emphasis is on providing a comprehensive description of the study area, encompassing its topographical features, climatic conditions, soil composition, and any other pertinent geographical details, physical traits, and the rich tapestry of biodiversity it supports. Additionally, a more detailed understanding of the intensive study area has also been discussed.

Chapter III (Study design and methodologies): This chapter offers detailed insights into the sampling design and methodologies employed in defining the sampling location, data collection, and analysis. This includes details on the selection of sampling sites as per different LULC classes and other important factors, the techniques utilized for sample collection, and the protocols followed to preserve their integrity during transportation and storage. Furthermore, the chapter sheds light on the analytical approaches adopted to examine the collected samples.

Chapter IV (Assessment of spatio-temporal changes in landscape composition over time): In this chapter, the first objective is accomplished through a thorough analysis that tracks the evolution of the landscape spanning the period from 2000 to 2022. This analysis delves into the intricate changes observed in the LULC classes over the specified timeframe. By scrutinizing historical data and employing spatial analysis techniques, remote sensing data, and GIS to visualize and interpret the observed changes effectively, the chapter provides a detailed account of how the landscape has transformed over the past two decades. By employing these tools and methodologies, the analysis gains depth and accuracy, enabling more accurate scenarios of the landscape's evolution over time.

Chapter V (Effect of change in landscape configuration and horticultural practices on pollinator community): In this chapter, the second objective is addressed through a systematic approach of compiling a comprehensive inventory of insect pollinator diversity observed across different landscape configurations within the study area. Additionally, the chapter assesses how different landscape configurations influence pollinator communities. This analysis entails assessing the relationships between pollinator richness, diversity, and abundance with landscape elements, such as the presence of natural forests, elevational gradients, presence of agricultural land and large settlements, and management practices. Overall, this chapter plays a critical role in explaining the intricate connections between landscape structure and pollinator diversity, providing valuable insights into the factors influencing pollinator populations and their ecological roles within the study area.

Chapter VI (Modelling the distribution of major pollinators of different orders): This chapter focuses on the third objective, aiming to evaluate the distribution ranges of major pollinators within the study area as well as across the entire state of Himachal Pradesh. This involves a comprehensive assessment of the spatial distribution patterns of key pollinator species, encompassing factors such as climatic conditions and elevation. To identify spatial patterns, and richness hotspots of pollinators field surveys, ecological modeling techniques, and remote sensing data have been employed. Furthermore, the chapter investigates how future climate conditions may impact the distribution of these pollinators under different scenarios by employing ecological niche modeling. Overall, this chapter plays a critical role in developing an understanding of the spatial dynamics of pollinator distributions and their vulnerability to climate change within the context of Himachal Pradesh and underscores the importance of proactive conservation efforts to safeguard their long-term survival.

Chapter VII (Syntheses and recommendations): In the final chapter, the conclusion of the study is presented through a comprehensive overview of the key findings and insights gleaned from the research. This section serves as a synthesis of the preceding chapters, drawing together the analysis, results, and conclusions to provide a holistic understanding of the study's outcomes. In addition to summarizing the findings, the final chapter concludes with constructive recommendations for future research directions and practical interventions. These recommendations encompass strategies for enhancing pollinator habitat and fostering community engagement in conservation efforts. By proposing actionable suggestions justified in the study's findings, this section aims to contribute to informed decision-making and sustainable management practices.



Chapter 2: Study Area

2.1. Overview

The Indian Himalayan Region (IHR) stands as majestic evidence of the beauty and ecological diversity that characterizes this unique geographical region. Spanning across the northern part of India, the Himalayas extend over 2,400 kilometers, serving as a natural boundary between the Indian subcontinent and the Tibetan Plateau. This region is home to some of the world's highest peaks, including Mount Everest. The Himalayas play a crucial role in shaping India's climate, influencing the monsoon patterns and acting as a source for major rivers like the Ganges, Brahmaputra, and Yamuna. Beyond its geological significance, the IHR harbors rich biodiversity, providing habitat to numerous plant and animal species, many of which are endemic to the region. The Himalayas also hold cultural and spiritual significance, with various pilgrimage sites and ancient monasteries nestled amidst the towering peaks. The delicate balance of ecosystems, the challenge of sustainable development, and the resilience of local communities characterize the complex tapestry of the IHR.

Nestled in the lap of the mighty Himalayas, the Kullu district of Himachal Pradesh, India, stands as a pristine haven of ecological richness and biodiversity. The district falls in toposheet No. 53E/NW and spans between latitudes 31°41' and 31°58' and longitudes 77°10' and 77°21', bordered by Lahul and Spiti, Kinnaur, Mandi, and Kangra districts to the North, Northeast, East, West, and South of Kullu respectively, encompassing a total area of 5503 square kilometers. This district lies in central Himachal fall in the biogeographic zone Himalaya (2) and biogeographic province Himalaya: North-West (2A) (Rodgers & Panwar, 1988 and Rodgers et al., 2002). Kullu is renowned for its lush forests, vibrant flora, and diverse fauna. The dense coniferous and broad-leaved forests that cloak the hillsides are home to numerous plant and wildlife species. Kullu district hosts a diverse array of fauna, including Himalayan brown bears, snow leopards and common leopards, musk deer, and a variety of bird species including pheasants. The forests of this region play a vital role in maintaining ecological balance, regulating water flow, and preventing soil erosion. The ecological significance of Kullu district extends beyond its borders, contributing to the overall health and resilience of the Himalayan ecosystem (Gardner & Saczuk, 2004).

2.2. General profile of the district

Kullu district possesses a distinctive geography characterized by mountainous terrains, with approximately 90% of its population residing in villages located in remote and hard-to-reach areas. It comprises four subdivisions: Manali, Kullu, Banjar, and Anni, as well as five

developmental blocks: Naggar, Banjar, Kullu, Anni, and Nirmand. The entirety of Kullu district falls under the Mandi parliamentary constituency. The district is prone to frequent natural disasters, resulting in significant loss of life and property.

2.2.1. Physiography

Kullu district, nestled in the lesser Himalayas, boasts a complex system of mountain ranges formed through successive compression movements of the earth's crust (Burrard & Hayden, 1933). It is bordered by the Pir-Panjal range to the north, Bara Bhangal to the northwest, the Greater Himalayas to the east, and the Dhauladhar range to the southwest, with the River Sutlej demarcating its southern boundary. Spanning altitudinal gradients from 750 to 6200 meters, the district exhibits diverse geomorphological features shaped by both glacial and fluvial processes (Sah & Mazari, 2007). The landscape of Kullu can be broadly categorized into glaciers and permanent snow fields, rocky or barren slopes, valley slopes and ridges, and the main valley floor. Glaciers and permanent snow fields are prevalent in the eastern regions above 4500 meters, while barren or rocky surfaces dominate the lower sections of glaciers and permanent snow fields. Valley slopes, occupying a significant portion of the district, encompass steep to moderately steep inclines, ridges, and narrow valleys with slopes typically ranging from 30 to 40 degrees. The primary valley floor along the River Beas is characterized by outwash fans, alluvial fans, and river terraces.

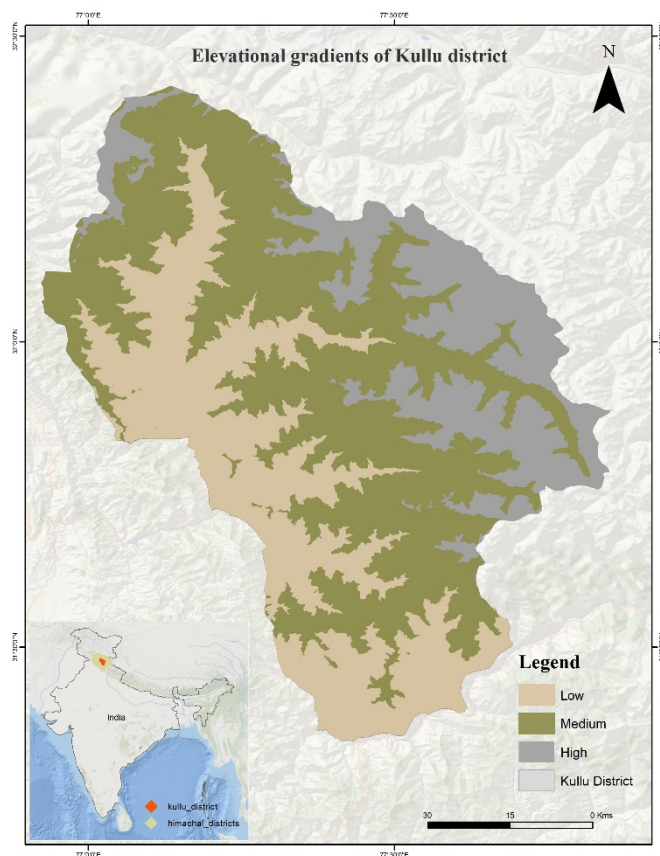


Figure 2.1. Map of elevational gradients of Kullu district

2.2.2. Geology

The district encompasses a variety of rock types, including phyllite, slate, quartzite, limestone, schists, and granites. These rocks have been categorized based on their physical characteristics, mode of formation, and the period during which they were formed. They are

often named after either their rock type or the local areas where they were initially studied. These groupings include central gneiss, Kullu formation, Banjar formation, and tourmaline granites. The central gneiss, believed to be the oldest rocks formed over 1,500 million years ago, consists of various types of gneissic rocks layered with quartzite, granite, and pegmatites. This extensive formation also contains thick layers of grey dolomite and pink limestone, as well as slate, phyllite, and quartzite. Tourmaline granites are thought to be intrusive in nature and are likely responsible for the high radioactivity observed in the area, where numerous hot water springs are found (<https://hpgeneralstudies.com/brief-geography-of-district-kullu-himachal-pradesh/>).

2.2.3. Major rivers

The primary river that flows through the majority of the Kullu district is the Beas river. Alongside the Beas, there are three secondary rivers, that play significant roles in the district's drainage system, viz., river Parvati, which traverses through the central part of the Kullu district, river Sainj drains the central southern part of the district, and river Tirthan flowing through the southern part of the district. All these rivers serve as a vital lifeline for the surrounding areas, providing water for irrigation, domestic use, and other purposes contributing to water resources and the overall ecosystem of the district. In the extreme southern part of the district, there are two smaller tributaries as well, and all of them together join the river Sutlej in the Shimla district. Overall, the intricate network of rivers and tributaries in the Kullu district forms a crucial part of its geographical and ecological makeup, shaping the landscape, supporting livelihoods, and sustaining biodiversity. Their eventual convergence into larger rivers like the Sutlej further

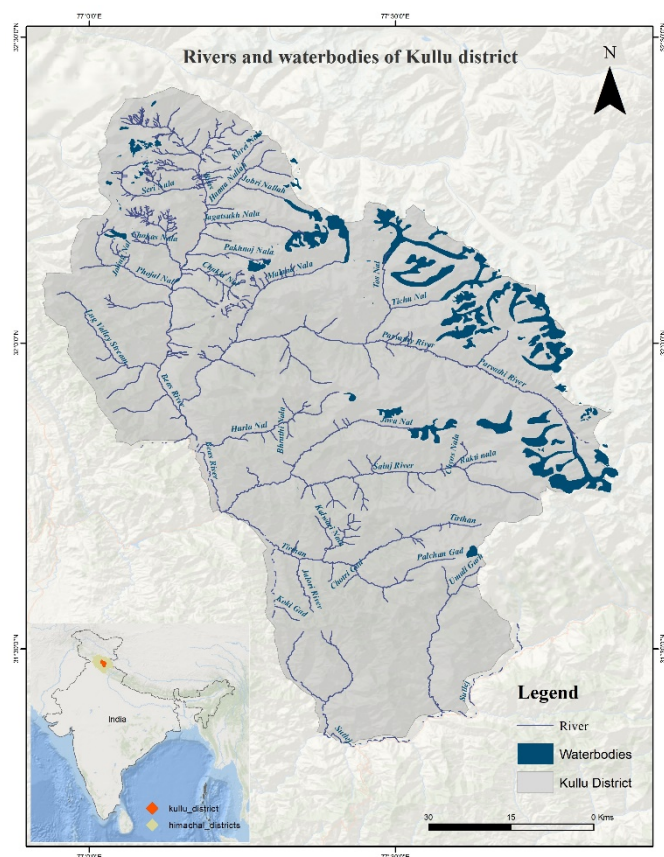


Figure 2.2. Map of rivers and waterbodies of Kullu district

underscores their importance in the broader context of regional hydrology and water resource management (<https://docslib.org/doc/10063249/survey-document-district-kullu>).

2.2.4. Climate

Kullu district experiences diverse climatic conditions, characterized by cold and dry weather throughout the year. The year can be broadly categorized into three main seasons: Summer (March to June), Rainy (July to September), and Winter (October to February). During the summer months, daytime temperatures can reach up to 30 °C, while nights remain cool. From December to February, the weather becomes very chilly, often accompanied by heavy frost. Snowfall typically occurs during December and January, with occasional early snowfalls in November. During this period, much of the district is covered in snow, with minimum temperatures dropping below freezing. Annual average rainfall varies significantly across different parts of the district, ranging from 577mm to over 1150mm. Snowfall during winter often extends to elevations as low as 1300 meters above sea level. During the rainy season, natural calamities such as cloud bursts and heavy floods have occurred in the district over the past two to three decades.

Table 2.1. Min. Temperature °C (°F), Max. Temperature °C (°F), Precipitation / Rainfall mm (in), Humidity, Rainy days, avg. Sun hours (Data: 1991 – 2021; source: climate-data.org)

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	-1.2 °C (29.9) °F	0.8 °C (33.5) °F	4.4 °C (39.9) °F	9 °C (48.2) °F	13.1 °C (55.6) °F	16 °C (60.9) °F	17.3 °C (63.1) °F	16.9 °C (62.3) °F	14.5 °C (58) °F	9.7 °C (49.4) °F	5.1 °C (41.1) °F	1.1 °C (34) °F
Min. Temperature °C (°F)	-7.8 °C (17.9) °F	-5.8 °C (21.5) °F	-3.6 °C (25.4) °F	0.4 °C (32.6) °F	4.3 °C (39.7) °F	9.2 °C (48.5) °F	14.1 °C (57.3) °F	14 °C (57.3) °F	9.2 °C (48.6) °F	2.1 °C (35.8) °F	-2.2 °C (28) °F	-5.7 °C (21.7) °F
Max. Temperature °C (°F)	5.7 °C (42.2) °F	7.1 °C (44.8) °F	11.3 °C (52.3) °F	16.2 °C (61.1) °F	20.2 °C (68.4) °F	21.5 °C (70.7) °F	20.6 °C (69) °F	20 °C (68) °F	19.1 °C (66.4) °F	16.5 °C (61.7) °F	12.8 °C (55) °F	8.9 °C (48) °F
Precipitation / Rainfall mm (in)	124 (4)	171 (6)	149 (5)	105 (4)	114 (4)	219 (8)	582 (22)	536 (21)	177 (6)	44 (1)	30 (1)	55 (2)
Humidity(%)	55%	58%	56%	53%	54%	66%	85%	86%	76%	62%	51%	49%
Rainy days (d)	9	10	10	11	17	19	22	22	17	8	4	4
avg. Sun hours (hours)	8.2	8.4	9.6	10.6	10.7	9.4	6.3	5.7	8.1	9.1	9.0	8.6

2.2.5. Agriculture and Horticulture

The agricultural and horticultural practices in this region differ from those in other parts of India because of the distinctive climate and landscape of the Himalayas. The mountainous terrain significantly shapes both the methods used and the types of crops grown.

In the Kullu district, agriculture primarily adopts the method of terrace cultivation, where narrow strips of mountain slopes are thoroughly leveled to create arable land. The soil quality in these terraced fields is often less than ideal, characterized by nutrient deficiencies, rocky patches, and the presence of small stones. The region's high altitude contributes to a harsh climate, impacting agricultural productivity. While cultivation is feasible in valleys with altitudes around 1500 meters above sea level for most of the year, it becomes increasingly challenging in areas surpassing 2500 meters, particularly during the summer months. Despite these challenges, agriculture remains the backbone of the local economy, sustaining livelihoods in remote villages where alternative means of income are limited. The area relies solely on rainfall for irrigation, making it vulnerable to erratic weather patterns such as monsoon failures and heavy snowfall. Furthermore, the rugged terrain exacerbates issues of accessibility and transportation, posing additional hurdles for farmers in accessing markets and essential resources (<https://docslib.org/doc/10063249/survey-document-district-kullu>).

Horticulture plays a pivotal role in the economic profile of the district. Over the past three decades, Kullu has witnessed remarkable advancements in horticulture. There is a growing emphasis on this sector due to the district's favorable geographical features and climatic conditions, which are ideally suited for fruit cultivation. Among the various fruits cultivated in Kullu, apples are predominant and constitute the most significant commercial fruit crop. According to government records (eudyan.hp.gov.in), the cultivated area under apple cultivation reached 27,390 hectares in 2023. The annual apple production typically ranges between 100,000 to 150,000 metric tons. However, the apple belt in this region is shifting towards higher altitudes due to climate change, which has adversely affected lower areas and led farmers to shift to other cash crops (Singh et al., 2014). Apple productivity in the district has decreased over the last decade, with a decreasing trend of 0.183 tons/ha/year (Chand et al., 2016), however a little improvement in the production observed since 2019. Plum is the second highest-producing fruit crop in Kullu district which has approximately 2,225 ha. area under cultivation with a production of 8,152 metric tons of plum in the year 2023 (eudyan.hp.gov.in). Apart from apples and plums, other major varieties of fruits grown in Kullu are peach, apricot, cherry, pear, pomegranates, and kiwi as well as nuts, especially almonds and others (Ahmad et al., 2021). These fruit plantations cover an area of 1,709 hectares with an annual production of approximately 8,023 metric tons (eudyan.hp.gov.in). The traditional horticultural practices in Kullu, coupled with modern techniques and varieties, contribute to a bountiful harvest. The cultivation of fruits not only supports the local economy but also adds to the visual splendor of

the landscape, with blossoming orchards painting the hills in hues of pink and white during the spring season (<https://docslib.org/doc/10063249/survey-document-district-kullu>).

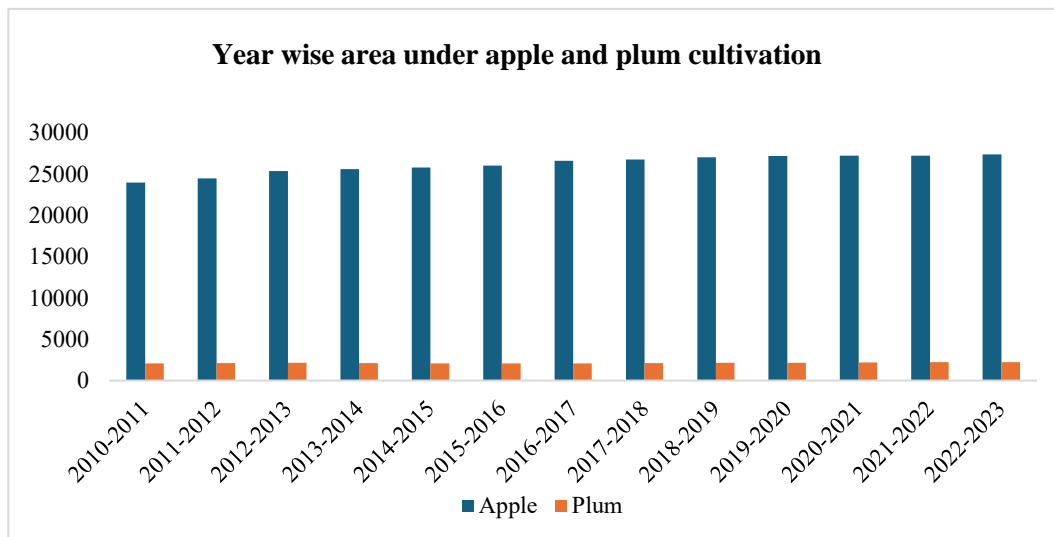


Figure 2.3. Year wise area under apple and plum cultivation in Kullu district over last decade (eudyan.hp.gov.in)

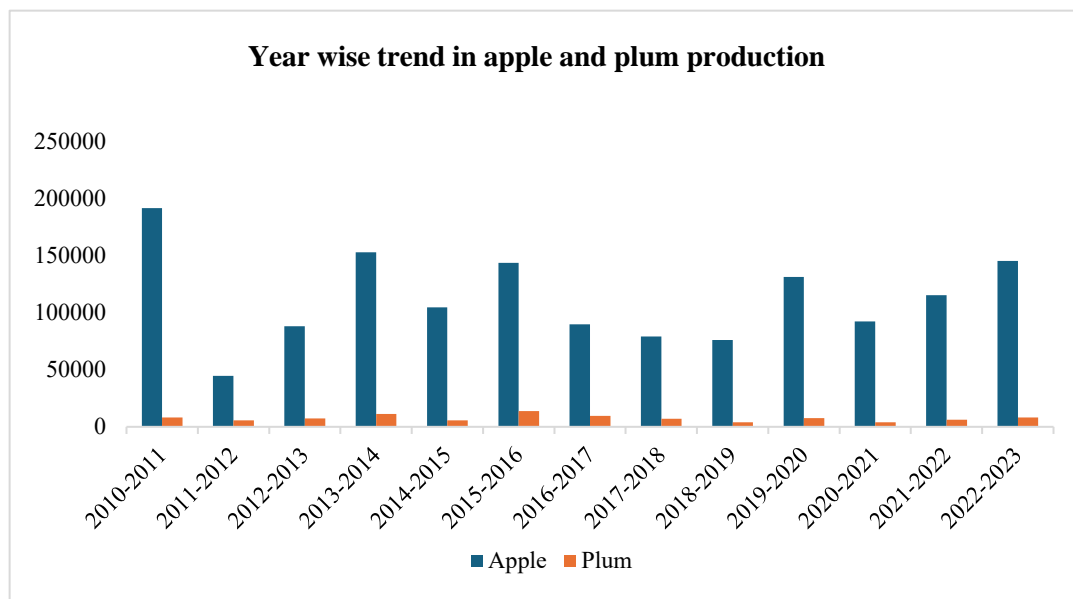


Figure 2.4. Year wise trend in apple and plum production in Kullu district over last decade (eudyan.hp.gov.in)

2.2.6. Landuse and Landcover

Historical records on land use in Kullu district during the 19th and early 20th centuries indicate that land utilization was organized around village-based areas. Forests and pasture lands were commonly considered as communal property belonging to the villages. Following

independence, the region experienced significant socio-economic developments attributed to improved connectivity with the outside world. This led to a notable expansion in the cultivation of cash crops and the establishment of settlements (Tucker, 1982; Saczuk, 2001; Gardner et al., 2002). Changes in forest cover and the emergence of apple orchards were particularly evident in the Beas valley. From the 1970s onwards, the district underwent drastic transformations due to developmental activities. The construction of roads spurred the development of horticulture and connected the area to other regions, resulting in increased tourism and economic opportunities. Analysis of remotely sensed data from the early 1970s reveals that approximately 40% of the district's total area was covered by permanent snow or glaciers and rocky or barren surfaces, with both classes sharing a similar proportion. Over the past four decades, there has been a consistent decline in snow cover, leading to an increase in rocky or barren surfaces, either in previously snow-covered areas or in barren land just below the permanent snow line. Snow cover decreased by approximately 10%, while barren surfaces increased by around 9% between 1972 and 2005. However, forest cover in the area has not undergone significant change, experiencing only a 6% reduction.

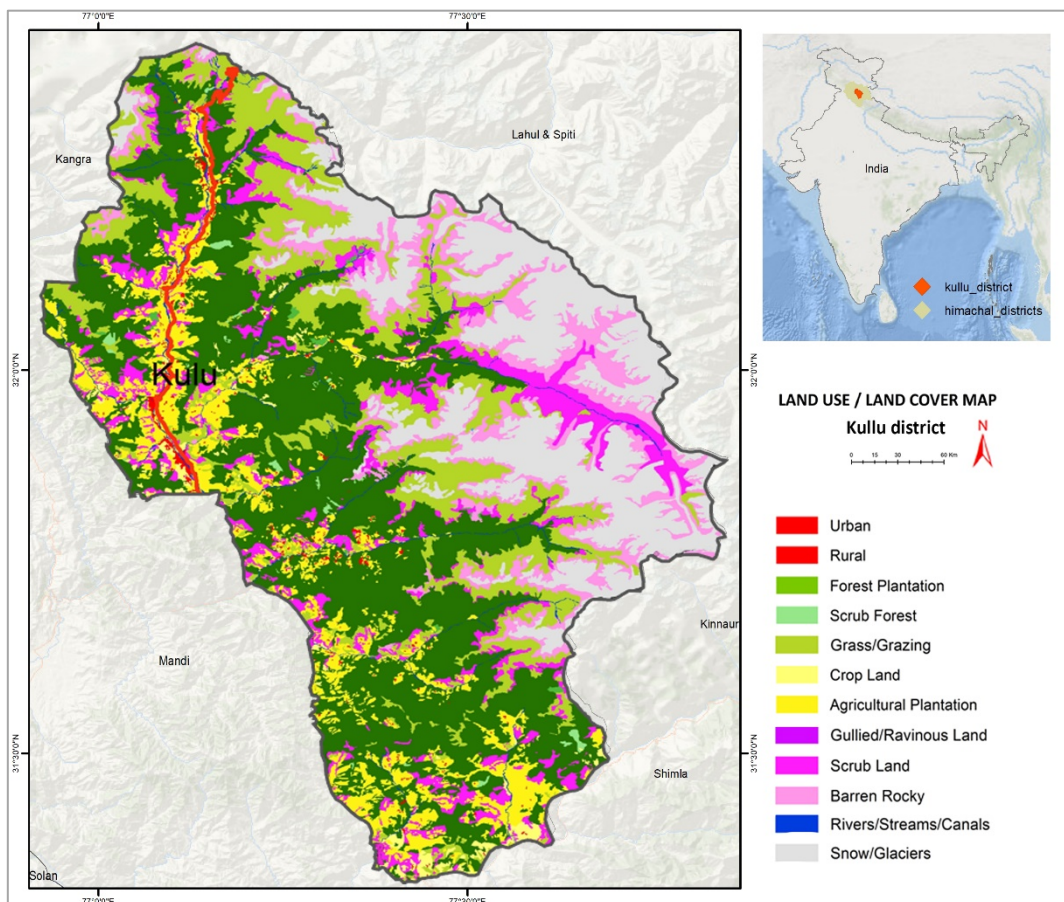


Figure 2.5. Map of Land Use Land Cover (LULC) of Kullu district

2.2.7. Forest profile

The forests in Kullu district hold significant importance as they are part of one of India's four biodiversity hotspots. These forests are home to a diverse array of plant and animal species, including some that are exclusive and endemic to the region. Table 2.2 provides an in-depth overview of the forest profile for the Kullu Forest Circle, detailing the administrative structure, forest cover, types of forests, and the network of protected areas. Further trend in forest cover change of this district is shown in figure 2.6.

Table 2.2. Forest profile of Kullu Forest Circle (Source: HPFD, 2021)

Forest area	Geographical Area (sq. km): 5503	Total Forest Area (sq. km): 1,975.57	Percentage (%) of Forest Area in the district: 35.9	Percentage (%) of Forest Area of state: 3.54
Forest status of different forest divisions of Kullu Forest Circle	Reserved (sq. km): 129.05	Demarcated Protected (sq. km): 2458.96	Un-demarcated Protected (sq. km): 6166.7	Total area
Kullu	3.25	408.56	204.48	616.29
Parvati	45.1	1534.07	190.45	1769.62
Seraj	10.16	119.72	140.57	6098.35
Lahaul	70.54	396.61	5631.2	270.45
Forest Cover	Very Dense (sq. km): 586.08	Moderately Dense (sq. km): 879.25	Open Forest (sq. km): 510.96	
Protected Area network	<ol style="list-style-type: none"> 1. Great Himalayan National Park 2. Khirganga National Park 3. Inderkhila National Park 4. Kais Wildlife Sanctuary 5. Kanawar Wildlife Sanctuary 6. Khokhan Wildlife Sanctuary 7. Manali Wildlife Sanctuary 8. Sainjh Wildlife Sanctuary 9. Tirthan Wildlife Sanctuary 			
Major Forest Types in the different forest divisions	Kullu Wildlife Division	Tropical Dry Deciduous Forest		
	Division – Kullu, Parvati, Seraj, Lahaul	<ol style="list-style-type: none"> 1. Sub-tropical Pine Forest, 2. Himalayan Moist Temperate Forest, 3. Himalayan Dry Temperate Forest, 4. Sub-Alpine Forest, 5. Moist Alpine Scrub, 6. Dry Alpine Scrub 		

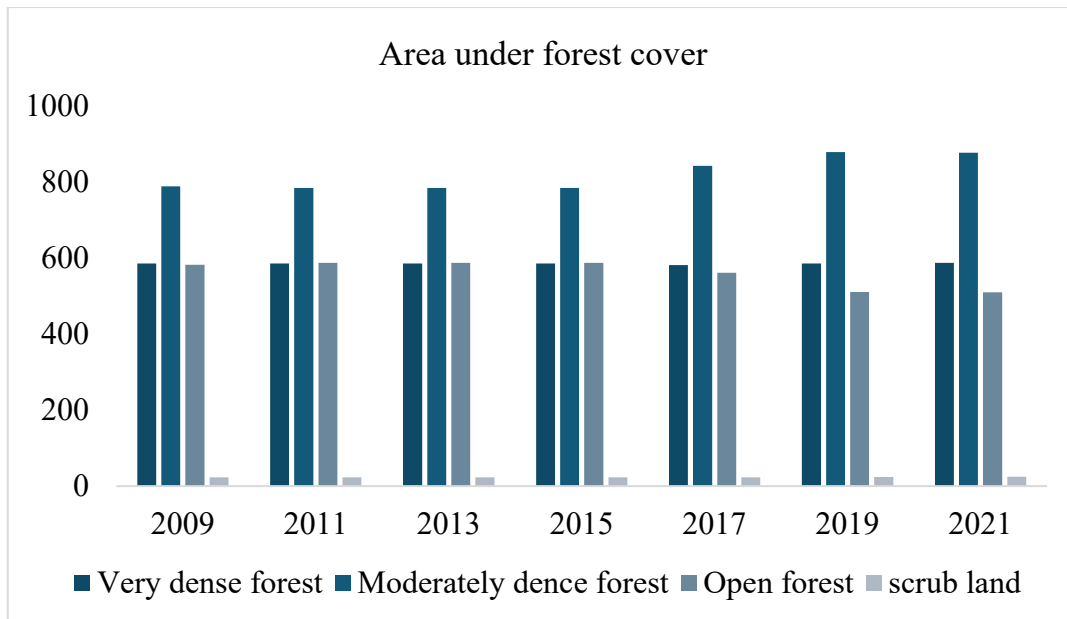


Figure 2.6. Trend of change in the forest cover of Kullu district in last ten years

2.2.8. Flora and Fauna

Kullu district is renowned for its rich biodiversity, contributing significantly to the ecological wealth of Himachal Pradesh. The state boasts 36 Protected Areas (PAs) covering a total area of 8153.893 square kilometers, of which Kullu district alone houses six Wildlife Sanctuaries (WLS) and three National Parks (NP). This network of PAs forms the largest contiguous protected area network in the Western Himalayan landscape, highlighting the region's importance in terms of wildlife (flora and fauna) diversity. The forests of Kullu district exhibit a diverse range of vegetation, representative of the Himalayan region. From dry scrub vegetation with broad-leaved trees in the lower Shivalik mountains to dense coniferous and oak forests in the mid-hills, and alpine pasturelands above the treeline, the flora of Kullu is characterized by its richness and variety. Important species include medicinal plants like *Dactylorhiza hatageria* and *Saussurea obvallata*, alongside conifer trees such as pine, spruce, fir, and deodar.

Among the protected areas, the Great Himalayan National Park (GHNP) stands out as a biodiversity hotspot, harboring a multitude of flora and fauna. The park boasts an impressive 832 plant species spanning across 427 genera and 128 families, representing approximately 26% of Himachal Pradesh's floral diversity. Additionally, GHNP provides habitat to a diverse array of wildlife, including 31 species of mammals, 209 avifauna, 12 reptiles, nine amphibians, and 127 recorded insect species, many of which are of conservation concern (FREEP, 1999). The forests of Kullu district serve as crucial habitats for several charismatic and endangered

species. Among them are the elusive snow leopard, Himalayan Thar, Serow, Musk Deer, and Himalayan brown bear. Furthermore, the region provides a sanctuary for threatened bird species such as the Western Tragopan, Cheer Pheasant, and Koklas Pheasant, emphasizing its importance for avian conservation efforts (Dikshit & Dikshit, 2014).

In summary, the Kullu district and its surrounding areas represent a biodiverse and ecologically significant region within the Western Himalayas, characterized by its varied vegetation, diverse wildlife, and commitment to conservation through an extensive network of protected areas.

2.3. Intensive study area

The intensive study area for this research in the Kullu district encompasses two major valleys: the Kullu Valley, situated along the Beas River, and the Tirthan Valley, situated along the Tirthan River. The Kullu Valley stands out as a significant horticultural hub, experiencing heightened tourism and considerable anthropogenic activity. It features diverse land use patterns with a mosaic-like nature, making it an ideal location for investigating the impact of LULC changes on pollinator communities. Conversely, the Tirthan Valley is designated as a conservation area, characterized by minimal disturbance and dense forest cover, providing a habitat for a variety of wild and rare pollinator species. Thus, the Tirthan Valley was chosen as a study site to gain insights into the status of pollinator communities within a less disturbed landscape.

2.3.1. Kullu Valley

The valley extends primarily up to 3-4 kilometers on either side of the Beas River, as well as the lower reaches of its major tributaries such as the Parvati and Tirthan rivers. It encompasses the majority of Manali and Kullu tahsils, along with the Sainj sub-tehsil and a small portion of the Banjar tehsil. The main Kullu valley falls between the Pir-Panjal Himalayas and the Northern edge of the Dhauladhar or Bhangal region within 32°21'13.90"N latitude and 77°7'38.57"E longitude to 31°43'27.64"N latitude and 77°12'52.54"E longitude. The valley has been formed by the Beas River between Manali and Largi over a stretch of 76 kms. and lies at an elevation ranging between 833m to 3330m. The valley is narrow in the north and widens considerably in Kullu, as well as in the central and southern parts of the Manali tahsils. The slope of this valley rises gradually from the riverbanks and is densely covered with various orchards. The Beas River originates in the Pir Panjal range near the Rohtang Pass and enters the region near Rohla from the north. Flowing through the central part of the region in a

southerly direction until Aut, where it is joined by the Tirthan river, which merges with the Koki and Sainj khads before joining the Beas from the south. The combined course then flows westward. A significant tributary of the Beas in this area is the Parvati river, which also receives water from Malana nalla and Tos nalla before joining the Beas on its left bank near Bhuntar town. Other minor tributaries include Manalsu, Solang, Phojal, Debar, Sanjoin, Siriv nalla, and Sarwari khad on the right side, and Chaki, Pakhnoj, Duhangan, Aliaini, and Hurla nalls on the left side. Climate in the region is typically characterized by cold and arid conditions, with the year divided into three distinct seasons: summer, monsoon, and winter. From December to February, temperatures plummet, resulting in extremely chilly weather. Most of the valley experiences snow during winter, although it doesn't linger on the ground for an extended period. The average annual rainfall measures around 80 cm. Maximum temperatures can reach up to 38.8 °C, while minimum temperatures drop to as low as 3 °C during the winter months. The geological composition of the valley primarily consists of middle Proterozoic formations. Granites (unclassified) are found along the northern fringe, while the southeastern part contains Shali-Deoban and Largi groups, as well as Rampur-Banjar formations. The soils in this valley are predominantly orthents-Ustochrepts, with Udalfs type of soil present in the northern extreme. Renowned for its temples, scenic beauty, and majestic hills adorned with pine and deodar forests, as well as vast apple orchards, this valley is a celebrated destination. The course of the Beas River offers a striking panorama, lined with forests of deodar that rise majestically above pine trees on the lower rocky ridges.

2.3.2. Tirthan Valley

Known as 'Himachal's best kept secret', Tirthan valley is situated in Banjar tehsil of the district of Kullu in Himachal Pradesh (31°43'29.63"N and 77°13'20.68"E to 31°36'45.13"N and 77°30'52.72" E) along the bank of river Tirthan over a stretch of 45kms. The valley derives its name from a sacred water spring known as 'Tirath,' which originates at Hanskund Peak (4800 meters) and meanders through deep, untouched forested regions. The spring is the source point of the Tirthan stream which forms the valley between its origin at Tirath and a place called Larji where Tirthan is joined by another stream Sainj. The two ultimately merge into the Beas river further downstream. An important tributary under the Indus river system, the Tirthan river is joined by several tributaries all along its course. Tirthan khad and Palachan gad merge at Gushaini to form the Tirthan river. The region experiences a typical western Himalayan temperate and alpine climate characterized by four distinct seasons: spring, rainy, summer, autumn, and winter. Precipitation levels are moderate throughout most of the year, with

abundant rainfall occurring during the rainy season (Ramesh et al., 1999). During the summer season, average temperatures range between 20°C to 30°C, while in winter, temperatures drop to 0°C to 5°C. The precipitation is mostly in the form of snow during the winter season where higher areas receive heavy to very heavy snowfall. Alpine, sub-alpine, temperate, and sub-tropical coniferous and deciduous forests blanket the entire catchment area of this river. The main geomorphic processes that are active in the area are glacial, fluvial, denudation, and structural where glacial and periglacial processes are dominant in the high-altitude areas and the fluvial process is active in the lower valley floor. Tirthan valley is composed of incised meanders, river-built and river-cut terraces, cliffs, and steep slopes. The area comprises of rocks belonging to three litho-tectonic groups referred to as the Vaikrita group, the Kullu group, and the Rampur/Naraul group comprising mostly schist, gneiss, migmatite, quartzite, marble, phyllite, limestone, white-green quartzite, and basic flows. Due to varied altitudinal zones, physiographic features, and climatic conditions, the Tirthan Valley is home to diverse floral and faunal species marked by a high rate of endemism thereby making it an important biodiversity hotspot. The Great Himalayan National Park (GHNP), a UNESCO World Heritage Site is situated in this valley and spread over an area of 1100 sq. kms.

The national park is surrounded by high ridges and snow-covered peaks in the northern, eastern, and southern parts and thus is open and accessible towards the western side where most of the human settlement is present. Therefore, a buffer zone of 5 km was delineated from the western boundary of the park as ecozone accommodating around 89 villages. GHNP and its eco-development zones situated along Tirthan and Sainj valley are collectively referred to as the Great Himalayan National Park Conservation Area (GHNPCA). The administrative arrangements of the villages in the ecozone have been entrusted to the park administration so that the developmental activities do not impinge upon the biological sensitivity of the buffer zone. There are a total of eight panchayats in the ecozone of the Tirthan valley namely Kandidhar, Kalwari, Shirikot, Nohanda, Pekhri, Tung, Shilhi, and Mashiyar.

In Kullu valley sampling was conducted in altogether 28 plum and apple orchards across the entire valley of 76 kms stretch considering different landscape configurations and types of management practices followed in the orchards to understand their impacts on the diversity and abundance of pollinators in this valley. In Tirthan there are total 14 sampling locations across the valley over a stretch of 45 kms. As the valley is comparatively narrow, less disturbed and none of the orchards are situated far from natural forests, hence, in this valley sampling was done rationally without concerning the landscape configurations. The major varieties of the

plum crops in the sampling sites include Centa Rosa, Mariposa, Red Beaut, Frontier, Black Amber, Fortune, Satluj purple, Methley, Chamba Black, etc. Apple crop varieties include Royal Delicious, Golden Delicious, Vance Delicious, Super Chief, Red Chief, Scarlet Spur, Gale Gala, Red Velox, Golden Spur, Jeromine, Granny Smith, Redlum Gala, Jeromine, Scarlet, Kalidevi, Kingrot, etc. Details of sampling sites for both the valleys have been provided in table 2.3.

Table 2.3. Details of sampling sites

Kullu valley				
Place	Site code	Orchard type	Latitude	Longitude
Jhiri	KL(A)1	Apple	31.8324	77.17377222
Jhiri	KL(P)1	Plum	31.8363	77.1737
Panarsa	KL(A)2	Apple	31.76961111	77.19061111
Jia	KL(A)3	Apple	31.90128889	77.14293611
Jia	KL(P)2	Plum	31.9013	77.1417
Mohal	KL(A)4	Apple	31.90719444	77.11405556
Chharsu	KL(P)3	Plum	31.91841667	77.111
Badah	KL(P)4	Plum	31.93363889	77.11627778
Seobagh	KL(A)5	Apple	31.98208333	77.13044444
Seobagh	KL(P)5	Plum	31.98322778	77.13159722
Kais	KL(A)6	Apple	32.009137	77.135878
Nangabagh	KL(P)6	Plum	32.0363	77.1251
Katrain	KL(A)7	Apple	32.09816667	77.13541667
Katrain	KL(P)7	Plum	32.10444444	77.13630556
Kamarda	KL(A)8	Apple	32.06394444	77.11525
Naggur	KL(P)8	Plum	32.10958333	77.16016667
Ramsu	KL(A)9	Apple	32.11588889	77.18155556
Larenkelo	KL(A)10	Apple	32.08754167	77.14776111
Moila	KL(A)11	Apple	32.16221389	77.16515
Mansari	KL(A)12	Apple	32.15508333	77.17966667
Mansari	KL(P)9	Plum	32.15258333	77.17733333
Jagatsukh	KL(P)10	Plum	32.19513889	77.1996
Jagatsukh	KL(A)13	Apple	32.19404722	77.19690278
Kanyal	KL(A)14	Apple	32.22533056	77.17812222
Vashisth	KL(A)15	Apple	32.26630556	77.18611111
Burwa	KL(A)16	Apple	32.28686111	77.16913889
Solang	KL(A)17	Apple	32.32163889	77.15805556
Kothi	KL(A)18	Apple	32.31272222	77.18561111

Tirthan valley				
Place	Site code	Orchard type	Latitude	Longitude
Banjar	TN(A)1	Apple	31.64183056	77.33775278
Banjar	TN(P)1	Plum	31.64183056	77.33775278
Manglor	TN(P)2	Plum	31.6748	77.2919
Rahi	TN(P)3	Plum	31.70567222	77.26013056
Rahi	TN(A)2	Apple	31.70567222	77.26013056
Sairopa	TN(A)3	Apple	31.6388	77.40039722
Sairopa	TN(P)4	Plum	31.64122222	77.38806944
Gushaini	TN(A)4	Apple	31.64099444	77.41736667
Gushaini	TN(P)5	Plum	31.64099444	77.41736667
Bathad	TN(A)5	Apple	31.6563	77.456
Bathad	TN(P)6	Plum	31.6563	77.456
Sarchi	TN(A)6	Apple	31.618925	77.42115556
Kameda	TN(A)7	Apple	31.61444167	77.51372222
Pekhri	TN(A)8	Apple	31.6482	77.4343

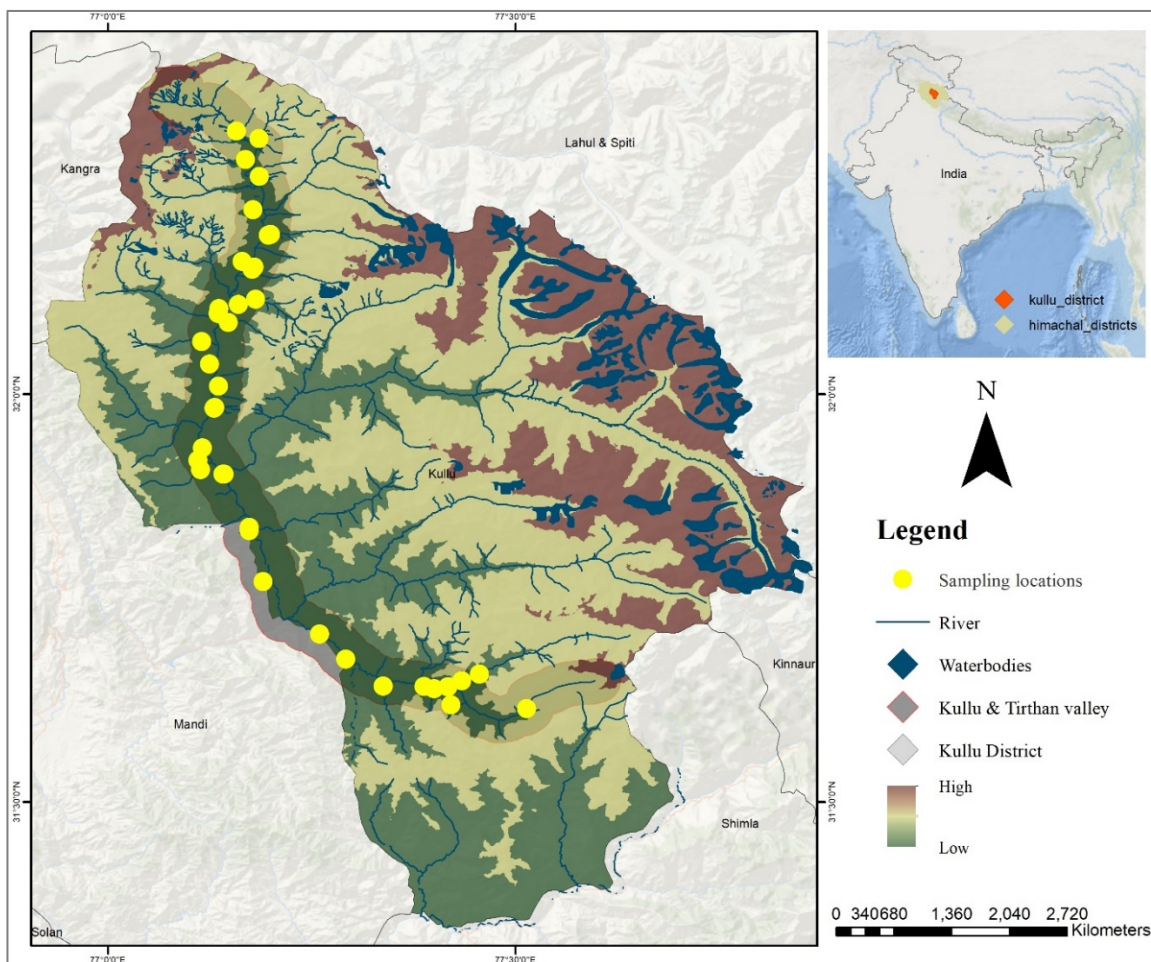


Figure 2.7. Map of the intensive study area

Photo plate 1: Pictorial representation of the landscape



Photo plate 2: Pictorial representation of different types of sampling sites from Kullu and Tirthan valley





Chapter 3: Study Design and Methodologies

3.1. Study design

This study was carefully designed to capture the complex dynamics of pollinator diversity in the Kullu and Tirthan valleys. In January 2021 a reconnaissance survey was conducted in Kullu and Tirthan valley to understand the ground situation and the study design was planned accordingly. The research was conducted across 42 orchards of apple and plum fruits, of which, 28 locations are in the Kullu valley and 14 are in the Tirthan valley. Field sampling was conducted during the full blooming period of apple and plum trees, which typically occurs between February and May and spanned two years, during 2021 and 2022. As pollinators are more active on bright, sunny days, therefore, sampling was strategically planned to avoid windy, rainy days and periods of snowfall. This ensured that the data collected accurately represented the pollinator activity under optimal conditions. The study employed both active and passive sample collection methods along with other primary and secondary data for analysis.

In the Kullu valley, a stratified random sampling method was utilized, with each landscape configuration identified based on the region's LULC. This approach helped in a thorough assessment of the diverse habitats within the valley, each with its unique ecological characteristics and pollinator communities. For data collection at the very beginning, broad locations were identified using satellite data to finalize the area where sampling sites were to be chosen. This was identified depending on the distance of these areas from dense forest patches (viz., less than 1km, 1-2 km and more than 2km), elevational gradients (viz., below 1500m, 1500-2000m and above 2000m) and distance from dense settlements (within 1km and far away from 1km). Further with the help of local researchers and institutes present in these areas, orchards were identified near the selected area and two more land use criteria such as the presence of agricultural land (viz., within 50m of the periphery of the orchard and far from 50m) and orchard management practices (viz., modern and both traditional and modern) were also taken into consideration. Orchards, where management is done entirely using modern tools and techniques with complete clearing of orchard beds and peripheries and complete inorganic practice have been categorized as "modern". However, where orchard beds are not completely cleaned and wild vegetation and grasses are kept in the bed and peripheries, traditional manual management of trees is practiced along with some adaptation of modern tools, and less use of chemical pesticides and insecticides is observed have been categorized under the criteria "both traditional and modern" Orchard owners were contacted gather permission for the sampling. The sampling locations are equally divided in each category to reduce sampling bias.

However, the Tirthan valley, being part of the Great Himalayan National Park (GHNP) Conservation Area, presented a different scenario. After the reconnaissance survey, it was observed that this valley is less disturbed and is characterized by its narrowness and proximity of orchards to dense forest patches. Also, commercial horticultural practices and very large settlements are not present in this area. These factors made it challenging to categorize the sampling sites according to different LULC categories. Therefore, landscape configurations were not considered in this valley for the study, and sampling was conducted randomly at regular intervals across the valley.

After finalizing the sites, a stratified random sampling approach was followed in each site. Sample collection was done within a 50m x 50m plot (figure 3.1) during daylight hours from 9 am to 5 pm in each sampling site. Questionnaire

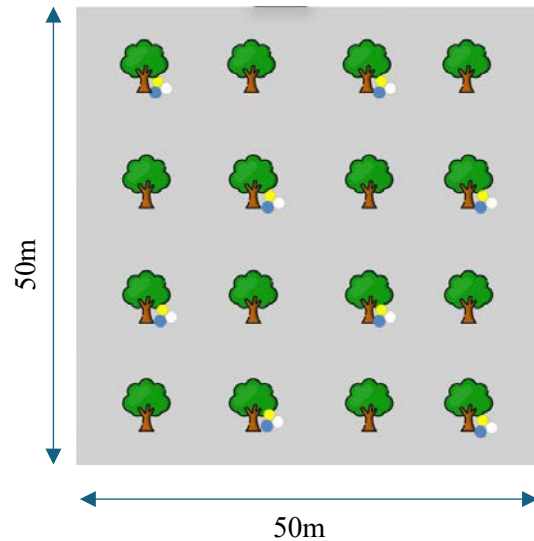


Figure 3.1. Visual representation of the sampling plot.

surveys were conducted in both the valleys with the owners (who showed a willingness to respond) of the orchards where sampling was done to gather information on the use of pesticides and insecticides, management practice, yield, and if any bee-keeping practice adopted.

3.2. Methodologies

3.2.1. Primary data collection

All the primary data were collected by conducting field surveys which included collection of pollinator species visiting apple and plum flowers, gathering observational records on pollinators, questionnaire surveys and collection of GPS points of different LULC features for ground truthing future reference.

3.2.1.1. Pollinator data collection

There are two types of sampling methods used for recording and collecting pollinator specimens which are active sampling and passive sampling. For this study, I have used both types of sampling techniques (figure 3.3).

- **Active method:** Active insect sample collection methods involve direct and hands-on approaches to capture and study insect specimens in their natural habitats. A variety of tools and techniques are used to actively collect insects, such as focal observations, sweep nets, handpicking, and bush beating (Arora, 1990; Joseph, 1990; Gibson et al., 2011). Sweep nets are commonly employed for capturing flying insects in vegetation by sweeping the net through the air. Aspirators use suction to gently collect small insects and arthropods, allowing for careful observation without causing harm. Handpicking involves manually collecting insects from surfaces or plants. These methods are particularly useful for studying the diversity, behavior, and abundance of insects in specific ecosystems. Active collection allows researchers to target specific habitats, microhabitats, or plant species, providing detailed information about insect communities. Focal observations are also used to collect information on foraging methods and record the types of visitors.

- **Passive method:** Passive insect sample collection methods are techniques that do not involve direct interference with insect habitats, but instead rely on traps, baits, or other stationary devices to capture insects over time. These methods are designed to attract, intercept, or retain insects without the need for continuous human involvement. Common passive collection techniques include pitfall traps, malaise traps, light traps, and pheromone traps. One of the most effective passive insect sample collection methods is the use of pan traps. These traps consist of shallow containers, often colored UV bright yellow or blue to attract a broad range of insect species, filled with soap water (Westphal et al., 2008). Placed strategically in the study area, the pan traps passively attract and capture various flying insects that mistake the colored surfaces for flowers or other desirable habitats. The soapy water prevents the insects from escaping, and over a specified period, the accumulated specimens provide valuable data on the local insect community. Pan traps are particularly effective for sampling bees, wasps, and other flying insects, offering a non-intrusive and standardized method for assessing insect abundance and diversity. This technique allows the collection of valuable information without disrupting the natural behavior of the insects, providing insights into their distribution and activity patterns within a given ecosystem.

For this study, focal observations, sweep netting, handpicking as active methods, and pan trapping as passive sampling method were used. For focal observations (Gibson et al., 2011), pollinators were recorded for 10 minutes within 1m x 1m plots along flowering branches of the randomly selected trees at three different time frames: 09:30-10:30 h, 12:30-1:30 h, and 15:30-16:30h. Total five trees were randomly chosen within the 50m x 50m plot apart from the trees

where pan traps were deployed to reduce disturbance. Bees have a nuanced visual physiology and can distinguish flowers with ultraviolet and iridescent patterns (Whitney et al., 2009). They have a trichromatic vision with high sensitivities at 350 nm, 440 nm and 525-570 nm (Peitsch et al., 1992; Skorupski et al., 2007) which is seen as ultraviolet, blue and green to yellow-green colors. Hence, the pan traps, colored in UV-bright yellow, white, and blue colors (Westphal et al., 2008) and filled with soapy water, were arranged in clusters (figure 3.1). 15 Pan trap clusters were put randomly in each 50m x 50m plot in the morning around 8.30 to 9 am and were collected in the evening around 5.30 pm before sunset.

3.2.1.2. Questionnaire surveys

A survey involving semi-structured questionnaires was conducted with 35 farmers and orchard owners to gain insights into their management practices, annual yields, and the usage of pesticides and insecticides. The data collected also included information on crop varieties, pollinizer amounts, and the adoption of commercial bee hives for pollination. These details were then utilized for assessment of the impact of cropping and management practices on pollinator diversity in the study area.

Initially, the research also aimed to investigate the influence of pesticide use on the pollinator community. However, survey data indicated that none of the horticultural farms in Kullu valley adhered to entirely organic practices. Farmers cited high market demand, commercial farming necessities, and significant economic dependence as reasons for avoiding risk and experimental practices. Nevertheless, a few farmers reported engaging in mixed organic farming, incorporating a limited number of inorganic substances such as pesticides and insecticides. Consequently, this criterion was excluded from further analysis.

3.2.1.3. Ground truthing point collection

This study also includes LULC change analysis of the study area over the past two decades. Hence, apart from the pollinator data collection, coordinates were collected for different LULC categories for future reference for ground truthing. Ground truthing data collection involves the process of validating or calibrating remote sensing data by collecting on-site information or measurements. This methodology is crucial for ensuring the accuracy and reliability of remote sensing data interpretations. Ground truthing typically involves physically visiting locations within the study area to gather information on land cover types,

vegetation characteristics, or other relevant environmental parameters. Field observations, measurements, and sample collections are conducted to provide direct evidence that can be compared with remote sensing data outputs. Ground truthing helps to identify potential errors, assess the performance of classification algorithms, and refine interpretation techniques. Additionally, it contributes to enhancing the overall quality and credibility of remote sensing-based analyses and findings.

3.2.2. Preservation and identification of pollinators

Insects obtained through sweep netting and handpicking were carefully transferred to a killing jar containing Ethyl Acetate ($C_2H_8O_2$) for a minimum of 15 minutes or until they became unconscious. Subsequently, these desiccated specimens were placed in collection pouches labeled with field codes for easy transport from the field. The collected insects were then meticulously spread using insect spreading

boards, pinned, and subjected to drying under a warm bulb, following the established protocol (Grootaert et al., 2010). The stretched and dried specimens were finally stored in insect storage boxes. During the labeling process, the labels were arranged in a standardized order from top to bottom (figure: 3.2) beginning with Locality, followed by additional locality/voucher label/accession numbers, and concluding with

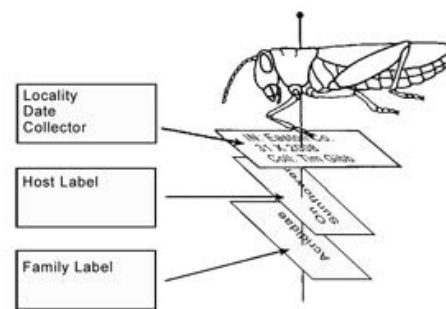


Figure 3.2. Standard labelling process of pinned specimen (source: Wikipedia)

insect identification details, following the guidelines outlined by Uys and Urban (2006). Phenol (C_6H_6O) based solution and naphthalene ($C_{10}H_8$) balls were used inside the insect boxes to prevent any parasites, fungus, or mold infestation. Samples collected in pan traps or the wet collections were washed with clean water using a sieve and stored in labeled vials filled with 70-80% ethanol (C_2H_6O) for further identification.

Specimens were identified using standard identification keys based on their body parts (annexure 1). The identification process involved referencing published descriptions from Mitra et al., 2005, 2008; Bhardwaj et al., 2011; Mahmood et al., 2012; Singh & Sondhi et al., 2016; Sengupta et al., 2016, 2020; and Chandra et al., 2019. While some specimens were identified using these references, most of the specimens were identified with the help of experts

from Zoological Survey of India (ZSI) Kolkata's Diptera, Lepidoptera, Hymenoptera, and Coleoptera sections, as well as from other specialists in the field of insect taxonomy.

3.2.3. Secondary data collection

For analyzing the LULC change in both the valleys over two decades and the distribution of important pollinators in present and future climate scenarios, Landsat and WorldClim data have been used respectively.

3.2.3.1. Species occurrence data

For species distribution modeling landscape-level data tends to be more effective in predicting suitable niches for species. Hence, apart from primary data, secondary species occurrence data were collected from various published literature and the Global Biodiversity Information Facility (GBIF) for the states of Himachal Pradesh and Uttarakhand since they are part of the same biogeographic zone and province with similar geophysical features. GBIF is known for being the largest global network and data repository, funded by various governments worldwide, offering open access to data on various living organisms on Earth. The GBIF dataset is an accumulation of numerous datasets from across the globe. Subsequently, the downloaded records underwent cross-verification to minimize locational inaccuracies.

3.2.3.2. Landsat data

The Landsat data was obtained through the United States Geological Survey's (USGS) Earth Explorer portal. Specific datasets selected were based on the study's requirements, including the geographical area of interest, the time period under investigation, and the spectral bands necessary for the analysis. Prior to downloading, the datasets were carefully screened for cloud cover, acquisition dates, and data quality. Once downloaded, the raw data was pre-processed using various geospatial software tools. This preprocessing included radiometric correction, atmospheric correction, and geometric correction to ensure the data was suitable for subsequent analysis. Selection and acquisition of Landsat data is a critical step in remote sensing studies, as it directly influences the accuracy and reliability of the results. For this study Landsat 7 and Landsat 9 satellite imageries were used for the years 2000 and 2022 respectively.

3.2.3.3. WorldClim data

WorldClim data was used as a key resource for distribution modeling. This is a set of worldwide climate layers of about 1sqkm spatial resolution. The data was downloaded from

the WorldClim website. Specific datasets chosen were based on the requirements of the study, including variables such as temperature, and precipitation. The bioclimatic variables, including layers of temperature and precipitation, were produced through interpolation using a thin-plate leveling spline with approximately 1km resolution, spanning 30 years from 1960 to 1990 (Hijmans et al., 2005). Before downloading, the datasets were carefully selected to match the geographical area and time period under investigation. The acquisition and utilization of WorldClim data is a critical step in distribution modeling, as it provides valuable environmental variables that can influence species distributions.

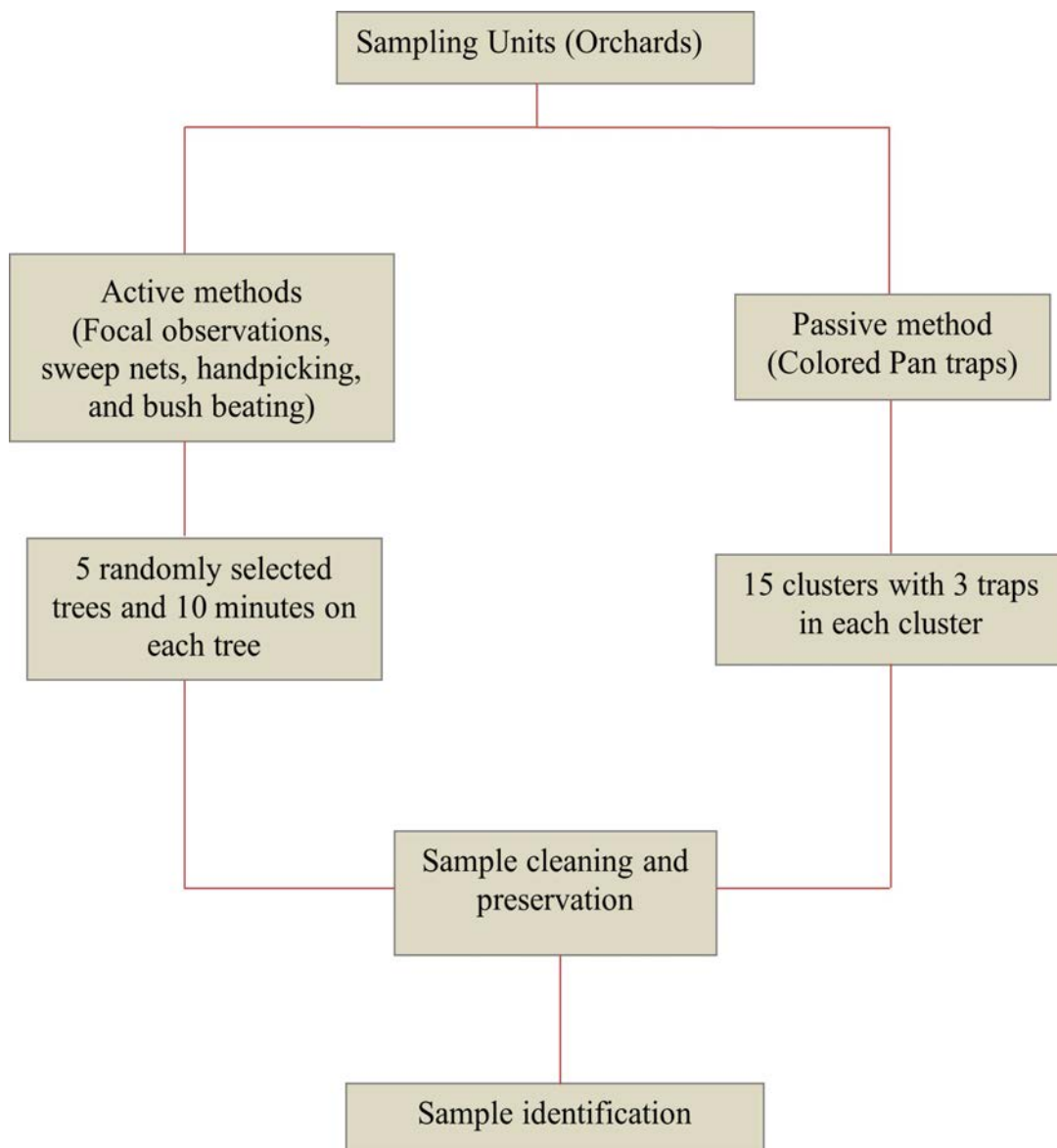


Figure 3.3. Field data collection protocol

Photo plate 3: Pictorial representation of different sampling techniques



3.3. Analyses

3.3.1. Species diversity, richness, and abundance estimation

A diversity index serves as a numerical representation of the species diversity within a community, considering all the variety of species present and in their respective abundances. This index is categorized into two types: dominance indices and information statistic indices. In this study, to understand the species diversity of insect pollinators across the study area and to understand the impact of different landscape configurations on their diversity, statistical indices including Shannon's index (Shannon, 1948; Shannon and Weaver, 1963) and Simpson index (Simpson, 1949) have been used. These indices integrate both richness and abundance data to provide a holistic measure of biodiversity.

- **Shannon's diversity index:** Shannon's index (Shannon-H) is a statistical index related to information that assumes that sampling is done randomly and all species are represented in a sample.

This index takes into consideration both the abundance and evenness of the species present. The formula for the Shannon index is,

$$H' = - \sum_{i=1}^s p_i \ln(p_i)$$

- **Simpson's diversity index:** On the other hand, the Simpson index (Simpson 1-D) functions as a dominance index, assigning greater weightage to common or dominant species. This approach ensures that the diversity calculation considers the prevalence of a few dominant species, thus preserving the diversity of less common species with limited representation. This index measures the probability of selecting two individuals randomly from a sample will belong to the same species. The formula for the Simpson's index is,

$$D = \sum_{i=1}^s p_i^2$$

- **Species Richness:** It is a simple count of the number of different species in a given area or community. It does not consider the abundance of individual species. However, species richness can be positively correlated to the sampling effort. For this study both the species

richness and Chao 1 of the pollinator community have been calculated for each landscape category. To evaluate the overall effort of sampling, the determined species richness was compared with the species richness in the Chao 1 bias correction estimator, version 9.1 (Chao, 1984; Colwell et al., 2004). The Chao 1 estimator, as outlined by Chao (1984) and Colwell & Coddington (1994), employs a specific equation to compute the assessed true species diversity within a given sample. This comparative analysis provides valuable insights into the effectiveness of the sampling approach and enhances the accuracy of estimating the actual species diversity present.

- **Species Abundance:** This refers to the number of individuals of each species in an ecological community. It provides a more detailed view of the community structure than species richness alone. Species abundance can be measured directly by counting individuals, or indirectly through methods such as mark and recapture.
- **Rank abundance:** Rank abundance curves were also generated to understand how different pollinator species are occupying the niche. A rank abundance curve, also known as a Whittaker plot, serves as a visualization tool utilized by ecologists to represent the relative species abundance, which is a structural aspect of biodiversity. This graphical representation aids in understanding species richness and evenness within an ecosystem while addressing the limitations of traditional biodiversity indices.

The curve is depicted as a 2D chart, where the Y-axis indicates relative abundance, and the X-axis represents abundance rank. In the figure 3.4, X-axis: Abundance rank assigned to each species, with 1 being the species with maximum abundance, the second most abundant ranked 2, and so forth.

Y-axis: Relative abundance, typically measured logarithmically, which denotes the abundance of a species relative to others within the ecosystem.

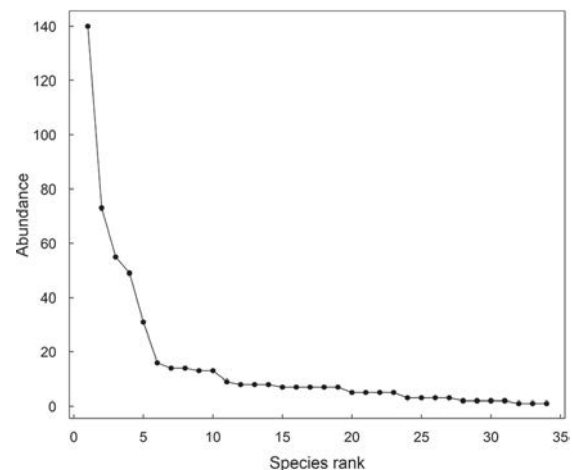


Figure 3.4. A standard rank abundance curve with skewed distribution

- **Shannon Evenness Index ($e^{H/S}$):** also known as Shannon's equitability index, is a measure of biodiversity that quantifies how equal the community is numerically. It's a way of expressing the balance between the richness of species (the number of species) and species abundance (total number of individuals for each species). The formula for Shannon Evenness Index is represented by,

$$E_H = \frac{e^H}{S}$$

Where, e^H is the exponential of the Shannon Diversity Index (H), and S is the total number of species (species richness). The Shannon Evenness Index ranges from 0 to 1, where 1 shows perfect evenness (all species are equally abundant), and 0 suggests perfect unevenness (one species dominates the community). This index provides a more nuanced understanding of community structure, as it considers not just the number of species, but also how individuals are distributed among those species. It's a valuable tool in ecological studies for comparing biodiversity across different habitats or communities.

- **Regression analysis:** A Generalized Linear Model (GLM), was used to explore the relation between pollinator abundance and varying elevational gradients, as well as the changing distance to forests. GLM is a versatile statistical model devised by John Nelder and Robert Wedderburn in 1972. It extends regular linear regression by incorporating a link function that helps in relating the linear model to the response variable and allows the variance of individual measurement to be a function of its own predicted value. This flexibility enables GLM to handle data that doesn't follow a normal distribution. GLM includes various models like linear regression, logistic regression, and Poisson regression, which accommodate different error distributions for the response variable, making it a potent tool for statistical analysis. The formula for a GLM is typically expressed as follows:

$$g(E(Y_i)) = \eta_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \dots + \beta_p x_{pi}$$

Where:

$E(Y_i)$ is the anticipated value of the response variable.

g is the link function.

η_i is the linear predictor.

$\beta_0, \beta_1, \dots, \beta_p$ are the parameters to be estimated.

$x_{1i}, x_{2i}, \dots, x_{pi}$ are the explanatory variables.

The variance of the response variable is typically a function of its mean: $\text{Var}(Y_i) = V(\mu_i)$.

- **Student's t-Test:** t -Test (Student, 1908) was performed between pollinator diversity in different agricultural and management practices and in case of the presence of a large settlement nearby to understand if there is any significant difference present. The t -test is a statistical hypothesis test used for determining whether any significant difference present between the means of two groups. It's a technique for testing hypotheses that can be used to

evaluate a population-based assumption. The formula for the t-statistic in an independent sample is given by;

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(s^2(\frac{1}{n_1} + \frac{1}{n_2}))}}$$

Where, n_1 and n_2 represent the sizes of the group and \bar{x}_1 and \bar{x}_2 the mean of the groups.

- **Analysis of variance (ANOVA):** To understand the difference between pollinator diversity in orchards situated at various distance from forests and elevational gradients, an ANOVA (Stahle & Wold, 1989) followed by a Tukey's pairwise test (Tukey, 1953; Smith, 1971) was performed. ANOVA (Stahle & Wold, 1989) is used for separating observed variance data into different components using a statistical approach. A one-way ANOVA is used for data sets with three or more groups. Tukey's pairwise comparison statistical test (Tukey, 1953; Smith, 1971) is a one-step multiple comparison procedure that is frequently used in conjunction with ANOVA. It can be used to find mean that are immensely different from one another. Tukey's null hypothesis says that the means being compared are taken from the same lot of population (i.e., $\mu_1 = \mu_2 = \dots = \mu_k$), and thus the means should be distributed normally. This results in the normality assumption of Tukey's test. The following formulas are used.

$$F = \frac{MS_{group}}{MS_{error}}$$

Where, MS_{group} is the mean squared error of the variance of between-group and MS_{error} is the mean squared error of variance of within-group variance.

The data underwent analysis using both Excel, PAST (version 4.03), and R (R Core Team 2023), with the biodiversityR package (Kindt, 2019) and vegan package (Oksanen, 2016, 2018) being utilized for statistical computations.

3.3.2. Land-cover change estimation

The analysis of LULC changes involved a series of methodical steps, each contributing to the overall insight of how the LULC has changed over time in the study area. The analysis involved the utilization of Landsat 7 and Landsat 8-9 satellite imagery obtained from the USGS Earth Explorer portal. The USGS Earth Explorer portal is a comprehensive online tool for accessing various types of geospatial data. The images were selected based on specific criteria

such as the percentage of cloud cover and seasonal variations to ensure optimal visibility and relevance to the study period.

- **Band selection and Image pre-processing:** Once the images were obtained, specific image bands were chosen and masked to focus on the study area. This step is crucial to eliminate unnecessary information and focus on the geographical area of interest. The acquired images then underwent a series of pre-processing steps. These included geometric correction required for rectifying any spatial distortions, and atmospheric correction to remove atmospheric influences, thereby enhancing the quality of the data for further analysis.
- **Supervised Classification:** For the classification of LULC, a supervised image classification technique known as Random Forest was employed. This technique is based on machine learning algorithms that use training data (in this case, data from previous field visits) to classify the images into different LULC classes.
- **Accuracy assessment and Recoding:** Following the classification process, a primary accuracy assessment was conducted using reference data from field surveys and Google Earth imagery. This step is crucial to validate the results of the classification. Any misclassified pixels were identified and corrected through a process called recoding, and further accuracy checks were performed to ensure the reliability of the classification. Acceptable values for both the overall accuracy of classification and the kappa coefficient were obtained for the classified images and a confusion matrix was prepared.

Formulas used for accuracy assessment include,

$$\text{Overall Accuracy} = \frac{\text{Total number of correctly classified pixels (diagonal)}}{\text{Total number of reference pixels}} \times 100$$

$$\text{Users Accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of classified pixels in that category (the row total)}} \times 100$$

$$\text{Producer Accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of reference pixels in that category (the column total)}} \times 100$$

$$Kappa\ Coefficient\ (T) = \frac{(TS \times TCS) - \Sigma (Column\ Total - Row\ Total)}{TS^2 - \Sigma (Column\ Total - Row\ Total)} \times 100$$

Here,

TS = Total sample

TCS = Total correctly classified sample

- **Change matrix generation:** Upon achieving satisfactory accuracy, a comparative analysis of the classified images from different time periods was undertaken. This involved performing a change detection analysis, a process that identifies areas of change between two or more time periods. A Change Matrix was generated as part of this analysis, providing a detailed account of the conversion of LULC classes over the analyzed time periods. The transition matrix offers a systematic way to examine and represent the magnitude of change in various LULC classes over the specified time interval. Each cell in the matrix corresponds to a specific combination of LULC classes, showing how land has transitioned from one category to another.

After generating the change matrix final changes in the area under each category were analyzed. Final maps were prepared using the Arc GIS platform. All the analyses were done using Google Earth Engine, ERDAS IMAGINE, and Arc GIS platform.

3.3.3. Species Distribution Modelling

In conducting distribution modeling, I utilized presence-only data for the species under investigation. Primary presence points were collected directly from field surveys. In addition to this primary data, supplementary presence points were gathered from various sources such as GBIF, Butterflies of India, iNaturalist, and published literature focusing on the Western Himalayan region.

Climate data, crucial for this analysis, was sourced from WorldClim for both current and future climate scenarios. Digital Elevation Model (DEM) data was also incorporated into the study. 12 bioclimatic variables alongside DEM were utilized for this purpose. The selection of elevation and bioclimatic variables was further refined following the approach outlined by Rissler & Apodaca (2007). A correlation matrix was generated for the 19 bioclimatic variables alongside elevation, with a Pearson correlation coefficient of 0.75 employed to identify highly correlated variables (Rissler et al., 2006). In instances of high correlation, the variable deemed more relevant and easier to interpret within the niche of our study species was selected.

MaxENT was employed for modeling the distribution map under current climate conditions. Prior to modeling, preprocessing steps were undertaken to ensure data cleanliness, removal of duplicates, and proper formatting to suit MaxENT requirements. The modelling process involved integrating presence data and current climate layers into MaxENT and defining parameters such as regularization multiplier, random test percentage, and number of replicates. The dataset was divided into 80% training points and 20% testing points to validate the model's performance. In default settings, the MaxEnt algorithm operates with 10,000 background points, which are a set of raster grid cells selected randomly across the area of concern and are utilized to ascertain species' habitat preferences. It employs a convergence threshold of 0.00001, representing the probability of the model to predict species absence where the species is truly present. The algorithm iterates 500 times until reaching the convergence threshold. A prevalence of 0.50 is set, indicating the percentage of pixels in the raster dataset where the algorithm assumes the species exhibits for modeling purposes. Output maps are presented in a logistic format, where suitability ranges between 0 and 1 are derived from a logistic transformation of particular data depending on the user-specified prevalence value.

Simultaneously, the model was projected into future climate scenarios by incorporating future climate layers into MaxENT. The model developed under current climate conditions was utilized to project the distribution of species into future climate scenarios. Model performance was assessed using the values of Area Under Curve (AUC) value of the Receiver Operating Characteristic (ROC) curve, where an AUC value >0.7 is indicative of good model performance (Araújo et al., 2005; Ancillotto et al., 2019). Additionally, Jackknife evaluation was adopted to estimate the relative significance of different variables for model building.

Further post-processing was done using Arc GIS. Individual species outputs were assessed using the "Minimum training presence Cloglog threshold" to transform output rasters into binary maps (absence (0)/ presence (1)). Subsequently, range shift and distribution change for each species were estimated using tools such as "Centroid change" and "Distribution change" to measure shifts in suitable climatic niches and changes in distribution ranges for different pollinator species in future scenarios. Distribution maps were prepared for both present and various future climate scenarios for each species, providing insights into potential changes in distribution patterns over time.



**Chapter 4:
Assessment of Spatio-temporal
Changes in Landscape Composition**

4.1. Introduction

Landscape composition acts as a crucial component in shaping species diversity and community dynamics. Landscape composition exerts significant influence on species diversity, community structure, population dynamics, and functional trait selection, consequently impacting ecosystem services and functioning (Tscharntke et al., 2012). The arrangement and distribution of different habitat types within a landscape directly influence the availability of resources and the suitability of environments for various species. The composition of landscape, configuration, and intensity of land use within a landscape shape the resemblance of plant and animal communities, leading to diminished species exchange between communities, particularly evident in landscapes predominantly characterized by agricultural activities (Dormann et al., 2007). Land use, whether at the local or landscape scale, plays a pivotal role in influencing the functional composition of insect communities as well (Felix et al., 2019). Diverse landscapes encompassing a mosaic of habitats offer a multitude of niches, fostering greater species richness and abundance. Moreover, connectivity between habitats facilitates species movement, gene flow, and colonization, vital for maintaining robust and resilient ecological communities. By understanding and manipulating landscape composition, conservationists and land managers can enhance biodiversity conservation efforts, ensuring the persistence of species and the stability of ecosystems in the context of environmental alterations.

Land Use Land Cover (LULC) change stands as a pivotal element in the defining of plans and strategies for managing and monitoring natural resources (Sinha et al., 2015). Land cover denotes the biophysical state of an area, while land use pertains to the alterations made by humans to fulfill their resource requirements (Meyer & Turner, 1996). Various factors influence these changes in land use, however, climate, technological advancements, and socio-economic conditions are considered as key contributing factors to land-use alterations across different temporal and spatial scales. In recent times, there has been a remarkable surge in human activity impacting land due to rapid population growth, leading to alterations in land cover (Vivekananda et al., 2020). Anthropogenic disruptions, such as alterations in land use, air and water pollution, soil degradation, and the loss of productive lands, are increasingly endangering ecosystem health across local, regional, and global scales. Among these disruptions, shifts in LULC are acknowledged as primary factors contributing to various implications for the global environment, degradation of ecosystem functionality (Turner et al., 1994; Riebseme et al., 1994), biodiversity decline, soil degradation, and alterations in

hydrological processes both globally and locally (Meyer & Turner, 1996; Chhabra et al., 2006). Farmers employ adaptive strategies to mitigate climate variability through land transformations. Globally, traditional crop areas are declining, replaced by cereals, vegetables, fruits, and oil crops. Urbanization is rapidly consuming agricultural, forest, and grassland areas at alarming rates (Holmgren, 2006).

The Belt and Road countries are expected to experience concentrated population growth and urbanization, particularly in West Asia, South Asia, and Southeast Asia. By 2050, urban populations in these regions are projected to reach 64%, with notable hotspots such as India, China, Pakistan, and Indonesia (Liu et al., 2018). With increasing population, rapid industrialization, urbanization, and associated infrastructure development are anticipated to intensify the demand for land. In such scenarios, meeting the demand for additional land may entail encroachment upon agricultural or forested areas, posing significant risks to ecosystem functionality. Therefore, it is essential to figure out these processes in a temporal context (Gregrio & Jansen, 2000). Similar to other regions globally, India is undergoing substantial changes in land use. Over the past 50 years, India has witnessed an increase in the net sown area from 41.8% to 46.1%, and a notable expansion of forest area from 14.2% to 22.8%. Non-agricultural land usage, comprising industrial complexes, transportation networks, mining areas, heritage sites, water bodies, and urban and rural settlements, has expanded from 3.3% to 8.5%. Conversely, other uncultivated lands, excluding fallow ones, have seen a drastic reduction by nearly half, declining from 40.7% to 22.6% (Anonymous, 2013).

Over the past three decades, the Kullu valley in Himachal Pradesh has experienced significant alterations in land use patterns due to shifts in agricultural practices, industrialization, urbanization, tourism, and hydropower generation. Additionally, changes in climatic conditions have influenced preferences in land use. The region has observed a transition in agricultural patterns from traditional paddy and wheat cultivation to commercial fruits and vegetable production systems. Several studies conducted in the area have highlighted changes in the area under orchards and shifts in the apple belt (Bhardwaj & Sharma, 2013; Rana et al., 2009). The scenario is more or less similar in Tirthan valley as well with some sort of regulations, being a part of GHNPCA.

In addition to impacting crops, land use changes also have significant effects on associated pollinator communities (Rader et al., 2014). In recent years, there has been a significant decline in both the abundance and diversity of insect pollinators, including managed honeybees and various wild bee species, due to factors such as Colony Collapse Disorder and habitat loss

(Ghazoul, 2005; Steffan-Dewenter et al., 2005; Biesmeijer et al., 2006; Williams & Osborne, 2009). This decline has been observed across the Hindu Kush Himalayan (HKH) region, attributed primarily to anthropogenic practices, monoculture-dominated agriculture, pesticide use, and changes in landscape configuration (Ahmad et al., 2003; Aizen & Feinsinger, 1994; Allen-Wardell et al., 1998; Partap, 2010 a,b, 2011; Kennedy et al., 2013; Vanbergen et al., 2013). Forests play a critical role in providing habitats for pollinators, and their loss negatively impacts pollinator abundance (IPBES, 2016). Climate change exacerbates the situation by altering local weather conditions, affecting the lifecycle of natural pollinators (Partap & Partap, 2001, 2002). Understanding the impact of landscape structure changes on pollinator communities is essential for preventing further losses and designing effective conservation strategies in human-dominated landscapes (Viana et al., 2012).

In recent times, numerous research has been conducted to comprehend the patterns of LULC change, its driving forces, and its impacts on both the natural environment and human populations (Mustard et al., 2022). Remote sensing technology has been extensively employed to analyze land use dynamics, owing to its wide area coverage, high resolution, and extensive database (Erasu, 2017). Remote sensing offers immediate and cost-effective access to valuable information, contrasting with conventional methods (Vivekananda et al., 2021). Meanwhile, Geographic Information System (GIS) provides a flexible platform for the storage, presentation, and analysis of digital data (Wu et al., 2006). Since the early 1970s, satellite images from programs like Landsat have served as crucial datasets for remote sensing technology, extensively utilized by scientists to analyze LULC changes (Cohen & Goward, 2004). These images offer substantial spatial and spectral resolution, covering extensive areas over time. Integration of remote sensing technology with GIS has enabled regular and steady monitoring of LULC patterns (Rawat & Kumar, 2015). In India, various studies have been conducted using GIS technology and remotely sensed data to analyze LULC changes (Tiwari, 2008; Raman & Punia, 2012; Misra & Balaji, 2015; Fayaz et al., 2020). Additionally, studies in the Western Himalayan region have investigated LULC dynamics and their impacts on forest ecology, hydrology, extreme natural phenomena, and local climatic patterns (Singh, 1998; Vishwa et al., 2013; Singh et al., 2014; Shah & Sharma, 2015; Thakur et al., 2018; Vaidya et al., 2018 and Negi & Irfan, 2022).

Therefore, this study was done with the aim of identifying and quantifying the extent of various land use changes in the past two decades from 2000 to 2022 in Kullu and Tirthan valley of Himachal Pradesh.

4.2. Methodology

4.2.1. Satellite data collection

To gather evidence on land use changes in the Kullu Valley, two Landsat satellite images were obtained from the USGS Earth Explorer portal for the years 2000 and 2022. Landsat 7 satellite data with a resolution of 30 meters was utilized for the year 2000, while Landsat 9 data with the same resolution was employed for the year 2022. These images were specifically acquired during the month of October to ensure dense vegetation and minimal cloud cover. Both images were of high quality, with less than 2% cloud coverage, ensuring accurate analysis. The specifications of the satellite images used for the study are detailed in table 4.1.

Table 4.1. Details of satellite data used for the analysis

Year	Satellite data	Acquisition date	Spatial Resolution	Path/Row
2000	Landsat 7 (ETM+)	15/10/2000	30	147/38
2022	Landsat 8-9 (OLI/TIRS)	28/10/2022	30	147/38

4.2.2. Image processing and classification

The study focused on detecting changes in various land use types over time. These included water bodies, permanent snowbound areas, agricultural/orchard areas, built-up areas, open forest/barren areas, and dense forests. After obtaining the satellite images, specific bands were chosen and pre-processed, including geometric and atmospheric correction. Using Landsat data in a time series, change detection analyses were performed. Supervised classification, a method where the classifier is trained using predefined classes, was conducted using the Random Forest technique in the Google Earth Engine platform. In this method, training sample pixels were assigned for each land use class. These samples were evenly spread and scattered across the study area to ensure representative training data. In the process of identifying the land use type for every sample, various visual and spatial characteristics were utilized. These characteristics included the color, size, shape, and texture of the land areas. When encountering a land use type that was unfamiliar or difficult to distinguish using these visual cues alone, additional resources such as Google Earth images were employed. By combining these visual observations with auxiliary data, a comprehensive understanding of the land use types within the study area could be attained.

4.2.3. Accuracy assessment and recoding

Evaluating accuracy is crucial for identifying changes in LULC, with the Kappa coefficient index being utilized for this calculation (Mazhar & Fadia, 2019). After the classification process, an initial accuracy assessment was carried out utilizing reference data obtained during field surveys and Google Earth imagery. Any misclassified pixels were pinpointed and rectified through a recoding process, followed by additional accuracy checks to ensure the robustness of the classification using Arc GIS software (ArcMap 10.7.1). Reference data obtained from both field surveys and reference points from Google Earth were utilized for the assessment of accuracy. The test areas served as references to evaluate the accuracy of classification by comparing the total number of training points. Acceptable values for both overall classification accuracy and kappa coefficient were obtained for the datasets and a confusion matrix was prepared.

4.2.4. Change matrix generation and final map preparation

After completing the LULC classification process, the resulting maps for the years 2000 and 2022 were compared to assess changes in different land use and cover types over time. To quantify and visualize these changes, a change matrix was generated using the software ERDAS Imagine (version 2015). Change matrices are essential to understand the conversion that takes place between classes of LULC from one to another over the course of time. The change matrix offers a systematic way to examine and represent the magnitude of change in various LULC classes over the specified time interval. Each cell in the matrix corresponds to a specific combination of LULC classes, showing how land has transitioned from one category to another.

Following the classification process, the final maps were prepared using ArcGIS software for its robust analytical capabilities. Moreover, to enhance the clarity and precision of the classified maps, post-processing techniques were applied to understand a comprehensive and nuanced comprehension of the intricate dynamics underlying the changes in land use and land cover spanning the period from 2000 to 2022. Through this detailed analysis, a deeper understanding of the evolving landscape was attained, which can facilitate informed decision-making for land management strategies and conservation efforts.

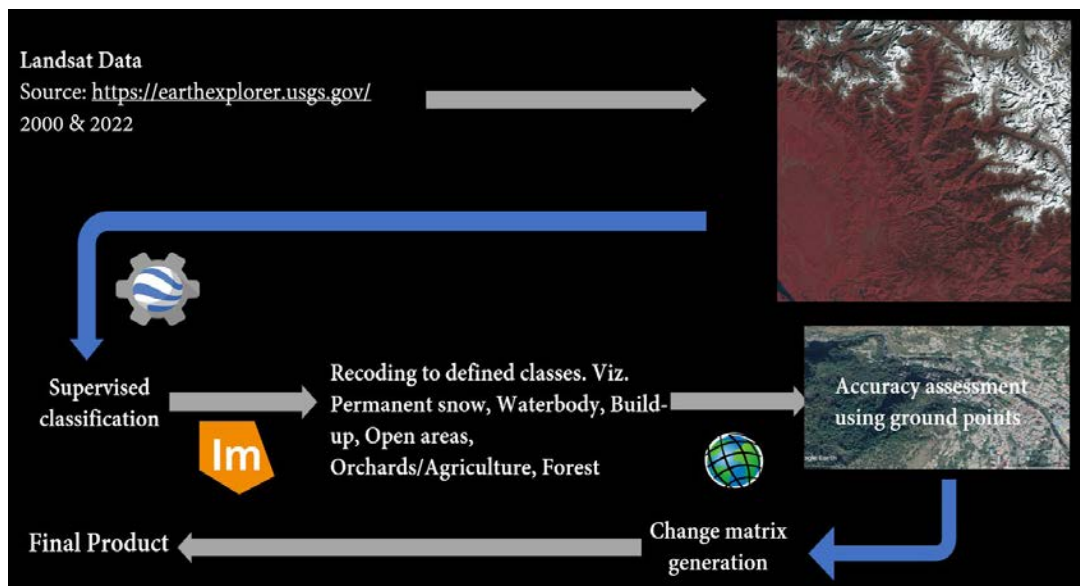


Figure 4.1. Flow chart of different steps of LULC change detection using RS and GIS

4.3. Results and Discussion

This study assesses LULC changes in the Kullu and Tirthan valleys over the past two decades, from 2000 to 2022. The data used for the study yielded high level of accuracy in the classification process, with an overall accuracy of 92% for the year 2022 and 87.5% for the year 2000. The Kappa coefficients, which were calculated to be 90.31% for the year 2022 and 84.65% for the year 2000, serve as indicators of agreement beyond chance between the classified maps and the reference data. The high Kappa coefficients suggest a strong agreement between the two datasets, indicating that the classification process produced reliable and accurate results (table 4.2, 4.3).

Table 4.2. User and producer accuracy of classified maps for the years 2000 and 2022

LULC Class	Year	User accuracy (%)	Producer accuracy (%)
Permanent snow-bound areas	2000	100	100
	2022	100	100
Waterbody	2000	100	100
	2022	100	100
Settlements/Buildup	2000	81.82	81.82
	2022	91.66	91.66
Open forest/ Barren lands	2000	88.88	80
	2022	85.71	85.71
Orchards/ Agricultural lands	2000	78.95	88.23
	2022	85.71	94.74
Dense forest	2000	88.88	80
	2022	100	100

Table 4.3. Overall accuracy and Kappa coefficient of classified maps for the years 2000 and 2022

Year	2000	2022
Overall Accuracy (%)	87.5	92.18
Kappa coefficient (%)	84.65	90.31

The results of the analysis highlighted notable changes in LULC patterns in the study area. In Kullu valley, a substantial expansion was observed in built-up areas, suggesting rapid urbanization and infrastructure development. This expansion in built-up areas was followed by a moderate increase in areas under dense forest cover. However, there was a decrease observed in areas under other LULC categories, including open forest or barren lands, orchards or agricultural land, and water bodies (figure 4.2, 4.4). The majority of increase in buildup areas observed in this valley is near Bhuntar airport, Kullu city, and Manali town (figure 4.4). This indicates the major reason behind this change is driven by developed communication facilities, easy access to offices, administrations, education system, and other facilities in the district town, and a growing tourism business.

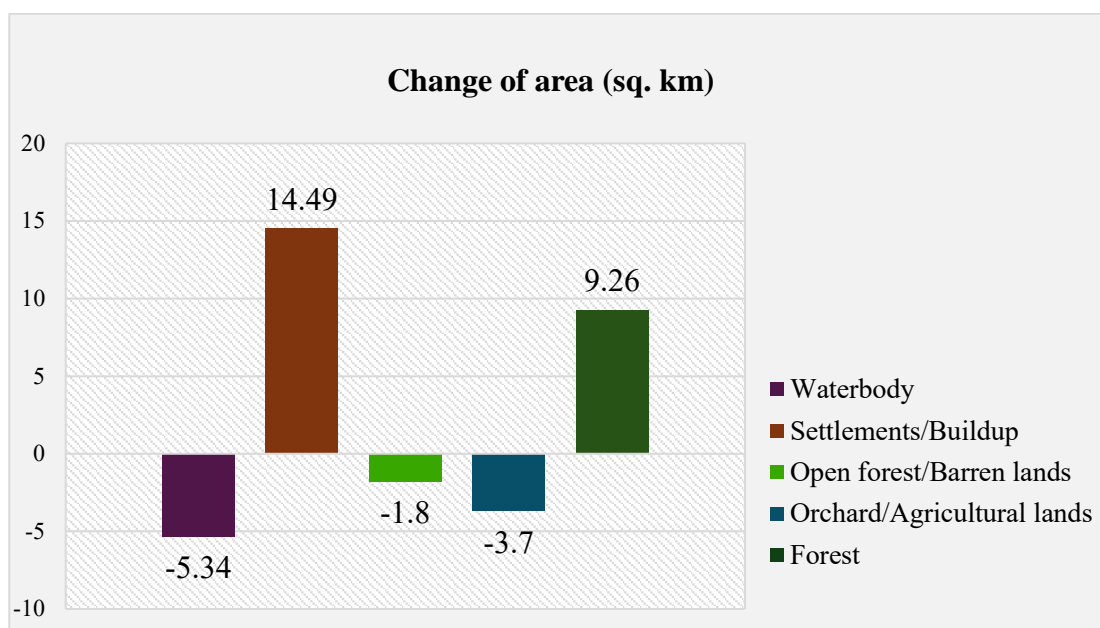


Figure 4.2. Total area changed under different land use categories in Kullu valley

Similarly, in the Tirthan valley, the pattern of land use change was comparable to that observed in the Kullu Valley, with some differences (figures 4.3, 4.5). While there was also a surge in built-up areas in the Tirthan valley, it was noted to be less significant compared to the Kullu valley. Additionally, the increase in forest cover in the Tirthan valley was nominal

compared to its counterpart. Also, in case of this valley as well, a major shift in buildup category was observed in areas near Banjar town, which is the headquarter of this tehsil, and due to easy access to administrative and other facilities. However, given the sensitive nature of the valley and its status as part of the GHNP, any increasing trend in built-up areas can pose a serious threat to the ecosystem of this region.

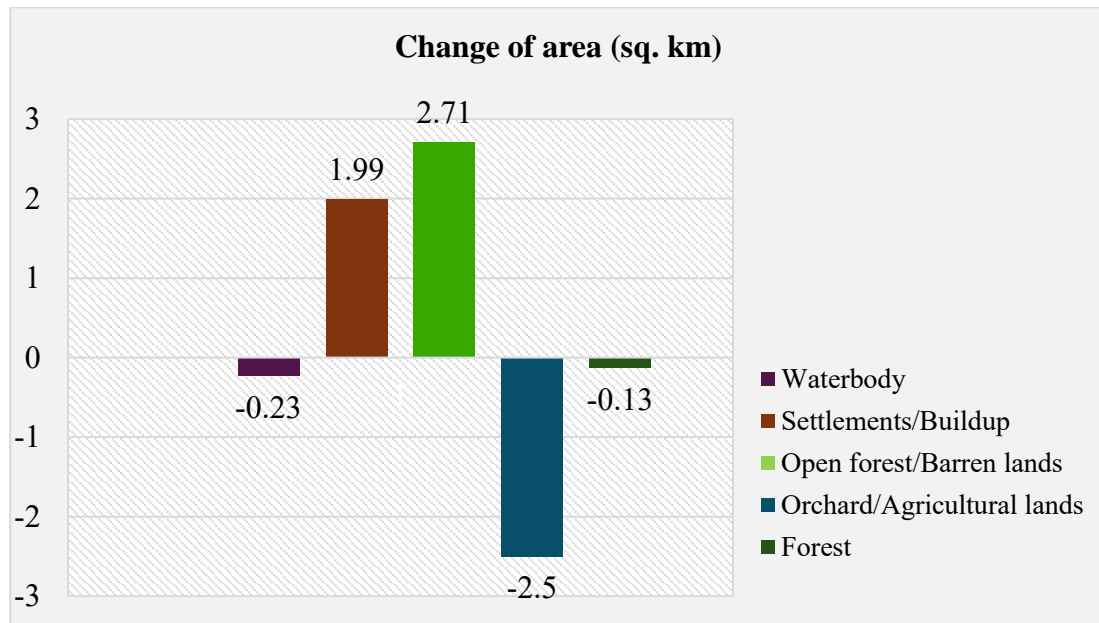


Figure 4.3. Total area changed under different land use categories in Tirthan valley

The change matrix reveals notable transformations within various LULC classes. A significant area of orchard land has transitioned into built-up areas, accounting for 7.34% of the total observed change. This conversion encompasses an area of 22 sq. km. Such a shift suggests urban expansion or infrastructural development encroaching upon previously agricultural or horticultural spaces. A considerable portion of open lands, constituting 13.72% (25 sq. km.), has undergone conversion into orchards or agricultural areas. This change signifies the expansion of cultivation or orchards onto previously undeveloped or natural areas. Approximately 10% of the area previously classified as open forest has transformed into dense forested areas. This shift may be attributed to natural succession processes, where pre-existing trees within open areas have grown denser, leading to the reclassification of the land cover. 9.5 sq. km. area previously categorized as built-up has been converted into orchards or agricultural land, which indicates a reversal of urbanization or the repurposing of developed land for agricultural use. These changes signify dynamic shifts in land use patterns, influenced by factors such as urbanization, agricultural practices, and natural ecological

processes. Detailed insights of information regarding these transformations within the landscape are provided in table 4.4.

Table 4.4. Change matrix of area (sq. km.) and percentage (%) of the total area of LULC classes between the years 2000 and 2022 for Kullu and Tirthan valley

Change in area (sq. Km.)						
	C0 (snow)	C1 (water)	C2 (buildup)	C3 (open area)	C4 (orchard /agriculture)	C5 (forest)
Z0 (snow)	45.8136	0.3195	0.0045	14.4783	0.2034	7.776
Z1 (water)	0.1269	11.4786	3.3498	2.0322	1.8774	2.3301
Z2 (buildup)	0.0063	0.7857	14.7528	1.0899	9.5634	1.9026
Z3 (open area)	6.3234	0.9981	1.9206	132.8292	25.8003	20.1168
Z4 (orchard /agriculture)	0.0036	0.9936	21.9978	15.2973	237.3921	23.8581
Z5 (forest)	6.7365	1.0449	2.5506	17.7534	18.504	302.5872
Change in area (percentage)						
	C0 (snow)	C1 (water)	C2 (buildup)	C3 (open area)	C4 (orchard /agriculture)	C5 (forest)
Z0 (snow)	66.79	0.47	0.01	21.11	0.3	11.34
Z1 (water)	0.6	54.16	15.8	9.59	8.86	10.99
Z2 (buildup)	0.02	2.8	52.5	3.88	34.03	6.77
Z3 (open area)	3.36	0.53	1.02	70.66	13.72	10.7
Z4 (orchard /agriculture)	0	0.33	7.34	5.11	79.25	7.96
Z5 (forest)	1.93	0.3	0.73	5.08	5.3	86.66

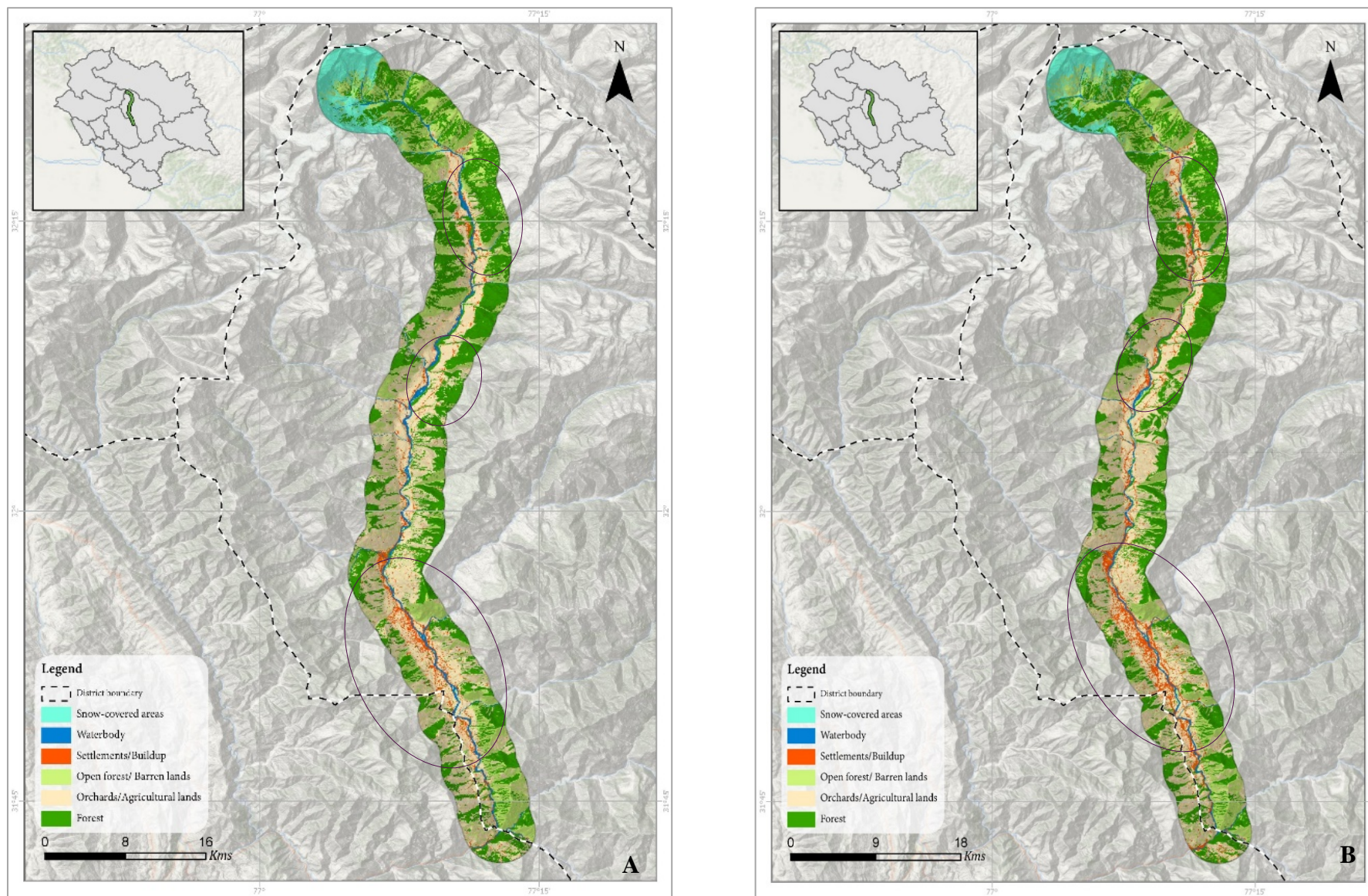


Figure 4.4. Classified map of Kullu valley for the years 2000 (A) and 2022 (B)

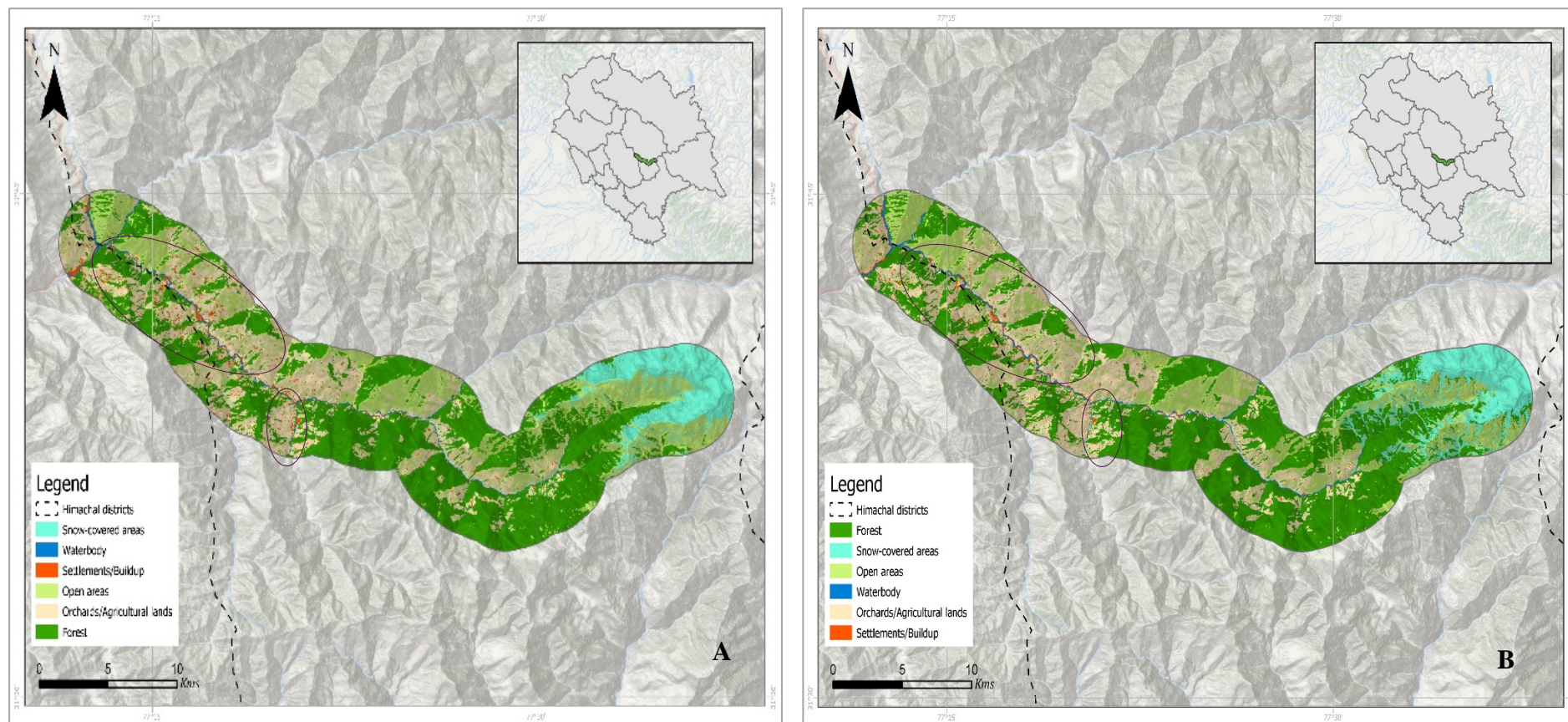


Figure 4.5. Classified map of Tirthan valley for the years 2000 (A) and 2022 (B)

4.4. Conclusion

The comprehensive analysis undertaken in this study reveals noteworthy and substantive alterations in the LULC patterns throughout the Kullu and Tirthan valleys, offering invaluable insights into the evolving landscape dynamics within these regions. The observed high accuracy rates and robust Kappa coefficients serve as compelling indicators of the reliability and credibility of the analytical approach employed, thereby reinforcing the validity and trustworthiness of the findings derived from this investigation. This meticulous assessment not only sheds light on the changes occurring within these valleys over the past two decades but also provides a solid foundation for understanding the broader environmental and socio-economic implications associated with these transformations. Various research has also underscored the significance of achieving high accuracy and utilizing the Kappa coefficient in detecting changes in LULC, as these metrics play a pivotal role in informing conservationists and policymakers about the necessity for implementing sustainable land management practices (Gupta & Sharma, 2020, Kafle et al., 2023).

In Kullu Valley, a marked surge in built-up areas has been noted, representative of a distinct trend towards swift urbanization and infrastructure development within the valley. This substantial expansion serves as a tangible indication of the region's increasing population and growing economic activities, accentuating the socio-economic forces driving the shifting land use dynamics. The change matrix offers further insights into the diverse conversions occurring within various LULC classes, shedding light on the multifaceted nature of land use changes in the study area. Conversion of former orchard lands into built-up areas and the repurposing of open spaces into orchards or agricultural plots underscore the intricate interplay between urban expansion, agricultural practices, and ecological processes molding the landscape. This transformation not only reflects the aspirations and needs of the local population but also raises pertinent questions regarding sustainable land management practices, habitat preservation, and ecosystem resilience in the face of rapid developmental pressures. As urbanization continues to exert its influence on the Kullu Valley, it becomes imperative to strike a delicate balance between socio-economic development and environmental conservation to safeguard the long-term well-being of both human communities and the natural environment. Additionally, the presence of dynamic processes, such as natural succession within open forest areas leading to the emergence of densely forested areas, adds complexity to the landscape dynamics observed in the region. The emergence of densely forested areas through natural succession and improved management contributes to the complexity of landscape dynamics as they can offer habitat

for a diverse array of flora and fauna and play crucial roles in ecosystem processes such as carbon sequestration, nutrient cycling, and water regulation (Song et al., 2001). Moreover, they can influence local microclimates, hydrology, soil quality (Liu et al., 20202), ecosystem services, and biodiversity patterns including important pollinators across the landscape.

In the Tirthan Valley, there are fewer noticeable changes compared to the neighboring Kullu valley, although there has been a gradual rise in built-up areas, primarily due to the steady growth of tourism and related development activities. The post-COVID era may have further fuelled this trend, as people are increasingly drawn to travel. Nevertheless, in a delicate ecosystem like the Tirthan Valley, any increase in disturbances has the potential to profoundly disrupt natural processes and endanger the rare and endemic biodiversity of the area.

Overall, the findings underscore the dynamic nature of land use and land cover change in the Kullu and Tirthan valleys, emphasizing the need for sustainable land management practices and conservation efforts. The relations between land use and biodiversity can be intricate and heavily reliant on specific contexts, where certain land uses or management approaches play crucial roles in maintaining specific biodiversity patterns (Haines-Young, 2009). In certain regions, land use and land cover change stand out as the foremost catalyst for biodiversity loss, whereas in other areas, pollution or disease emerge as critical threats to ecosystems (Baldwin, 2010). By recognizing the interconnectedness of ecological processes and the role of LULC in shaping landscapes, stakeholders can make informed decisions to promote resilience and biodiversity conservation in these dynamic ecosystems.



**Chapter 5:
Effect of Change in Landscape
Configuration and Horticultural
Practices on Pollinator Community**

5.1. Introduction

Pollinators play a crucial role in ecosystems by maintaining biodiversity, sustaining natural habitats, and supporting agricultural productivity (Misganaw et al., 2017). Beyond their ecological significance, pollinators contribute immensely to global food production, ensuring the growth of many crops for human and animal sustenance (Klein et al., 2007). Their economic contribution to global agriculture has been estimated at 153 billion pounds (€) annually (Gallai et al., 2009). Apart from bees, there are various non-bee pollinators such as flies, wasps, moths, butterflies, beetles, ants, birds, and bats, who play a crucial role in pollination by providing 39% of crop pollination visits, however, their contribution is little explored (Rader et al., 2016, 2020). Studies have recorded that 84% of total pollen is carried by non-syrphid dipteran flies (Orford et al., 2015).

In recent years, there has been a significant decline in both the abundance and diversity of insect pollinators (Ghazoul, 2005; Steffan-Dewenter et al., 2005; Biesmeijer et al., 2006; Williams & Osborne, 2009). While much attention has been given to the decline of managed honeybee populations due to Colony Collapse Disorder (Oldroyd, 2007), several wild bee species have also experienced sharp declines and, in many cases, have disappeared from their historic natural ranges (Biesmeijer et al., 2006; National Research Council 2007; Potts et al., 2010; Cameron et al., 2011). Studies proved that changes in landscape configuration, including alteration of natural habitats for anthropogenic use and agricultural intensification, have been identified as one of the major factors of pollinator declines (Kennedy et al., 2013; Vanbergen et al., 2013). Other key factors causing pollinator decline include an increase in monoculture-dominated agriculture and the use of pesticides (Verma & Partap, 1993; Aizen & Feinsinger 1994; Partap & Partap, 1997, 2002; Allen-Wardell et al., 1998; Ahmad et al., 2003; Partap, 2010 a, 2010b). Forests play a vital role by offering habitats for nesting, hibernation, and food resources for diverse pollinator species. Research indicates that orchards near forests host a higher diversity of insect pollinators compared to those situated farther away (Sharma & Gupta, 2010; Ulyshen et al., 2023). Thus, any reduction in forested areas, whether due to natural disasters or anthropogenic interventions, adversely affects pollinator abundance (IPBES, 2016). Climate change can impact pollinators by affecting the lifecycle of natural pollinators due to altered local weather conditions (Partap & Partap, 2001, 2002). The current situation poses challenges to the conservation of numerous pollinator species, as many of the threats they face seem to be intensifying across continents (Calderone, 2012; Potts et al., 2016). Studies also revealed that there is a considerable disparity in research and development (R&D)

expenses between high-income (developed) countries and middle and low-income (developing) countries (Porto et al., 2020). Identifying the influence of landscape changes on pollinator communities and gaps in management practices is critical to prevent additional pollinator loss and to develop effective strategies for their protection in human-influenced landscapes (Viana et al., 2012).

Along with the diversity and population of the pollinator community the ecosystem service provided by them is of undeniable economic value, and intricately linked to the well-being of humans through its impact on agricultural yields and securing food resources (IPBES, 2016). According to research done by Basu et al., 2011, the global economic value attributed to a single year of biotic pollination services for six crops in India amounts to \$358 million USD. The IPBES assessment highlighted a concerning trend of decline in the population of wild pollinators in North America and northwest Europe, emphasizing the urgent need for global monitoring efforts due to data deficiencies (IPBES, 2016). Contributing factors to pollinator decline and impacting the ecosystem services provided by them include the heavy use of pesticides, invasive species, genetically modified (GM) crops, parasites, and the intensification of agricultural practices (IPBES, 2016; Dicks et al., 2016; Potts et al., 2016). Fragmentation and loss of augmented by anthropogenic interventions, also play significant roles in this process (Potts et al., 2010; Xiao et al., 2016). The ongoing expansion of human-altered lands directly disrupts pollination in both ways, a dispersed functionality of the ecosystem (Aguilar et al., 2006; Ashworth, 2004) and the associated services (Garibaldi et al., 2016; Gibbs et al., 2016; Ricketts et al., 2008). However, studies on different pollinators and the quantification of their ecosystem services are limited including in India. Given their essential part in pollination, it becomes of utmost importance to document their diversity, habitat use, and their services which will aid in conserving the pollinators as well as maintain their ecosystem services.

Himachal Pradesh stands out as a prominent horticultural region in India, characterized by diverse agro-climatic zones spanning from subtropical areas to high-altitude cold deserts. This variety allows for the successful cultivation of a broad spectrum of horticultural crops. Consequently, there has been a notable shift in the agricultural landscape, witnessing a significant transition from traditional farming practices to the cultivation of high-value horticultural crops (Sharma & Chauhan, 2013; Slariya, 2014). Kullu district stands out as a leading producer of horticultural crops in Himachal Pradesh. The commonly grown temperate fruit crops are apple, plum, peach, cherry, pear, and apricot which occupy approximately 35% of the total area of the hill state (Sharma & Rana, 2015). According to Govt. database of the horticultural department of Himachal Pradesh, in Kullu district a total of 31,224 ha. and 31,324

ha. area was under horticulture during the years 2021-22 and 2022-23 respectively (eudyam.hp.gov.in). These cultivated areas facilitated the production of 130,508 metric tons and 161,278 metric tons of diverse fruit crops, respectively, during the consecutive years. There have been past studies on different insect pollinators in Himachal Pradesh including the Kullu district (Sharma & Gupta, 2010; Sharma & Mitra, 2011; Thakur & Mattu, 2014; Mattu & Bhagat, 2015; Sharma et. al., 2015; Kapkoti et. al., 2016; Sharma et. al., 2016; Chauhan et. al., 2021; Arya & Badoni, 2023). However, studies on pollinator diversity of important fruit crops in different land-use categories are still lacking. Also, in the past few years, a disturbance in crop pollination services due to a decline in the number and diversity of pollinators has been noticed throughout the Hindu Kush Himalayan region (Partap & Partap, 1997, 2002; Partap et al., 2001; Ahmad et al., 2003; Partap, 2010a, 2010b).

Therefore, the present study was conducted to know the diversity, richness, and abundance of insect pollinators of apple and plum crops in the Kullu and Tirthan valley of Himachal Pradesh and how the different landscape categories affect these pollinator communities and associated services in Kullu valley.

5.2. Methodology

Sample collection was done within a 50m x 50m plot during daylight hours from 9 am to 5 pm in each sampling site. There is a total of 28 sampling sites in Kullu valley and 14 sampling sites in Tirthan valley. Both active methods such as hand picking, sweep netting, and aerial netting (Joseph, 1990; Arora, 1990), and passive methods like pan traps were employed to collect insect samples. The pan traps, colored in UV-bright yellow, white, and blue colors (Westphal et al., 2008) and filled with soapy water, were arranged in clusters. 15 Pan trap clusters were put randomly in each sampling site. For focal observations (Gibson et al., 2011), pollinators were recorded for 10 minutes within 1m x 1m plots along flowering branches of the selected trees at three different time frames: 09:30-10:30 h, 12:30-1:30 h, and 15:30-16:30h. All specimens collected using wet methods were washed with plain water and preserved in 75% ethanol. Those obtained through active methods were euthanized using ethyl acetate in a killing jar and preserved in dry pouches. In the laboratory, specimens underwent further processing, including washing, drying, pinning, and labeling, followed by identification using standard identification keys. In Kullu valley sampling locations were chosen based on five landscape variables; i.e. proximity to large forest patches (i.e. less than 1km, 1-2 km, more than 2kms), elevation gradients (i.e. below 1500m, 1500-2000m, and above 2000m), the presence of agricultural fields within 50m of the periphery of the sampling site, presence of large

settlements within 1km, and the types of management practices employed (e.g. modern, modern and traditional). However, in Tirthan, I haven't considered different landscape configurations as this a a very narrow valley and it is very difficult to categorize within different LULC classes. Also, this area falls under the buffer zone of GHNP, hence less disturbed, and no big settlements are present.

The samples gathered through diverse sampling methods were collectively analyzed to find species diversity, richness, and abundance. Rank abundance curves were also generated to understand how different pollinator species are occupying the niche. To assess the influence of distinct landscape configurations on pollinator diversity, separate analyses were performed for each land use category. The analysis involved assessing Shannon and Simpson's diversity indices, the Shannon evenness index, species richness, and Chao-1. I have also run regression analysis (Generalized Linear Model) to see the relation between pollinator richness and abundance with different landscape configurations and management practices. t-test and ANOVA were run to understand if there is any significant difference in pollinator diversity across various landscape configurations. Data were analyzed in Excel, Past (version 4.03), and R (R Core team, 2013) using biodiversityR (Knidt, 2019), vegan (Oksanen, 2022), ggplot2 (Wickham et. al., 2016) and *iNEXT* (Hsieh et. al., 2016) packages. Observations were made on warm, sunny days when pollinators are more active, avoiding rainy and cloudy days to reduce bias. A detailed discussion of the methodology has been provided in chapter 3.

5.3. Results and Discussion

A total of 124 pollinator species were documented in both Kullu and Tirthan valleys. These species are distributed across 75 genera and 28 families, spanning five orders: Hymenoptera, Lepidoptera, Diptera, Coleoptera, and Thysanoptera. In my analysis, I have conducted a thorough assessment of the diversity, richness, and abundance of pollinators within these two valleys, providing detailed insights into the outcomes. However, it's important to note that I have not compared the results between the two valleys, and independent observations for each valley were reported.

5.3.1. Kullu valley

In Kullu valley, a total of 108 insect species were observed encompassing 66 genera and 27 families across five orders: Hymenoptera, Lepidoptera, Diptera, Coleoptera, and Thysanoptera. The order Hymenoptera comprised 41 species within 19 genera and eight families, while Diptera accounted for 39 species distributed among 22 genera and nine families. Lepidoptera included 18 species across 17 genera and five families, followed by Coleoptera

with seven species under seven genera and four families. Lastly, Thysanoptera was represented by three species within one genus and one family (figure 5.1). Sampling coverage in the Kullu valley exceeded 90%, suggesting a more accurate representation of the pollinator status within the area (figure 5.2).

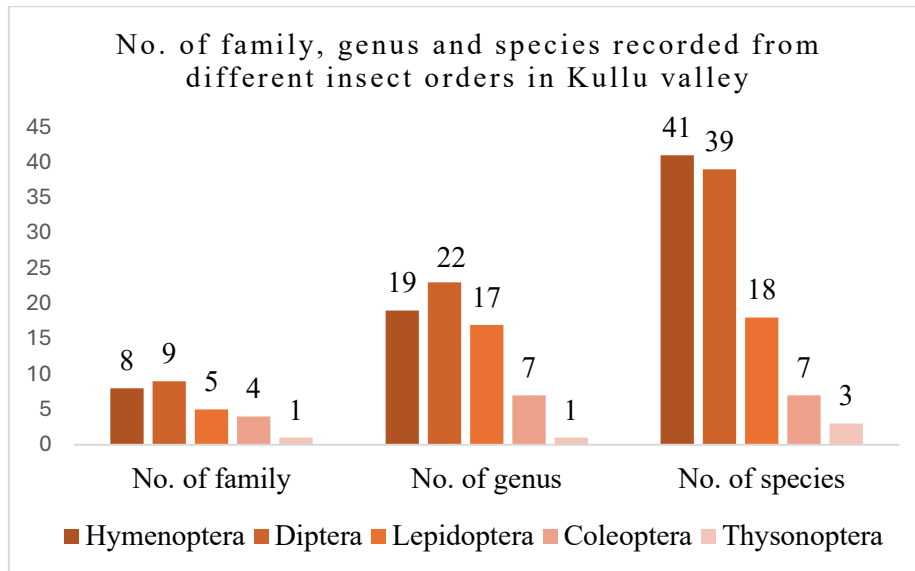


Figure 5.1. Account of family, genus, and species of different insect orders in apple and plum orchards of Kullu valley

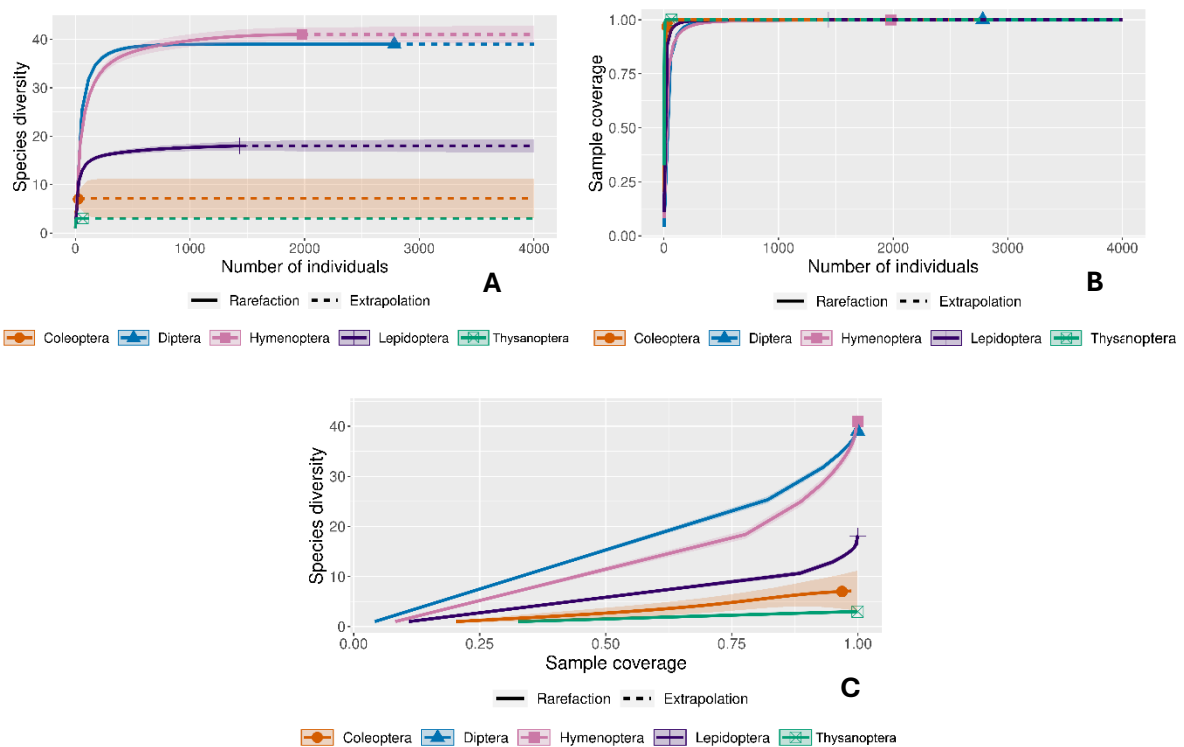


Figure 5.2. Sample size (A) and coverage-based (B) rarefaction and extrapolation curves linked to represent sample completeness (C) with 95% confidence intervals for different insect (pollinator) orders in Kullu valley

The reported Shannon's diversity index (Shannon-H) and Simpson's diversity index (Simpson 1-D) stood at 4.137 and 0.978, respectively, while Fisher's alpha was recorded at 18.32. The Shannon Evenness index (e^H/S) was calculated to be 0.585, followed by a Chao-1 estimate of 108.1. (table 5.1).

Table 5.1. Details of different indices of insect visitors in Kullu valley

Parameters	Values
Total number of species	108
Number of Individuals	6285
Shannon-H	4.137
Simpson 1-D	0.9778
Evenness e^H/S	0.5851
Dominance D	0.02223
Fisher_alpha	18.32
Chao 1	108.1
Brillouin	4.093
Menhinick	1.35
Margalef	12.12
Equitability_J	0.8853
Berger-Parker	0.06714
Relative species richness	3.821

Abundance assessments were carried out for each order, identifying the dominant species within each category (annexure 2). In Hymenoptera, *Apis cerena indica* stood out as the most prevalent species, comprising 6.71% of the total population. *Eristalis tenax* represented 3.83% of Diptera, while *Aglais caschmirensis* accounted for 3.91% of Lepidoptera. *Coccinella septempunctata* constituted 0.16% of Coleoptera, and *Thrips florum* comprised 0.4% of Thysanoptera.

Additionally, it was noted that despite of good pollinator diversity, only a few species were present in significant numbers, while others were scarce. Rank abundance curves were generated for each order to illustrate this distribution further (figure 5.3). In the case of Hymenoptera, the steep gradient indicates a skewed distribution, with certain species exhibiting notably higher abundances compared to others. This suggests a lower evenness of species within this order, potentially indicating competitive interactions or environmental preferences favoring certain species over others. Conversely, the broken stick model observed in Diptera suggests fragmented niche occupancy, where only a few species are well-adapted to the habitat and dominate in abundance. This pattern may reflect niche specialization or partitioning among dipteran species, with limited overlap in resource utilization or habitat preferences. The more normal to somewhat broken stick distribution pattern observed in Lepidoptera species indicates

higher and more stable niche occupancy, possibly facilitated by reduced competition and niche partitioning resulting from lower diversity. This suggests that lepidopteran species may have distinct ecological niches or resource requirements that allow for coexistence and stability within the community. Coleoptera and Thysanoptera display negative exponential distributions, reflecting specific habitat preferences and management practices. Coleopteran species, with their preference for woody structures and ground areas, may be more abundant in orchards with suitable habitat features. Conversely, the targeted removal of thrips as pests using insecticides and pesticides may contribute to their lower abundance and distribution within orchard ecosystems.

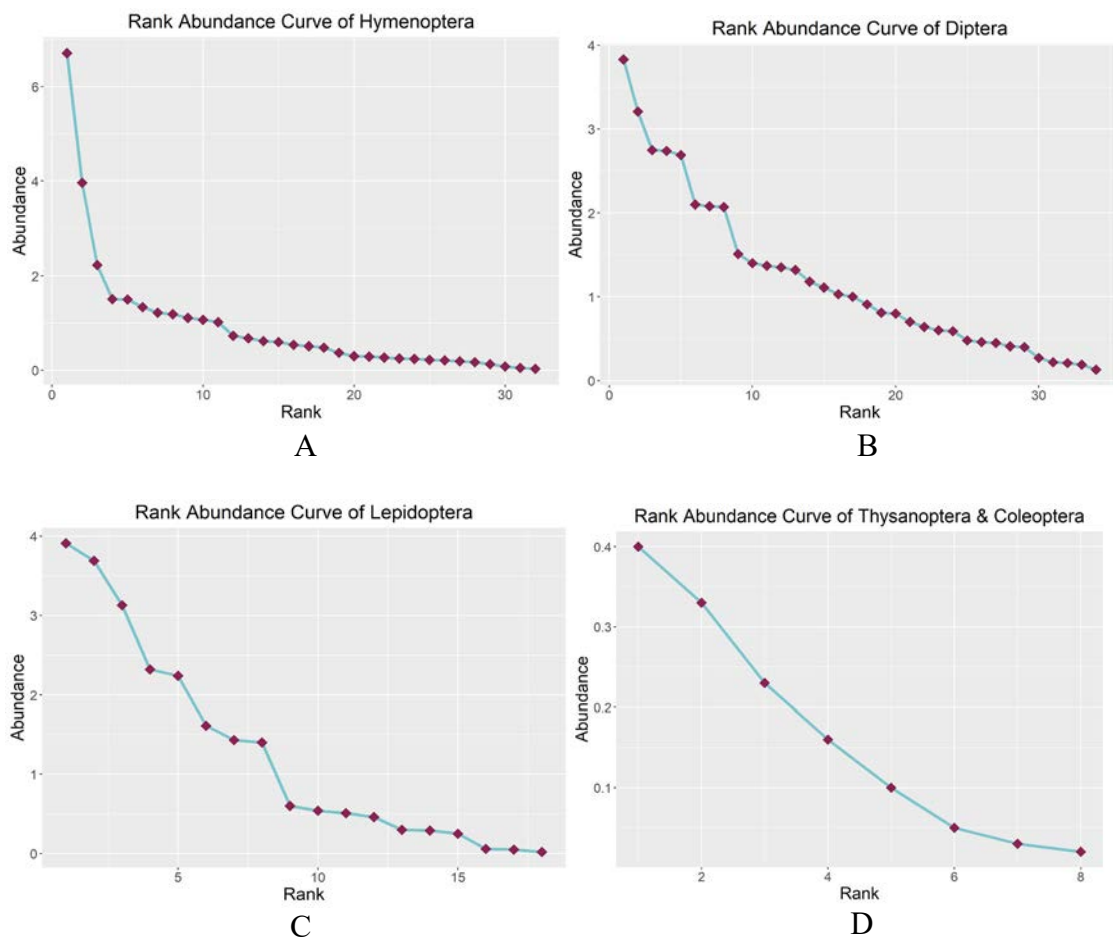


Figure 5.3. Rank abundance curve of various pollinator species belonging to five different insect orders from Kullu valley viz., Hymenoptera (A); Diptera (B); Lepidoptera (C); Coleoptera & Thysanoptera (D)

To assess the influence of different land use categories on pollinators, particular attention was directed towards three insect orders renowned for their effectiveness as pollinators: Hymenoptera, Diptera, and Lepidoptera. These orders were selected due to their significant role in pollination processes within ecosystems. By focusing on these specific orders, the study

aimed to acquire a deeper insight into how various land use practices impact the abundance, diversity, and distribution of key pollinator populations. This will aid in providing valuable insights into formulating conservation strategies and ecosystem management plans.

5.3.1.1. Impact of proximity to natural forest

When analyzing the proximity of orchards to forested areas, it was found that orchards located less than one kilometer from natural forests demonstrated the highest species richness and diversity for both Hymenoptera and Diptera. This pattern was followed by orchards situated within a 1-2 kilometer distance from forests, with those further than two kilometers away exhibiting lower richness and diversity. Regarding Lepidoptera, the highest species richness was observed in orchards within a 1-2 kilometer radius from forests, followed by orchards within one kilometer and those situated more than two kilometers away. However, maximum species diversity was recorded in orchards less than one kilometer from natural forests, followed by orchards within a 1-2 kilometer range and those situated more than two kilometers away (figure 5.4). The abundance of pollinators tended to increase with increasing distance from forests. Nonetheless, the R-squared values indicated that the distance from forests did not significantly contribute to the richness and abundance of the dipteran and lepidopteran communities but did have some impact on hymenopteran richness and abundance (figure 5.5).

Orchards located closer to natural forests, particularly within one kilometer, exhibited the highest species richness and diversity for Hymenoptera, Diptera, and Lepidoptera. This suggests that forested habitats play a crucial role in supporting diverse pollinator communities. The decreasing trend in species richness and diversity with increased distance from forests highlights the importance of maintaining connectivity between orchards and natural habitats. Forests likely provide essential resources such as nesting sites, food, and shelter, contributing to higher pollinator diversity in adjacent orchards.

However, it's noteworthy that while species richness was highest in orchards within a 1-2 kilometer radius from forests for Lepidoptera, maximum species diversity was recorded in orchards less than one kilometer from forests. This discrepancy may indicate varying responses among pollinator groups to different aspects of forest proximity, such as habitat structure, resource availability, or disturbance levels. These findings underscore the importance of forest proximity in shaping pollinator diversity and highlight the need for landscape management strategies that prioritize maintaining or enhancing connectivity between orchards and natural forest habitats. Furthermore, understanding the nuanced responses of different pollinator groups

to forest proximity can inform targeted conservation efforts aimed at preserving biodiversity and ecosystem functionality within a landscape.

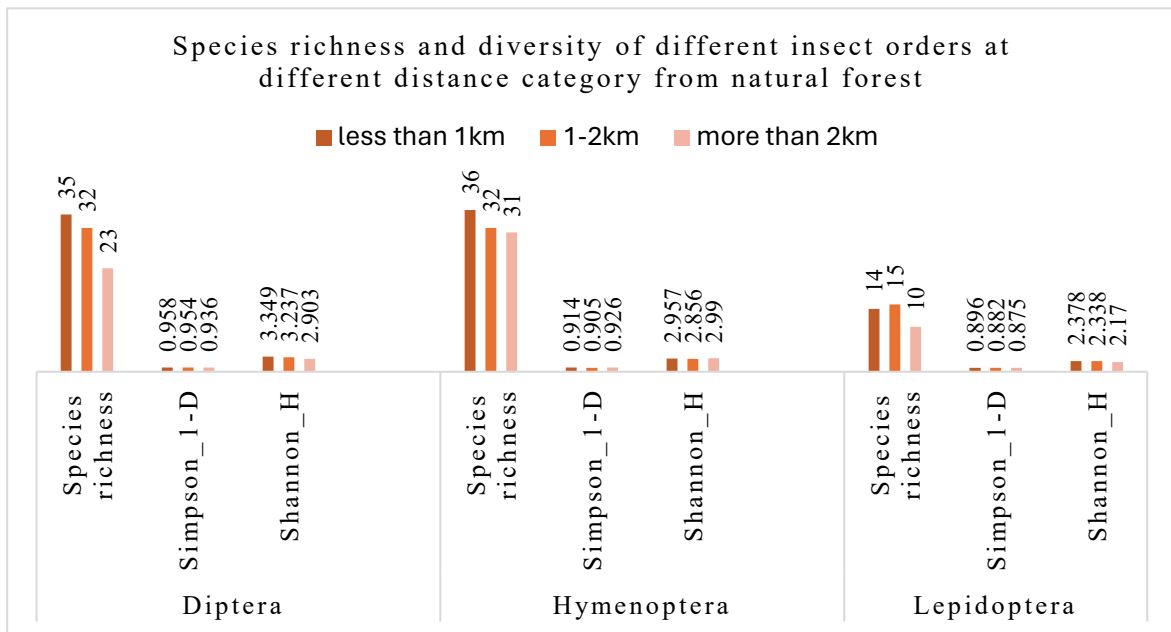
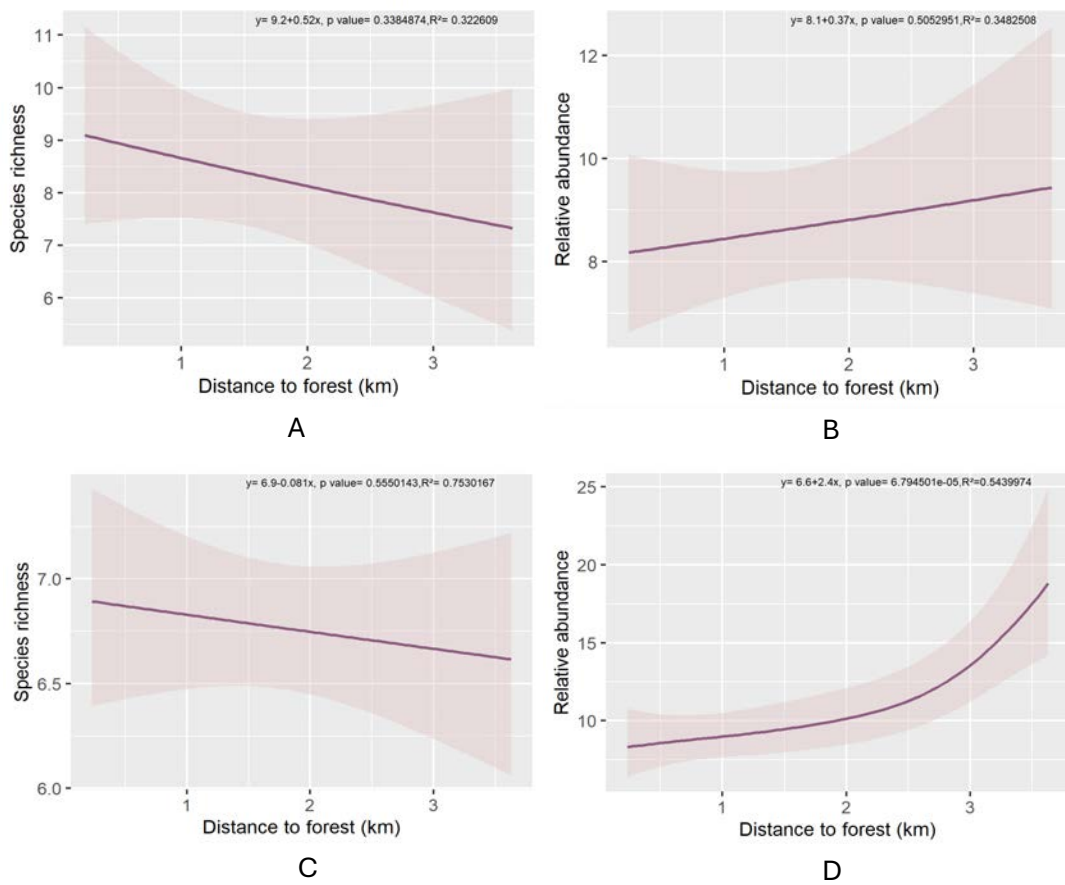


Figure 5.4. Account of species richness and diversity with changing distance from forest



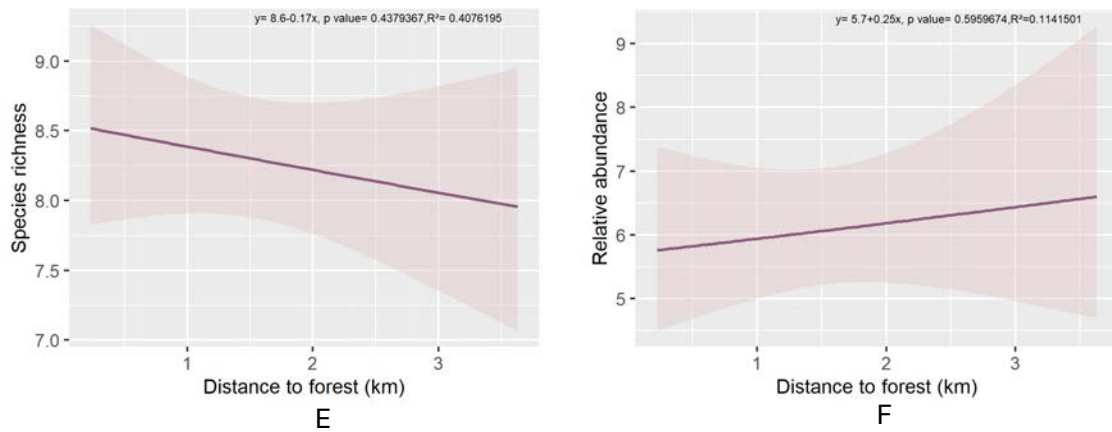


Figure 5.5. Correlation between pollinator species richness and abundance of different insect orders (A & B: Diptera; C & D: Hymenoptera; E & F: Lepidoptera) with changing proximity to forest in Kullu valley

5.3.1.2. Impact of elevational gradient

The analysis revealed that orchards situated below 1500 meters above sea level demonstrated the highest richness and diversity of pollinators. This trend persisted in orchards within the elevational range of 1500 meters to 2000 meters. In contrast, orchards located above 2000 meters elevation consistently exhibited the lowest richness and diversity across all three orders of pollinators: Hymenoptera, Diptera, and Lepidoptera (figure 5.6). Interestingly, when examining abundance patterns, both Hymenoptera and Diptera showed an increase with rising elevation. However, there were not many significant trends observed in the abundance of Lepidoptera across different elevational bands (figure 5.7).

This suggests that elevation acts as a crucial factor in shaping the diversity and abundance of pollinator species in orchard ecosystems. Lower elevations appear to provide more favorable conditions for a greater variety of pollinator species, while higher elevations may present more challenging environments, resulting in decreased richness and diversity. Additionally, the differing responses of Hymenoptera, Diptera, and Lepidoptera to elevation highlight the complexity of environmental factors influencing pollinator communities and underscore the importance of considering multiple variables in conservation and management strategies.

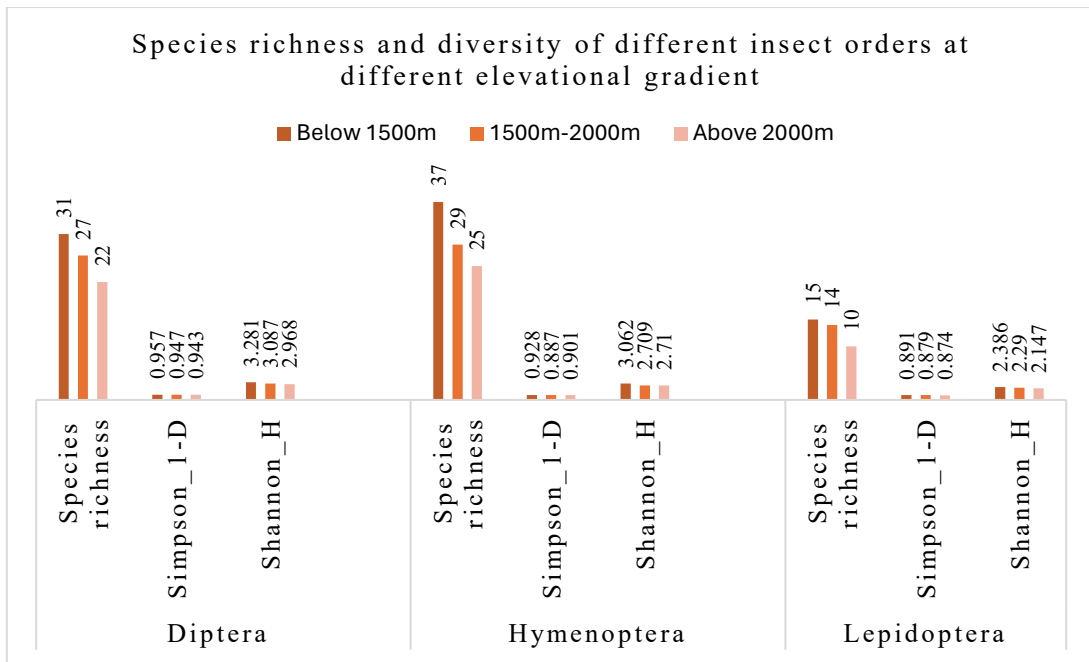
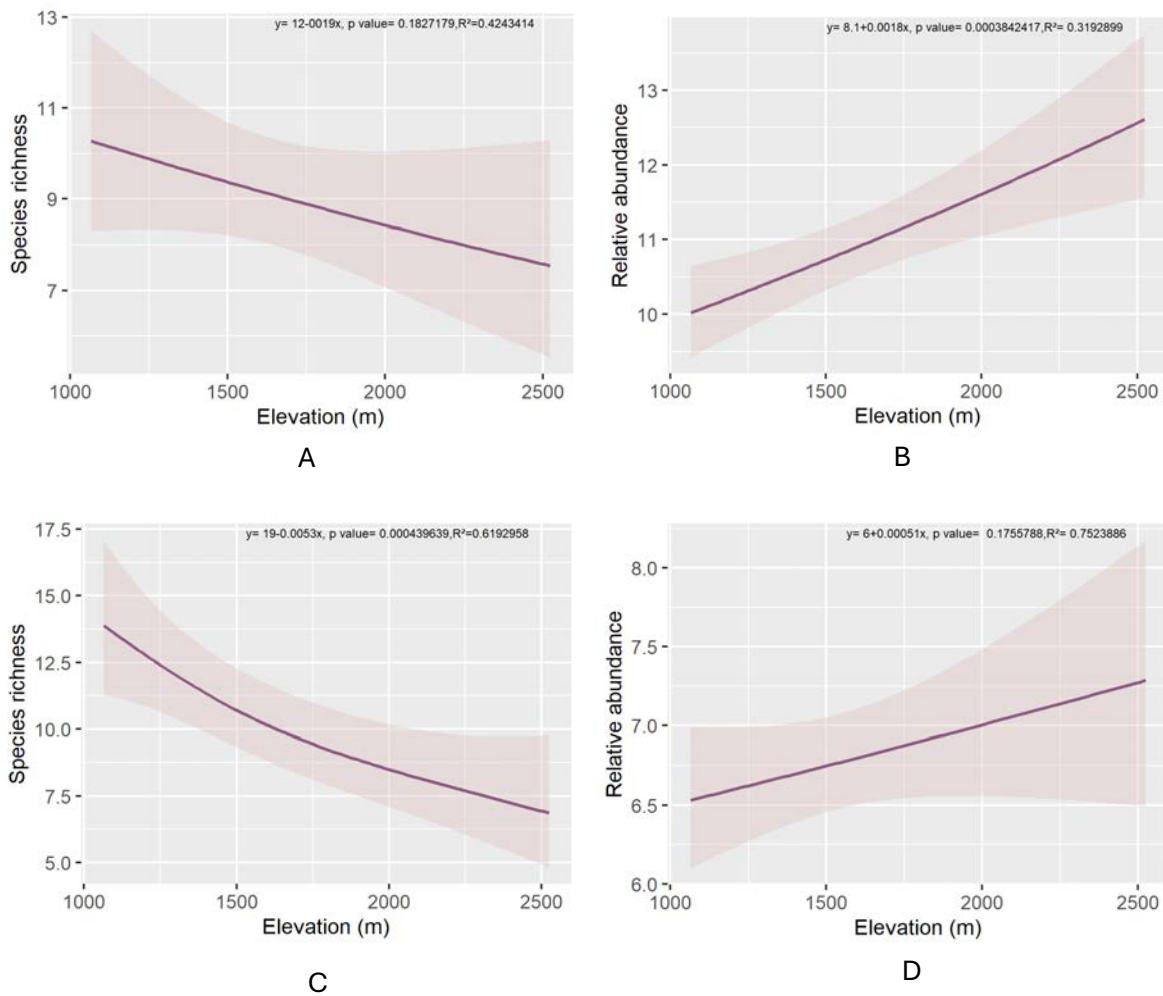


Figure 5.6. Account of species richness and diversity at different elevational gradients



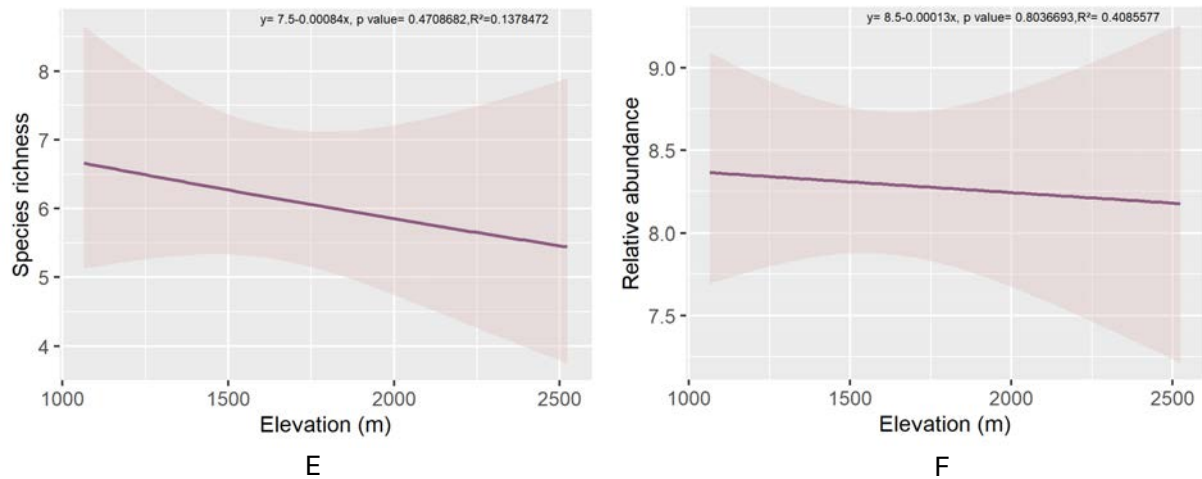


Figure 5.7. Correlation between pollinator species richness and abundance of different insect orders (A & B: Diptera; C & D: Hymenoptera; E & F: Lepidoptera) with elevational gradient in Kullu valley

5.3.1.3. Impact of presence of agricultural land

The presence of agriculture near orchard beds showed a higher richness of dipteran pollinators whereas the opposite in the case of orders Hymenoptera and Lepidoptera were observed, where higher insect diversity and richness were found in orchards that are not associated with agricultural fields nearby (figure 5.8). Most abundant species recorded in orchards that are situated near agricultural land included, *Apis cerena indica* (25%), *Apis mellifera* (16%), *Megachilae lanata* (6.3%), *Bombus haemorrhoidalis* (5.1%), and *Amegilla zonata* (4.2%) from the order hymenoptera; *Chrysoma megacephala* (8.81%), *Eristalis tenax* (7.82%), *Eristalis similis* (5.76%), *Eupeodes latifasciatus* (5.76%), *Eupeodes corollae* (5.31%), *Sphaerophoria Indiana* (5.17%) from the order Diptera.

On the contrary, most abundant species recorded from the orchards that do not have agricultural land nearby include *Apis cerena indica* (17.7%), *Apis mellifera* (9.2%), *Megachilae lanata* (7.86%), *Campsomeris sauteri* (5.4%), *Bombus haemorrhoidalis* (4.43%), *Amegilla zonata* (4.33%), *Ceratina smaragdula* (4.12%) and *Xylocopa latipes* (3.82%) from the order hymenoptera; *Eristalis tenax* (9.65%), *Meliscaeva cinctella* (8.32%), *Eupeodes corollae* (7.22%), *Episyrphus balteatus* (5.72%) and *Chrysoma megacephala* (5.41%) From the order Diptera. In case of lepidoptera most abundant species included, *Aglais caschmirensis* (19.4% & 14.54%), *Colias fieldii fieldii* (16% & 16.34%), *Pieris brassicae* (14.71% & 12.6%), *Eurema hecabe* (10.15% & 10.19%), *Pieris canidia* (7.68% & 10.94%) and *Kaniska canace* (7.68% & 8.9%) in orchards away from agricultural land and orchards near to agricultural land respectively.

It was also observed that in orchards situated adjacent to agricultural fields, there is a notable increase in the abundance of dipteran species whereas, no such pattern was found in the case of Hymenoptera and a slight decrease in lepidopteran abundance was noticed (figure 5.9). Increase in the richness and abundance of dipteran in the presence of agricultural land can be attributed to the presence of supplementary resources and habitat types offered by the nearby agricultural areas, which facilitate a broader range of dipteran species.

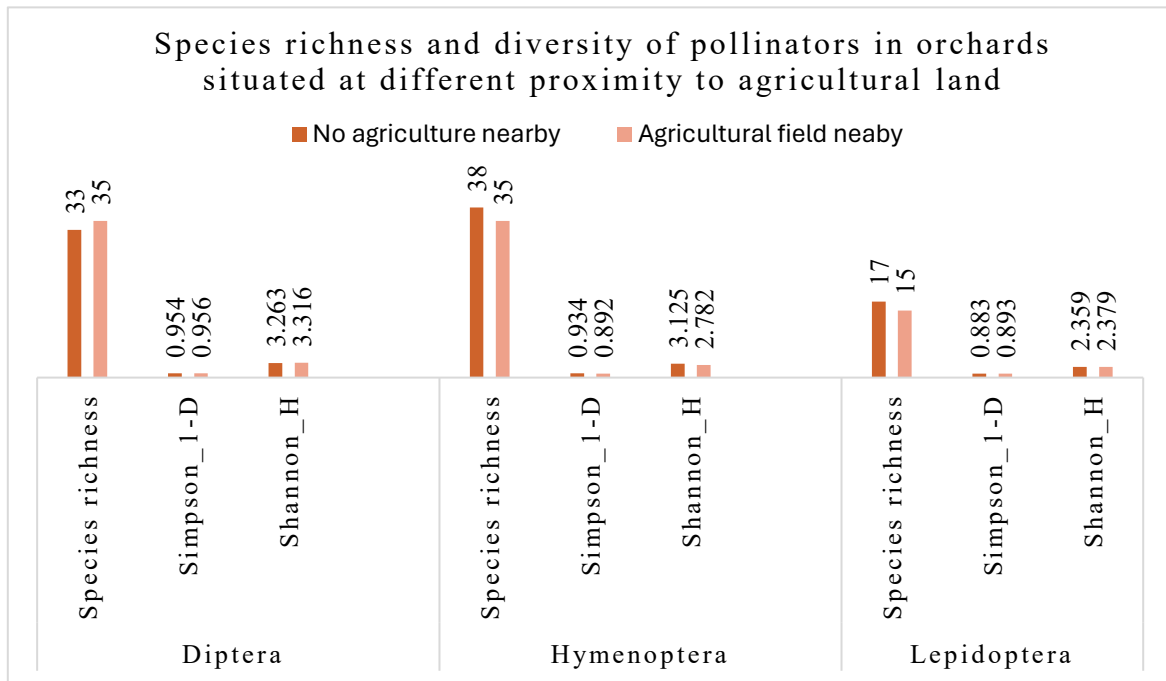
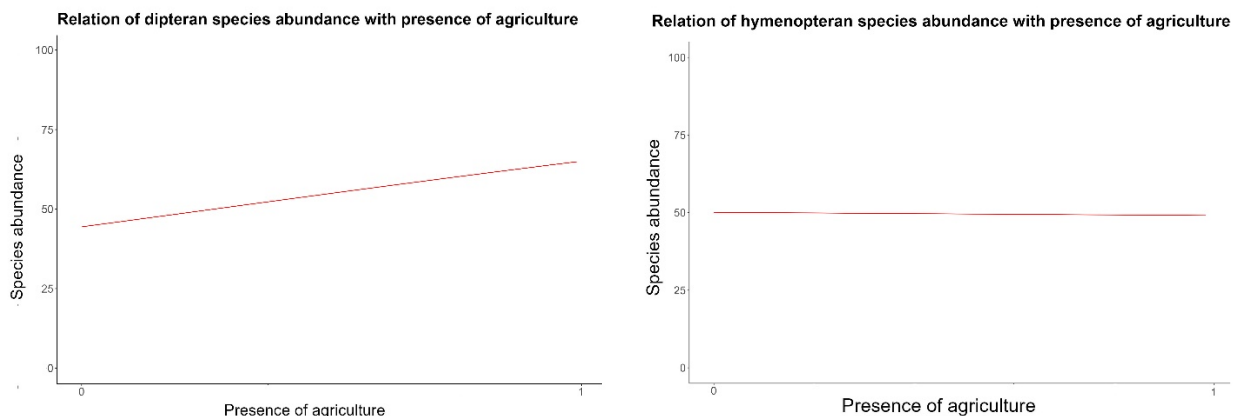


Figure 5.8. Account of species richness and diversity in orchards at different proximity to agricultural lands



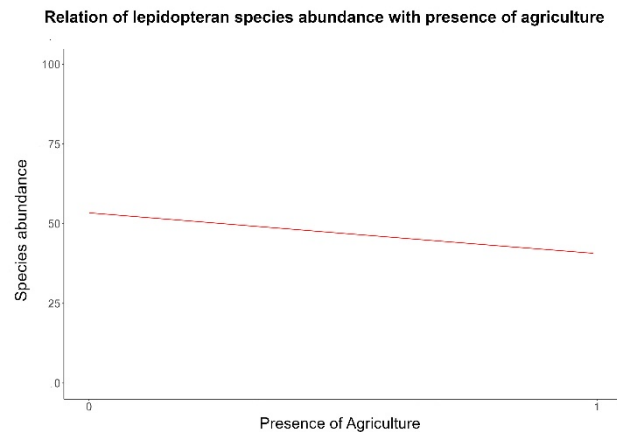


Figure 5.9. Relationship between abundance of pollinator species belonging to various orders (Diptera, Hymenoptera and Lepidoptera) with presence of agricultural practice nearby (0: Agriculture not present; 1: Agriculture present)

5.3.1.4. Impact of management practices

Significantly higher insect richness and diversity were observed in the Hymenoptera and Diptera orders in orchards that implemented both modern and traditional management practices, whereas no notable difference was observed in the case of Lepidoptera (figure 5.10). In orchards employing both modern and traditional management methodologies, the most abundant species in the Hymenoptera order included *Apis cerena indica* (19.62%), *Apis mellifera* (13.66%), *Megachilae lanata* (7.03%), *Osmia caerulea* (5%), *Amegilla zonata* (4.73%), *Bombus haemorrhoidalis* (4.73%), *Campsomeris sauteri* (4.73%), and *Ceratina smaragdula* (4.66%). For the Diptera order, prevalent species were *Eristalis tenax* (8.71%), *Chrysoma megacephala* (7.7%), *Episyrphys balteatus* (6.49%), *Eristalis similis* (5.74%), and *Eupeodes corollae* (5.43%).

However, in orchards managed solely using modern techniques, the most abundant species in the Hymenoptera order were *Apis cerena indica* (26.5%), *Apis mellifera* (9.43%), *Megachilae lanata* (7.22%), and *Bombus haemorrhoidalis* (4.82%). For the Diptera order, most abundant species were *Meliscaeva cinctella* (9.67%), *Eristalis tenax* (8.54%), *Eupeodes corollae* (8.04%), *Chrysoma megacephala* (6.15%), *Episyrphys balteatus* (5.52%), and *Sphaerophoria indiana* (5.15%). Regarding Lepidoptera, the most abundant species included *Aglais caschmirensis* (17.83% & 15.56%), *Colias fieldii fieldii* (16.43% & 15.56%), *Pieris brassicae* (11.42% & 18.99%), *Eurema hecabe* (10.32% & 9.84%), and *Pieris canidia* (11.42% & 6.17%) in orchards implementing both modern and traditional management practices and orchards with only modern management practices respectively.

It was also observed that management practice has a significant impact on shaping the pollinator abundance in the case of all three orders with increased abundance in orchards with both types of management implications possibly due to higher availability of additional foraging and nesting habitats (figure 5.11).

Findings highlight the complex interplay between management practices and insect diversity within orchard ecosystems. Orchards managed solely using modern techniques showed a somewhat different pattern, with notably lower richness, diversity, and abundance particularly in the case of Hymenoptera and Diptera compared to those employing both modern and traditional practices. Hence, incorporating a combination of modern and traditional techniques may be particularly effective in promoting pollinator richness and diversity, especially in hymenopteran and dipteran populations.

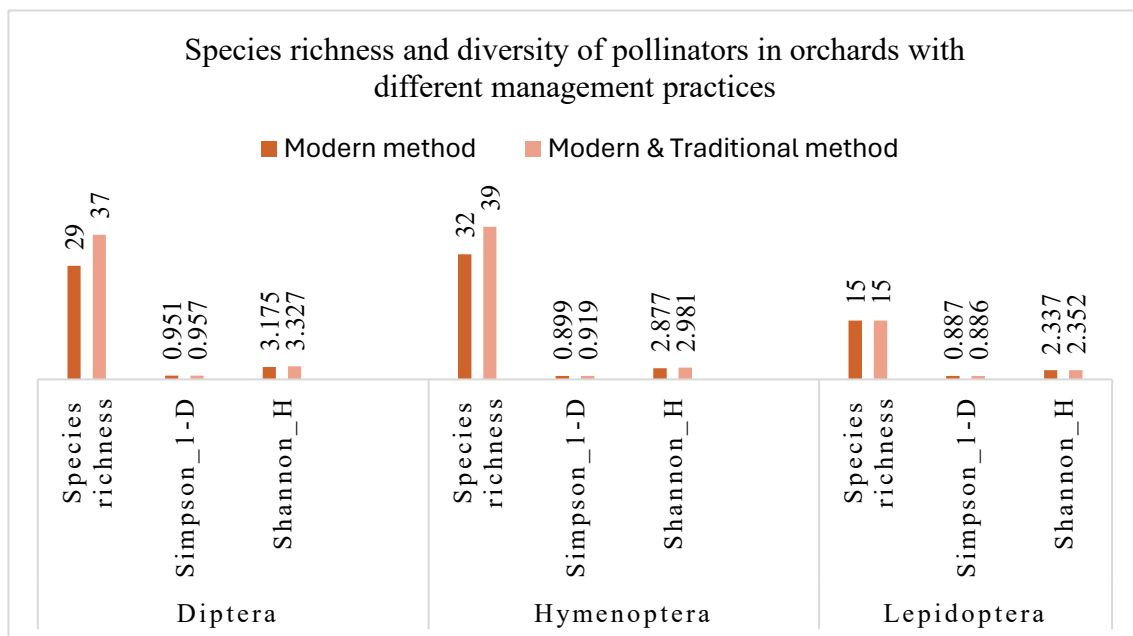
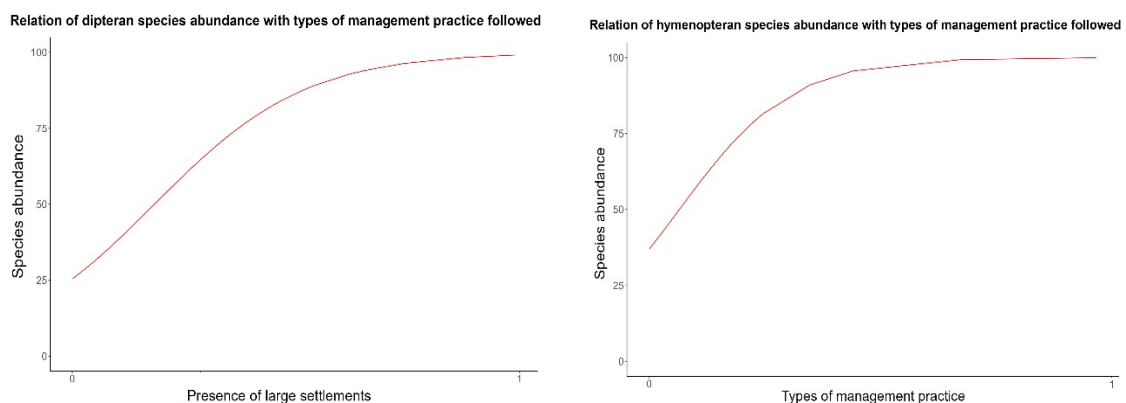


Figure 5.10. Account of species richness and diversity in orchards with different management practices



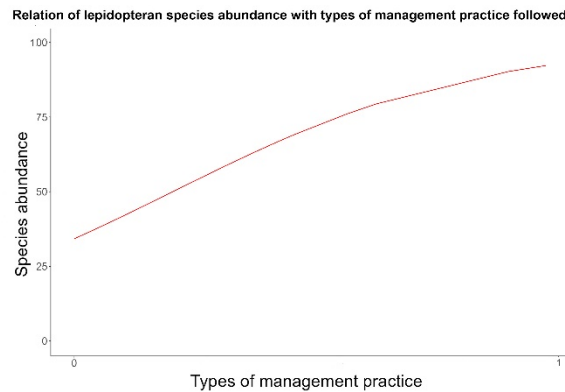


Figure 5.11. Relationship between abundance of pollinator species belonging to various orders (Diptera, Hymenoptera and Lepidoptera) with type of management practice followed (0: modern; 1: modern & traditional)

5.3.1.5. Impact of presence of large settlements

The entire Kullu valley is very much impacted by increased settlement and infrastructure. Orchards that are situated away from large settlement areas exhibit higher pollinator diversity and richness in all three orders (figure 5.12). Most abundant pollinators recorded in orchards situated far from large settlements included *Apis cerena indica* (23.68%), *Apis mellifera* (12.68%), *Megachilae lanata* (8.3%), *Osmia caerulescence* (6.69%), and *Bombus haemorrhoidalis* (4.9%) from the Hymenoptera order; *Eristalis tenax* (9.01%), *Chrysoma megacephala* (7.32%), *Meliscaeva cinctella* (7.01%), *Eupeodes corollae* (5.92%), and *Episyrphys balteatus* (5.44%) from the order Diptera.

On the other hand, and most abundant species in orchards located nearer to the settlement area include *Apis cerena indica* (18.97%), *Apis mellifera* (12.51%), *Megachilae lanata* (5.85%), *Ceratina smaragdula* (5.13%), *Amegilla zonata* (5.02%) and *Bombus haemorrhoidalis* (4.62%) from the order Hymenoptera; *Eristalis tenax* (8.14%), *Episyrphys balteatus* (7.35%), *Eristalis horticola* (7.17%), *Chrysoma megacephala* (7.17%), *Eupeodes corollae* (6.55%), *Eristalis similis* (6.28%), *Sphaerophoria indiana* (5.67%), and *Eupeodes latifasciatus* (5%) from the order Diptera. In case of Lepidoptera most abundant species include, *Aglais caschmirensis* (16.89% & 17.45%), *Colias fieldii fieldii* (17.02% & 15.12%), *Pieris brassicae* (15.64% & 11.37%), *Eurema hecabe* (10.84% & 9.34%), and *Pieris canidia* (10.72% & 8.72%) in orchards away from the large settlement and orchards near to large settlement respectively.

It was also observed that the abundance of Dipteran and Lepidopteran pollinators decreased in sites present close to large settlements, however, no visible pattern was observed in the case of Hymenopteran pollinators (figure 5.13).

The findings underscore the significance of considering the impacts of anthropogenic activities and landscape modifications on pollinator populations. Orchards situated away from large settlement areas exhibited higher pollinator diversity and richness across all three orders (Hymenoptera, Diptera, and Lepidoptera). This suggests that the presence of large settlements and associated infrastructure may harm pollinator populations by reducing suitable habitats and resources due to factors like habitat fragmentation, pollution, or human disturbance, leading to decreased species diversity and abundance.

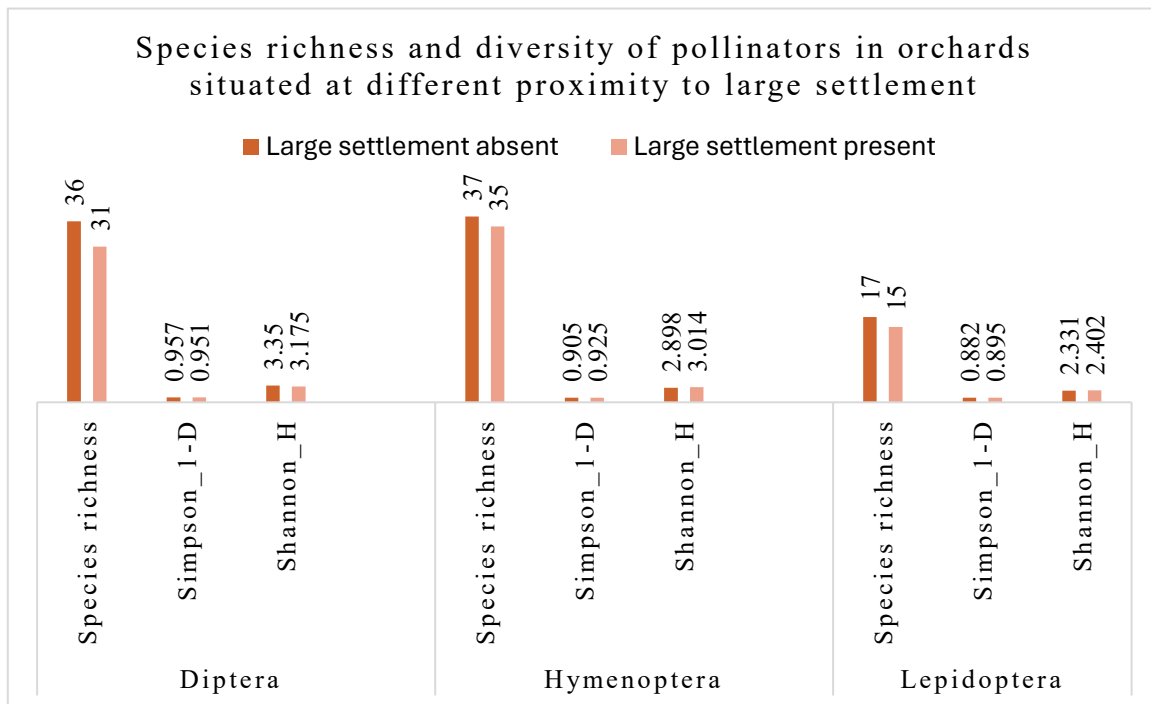
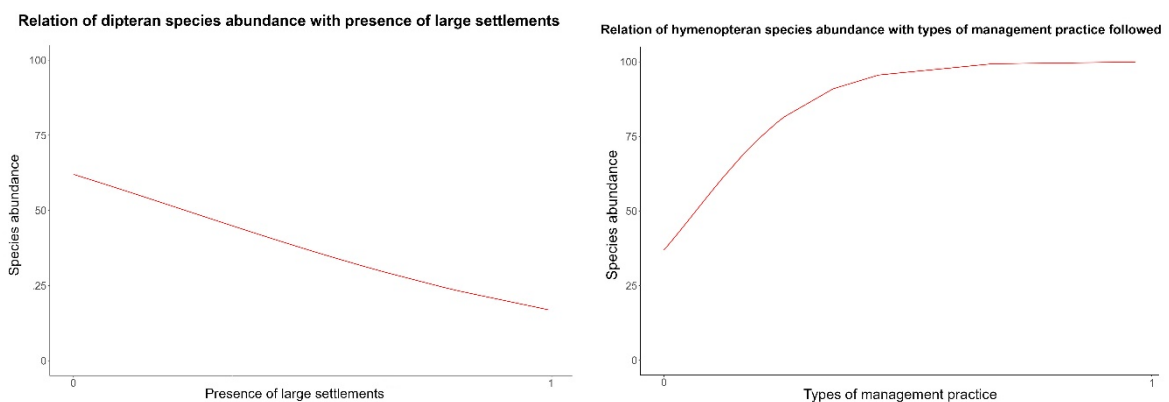


Figure 5.12. Account of species richness and diversity in orchards at different proximity to large settlement



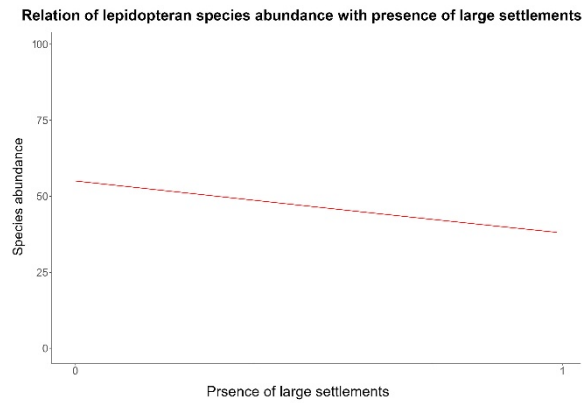


Figure 5.13. Relationship between abundance of pollinator species belonging to various orders (Diptera, Hymenoptera and Lepidoptera) with presence of large settlements nearby (0: no large settlement nearby; 1: large settlement present nearby)

The findings from the analysis, including t-tests and ANOVA (table 5.2), suggest that agricultural activities and settlement have no discernible impact on determining the diversity of pollinator communities within this landscape. This lack of significance may be attributed to the extensively interconnected and continuous mosaic-like structure of the Kullu valley, fostering habitat overlap and the development of a more uniform pollinator community throughout the area. However, the type of management practices adopted, distance of orchards from natural forest areas, and elevational gradients emerge as important factors in regulating the composition of pollinator communities. This could be attributed to the availability of nesting and foraging resources in orchards under traditional management, the presence of specific ecological niches in natural ecosystems, and the varied altitudinal distribution of habitats.

Table 5.2. Result of statistical significance tests (t-test and ANOVA)

Landscape configuration	t-value	p-value	Significance at p < .05
Presence of agricultural fields within 50ms of the periphery	0.66071	0.509513	Not significant
Presence of large settlements within 1km	1.25938	0.209279	Not significant
Management practice	4.95976	< .00001	Significant
Elevational gradient	12.61198	< .00001	Significant
Distance from forest	4.16853	0.016329	Significant

5.3.2. Tirthan valley

As a part of GHNPCA, commercial horticulture, and developmental activities aren't prominent in the region. Furthermore, Tirthan Valley, characterized by its narrowness and steep slopes, primarily comprises hill shades and dense natural forests within close proximity to the riverbed. Therefore, categorizing the valley into distinct land use and land cover classes proved challenging and sampling was conducted randomly, disregarding specific landscape configurations.

The result showed Tirthan valley accounted for a total of 76 insect pollinators in apple and plum orchards. These species were distributed among 49 genera and 18 families across five orders viz., Hymenoptera, Lepidoptera, Diptera, Coleoptera, and Thysanoptera. Hymenoptera comprised 30 species from 17 genera and eight families, while Diptera accounted for 26 species across 15 genera and four families. Lepidoptera included 17 species from 16 genera and four families, followed by Coleoptera with two species from one genus and one family and lastly, Thysanoptera was represented by one species within one genus and one family (figure 5.14). In the Tirthan valley, sampling coverage surpassed 90%, implying a more comprehensive depiction of the actual pollinator status (figure 5.15).

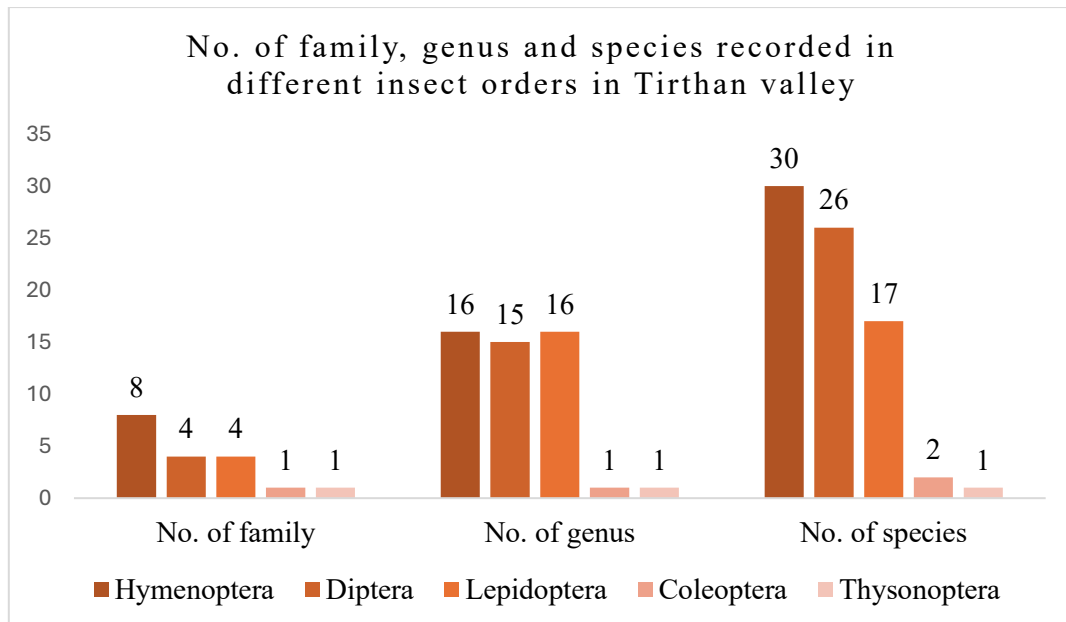


Figure 5.14. Account of family, genus, and species of different insect orders in apple and plum orchards of Tirthan valley

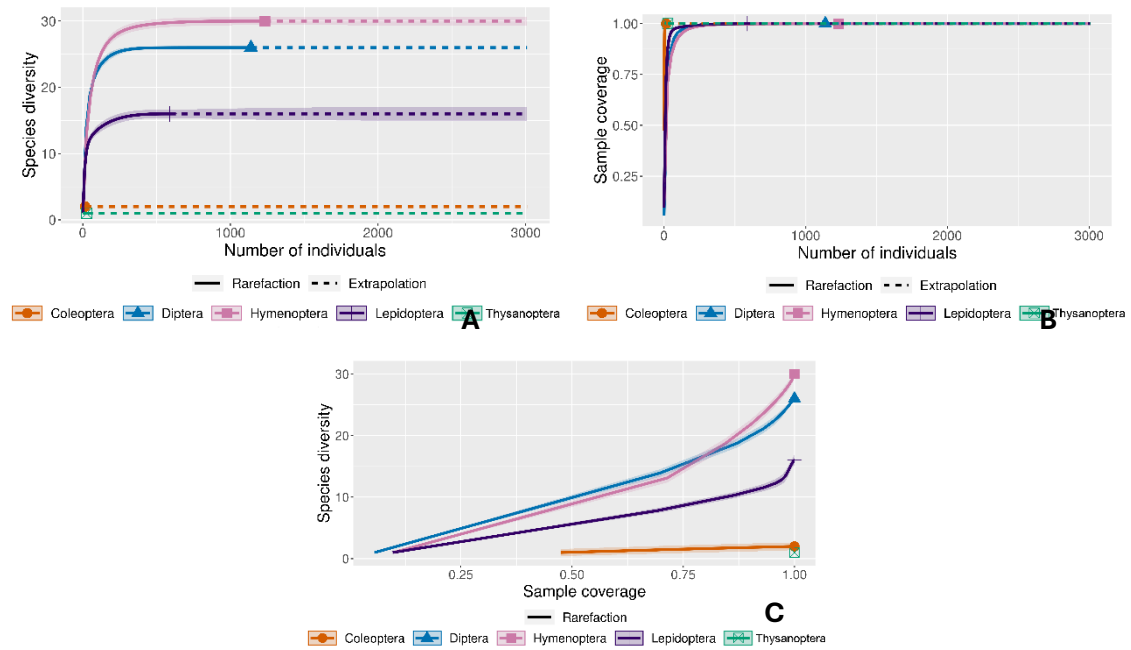


Figure 5.15. Sample size (A) and coverage-based (B) rarefaction and extrapolation curves linked to represent sample completeness (C) with 95% confidence intervals for different insect (pollinator) orders in Tirthan valley

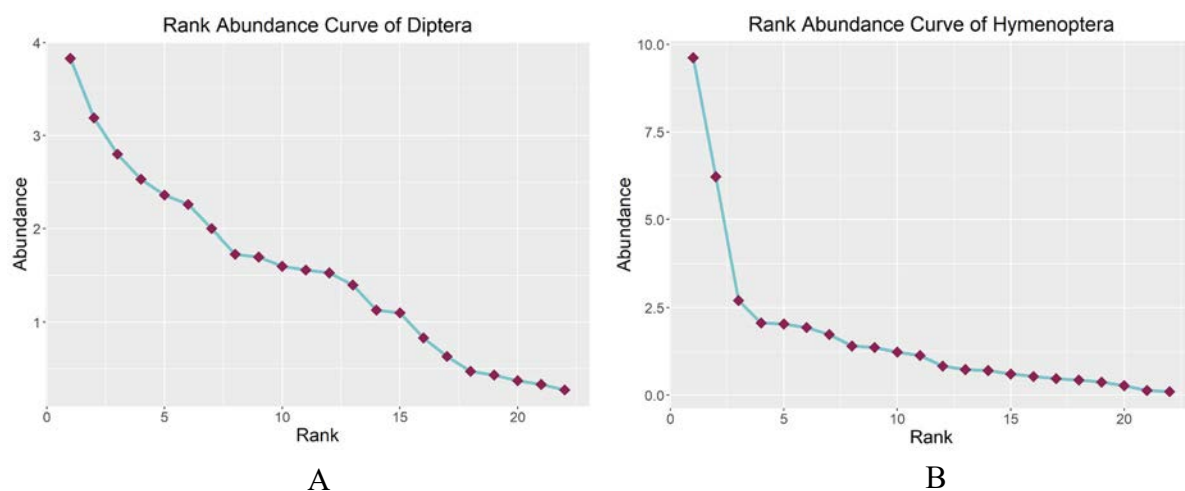
The Shannon diversity index (Shannon-H) was reported as 3.908, with Simpson's diversity index (Simpson 1-D) at 0.9714, and Fisher's alpha recorded at 13.95. The Shannon Evenness index (e^H/S) was calculated to be 0.6639, along with a Chao-1 estimate of 76 (table 5.3).

Table 5.3. Details of different indices of insect visitors in Tirthan valley

Parameters	Tirthan Valley
Total number of species	76
Total no. of individuals	3005
Simpson_1-D	0.9714
Shannon_H	3.908
Evenness_ e^H/S	0.6639
Chao-1	76
Fisher_alpha	13.95
Dominance_D	0.02859
Brillouin	3.846
Menhinick	1.368
Margalef	9.241
Equitability_J	0.9051
Berger-Parker	0.09617
Relative species richness	5.143

Abundance assessments were conducted for each order, identifying the dominant species within each group (annexure 3). Among Hymenoptera, *Apis cerana indica* emerged as the most prevalent species, making up 9.62% of the total population. In Diptera, *Episyrphus balteatus* accounted for 3.83%, while *Aglais caschmirensis* represented 3.06% of Lepidoptera. *Coccinella septempunctata* constituted 0.3% of Coleoptera, and *Thrips hawaiiensis* represented 0.9% of Thysanoptera.

Furthermore, it was observed that although there was a diverse array of pollinators, only a select few species were present in adequate numbers, with others being relatively scarce. Rank abundance curves were produced for each order to provide a visual representation of this distribution (figure 5.16). In the case of Hymenoptera, the sharp gradient curve indicates a skewed distribution, with certain species showing markedly higher abundances than others. This suggests a lack of evenness among species within this order, possibly indicating competitive interactions or environmental preferences that favor specific species. Conversely, the relatively normal to broken stick model observed in Diptera and Lepidoptera suggests a more balanced niche occupancy. This implies that these species may occupy distinct ecological niches or have differing resource requirements, enabling their coexistence and stability within the community. Coleoptera and Thysanoptera exhibit a broken stick model, indicating specific habitat preferences. Coleopteran species, which favor woody structures and ground areas, may thrive in orchards with suitable habitat features. Conversely, the targeted use of insecticides and pesticides to control thrips as pests may contribute to their lower abundance and restricted distribution within orchard ecosystems.



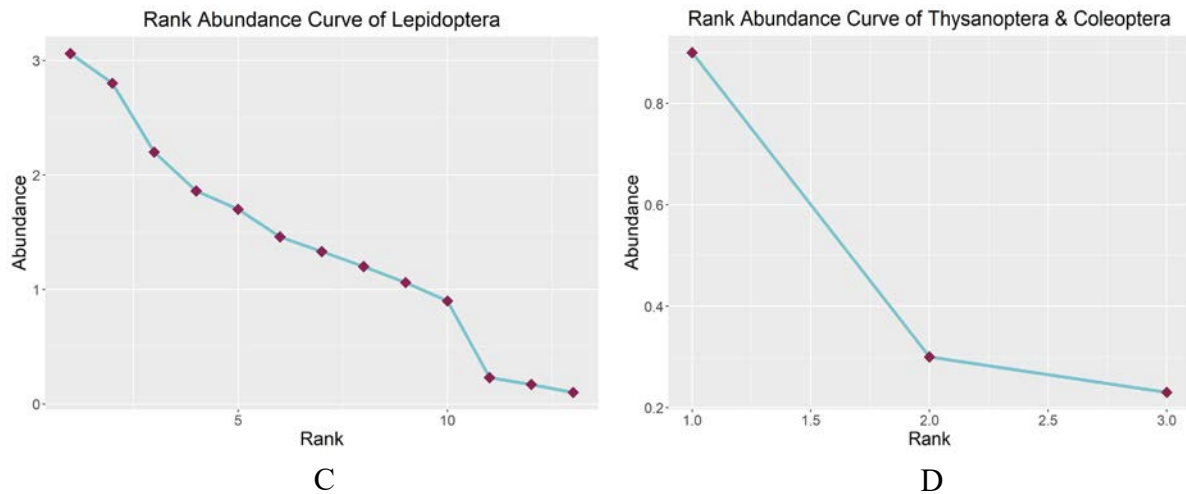


Figure 5.16. Rank abundance curve of various pollinator species belonging to five different insect orders from Kullu valley viz., Diptera (A); Hymenoptera (B); Lepidoptera (C); Coleoptera & Thysanoptera (D)

5.4. Conclusion

The diversity indices offer valuable insights into the richness and evenness of the pollinator community in both valleys. With a Shannon's diversity index (Shannon-H) of 4.137 for Kullu and 3.908 for Tirthan valley, there is a clear indication of high species diversity within the ecosystem. Similarly, Simpson's diversity index (Simpson 1-D) values of 0.978 and 0.9714 suggest a high likelihood of encountering various species in the environment. Fisher's alpha, measuring 18.32 in Kullu valley and 13.95 in Tirthan valley, further supports the presence of a diverse pollinator community. The Shannon evenness index (e^H/S) of 0.581 and 0.6639 respectively indicates a relatively even distribution of individuals among different species, reflecting a balanced ecosystem. Moreover, the Chao-1 estimate of 108.1 in Kullu valley and 76 in Tirthan valley underscores the potential total species richness within the community. Collectively, these indices indicate a diverse, balanced, and potentially rich pollinator community within the studied ecosystem.

The study also indicates that despite high pollinator diversity, only a few species were significantly abundant, indicating skewed distributions. Hymenoptera showed a steep curve, suggesting certain species dominate, possibly due to competitive interactions or environmental preferences. Diptera and Lepidoptera exhibited a somewhat broken stick model, indicating stable niche occupancy, with few species co-adapted to the particular habitat in both the valleys. Coleoptera and Thysanoptera displayed negative exponential distributions, reflecting specific habitat preferences and management practices. Coleopterans prefer woody structures and

ground areas, possibly leading to higher abundance in orchards. Thrips' lower abundance in orchards might result from targeted pest control measures (Morse & Hoddle, 2006).

The present study suggested that hymenopterans and dipterans were the most effective pollinators with higher species diversity and richness followed by Lepidoptera. Recent studies by Raj et al., (2012) and Mattu (2014) have also underscored the significance of hymenopterans and dipterans as the primary insect pollinators for apple and other temperate fruit crops in the Himalayan region. Apart from abundant species, some of the other important pollinators include solitary bees like *Xylocopa sp.*, *Ceratina sp.*, *Bombus sp.*, *Amegilla sp.*, *Osmia sp.*, and other syrphid flies and drone flies.

In Kullu valley, orchards near natural forests, especially within one kilometer, showed the highest pollinator species richness and diversity for Hymenoptera, Diptera, and Lepidoptera, indicating the vital role of forested habitats in supporting diverse pollinator communities, and the observation is also supported by other studies (Hussain et al., 2012; Sritongchuay et al., 2019). The decrease in pollinator richness and diversity as distance from forests increases underscores the importance of maintaining connectivity between orchards and natural habitats (Carvalho et al., 2010). While Lepidoptera richness peaked in orchards 1-2 kilometers from forests, maximum diversity was observed within one kilometer, suggesting varied responses among pollinator groups to forest proximity. Wild bee species such as *Megachilae sp.*, *Andrena sp.*, *Xylocopa sp.*, were found to be abundant in orchards which are less disturbed and situated near the natural forest and far from large settlements and agricultural practices. This finding also supports the earlier study by Kremen et al., 2004 and more recent study by Mattu & Bhagat, 2015 and aligns with the conclusions drawn by Ricketts et al., (2008) and Joshi et al., (2016), where authors similarly found that both pollinator richness decline with increasing distance from natural unmanaged habitats. These findings highlight the need for landscape management strategies prioritizing connectivity between orchards and natural forests to preserve biodiversity and ecosystem functionality.

Elevation significantly influences pollinator diversity and abundance in orchards, with lower elevations supporting more diverse species compared to higher elevations. The varied responses of Hymenoptera, Diptera, and Lepidoptera underscore the complexity of environmental factors shaping pollinator communities.

During the survey, it was recorded that every farmer in this valley uses a heavy amount of pesticides and insecticides on the crop for higher yield. In the case of modern management, farmers treat both the plant and soil with different pesticides, insecticides, and fertilizers and clean the ground removing any wild growth along with other standard methods. On the other

hand, where still management is done following traditional ways with adaptation to modern techniques, farmers use pesticides and insecticides along with organic fertilizers and don't clean the sideways or old logs from the ground. Hence, it was found that species diversity was higher in orchards with both types of management interventions due to the availability of natural resources for nesting and foraging as well. Species diversity and richness were comparatively less in orchards situated near agricultural lands. This can be due to the high use of pesticides in agricultural fields as well. However, orchards near agricultural fields show higher diversity and richness of dipteran insects compared to those farther away, likely due to the additional resources and habitat types provided by adjacent agricultural areas.

This valley is also highly prone to natural and anthropogenic disasters. Apart from tourism, agricultural shifts are also prominent, leading to frequent land use changes. It was observed that orchards near areas with large settlements and high tourism pressure were visited by a smaller number of wild pollinators. This indicates that the presence of large settlements and associated infrastructure may negatively affect pollinator populations by disrupting habitat availability and resources due to factors like habitat fragmentation, pollution, or human disturbance, leading to reduced species diversity and abundance which is also supported by (Vanbergen, 2014; Wenzel et al., 2020). These findings emphasize the significance of accounting for landscape context and land use patterns when evaluating insect diversity within orchard ecosystems. However, there are not many previous studies that show the impact of these types of land use practices on pollinators.

Insect pollinators provide vital ecosystem services, particularly in the pollination of agricultural and horticultural crops, as well as wild flora. Successful pollination is crucial for adequate food production and maintaining food security, with many human-consumed foods like fruits, vegetables, and nuts relying solely on pollinators. The monetary benefit of insect pollination services is substantial, providing direct economic benefits to farmers and the agricultural industry. Additionally, pollinators contribute to habitat maintenance for other wildlife, thereby enhancing overall biodiversity (Potts et al., 2016). According to feedback from farmers in Kullu valley, the cost of bee boxes is around Rs. 1000 per box, adding to production costs, which escalate with the number of boxes required. Moreover, the honey and wax produced from these bee boxes belong to the box sellers, offering no additional monetary benefits to orchard owners. Farmers also note that each box yields approximately 2-3 kgs of honey per season, with the highest quality honey being produced during the mustard season. Local market prices for honey are approximately Rs. 800 per kg. Therefore, maintaining beekeeping practices with native and

wild bee species could enable farmers to save costs associated with commercial bee hives while also generating revenue from honey and its by-products like wax.

The expansion of agriculture in Kullu is resulting in significant changes to land use patterns. Intensive farming practices, such as monoculture and the excessive application of pesticides and fertilizers (such as Durmet, Chloropyriphos, Bordo, Carbendazim, Bavistin, HMO, M45, TSO, Alanto, Taboconazol, Diethane, Danitol, Imidacloprid, etc.), pose a significant risk to pollinators and their services. These practices not only reduce floral diversity but also contaminate nectar and pollen, directly harming pollinator populations and the quality of products produced by the pollinators like honey and bee wax and others. Deforestation for timber, construction, and urbanization is leading to the loss of pollinator habitats. This loss deprives bees, butterflies, and other pollinators of nesting sites and foraging grounds, ultimately impacting their populations and the quality of pollination services they offer. The rapid development of the tourism industry in Kullu also poses a threat to pollination services. Infrastructure projects, such as roads, resorts, and recreational facilities, can fragment habitats and disrupt pollinator movements, hindering their ability to access flowers across a wide area. Climate change exacerbates the challenges faced by pollinators. Shifts in flowering times and pollinator emergence disrupt the synchronization between plants and their pollinators. Intense weather situations, such as heavy rainfall and snowfall, reduced chilling hours, and heatwaves, directly impact pollinator populations and disrupt their foraging activities, further compromising ecosystem services.

Conversely, traditional management practices like agroforestry and mixed cropping systems have the potential to enhance floral diversity, providing a continuous food source for pollinators (Isbell, 2017). Indigenous farming methods, characterized by minimal chemical use, help preserve pollinator populations and the pollination services they offer. Community-based conservation efforts, focusing on habitat restoration, the implementation of agroecological and sustainable land use practices, the establishment of pollinator-friendly gardens, and keeping native bee hives, can significantly contribute to supporting insect pollinators and preserving ecosystem services.

In summary, the influence of various land use practices on the insect pollinators and the ecosystem services provided by them in Kullu district is extensive and diverse. It underscores the priority of implementing sustainable land management practices that prioritize biodiversity conservation, habitat restoration, and the adoption of agroecological approaches. These measures are essential for safeguarding insect pollinators and sustaining the vital ecosystem services provided by them for human well-being and overall ecosystem health.

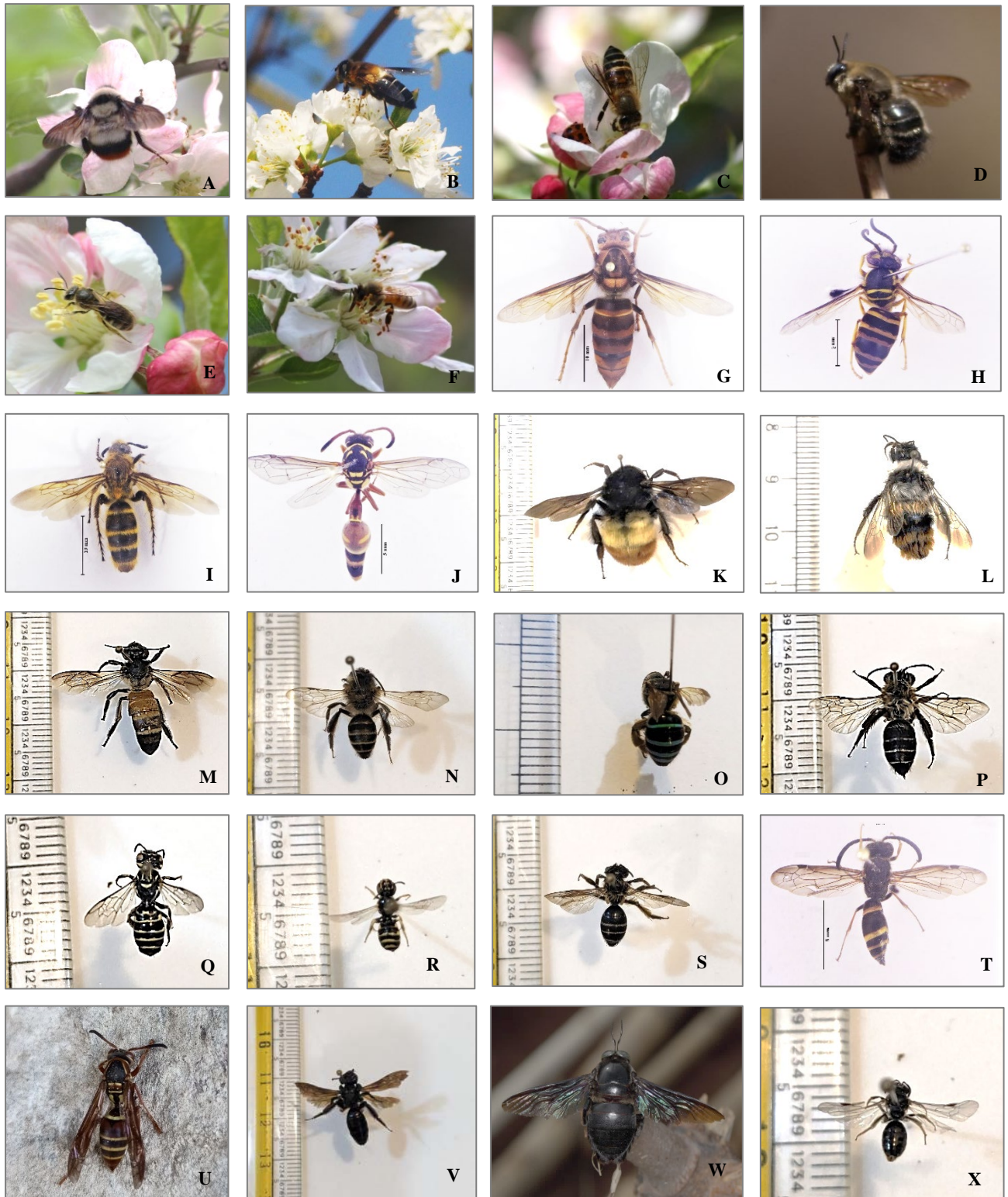


Photo plate 4: Pictorial account of some of the hymenopteran species recorded during the study. (A) *Bombus tunicatus*, (B) *Apis laboriosa*, (C) *Apis cerena*, (D) *Xylocopa dejeanii*, (E) *Hlictus* sp., (F) *Apis mellifera*, (G) *Vespa Auraria*, (H) *Vespula flaviceps*, (I) *Campsomeris sauteri*, (J) *Polistes dorsalis*, (K) *Bombus haemorrhoidalis*, (L) *Bombus* sp., (M) *Apis dorsata*, (N) *Andrena* sp.1, (O) *Amegilla zonata*, (P) *Andrena* sp.2, (Q) *Ceratina brayanti*, (R) *Ceratina* sp., (S) *Andrena* sp.3, (T) *Vespa* sp., (U) *Polistes* sp., (V) *Andrena* sp.4, (W) *Xylocopa latipes*, (X) *Andrena* sp.5.

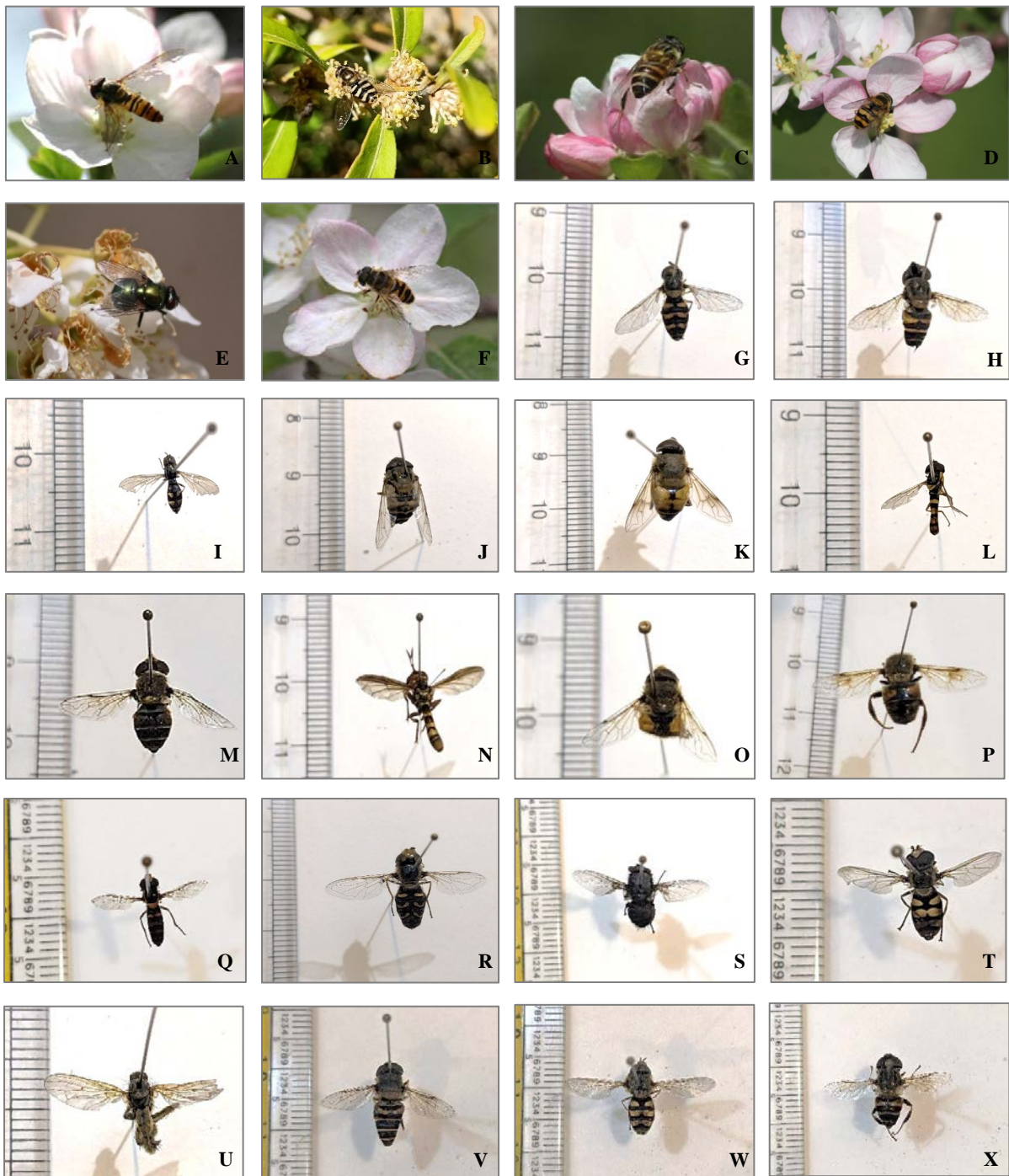


Photo plate 5: Pictorial account of some of the Dipteran species recorded during the study. (A) *Episyrphus balteatus*, (B) *Eupeodes* sp.1, (C) *Eristalinus arvorum*, (D) *Syrphus* sp.1, (E) *Chrysomya megacephala*, (F) *Eristalis cerealis*, (G) *Eupeodes* sp.2, (H) *Eristalinus paria*, (I) *Melanostoma orientale*, (J) *Eristalinus taeniops*, (K) *Mesembrius bengalensis*, (L) *Sphaerophoria indiana*, (M) *Eristalis himalayansis*, (N) *Conops* sp., (O) *Eristalis horticola*, (P) *Eristalis tenax*, (Q) *Sphaerophoria scripta*, (R) *Scaeva pyrastris*, (S) *Musca* sp., (T) *Syrphus* sp.2, (U) *Scaethophaga* sp., (V) *Eristalis* sp.2, (W) *Eupeodes colorrae*, (X) *Eristalinus* sp.

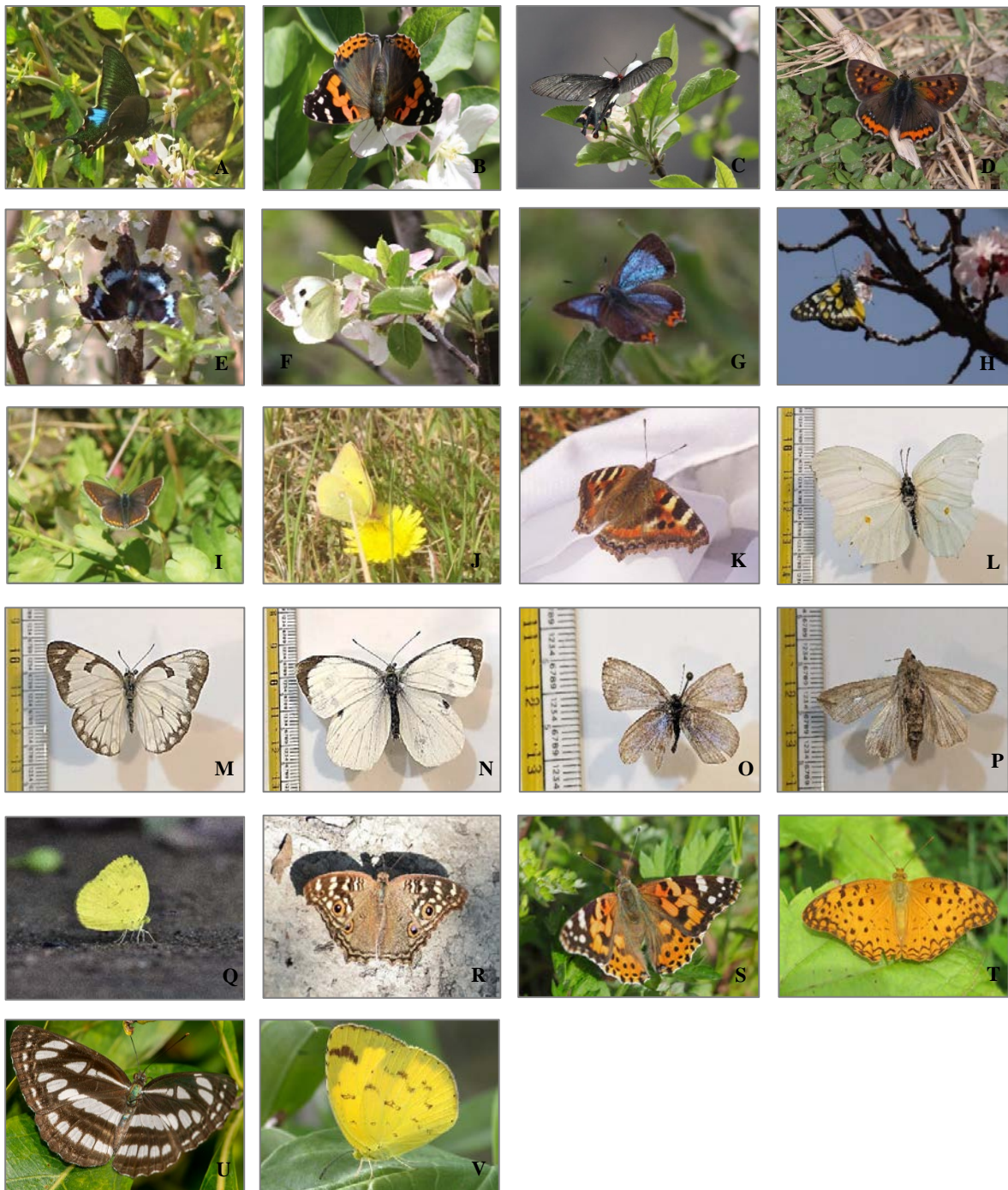


Photo plate 6: Pictorial account of some of the Lepidopteran species recorded during the study. (A) *Papilio binor*, (B) *Venesa indica*, (C) *Byasa polyeuctes*, (D) *Lycaena phlaeas*, (E) *Kaniska canace*, (F) *Pieris brassicae*, (G) *Heliophorus moorei*, (H) *Delias belladonna*, (I) *Aricia agestis nazira*, (J) *Colias fieldii fieldii*, (K) *Aglais caschmirensis*, (L) *Gonepteryx rhamni*, (M) *Belenois aurota*, (N) *Pieris canidia*, (O) *Pseudozizeeria maha*, (P) *Mythimna separata*, (Q) *Eurema andersoni*, (R) *Junonia* sp., (S) *Venesa cardui*, (T) *Phalantha phalantha*, (U) *Neptis hylas*, (V) *Eurema hecabe*.



Photo plate 7: Pictorial account of various types of insecticide and pesticide bottles that are used in horticultural practice



Photo plate 8: Pictorial account of Traditional bee keeping practice of Apis cerena in Tirthan valley.



Chapter 6:
Modelling the Distribution of Major
Pollinators of Different Orders

6.1. Introduction

Numerous human-induced disturbances are exerted on global biodiversity, leading to species extinctions (Alkemade et al., 2009; Newsome et al., 2017). The alteration of ecosystem services and functioning due to anthropogenic climate change is a significant concern (IPCC, 2021; Mooney et al., 2009). Preserving biodiversity is crucial amid shifting climate conditions (IPCC 2001, 2014). According to climate projections by the IPCC (2021), a minimum 1°C temperature increase is expected between 2030 and 2050 compared to preindustrial levels in the Himalayas. Climate change can induce various impacts on biodiversity, such as population fluctuations (Graae et al., 2018), alterations in species phenology (Visser & Both, 2005), shifts in ranges (Lenoir & Svenning, 2015), rapid changes in species composition and richness (Steinbauer et al., 2018), and localized extinctions (Bosso et al., 2022; Panetta et al., 2018). Endangered species can find themselves restricted to specific landscape patches, as they may struggle to adapt their habitat altitudinally or latitudinally (Freeman et al., 2018). It's crucial to comprehend the impacts of climate change on species diversity to formulate long-term and effective conservation strategies (Jones et al., 2013; Range et al., 2019; Ali et al., 2021; Jenkins et al., 2021).

Mountains are recognized as highly important ecological zones, providing a variety of ecosystem services to surrounding communities. However, these regions are very much threatened by the combined impacts of climate change and alterations in LULC (Das et al., 2023). The Himalayan Mountains, characterized by complex topography and climatic variations, harbor one of the world's richest biodiversity, specifically the floral diversity, with their distribution intricately linked to that of wild pollinators (Wambulwa et al., 2021). Over the period from 1951 to 2014, the Himalayas underwent notable warming, with a rate of 0.2 °C per decade, particularly pronounced at higher elevations, where the rate reached 0.5 °C per decade. Climate predictions indicate a further rise in average temperatures by 2–5 °C by 2050, accompanied by an increase in annual rainfall of up to 12% (Maharjan et al., 2022).

As insects constitute the most diverse animal group on earth representing more than 50% of all known multicellular fauna, understanding their response to global climate change, driven by rising temperatures, elevated atmospheric CO₂ levels, and shifting rainfall patterns, is of significant interest to researchers (Skendžić et al., 2021). Recent investigations have highlighted a concerning decline in insect populations, especially flying populations, in the north-temperate region due to the aforementioned factors, with profound implications for the ecosystem services they provide (Eggleton, 2020). The impacts of climate change on insect species and phenological shifts, such as earlier flight periods, enhanced survival capabilities in

winter, alterations in developmental rates, range expansions beyond current thermal regimes, and interaction with invasive species, will exacerbate these effects (Eggleton, 2020). The diversity and association of insect communities reflect ecosystem functioning (Correia & Pinheiro, 1999) and are crucial for landscape structure analysis (Fagundes et al., 2011). Bees (Hymenoptera: Apoidea) are particularly important for animal pollination and are the primary contributors to pollination services globally (Roubik, 1995). They have the capability to act as continuous biomonitoring species on a global scale, aiding in the monitoring of rising threats such as climate change (Cunningham et al., 2022). Climate change has the potential to irreversibly impact ecosystems and associated biodiversity, causing the extinction of several Himalayan species, especially pollinators, by modifying their behavior, physiology, and synchrony with the phenology of host plants. Although predictions suggest a decrease in potential habitat suitability for bumblebees in the GHNPCA (Singh et al., 2022, 2024), there has been no comprehensive attempt to incorporate various climate change consequences to assess future habitat changes for other crucial pollinator species across the Himalayas.

Mapping out species distributions and identifying suitable habitats are crucial steps for creating species conservation and management strategies at the habitat or landscape level (Ortega-Huerta & Peterson, 2004; Zai et al. 2009; Gelviz-Gelvez et al., 2015). Species distribution modeling tools are very popular in ecological research and find wide application in various ecological contexts (Elith et al., 2006; Peterson et al., 2006). Generally, SDMs estimate the likelihood of a species presence in a specific geographical area, aiding in the identification of critical habitat for targeted species management (Araújo & Williams, 2000; Graham et al., 2004; McFarland et al., 2013). Additionally, delineating ecologically meaningful units is essential for large-scale habitat management, allowing for similarity or dissimilarity of threats and status across similar ecological regions (Rice et al., 2010). Ecological niche modeling helps establish the relationship between environmental variables and species occurrence (Jose & Nameer, 2020), facilitating the prediction of formerly unspecified habitats for species (Elith et al., 2011; Paul et al., 2020). However, many SDM techniques are sensitive to the sample size (Wisz et al., 2008), potentially leading to inaccuracies in predicting distributional patterns of habitat, particularly for endangered and threatened species.

Several SDMs are available for estimating species' geographic distributions, including DOMAIN, BIOCLIM, GLMs, GAMs, GARP, and MaxEnt, each differing in input criteria and parameters (Busby, 1991; Carpenter et al., 1993; Stockwell, 1999; Elith & Leathwick, 2009). While most SDMs require data for both species presence and absence, MaxEnt stands out as it can operate using presence-only data (Phillips et al., 2006). MaxEnt is a software package

utilized to correlate documented species occurrences with environmental descriptors, including climate, topography, anthropogenic features, or soil data, and predict the presence or absence of a species at locations where no sampling has been conducted. This method is widely favored among species distribution modeling techniques due to its consistently strong predictive accuracy and straightforward implementation. MaxEnt employs machine learning based on maximum entropy to estimate the probability distribution of species occurrence using environmental data. It takes two main inputs: GPS points marking species locations and environmental layers. With these inputs, the software analyzes and predicts species distribution in areas of concern (Phillips et al., 2006), making it a valuable means for forecasting species' geographical ranges.

This study utilized the MaxEnt model to assess the present geographic distributions and projected changes in habitat suitability for 26 insect pollinator species of IHR under future climate scenarios in the state of Himachal Pradesh, a western Himalayan landscape. The objective was to determine the critical environmental factors influencing the distribution of these species and analyze the underlying reasons for shifts in climatic suitability. The findings will help in the formulation of management and conservation strategies adapted to the needs of these species and many others.

6.2. Methodology

6.2.1. Species occurrence data collection

For species distribution modeling primary data on species occurrence were collected from field surveys conducted during 2021 and 2022 at 42 different sampling locations (Plum and Apple orchards) across Kullu and Tirthan valley of Himachal Pradesh. Secondary occurrence data of these pollinator species in the Himalayas were collected through literature surveys. However, GPS locations were not available for most of the species in these references, and only the names of the localities along with the elevational scope were provided. Hence, the GPS coordinates of each species for each location were extracted using Google Earth Pro. Species occurrence data from GBIF were also utilized. Post-download, records were verified to minimize the inaccuracies. Conditions of systematic sampling are not always fulfilled by citizen science data, and also, the data available at GBIF are often clustered and biased, leading to model overfitting. Thus, downloaded data were thoroughly cleaned before use to enhance model performance. The "spatially rarefy tool" in the SDM toolbox in ArcGIS 10.7.1 (Brown, 2014) was used, and a single record per 1 km² grid was retained to eliminate duplicate presence

points and minimize probable spatial clusters in the occurrence localities. A total of 26 pollinator species belonging to Hymenoptera (10 species), Diptera (8 species), and Lepidoptera (8 species) were used for distribution modeling. These species were selected depending on their suitability as primary pollinators as per published data and the availability of secondary occurrence records, as most species are data deficient. A total of 489 occurrence (presence-only) records for Hymenoptera, 220 occurrence records for Diptera, and 1484 occurrence records for Lepidopteran pollinators retrieved from secondary sources for the North-western Himalaya biogeographic province 2A (Himachal Pradesh and Uttarakhand) (figure 6.1) were utilized for distribution modeling for the entire landscape.

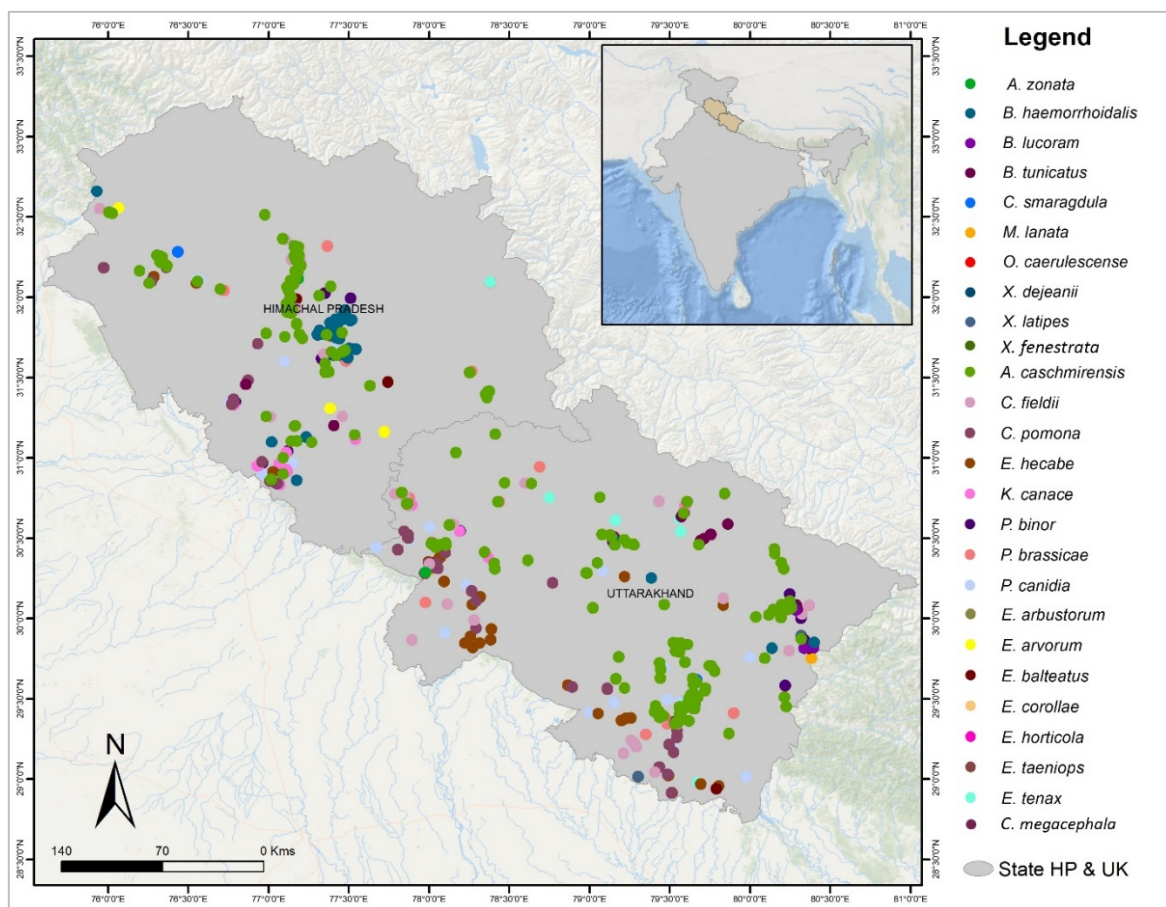


Figure 6.1. Occurrence points of 26 pollinator species retrieved through a secondary source from the western Himalayan Biogeographic Zone

6.2.2. Spatial data preparation

Nineteen bioclimatic variables for both present and future scenarios were acquired in Geotiff format from WorldClim V2.1 (Fick & Hijmans, 2017) (www.worldclim.org), and Digital Elevation Model (DEM) data were obtained from <https://asterweb.jpl.nasa.gov/gdem.asp>. The bioclimatic data layers were generated by

interpolating average monthly climate data collected from weather stations worldwide onto a grid with a resolution of 30 arc-seconds, approximately equivalent to 1 km². (Hijmans et al., 2005). The current climatic data represent averages from 1970 to 2020 and were obtained with a spatial resolution of 2.5 arc minutes. Future climatic data from the MIROC-E2SL Global Circulation Model (GCM) were obtained for the mid-century period of 2041 to 2060. These data correspond to two distinct Shared Socioeconomic Pathways (SSPs) from the Coupled Model Intercomparison Project Phase 6 (CMIP6), namely SSP126 and SSP585. SSPs delineate a recent dataset of future emission scenarios based on diverse socioeconomic assumptions, where SSP126, or the “green” pathway (1.5°C - 2°C increase in temperature: an optimistic scenario designed to align with the 2°C targets), represents sustainability, and SSP585 represents the “fossil-fuelled development” situation (more than 4°C increase in temperature). The SSP126 optimistic scenario (also considered the best-case scenario), was chosen as under the Paris Agreement 2015, nations are committed to reducing the emission of greenhouse gases aiming to ‘hold the increase in the global average temperature to well below 2°C above pre-industrial levels.’ Moreover, as a result of elevation-dependent warming, it is projected that Asian high mountains will undergo a more pronounced warming of 2.1°C ± 0.1°C (Mountain Research Initiative EDW Working Group, 2015; Maurer et al., 2019; Han et al., 2023) However, the later scenario (SSP585) was considered to understand the worst climate impact on the distribution of these species. Abiotic factors exert a significant influence on tropical and subtropical regions. However, employing species distribution models with numerous possibly relevant datasets can result in overfitting and unreliable prediction performance, as indicated by several studies (Franklin et al., 2006; Li et al., 2012; Guyon et al., 2010). Additionally, it is essential to select appropriate variables—those pertinent to species ecology—while considering the intricate interplay among bioclimatic variables to forecast climatically suitable areas for a species (Hu et al., 2020). Therefore, recommended bioclimatic variables (Warren et al., 2013) capturing annual trends (such as BIO1 = Annual Mean Temperature and BIO12 = Annual Precipitation), extreme environmental factors (including BIO5 = Max Temperature of Warmest Month, BIO6 = Min Temperature of Coldest Month, BIO16 = Precipitation of Wettest Quarter, and BIO17 = Precipitation of Driest Quarter), as well as seasonality (such as BIO4 = Temperature Seasonality and BIO15 = Precipitation Seasonality) were utilized for analysis alongside DEM data.

6.2.3. Modelling and map preparation

The MaxEnt model underwent bootstrapping with 10 replicates for each species. Eighty percent of the presence data were used to generate predictive models, while the remaining 20% were held out for model testing (Lozier et al., 2023). Default settings were retained for other parameters. The default parameter settings of MaxEnt were applied for the modeling, with the regularization multiplier (Phillips & Dudík, 2008; Radosavljevic et al., 2014) set to 1 and a background sampling density of 10,000 points. This decision was made for several reasons: (1) Previous studies have shown that altering MaxEnt's default settings did not enhance its performance, and default settings for presence-only data yielded similar results to tuned settings (Phillips & Dudík, 2008; Valavi et al., 2023); (2) Default settings allow flexibility for running the model even with limited data availability (Elith et al., 2010); and (3) By default, the MaxEnt algorithm assumes uniform probability for selecting every pixel in the spatial dataset, leading to predictions that align with the largest feasible range size consistent with the available data (Merow et al., 2013). However, for a few dipteran species, the regularization multiplier was set as 2 because the predicted models were suboptimal due to data unavailability. The input of individual variables in each model was assessed using the Jackknife test. Furthermore, model performance was assessed using the Receiver Operating Characteristic (ROC) method, where an Area Under the Curve (AUC) value of 0.7 to 0.8 indicates satisfactory models, values of 0.8 to 0.9 indicate excellent models, and values exceeding 0.9 indicate outstanding models (Hosmer & Lemeshow, 2000; Quinn et al., 2013).

The model was run for both Himachal Pradesh and Uttarakhand using presence points acquired for both these states to increase the robustness of the models since they are part of the same biogeographic province and exhibit similar geophysical features. After modeling the current habitat suitability, the models for each species were projected into two SSPs (i.e., SSP126 and SSP585) of mid-century (2041–2060). Further, the predicted model was masked for the state of Himachal Pradesh in ArcGIS and further analyses were carried out. The mean cloglog output of each species from both present and future scenario models was used for subsequent analysis. The "Minimum training presence cloglog threshold" for each species output was utilized to convert the output rasters into binary maps, distinguishing between absence (0) and presence (1). Following this, the "Distribution change between binary SDM" tool within the Universal tools of SDM Toolbox in ArcGIS was employed to compute the alteration in species' distribution concerning suitable habitat. Subsequently, the "Centroid change estimation" tool in the SDM Toolbox was utilized to assess the directional shifts of the suitable climatic niche for each species in the future, estimating the range shift. Furthermore, using the "Species

richness estimation” tool from SDMToolbox in ArcGIS (Brown, 2014), the richness hotspot of diverse pollinator species under both present and future scenarios was determined.

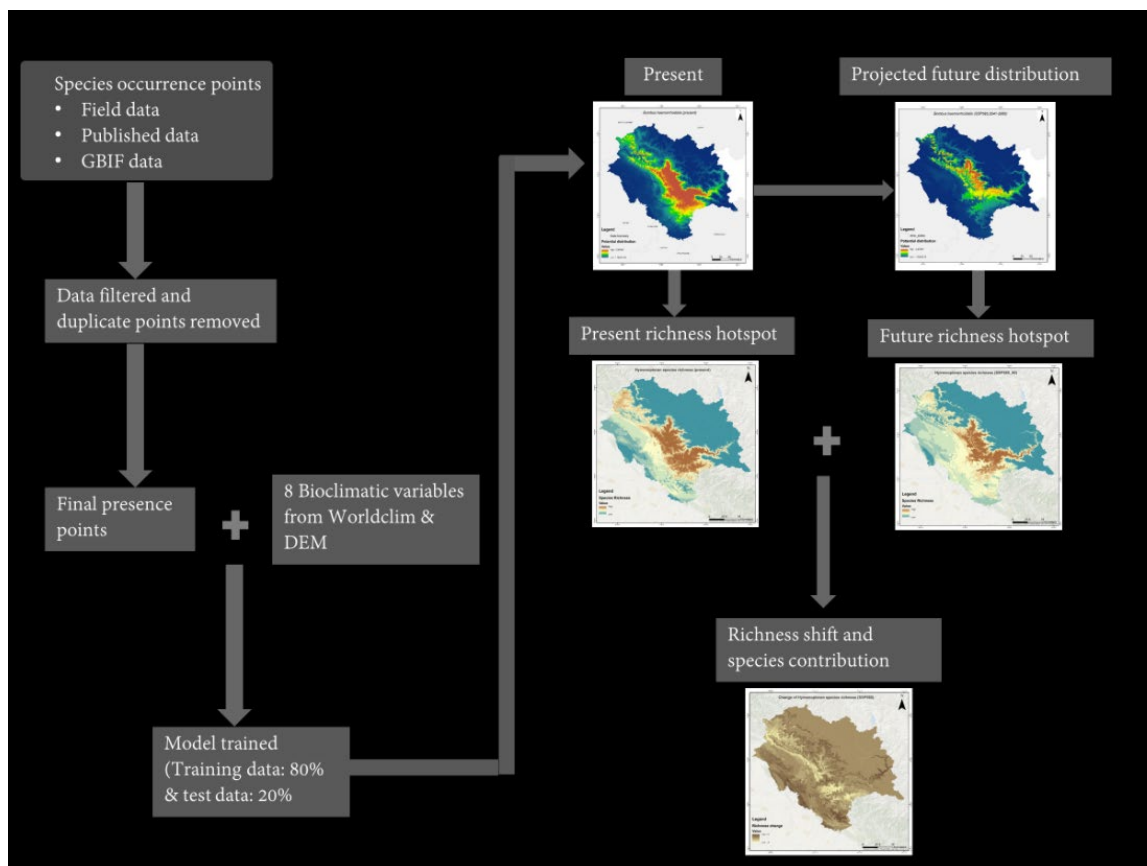


Figure 6.2. Flow chart of different steps of species distribution modelling using MaxEnt software

6.3. Results and Discussion

6.3.1. Model accuracy and predictor variable importance

The model performance was assessed using the area under the ROC curve (AUC) value, indicating robust performance across different species. For Hymenoptera, AUC values ranged between 0.930 to 0.979, for Diptera from 0.949 to 0.996, and for Lepidopteran species from 0.955 to 0.979.

The importance of each variable as a predictor in the MaxEnt SDM varies across different species, as summarized in figures 6.3, 6.4, and 6.5. For *Osmia caerulea*, *Amegilla zonata*, and *Ceratina smaragdula*, Bio6 (Minimum temperature of coldest month) influenced the most, while for *Xylocopa fenestrata* and *Xylocopa dejeanii*, the maximum contribution was by Bio5 (Maximum temperature of warmest month). For all three *Bombus* species, Bio4 (Temperature seasonality) had the highest contribution. In Dipteran species, Bio6 which is the Minimum

temperature of coldest month, was predominantly significant, although Bio12 (Annual precipitation) played a notable role in *Eristalix tenax* and *Eristalis balteatus*. Among Lepidopteran species, Bio12 (Annual precipitation) was the most influential, followed by Bio4 (Temperature seasonality).

The consistent AUC values affirm the reliability of MaxEnt models in capturing species-environment relationships. Variability in predictor importance highlights the complex nature of these relationships, crucial for conservation planning. Understanding the ecological preferences of insect species aids targeted conservation strategies. Identifying key environmental drivers informs habitat restoration and predictive modeling efforts. MaxEnt SDMs serve as valuable tools for studying and conserving insect biodiversity amidst environmental changes. Continued refinement of these models enhances our ability to make informed conservation decisions and adapt to evolving ecosystems.

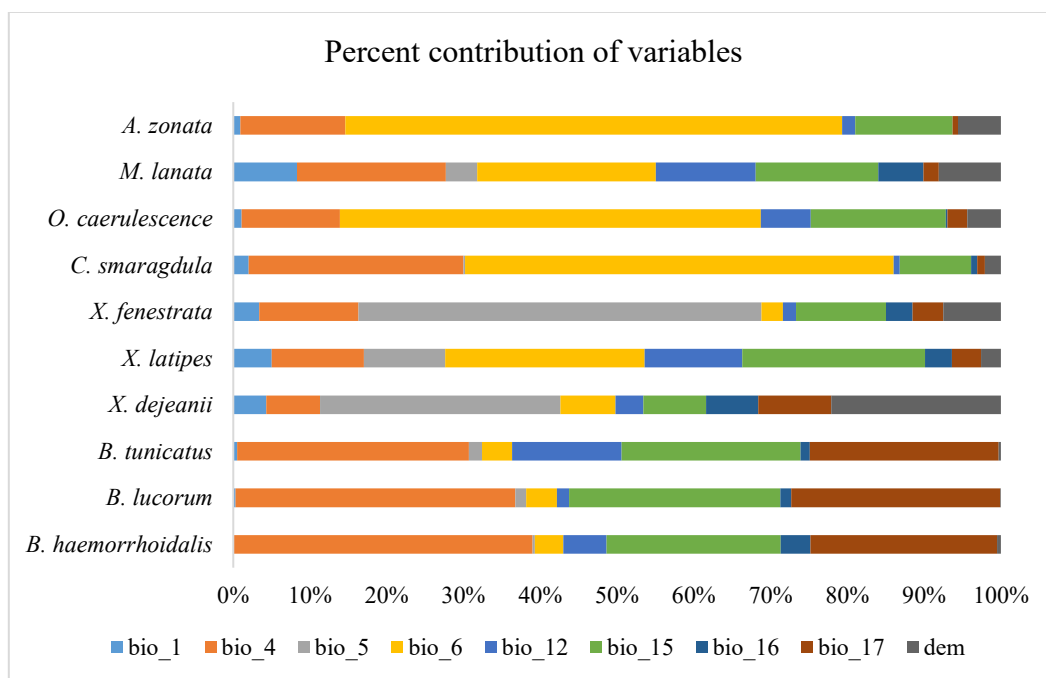


Figure 6.3. Percent contribution of the variables used in modeling the distribution of hymenopteran species

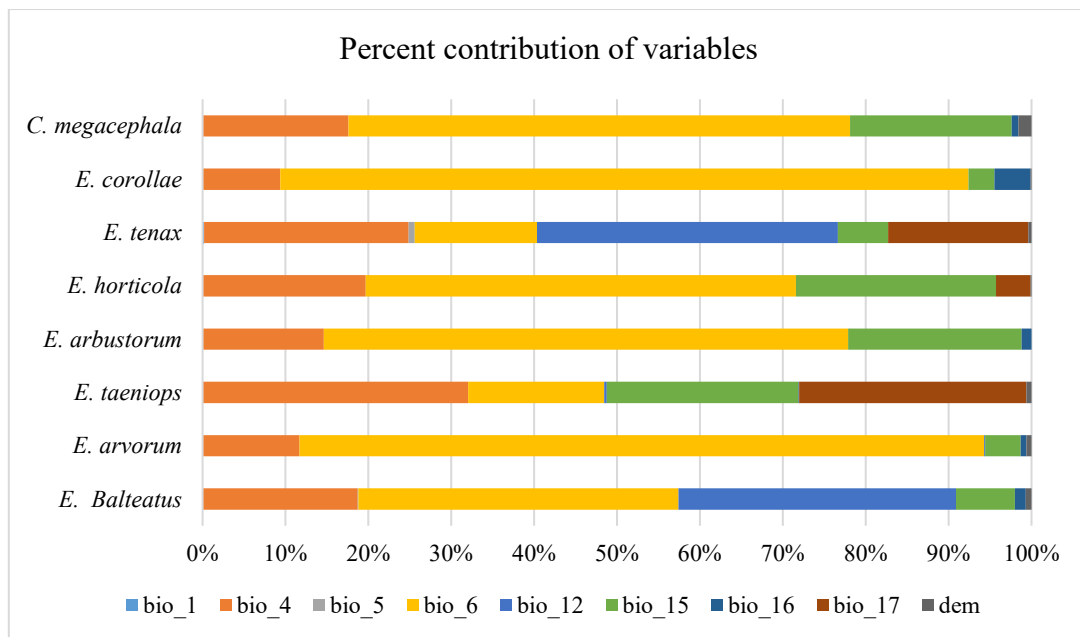


Figure 6.4. Percent contribution of the variables used in modeling the distribution of dipteran species

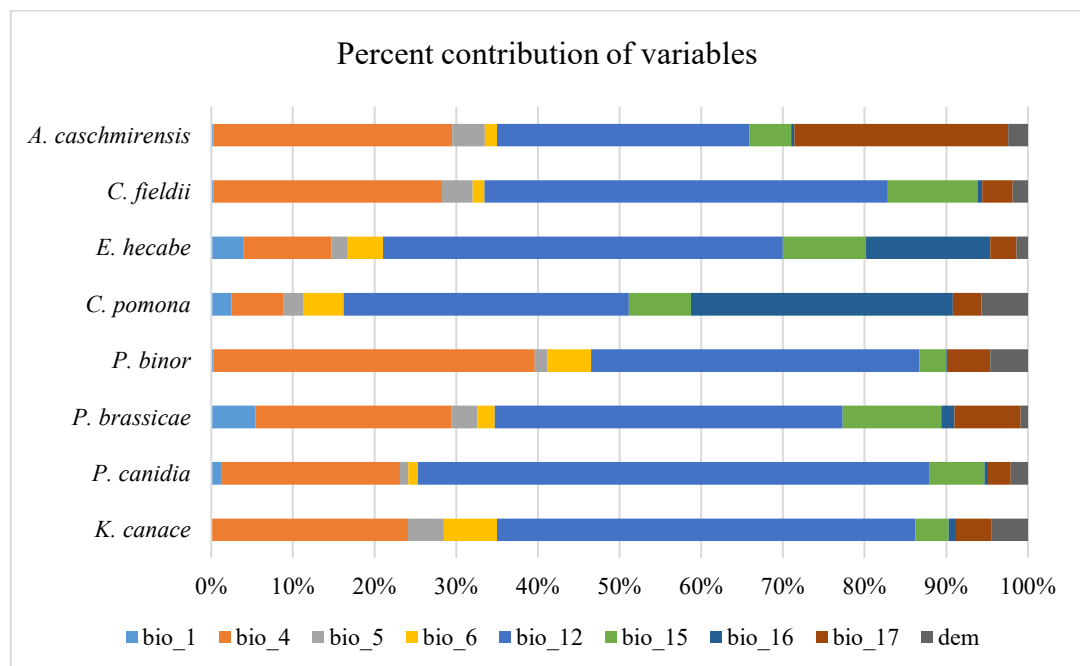


Figure 6.5. Percent contribution of the variables used in modeling the distribution of lepidopteran species

6.3.2. Current and future habitat suitability

The results suggest that many hymenopteran species are likely to experience habitat contraction and range loss in future climatic scenarios, with exceptions (table 6.1; figures 6.12, 1-10). *Bombus haemorrhoidalis* faces a significant loss, with over 28% reduction in suitable

niches under SSP126 and more than 33% under the SSP585 scenario, rendering it highly vulnerable to climate change. Similarly, *Bombus tunicatus* may lose over 14% of its current suitable habitat in both future scenarios. Among the most vulnerable species are *Osmia caerulescence*, with an expected loss of more than 31% habitat in the SSP126 scenario and over 27% in the SSP585 scenario; and *Xylocopa fenestrata*, facing reductions of over 28% in the SSP126 scenario and more than 20% in the SSP585 scenario. *Amegilla zonata* is expected to lose 20% of its habitat in the SSP126 scenario but experiences somewhat lesser contraction (7%) in the SSP585 scenario. *Ceratina smaragdula* and *Xylocopa dejeanii* are also predicted to face habitat loss. Conversely, *Xylocopa latipes*, *Megachillae lanata*, and *Bombus lucorum* may find increased suitable habitat in this landscape under future conditions.

Table 6.1. Change in area (%) of hymenopteran species in SSP126 and SSP585 scenarios in mid-century (2042-2060)

Species name	SSP126_60 (2041-2060)	SSP585_60 (2041-2060)
<i>Amegilla zonata</i> (Fabricius,1775)	-20.121	-7.522
<i>Bombus haemorrhoidalis</i> (Smith,1852)	-28.521	-33.891
<i>Bombus lucorum</i> (Linnaeus,1761)	1.058	10.336
<i>Bombus tunicatus</i> (Smith,1852)	-14.027	-14.412
<i>Ceratina smaragdula</i> (Fabricius,1787)	-10.804	-3.472
<i>Megachillae lanata</i> (Fabricius, 1775)	28.503	36.460
<i>Osmia caerulescence</i> (Linnaeus,1758)	-31.551	-27.762
<i>Xylocopa fenestrata</i> (Fabricius,1798)	-28.391	-20.025
<i>Xylocopa dejeanii</i> (Ma, 1938)	-3.161	-7.389
<i>Xylocopa latipes</i> (Drury,1773)	18.693	22.679

The maps depicting species richness indicate a significant decline in distribution hotspots for Hymenoptera across both future SSP scenarios. Furthermore, a large number of species are projected to experience a shift in their distribution range towards the north and northwest. (figure 6.6). In the context of the new richness hotspot observed within SSP126, it was documented that four hymenopteran pollinators have undergone relocation to previously unoccupied areas. Conversely, within the reduced hotspot, the shift was attributed to the movement of five distinct species. In the case of the SSP585 scenario, it is observed that in both instances, within the new richness hotspot and the reduced hotspot, five species have played a role in the distributional shift (figure 6.7).

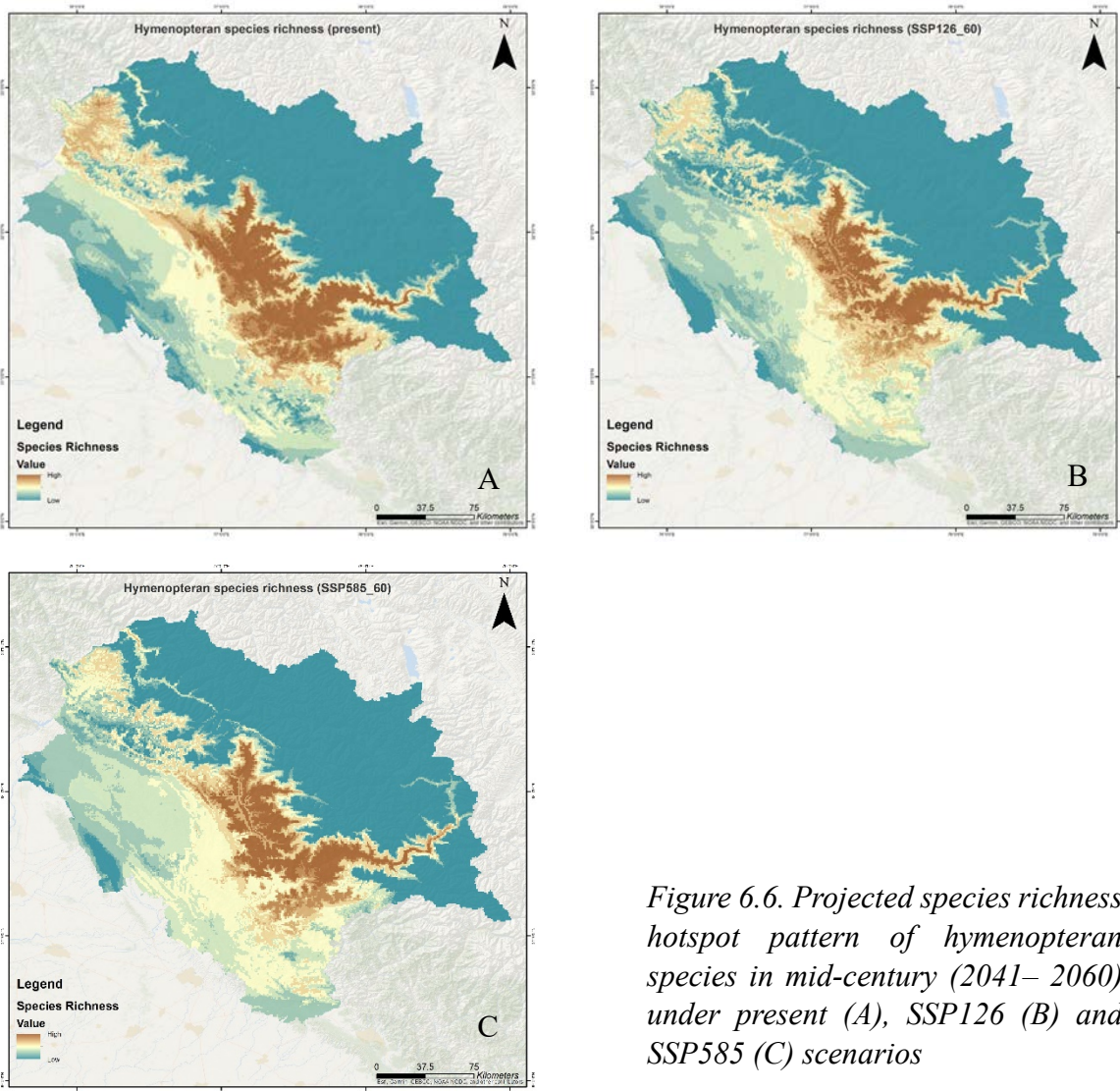


Figure 6.6. Projected species richness hotspot pattern of hymenopteran species in mid-century (2041–2060) under present (A), SSP126 (B) and SSP585 (C) scenarios

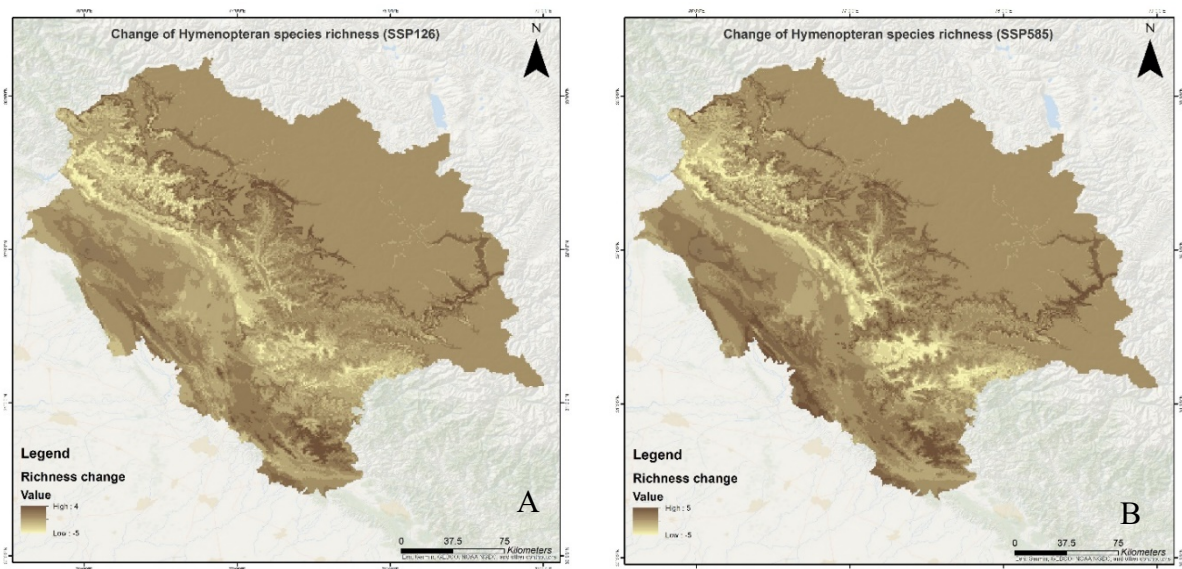


Figure 6.7. Change in species richness pattern of hymenopteran pollinators in mid-century (2041–2060) under SSP126 (A) and SSP585 (B) scenarios

Regarding dipteran species, the majority are anticipated to experience habitat loss in the SSP126 scenario, although trends may differ under SSP585 conditions (table 6.2; figures 6.12, 11-18). Notably, *Chrysomya megacephala* and *Eristalis arbustorum* are expected to face the most significant habitat loss of >34% and >25% respectively in SSP126, but the loss is comparatively less in SSP585 with 11% and 3%, respectively. *Eupeodes corollae* and *Episyrphus balteatus* are the next in line with >17% and >16% loss in suitable habitat in the SSP126 scenario. However, in SSP585, *Eupeodes corollae* might lose 8% of its habitat but *E. balteatus* can expect a slight increase in habitat suitability. In the case of *Eristalinus taeniops* there will be a 6% loss of habitat in SSP126 followed by a slight increase of habitat in SSP585. Other species such as *Eristalinus arvorum* and *Eristalis horticola* are expected to lose >2% area in SSP126 but a much greater area of >10% in the SSP585 scenario. *Eristalis tenax* is the only dipteran that is projected to undergo a range expansion of >6% to >8% in both future climatic scenarios of SSP126 and SSP585 respectively, likely due to its wide range and adaptability. Additionally, it was observed that dipteran species tend to lose a greater range of habitat in the SSP126 scenario compared to SSP585.

Table 6.2. Change in area (%) of dipteran species in SSP126 and SSP585 scenarios in mid-century (2042-2060)

Species name	SSP126_60 (2041-2060)	SSP585_60 (2041-2060)
<i>Episyrphus balteatus</i> (De Gear, 1776)	-16.201	0.882
<i>Eristalinus arvorum</i> (Fabricius, 1787)	-2.400	-10.820
<i>Eristalinus taeniops</i> (Wiedemann, 1818)	-6.244	0.450
<i>Eristalis arbustorum</i> (Linnaeus, 1758)	-25.842	-3.711
<i>Eristalis horticola</i> (De Gear, 1776)	-2.911	-10.017
<i>Eristalis tenax</i> (Linnaeus, 1758)	6.713	8.524
<i>Eupeodes corollae</i> (Fabricius, 1794)	-17.838	-8.603
<i>Chrysomya megacephala</i> (Fabricius, 1794)	-34.777	-11.512

The species richness maps suggest a notable decrease in distribution hotspots for Diptera across both future SSP scenarios and a majority of species are expected to undergo a distribution range shift towards the north and northeast. (figure 6.8). In the case of the new richness hotspot within SSP126, it was noted that four dipteran pollinators have relocated to new areas. Conversely, in the reduced hotspot as well, five species have contributed to the shift. In the case of the SSP585 scenario in both cases of increased and decreased richness, four species have contributed (figure 6.9).

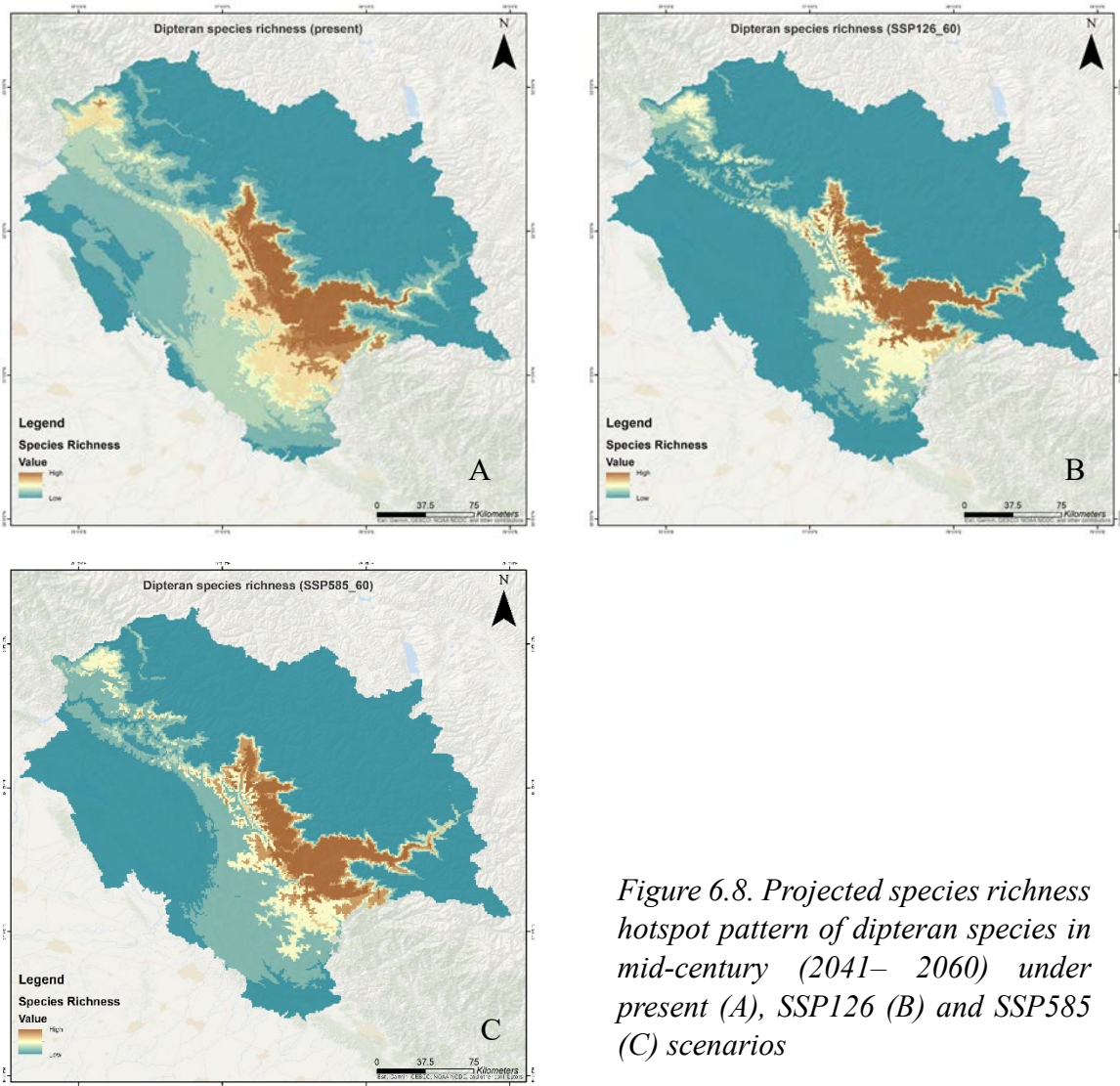


Figure 6.8. Projected species richness hotspot pattern of dipteran species in mid-century (2041– 2060) under present (A), SSP126 (B) and SSP585 (C) scenarios

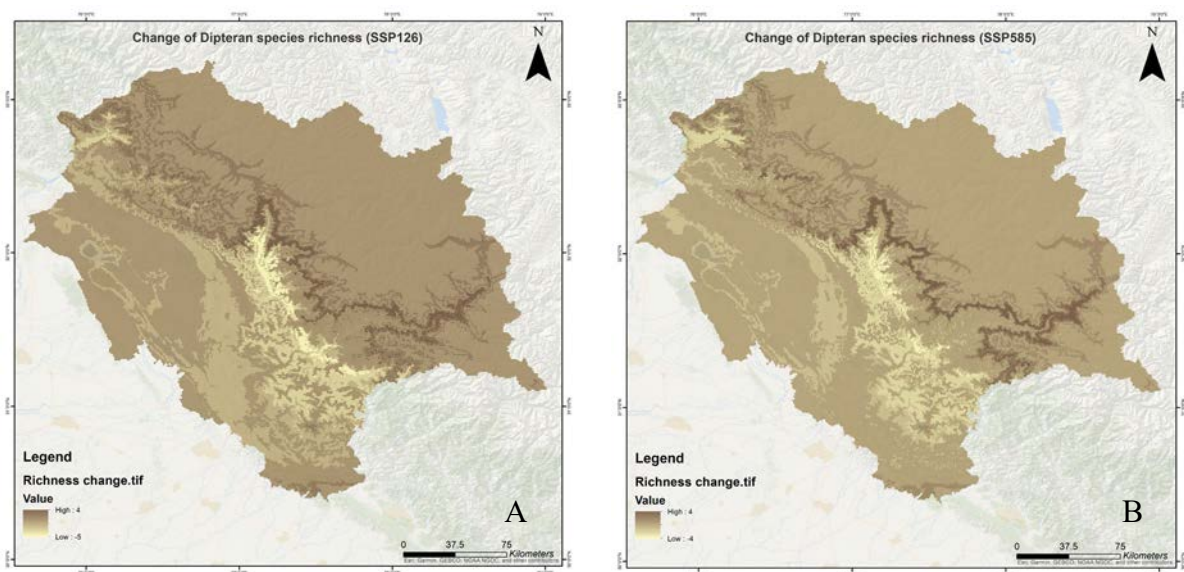


Figure 6.9. Change in species richness pattern of dipteran pollinators in mid-century (2041–2060) under SSP126 (A) and SSP585 (B) scenarios

Lepidopteran species are predominantly anticipated to witness expanded habitat in both future climatic scenarios, with few exceptions facing notable habitat loss, particularly under the SSP585 scenario (table 6.3; figures 6.12, 19-26). For example, *Colias fieldii*, or Dark clouded yellow may expect to lose >20% of its current suitable habitat in the SSP585 scenario, followed by *Aglais caschmirensis* or Himalayan tortoiseshell, which will lose almost 17% of its suitable habitat. The Blue admiral butterfly i.e., *Kaniska canace* may experience a loss of over 24% of its current suitable habitat in SSP126 condition, followed by over 37% in SSP585 condition being the most vulnerable among the lepidopterans. The majority of butterfly pollinator species identified were wide-ranging and habitat generalists, potentially explaining their enhanced adaptability to changing climates, leading to increased habitat suitability.

Table 6.3. Change in area (%) of lepidopteran species in SSP126 and SSP585 scenarios in mid-century (2042-2060)

Species name	SSP126_60 (2041-2060)	SSP585_60 (2041-2060)
<i>Kaniska canace</i> (Linnaeus, 1763)	-24.364	-37.386
<i>Pieris canidia</i> (Sparrman, 1768)	6.9138	6.087
<i>Papilio bianor</i> (Cramer, 1777)	-0.388	17.020
<i>Catopsilia pomona</i> (Fabricius, 1775)	6.042	8.592
<i>Eurema hecabe</i> (Linnaeus, 1758)	25.672	23.251
<i>Colias fieldii</i> (Ménétriés, 1855)	19.521	-20.541
<i>Aglais caschmirensis</i> (Kollar, 1848)	1.342	-16.913
<i>Pieris brassicae</i> (Linnaeus, 1758)	22.694	27.789

The species richness maps suggest lepidopteran pollinators are projected to experience an overall increase in suitable habitat hotspots under future climatic conditions. Additionally, a majority of species are expected to undergo a distribution range shift towards north and northeast (figure 6.10). Regarding the new richness hotspot identified within the SSP126 scenario, it was observed that six lepidopteran pollinators have migrated to previously unoccupied regions. Conversely, within the reduced hotspot, the shift was attributed to the movement of four distinct species. Transitioning to the SSP585 scenario, it is noticed that within the new richness hotspot, six lepidopteran pollinators have contributed, whereas, in the case of the reduced hotspot the shift was attributed to the movement of five distinct species (figure 6.11).

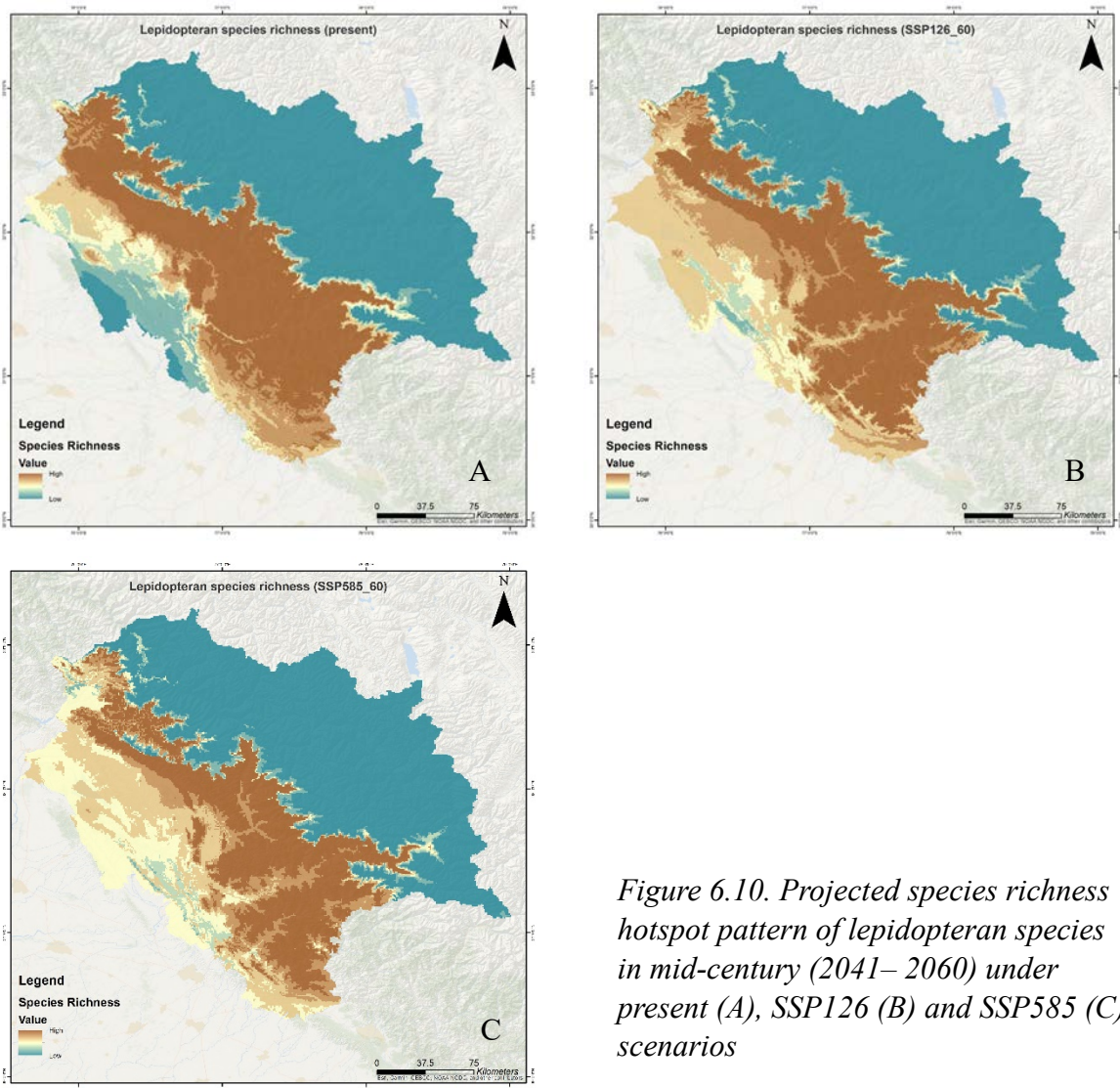


Figure 6.10. Projected species richness hotspot pattern of lepidopteran species in mid-century (2041–2060) under present (A), SSP126 (B) and SSP585 (C) scenarios

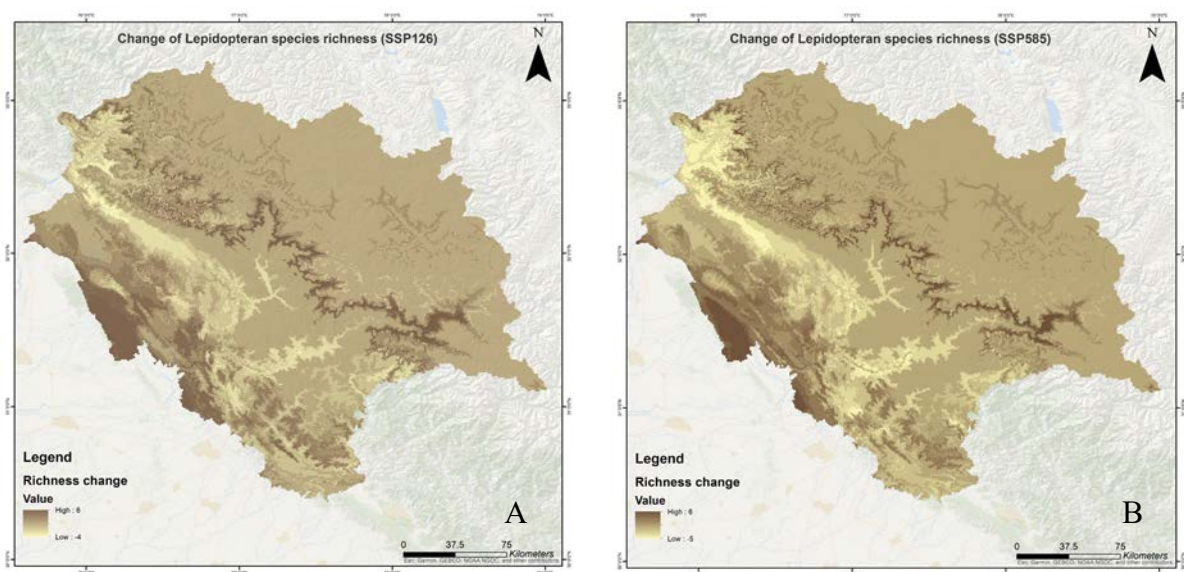


Figure 6.11. Change in species richness pattern of lepidopteran pollinators in mid-century (2041–2060) under SSP126 (A) and SSP585 (B) scenarios

Climate change will have varied impacts on different parts of the Himalayas, resulting in diverse climatic conditions within microclimatic pockets. Consequently, some species are likely to lose their habitat while others may see an expansion in their suitable habitat. Certain species may experience a decrease in niche under one SSP scenario but an increase in suitable niche under a different SSP condition. For instance, habitat generalists and wide-ranging species are expected to have increased suitable habitat, whereas more specialized species like Himalayan bumble bees may face significant habitat loss. This finding is consistent with previous studies on bumble bee distribution modeling by Singh et al. (2022, 2024). The variation in habitat suitability under different climatic conditions for these species indicates the need for further investigation into their ecology and the utilization of microclimatic niche conditions.

6.4. Conclusion

The findings highlight the complex and varied responses of different species to changing environmental conditions. The Himalayan region is characterized by diverse topography, resulting in microclimatic variations across different areas. This diversity creates unique challenges and opportunities for species inhabiting the region with diverse responses to changing climatic conditions (Telwala et al., 2013; Rashid et al., 2015). This study indicates that climate change will lead to a diminution of the suitable habitat for the majority of pollinators within the next 40-50 years, except for highly abundant and habitat-generalist species. The finding aligns with previous research (Pandit et al., 2006; Pandit and Grumbine, 2012; Pandit, 2020), which indicates that climate change and anthropogenic activities will dramatically reduce dense forest cover to only 10% by 2100 which consequently will push a wide range of biodiversity to the brink of extinction.

The consistent model performance across different species groups, as indicated by the AUC values, underscores the reliability and generalizability of the MaxEnt Species Distribution Models (Yuan et al., 2015; Rajabi et al., 2021, Zhao et al., 2023). This robust performance in this study with AUC values over 0.9 suggests that the models are effectively capturing the relationships between species occurrence and environmental variables, enabling accurate predictions across various insect taxa.

The observed variability in the importance of predictor variables among different species highlights the complex nature of species-environment relationships. Factors such as temperature, precipitation, and seasonality can have diverse impacts on species distributions, influenced by species-specific ecological requirements and behavioral adaptations (Tingley et

al., 2012, Ficetola et al., 2016). Understanding these patterns is essential for effective management planning and conservation strategies, specifically in the context of ongoing environmental changes and habitat alterations.

The loss of habitat for certain species, particularly specialized ones like Himalayan bumble bees, Blue admiral butterfly, and a few Palearctic species of dipterans underscores the vulnerability of these species to changing climatic conditions. Bumble bees, known for their specific habitat requirements, may struggle to adapt to shifts in temperature and rainfall patterns, leading to a reduction in suitable habitat. This loss could have cascading effects on ecosystems, impacting pollination services and plant communities that rely on these species for reproduction and survival. On the other hand, the increased suitable habitat for generalist and wide-ranging species suggests a potential for adaptation and resilience to climate change. These species, with broader ecological tolerances and the ability to utilize a range of habitats, might be better equipped to face the changing environmental conditions and this finding also aligns with the previous studies by Bulleri et al., 2018 and Theodoridis et al., 2018. Their expanded habitat could also provide opportunities for range expansion and colonization of new areas, contributing to biodiversity dynamics in the Himalayan region. The contrasting responses of different species highlight the need for consideration of species-specific traits and ecological requirements when measuring the influences of climate change. While some species may thrive in the face of changing conditions, others may face significant challenges and declines in population size. This underscores the need for targeted conservation efforts aimed at the protection of vulnerable species and their habitats, as well as adaptive management strategies to mitigate the effects of climate change (Oliver et al., 2016).

Future distribution predictions of species in this research may vary based on the degree of climate warming and the capacity of the species to adjust to these environmental changes, which can pose limitations to the current study. However, conducting research on the nectar host plant species of each pollinator can provide more accurate forecasts of their suitable distribution ranges. Furthermore, the study emphasizes the importance of incorporating detailed ecological studies and considering microclimatic conditions when modeling species distributions. Microclimatic pockets within the Himalayan landscape can create a refuge for species, offering opportunities for survival and adaptation in the face of changing climatic conditions (Vos et al., 2008). Identifying these nuances is crucial for accurate prediction of the response of each species to climate change and for informing effective and targeted conservation efforts, habitat restoration initiatives, and conservation strategies.

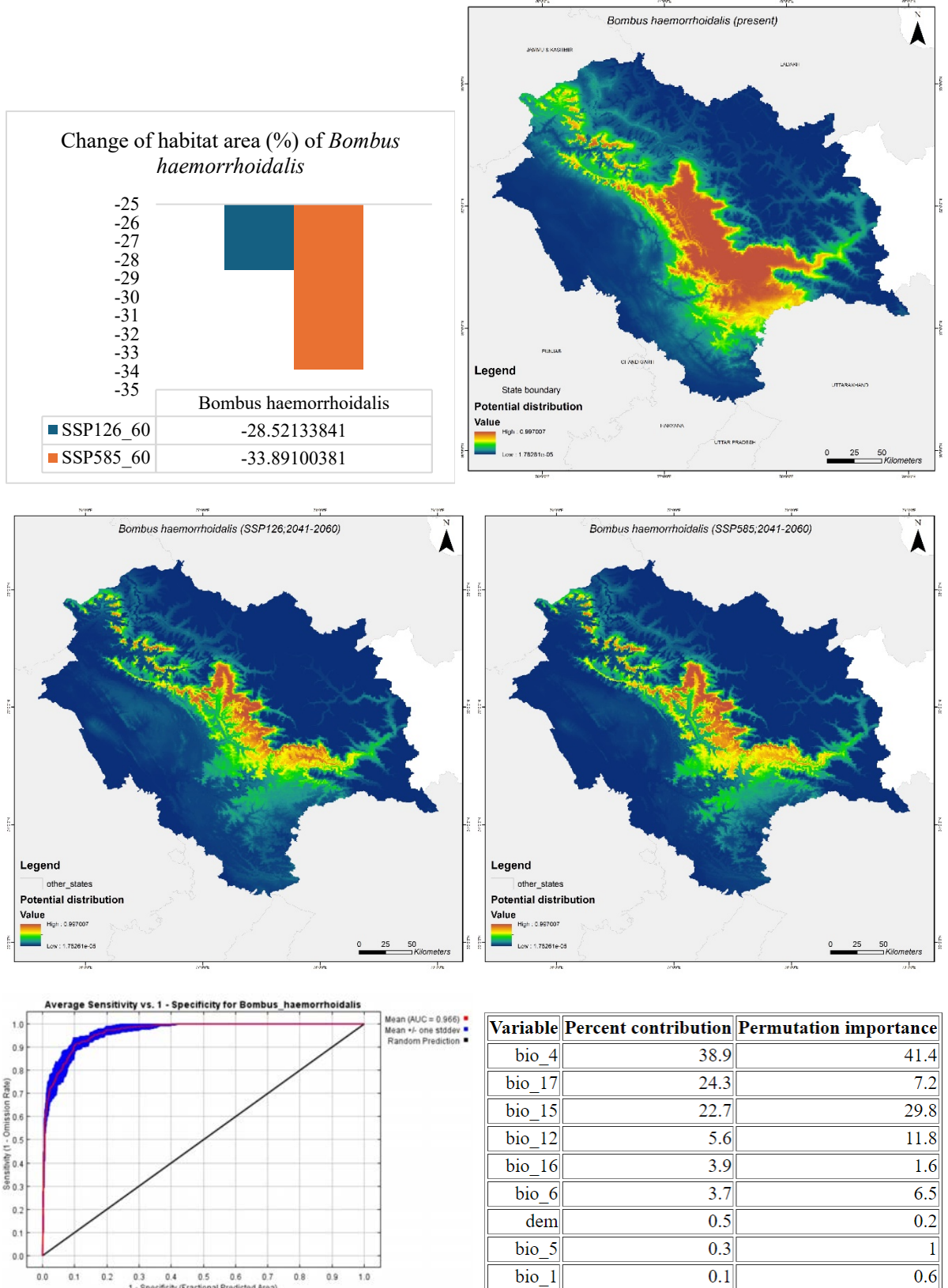
Furthermore, a crucial step toward comprehensive habitat management is the identification of ecologically significant units, which serves as the foundation for assessing threats and evaluating the status of similar ecological regions (Rice et al., 2011). This need has propelled biogeography beyond its purely academic scope into a vital tool for Systematic Conservation Planning (SCP), aimed at safeguarding the diverse array of species within designated planning areas extending beyond national borders (Lourie and Vincent, 2004; Whittaker et al., 2005; Margules and Pressey, 2000). For instance, countries such as Bhutan, Nepal, and India, which share their borders in the Himalayan region, have prioritized transboundary conservation efforts to protect populations of Bengal Tigers (*Panthera tigris tigris*) and Asian Elephants (*Elephas maximus*) in the Terai landscape—an area of marshy terrain with a maximum width of 13 kilometers south of the Himalayas (Borah et al., 2013). In the last two decades, various regional, national, and international policy developments have increasingly pointed out the importance of spatial management of wide-ranged species (Rice et al., 2010; Borah et al., 2013). International policymakers and management authorities have also highlighted the necessity to enhance the scientific and procedural foundations for the management of anthropogenic and natural activities beyond national jurisdictional boundaries (Richardson and Whittaker, 2010). Identification of zones that require prioritization within the same biogeographic units can be achieved by modeling-based studies (Moritz et al., 2001; Sala et al., 2002; Airamé et al., 2003; Higgins et al., 2005; Richardson and Whittaker, 2010). Despite a significant focus on the conservation of large mammals, there has been a conspicuous lack of an international agreement specifically targeting comprehensive initiatives for pollinator conservation or broader efforts to preserve invertebrate diversity in the region. Considering that suitable habitats and conservation priorities for insects transcend international borders, countries such as India, Pakistan, Nepal, Bhutan, China, and Afghanistan—sharing borders and natural habitats of bees across the Himalayas—should devise policies aimed at restoring and safeguarding transboundary natural habitats for these pollinators, as well as other wild species.

To conclude, effectively addressing the significant impact of climate change on Himalayan pollinators requires the adoption of scientific and evidence-based strategies supported by policies to safeguard their natural habitats in the region. This entails ecologists diagnosing issues and proposing solutions, while project managers and policymakers execute operational measures to mitigate the problem (Battisti et al., 2020).

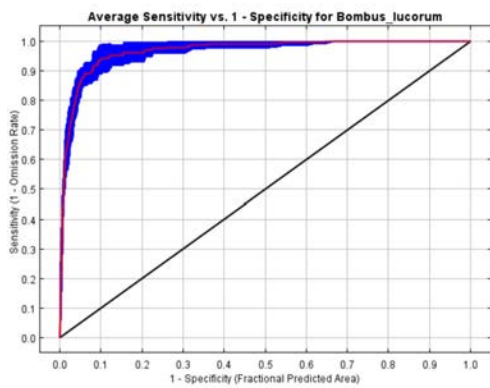
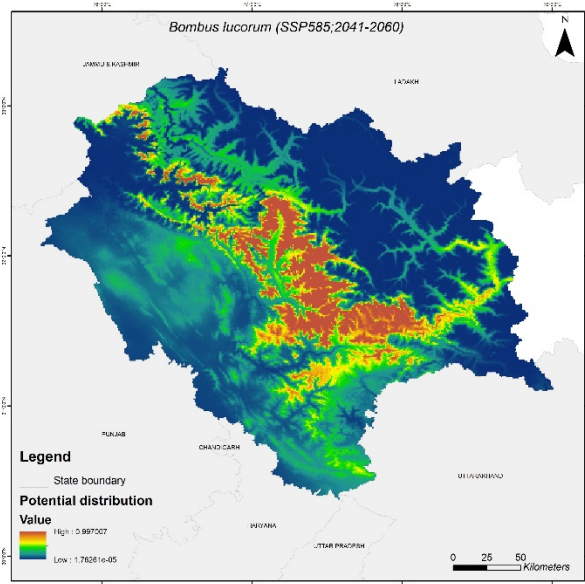
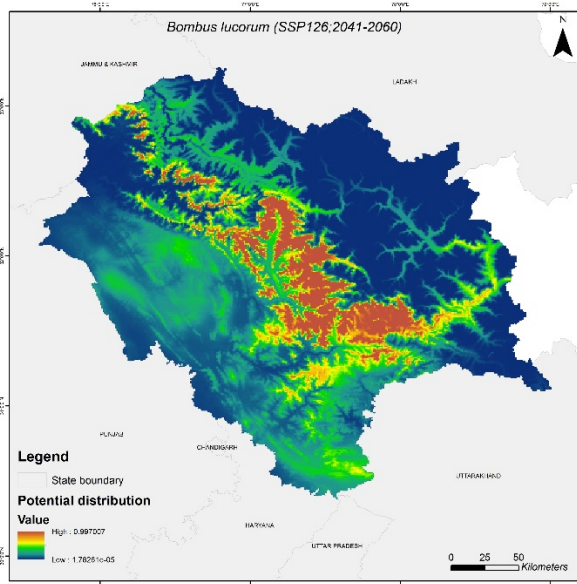
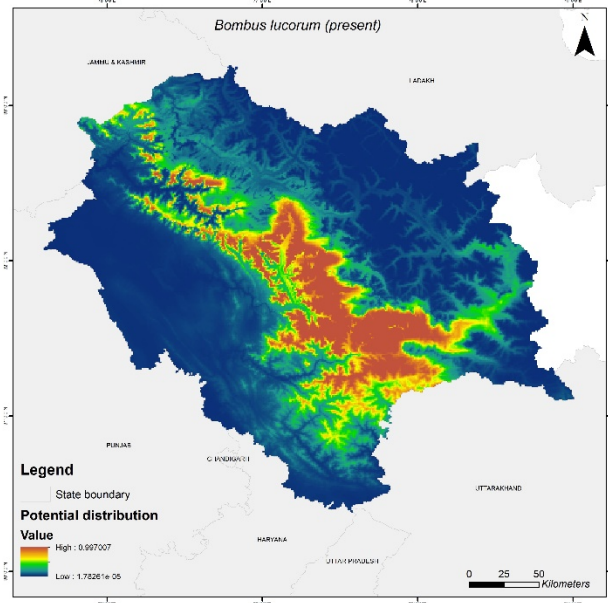
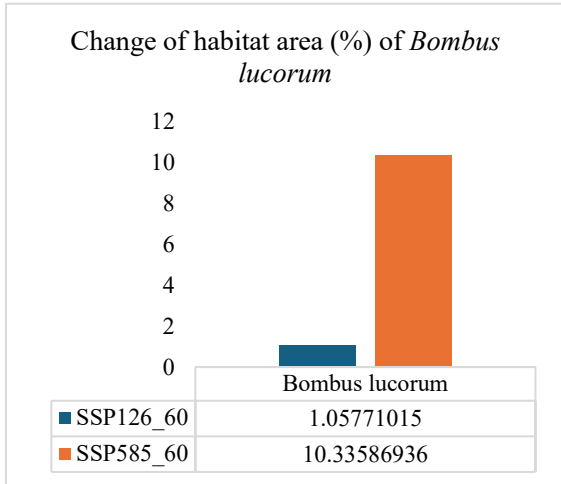
Figure 6.12. Potential distribution of some important pollinators belonging to different orders in present and future climate scenarios (SSP126 and SSP585) in mid-century (2041-2060)

Order: Hymenoptera

1. *Bombus haemorrhoidalis* (Smith, 1852)

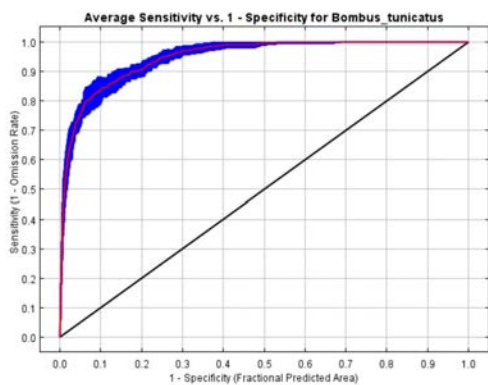
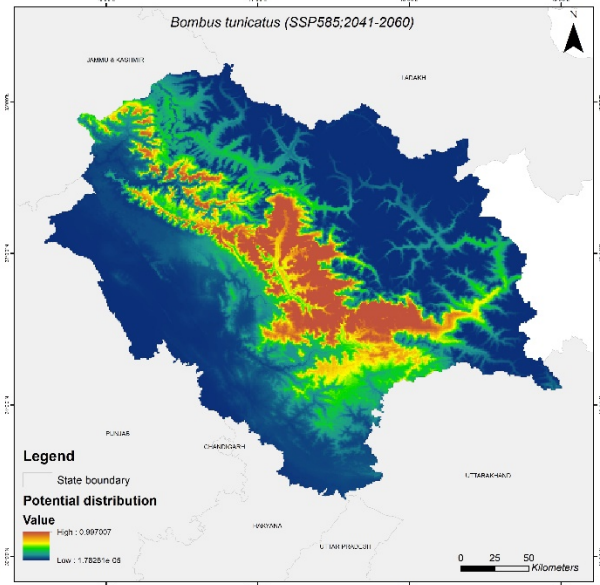
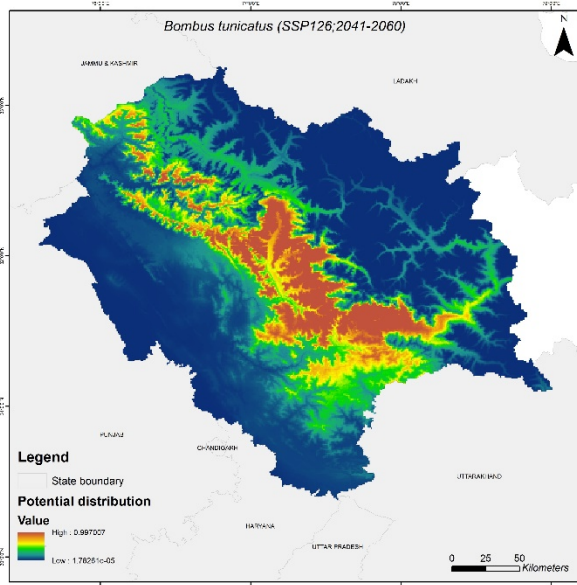
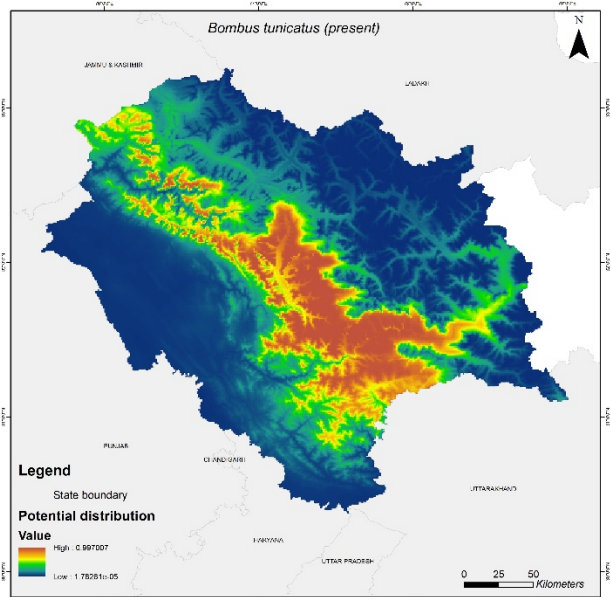
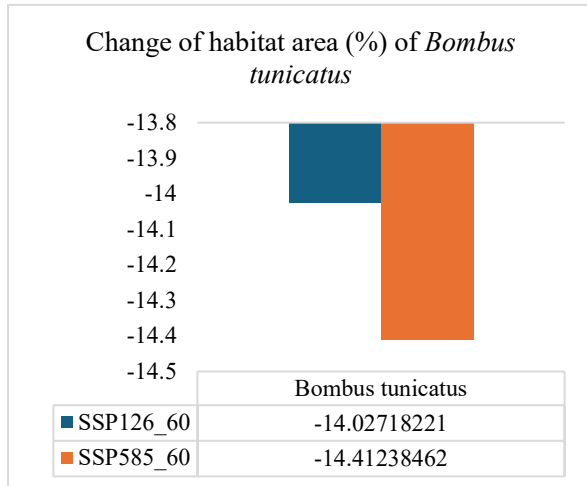


2. *Bombus lucorum* (Linnaeus, 1761)



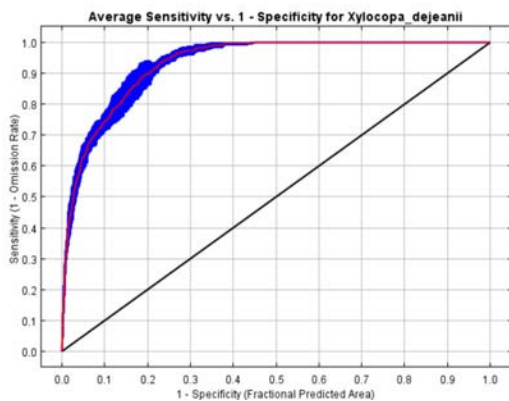
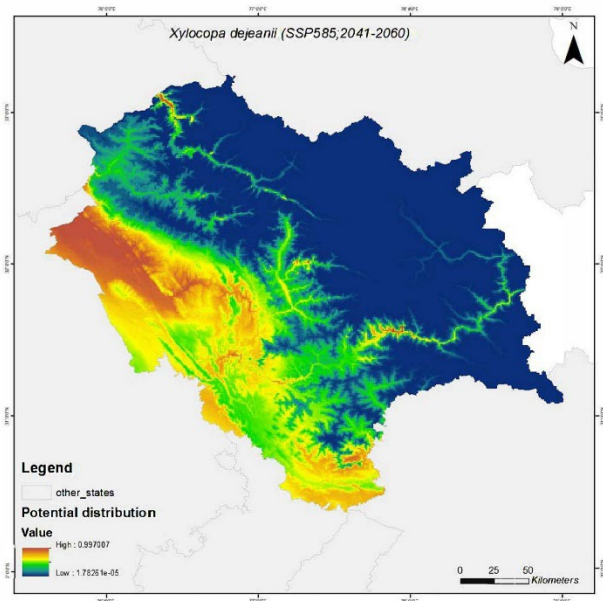
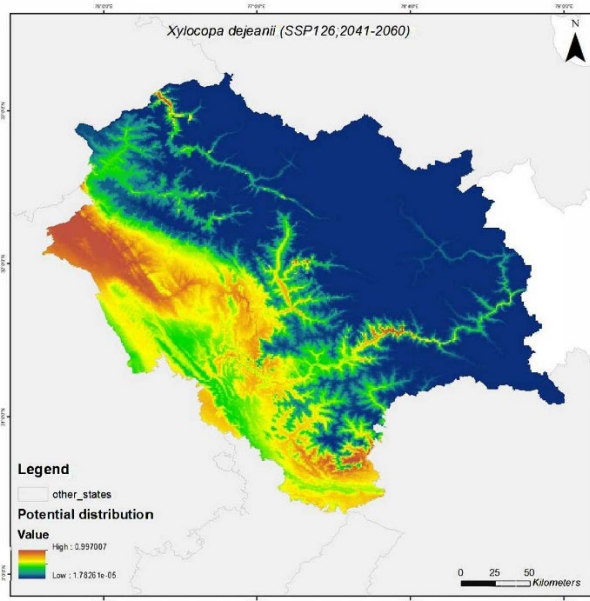
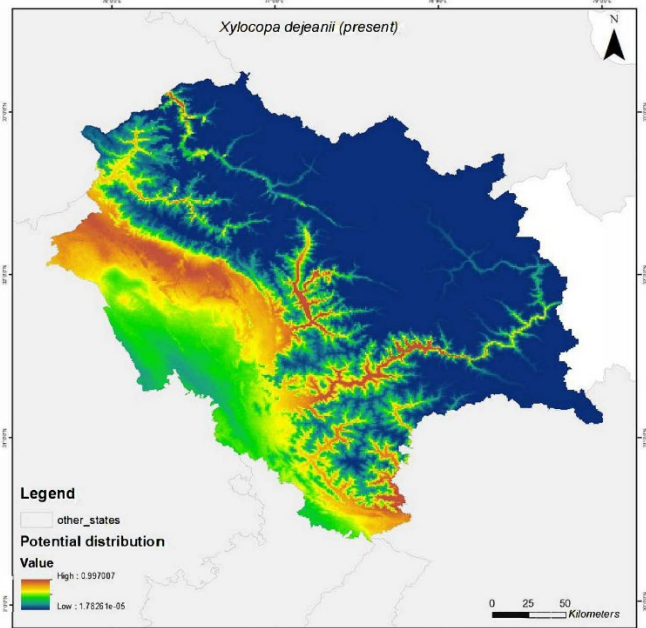
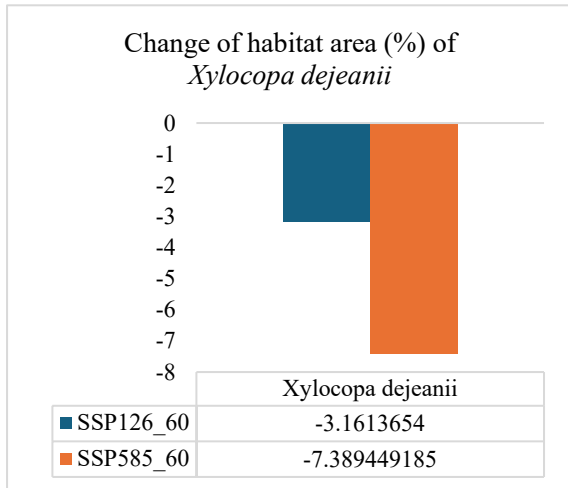
Variable	Percent contribution	Permutation importance
bio_4	36.4	46.8
bio_15	27.5	28.1
bio_17	27.2	7
bio_6	4	9.2
bio_12	1.6	3.5
bio_5	1.4	1.8
bio_16	1.4	1.6
bio_1	0.3	1.1
dem	0.1	1

3. *Bombus tunicatus* (Smith, 1852)



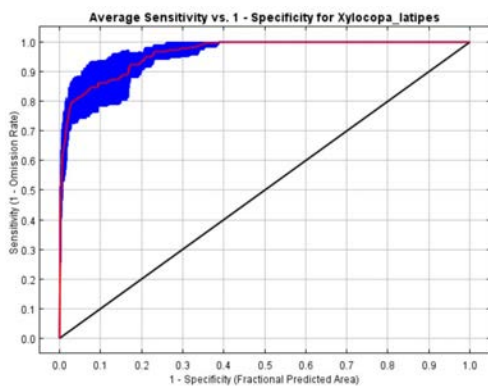
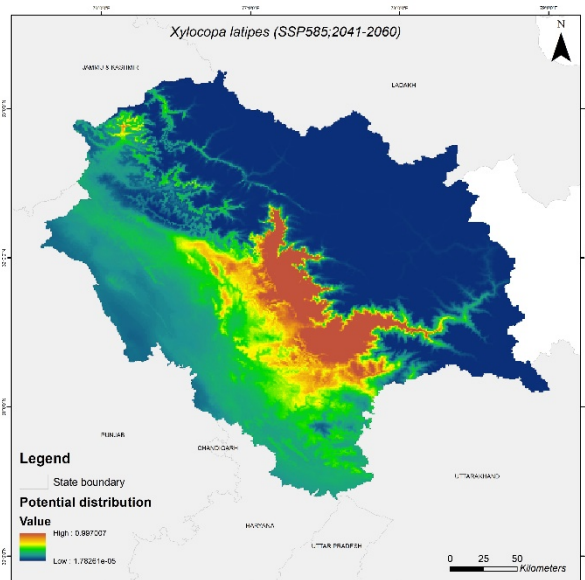
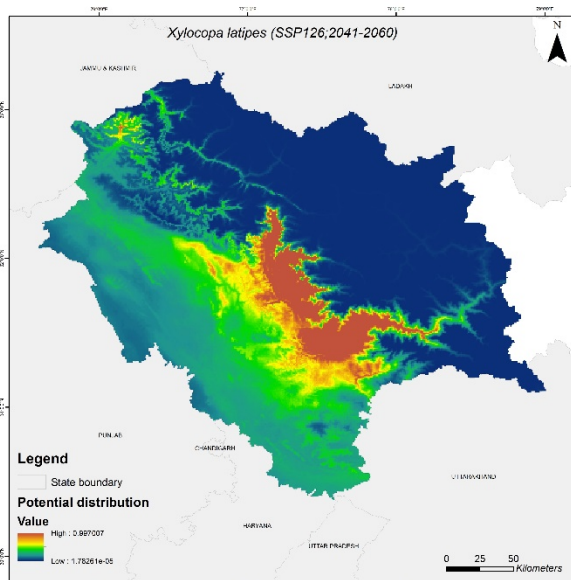
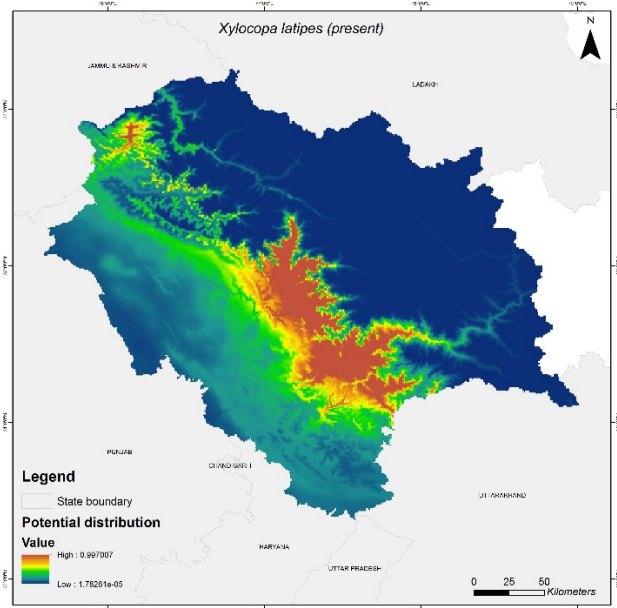
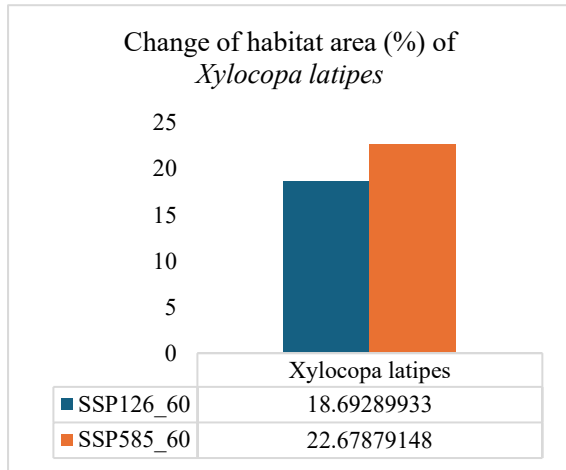
Variable	Percent contribution	Permutation importance
bio_4	30.2	27.1
bio_17	24.6	5.7
bio_15	23.3	27.7
bio_12	14.3	25
bio_6	3.9	7.6
bio_5	1.7	2.4
bio_16	1.2	1.7
bio_1	0.5	0.4
dem	0.3	2.4

4. *Xylocopa dejeanii* (Ma, 1938)



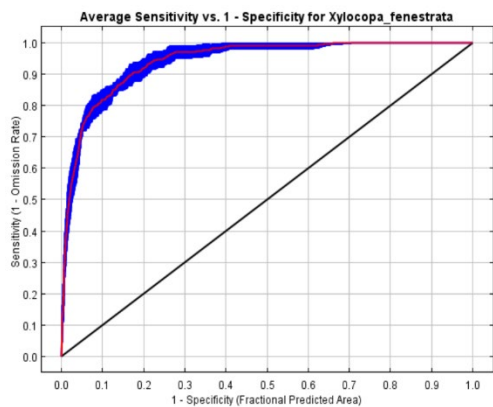
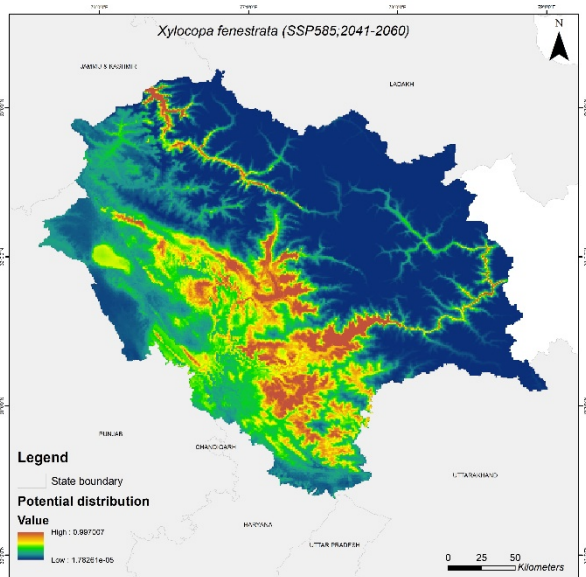
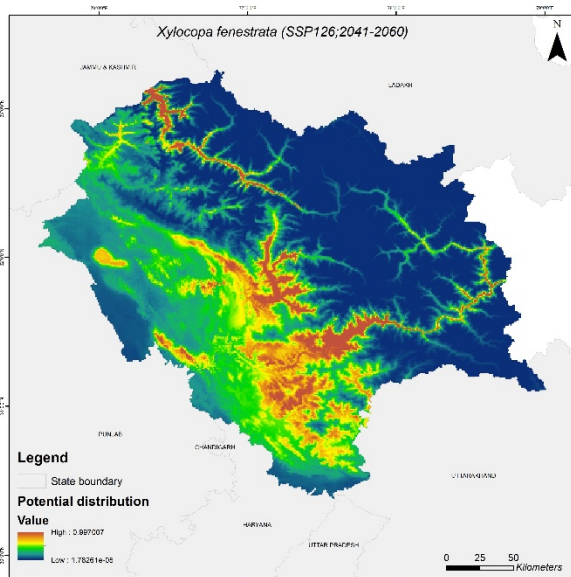
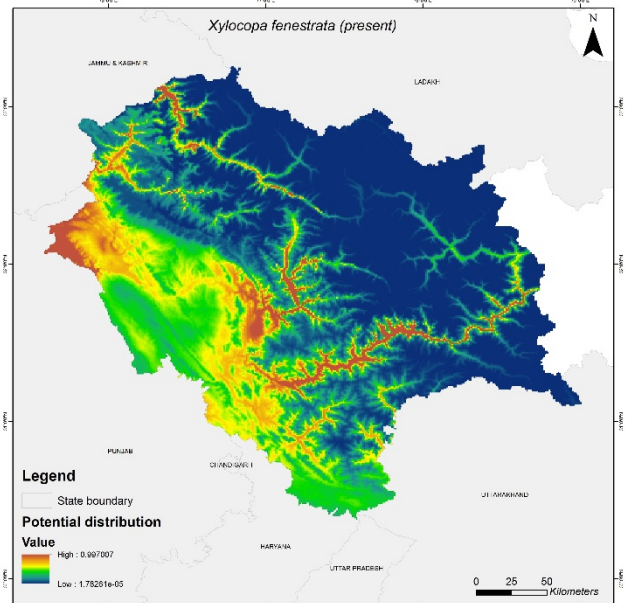
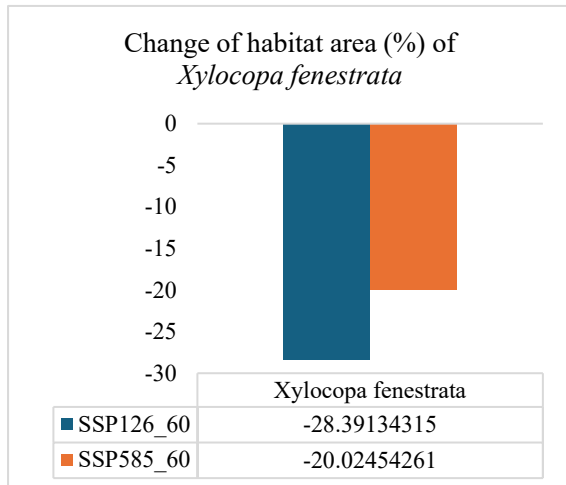
Variable	Percent contribution	Permutation importance
bio_5	31.3	16
dem	22.1	41.7
bio_17	9.5	19.7
bio_15	8.2	2.9
bio_6	7.2	2
bio_4	7	7.6
bio_16	6.8	7.6
bio_1	4.3	0.3
bio_12	3.6	2.2

5. *Xylocopa latipes* (Drury,1773)



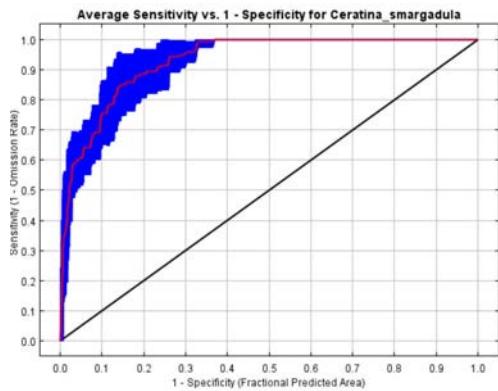
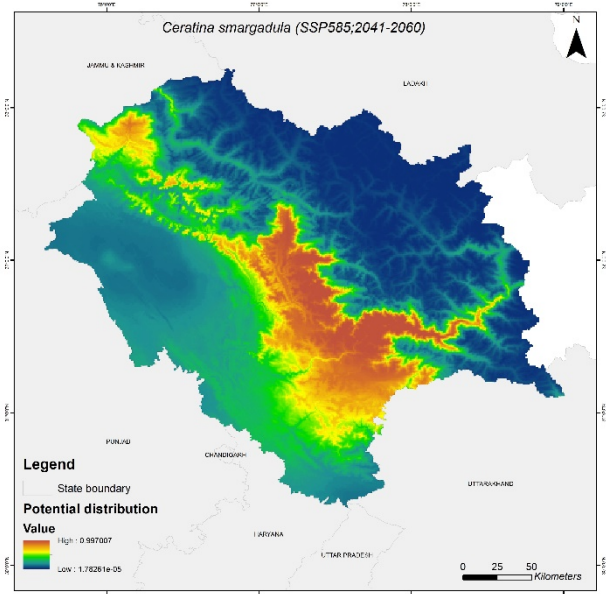
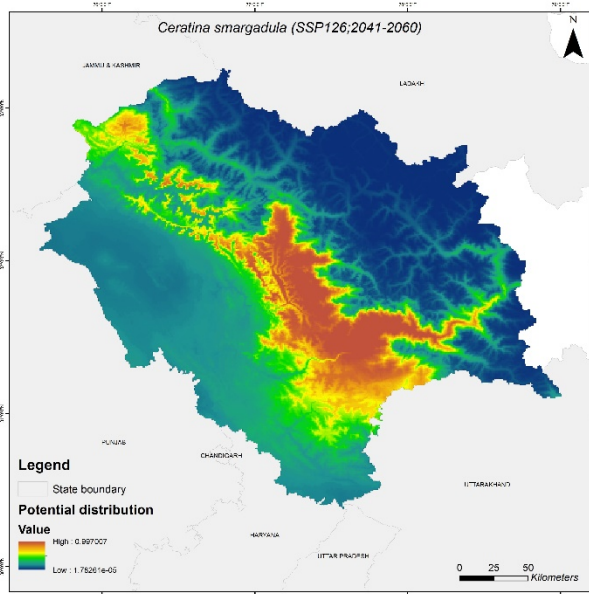
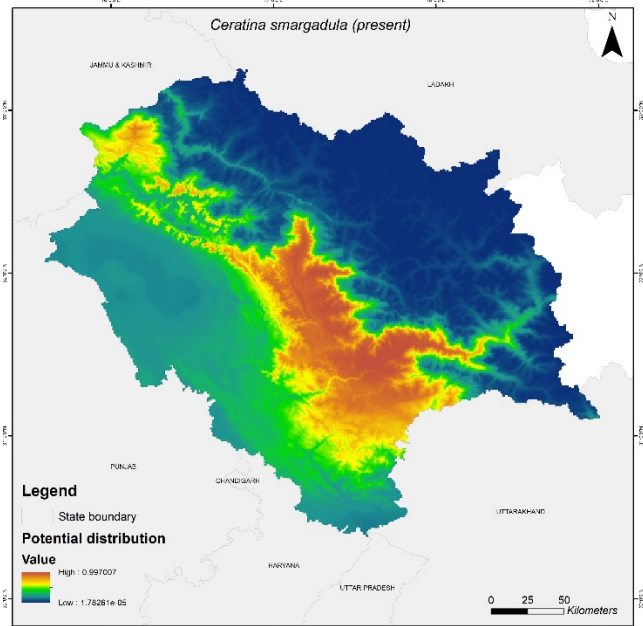
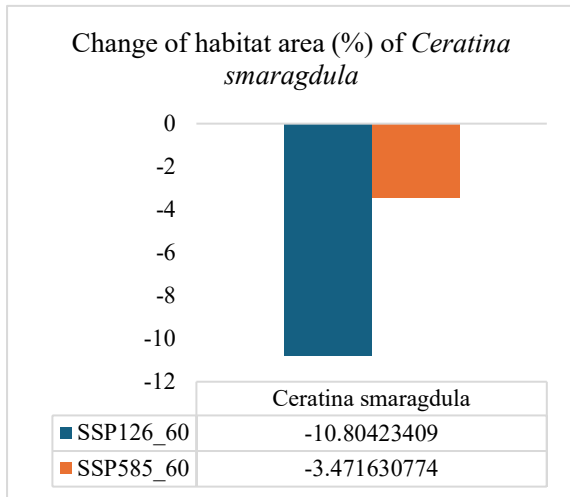
Variable	Percent contribution	Permutation importance
bio_6	26	12.8
bio_15	23.8	28.3
bio_12	12.7	17.3
bio_4	12	6
bio_5	10.6	3.3
bio_1	5	0
bio_17	3.8	8.4
bio_16	3.5	1.7
dem	2.6	22.2

6. *Xylocopa fenestrata* (Fabricius, 1798)



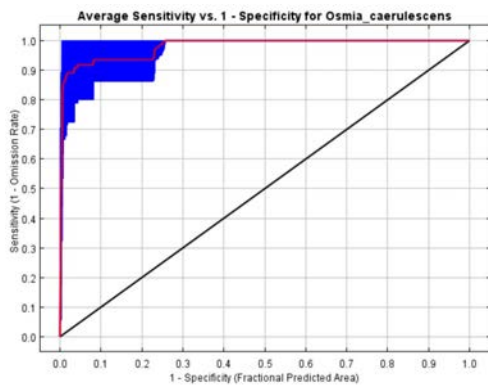
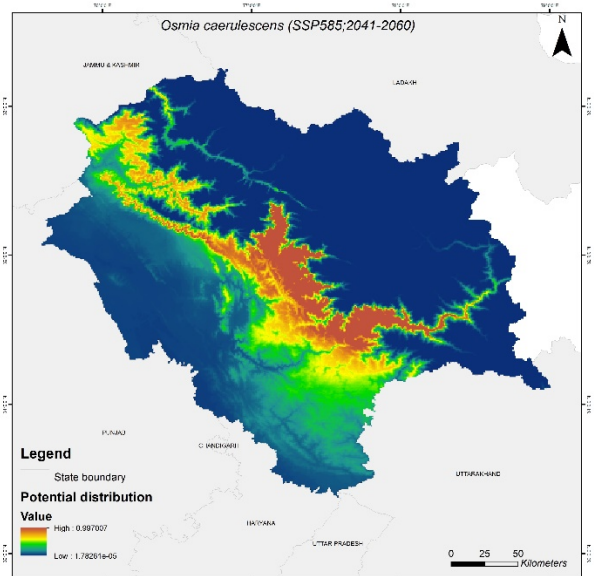
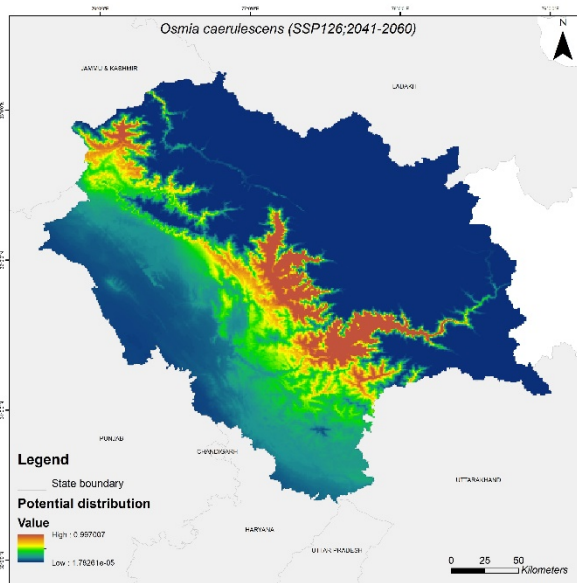
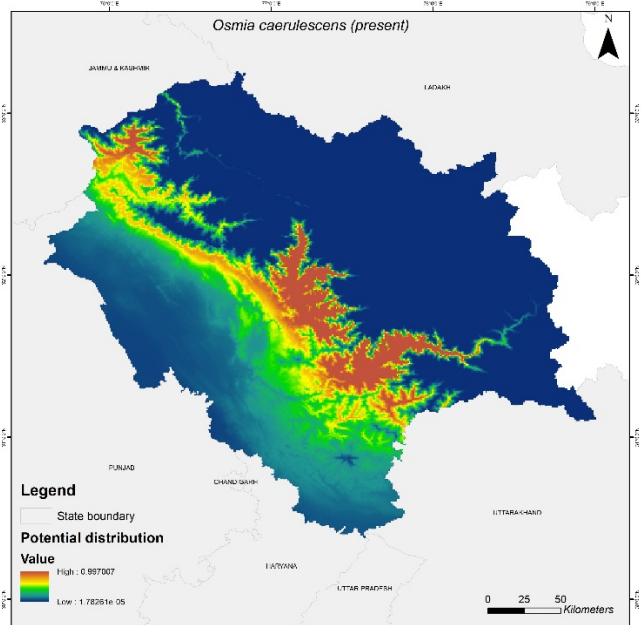
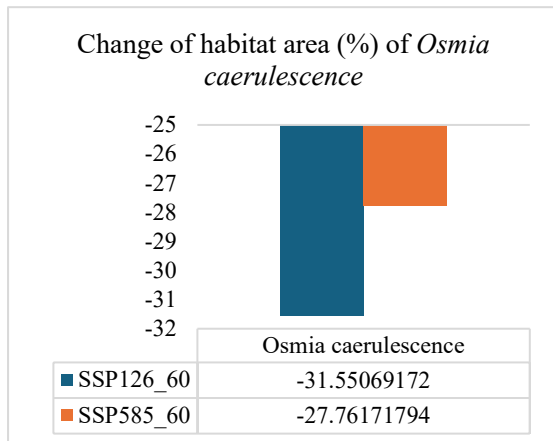
Variable	Percent contribution	Permutation importance
bio_5	52.5	10.4
bio_4	12.9	16
bio_15	11.7	8.6
dem	7.5	40.8
bio_17	4	8.7
bio_16	3.5	3.9
bio_1	3.4	2.6
bio_6	2.8	6.3
bio_12	1.7	2.7

7. *Ceratina smaragdula* (Fabricius,1787)



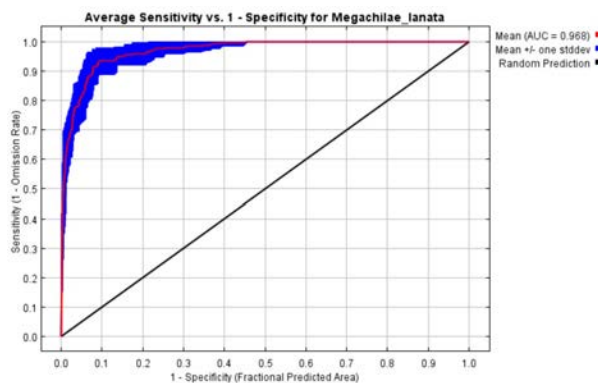
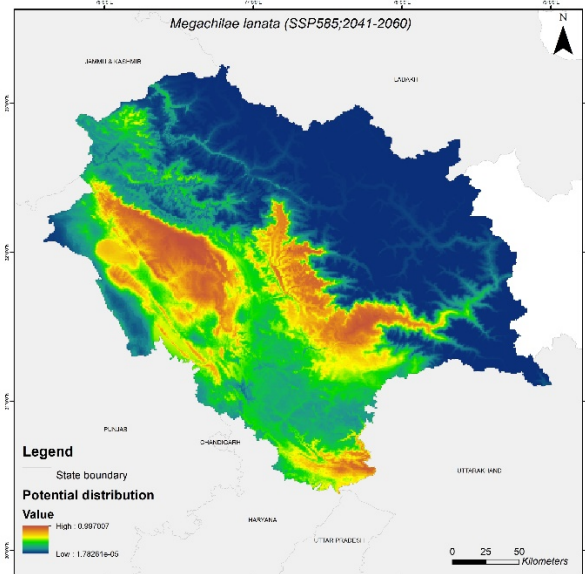
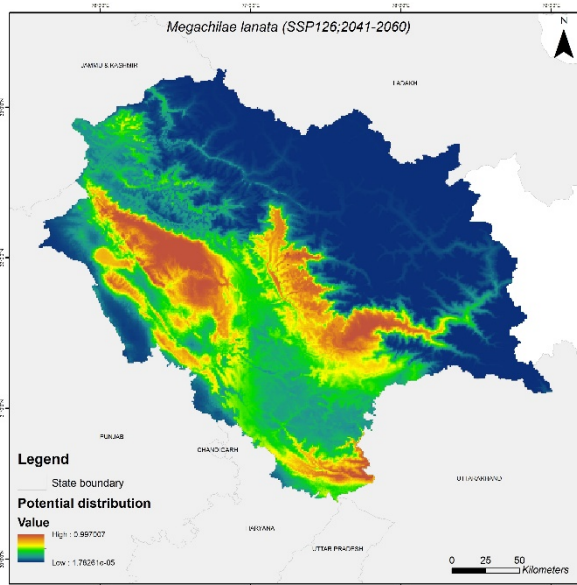
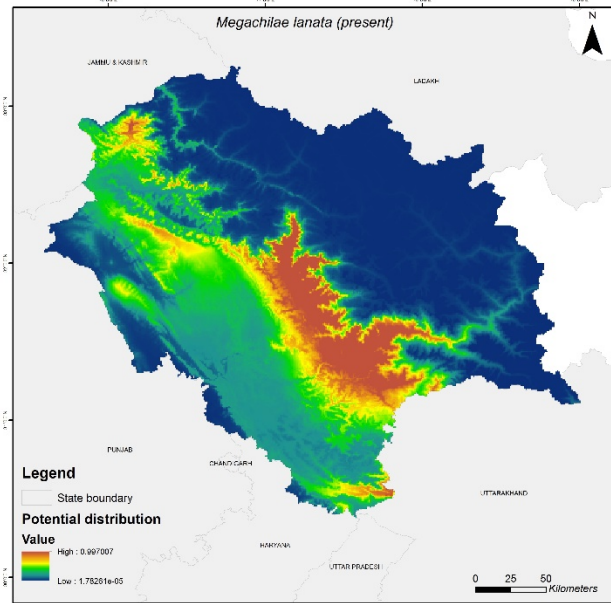
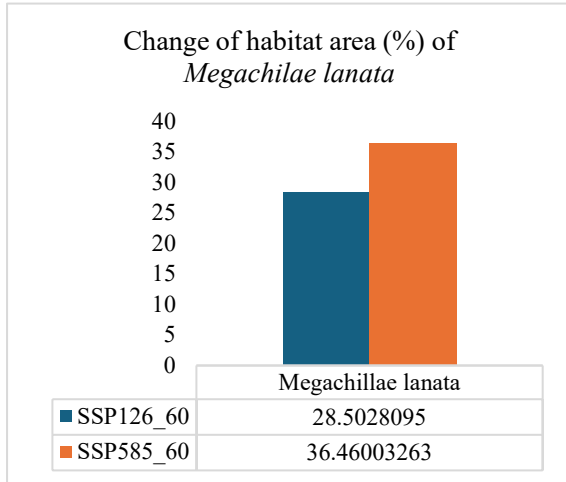
Variable	Percent contribution	Permutation importance
bio_6	55.8	14.1
bio_4	28	51.3
bio_15	9.3	11.3
dem	2.1	7.5
bio_1	2	4.8
bio_17	1	3.3
bio_12	0.8	2.9
bio_16	0.8	4.8
bio_5	0.2	0

8. *Osmia caerulescens* (Linnaeus,1758)



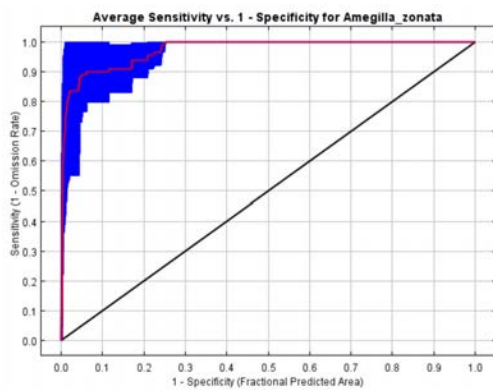
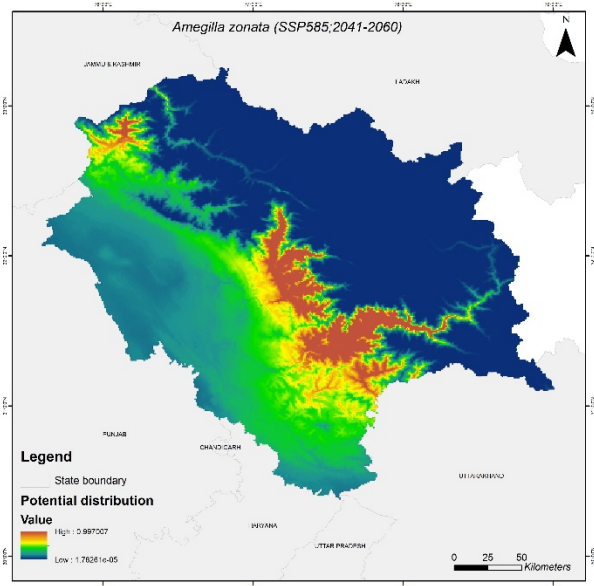
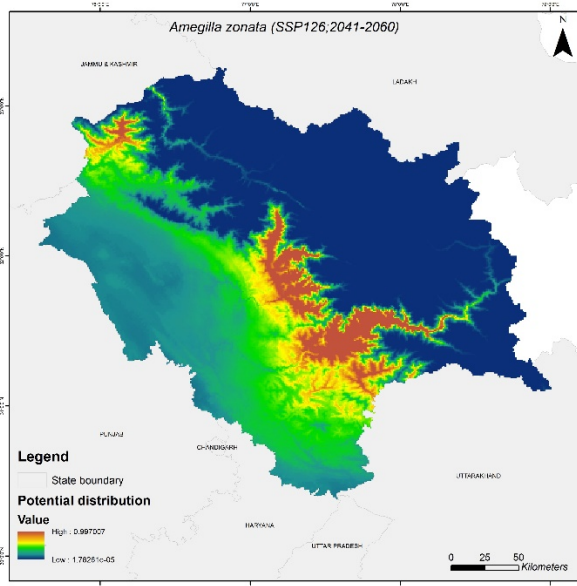
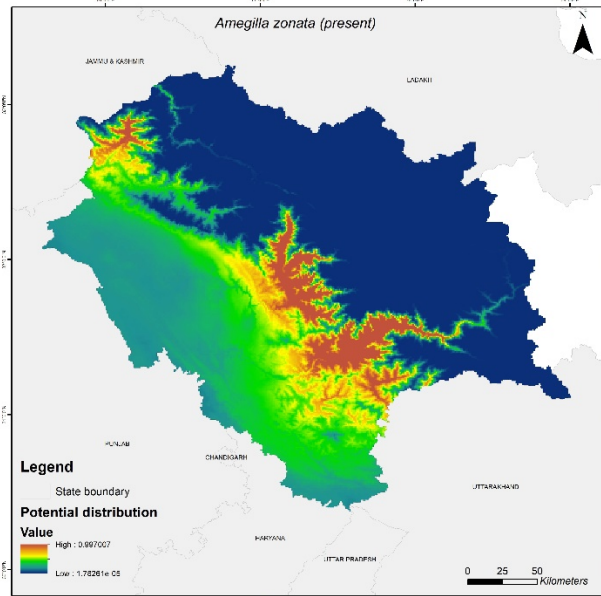
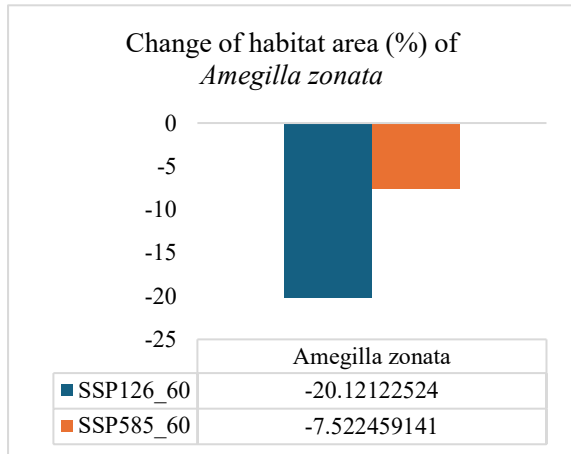
Variable	Percent contribution	Permutation importance
bio_6	54.9	19.8
bio_15	17.6	18.7
bio_4	12.8	7.4
bio_12	6.5	26
dem	4.4	19.8
bio_17	2.6	6.2
bio_1	1.1	0
bio_16	0.2	2.1
bio_5	0	0

9. *Megachilae lanata* (Fabricius, 1775)



Variable	Percent contribution	Permutation importance
bio_6	23.3	10.4
bio_4	19.4	19.2
bio_15	16	28.8
bio_12	13	11.1
bio_1	8.3	2.4
dem	8.1	16.2
bio_16	5.9	6.6
bio_5	4.1	3.9
bio_17	2	1.4

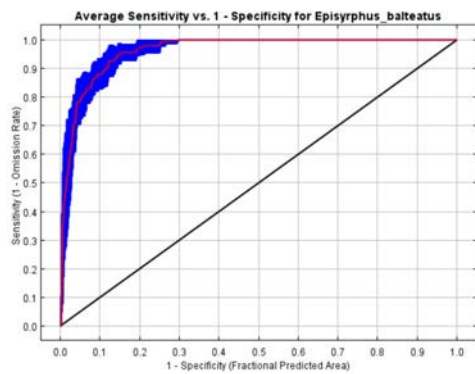
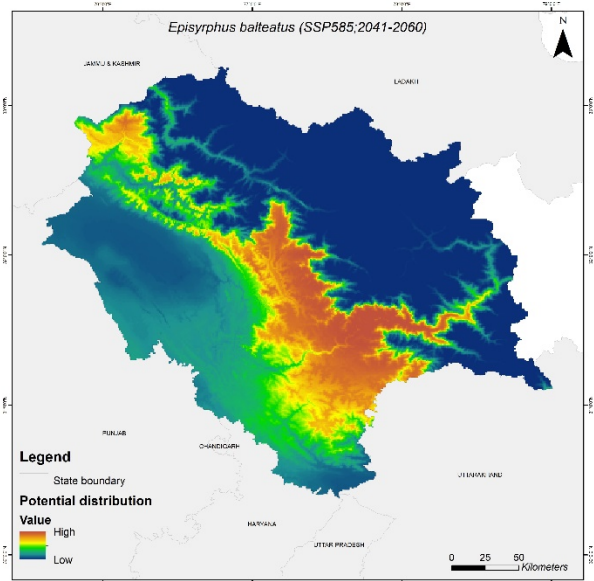
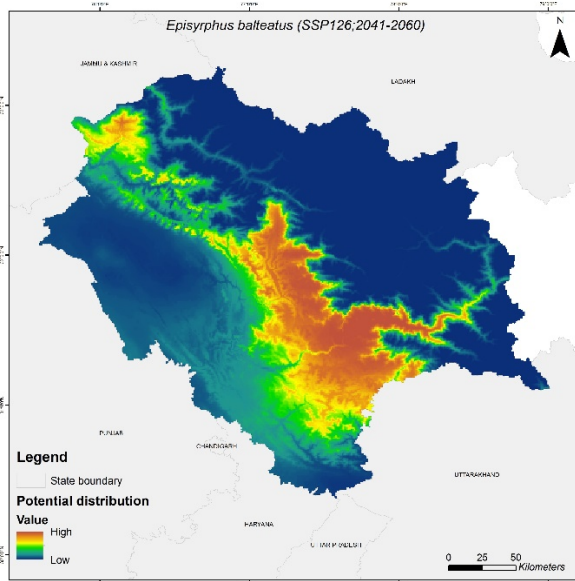
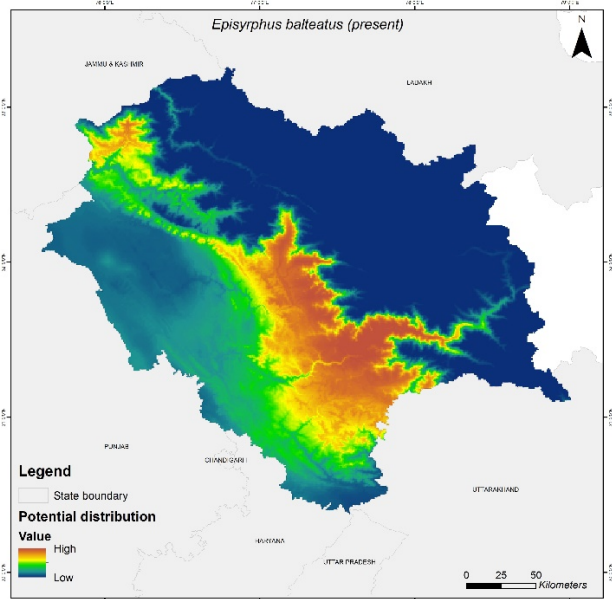
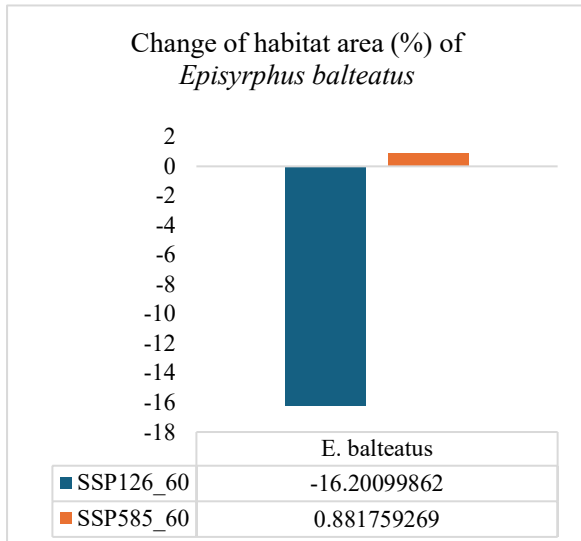
10. *Amegilla zonata* (Fabricius,1775)



Variable	Percent contribution	Permutation importance
bio_6	64.7	33.5
bio_4	13.7	14.9
bio_15	12.7	25.3
dem	5.6	23.5
bio_12	1.7	2.3
bio_1	0.9	0
bio_17	0.7	0.2
bio_16	0	0.1
bio_5	0	0

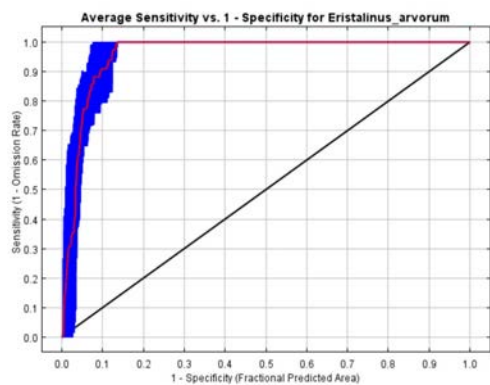
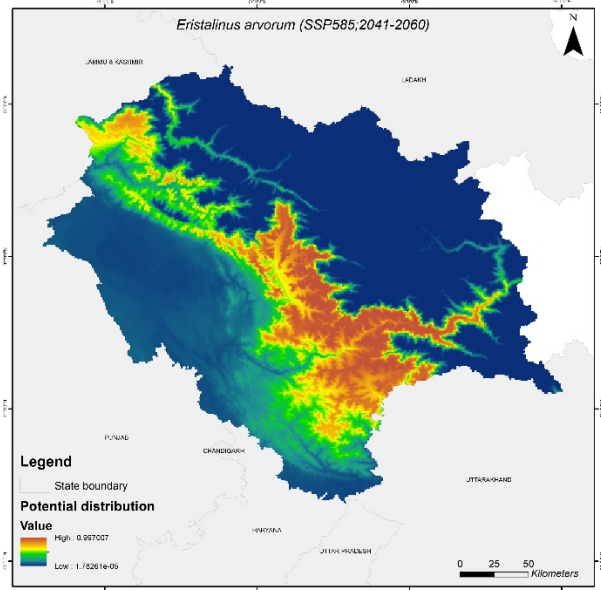
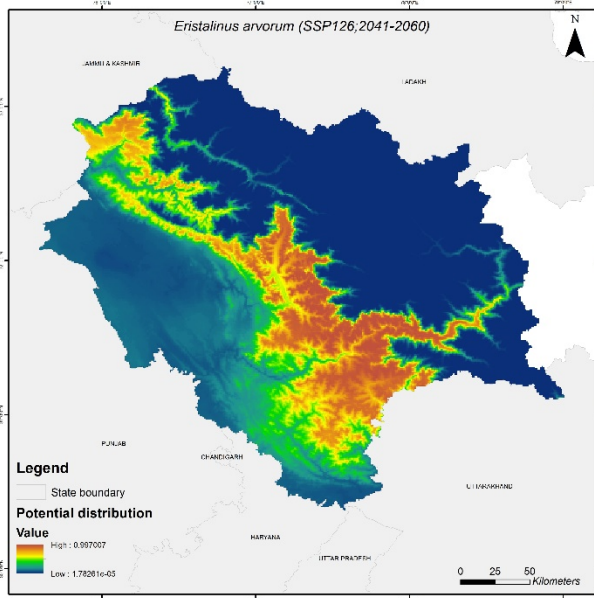
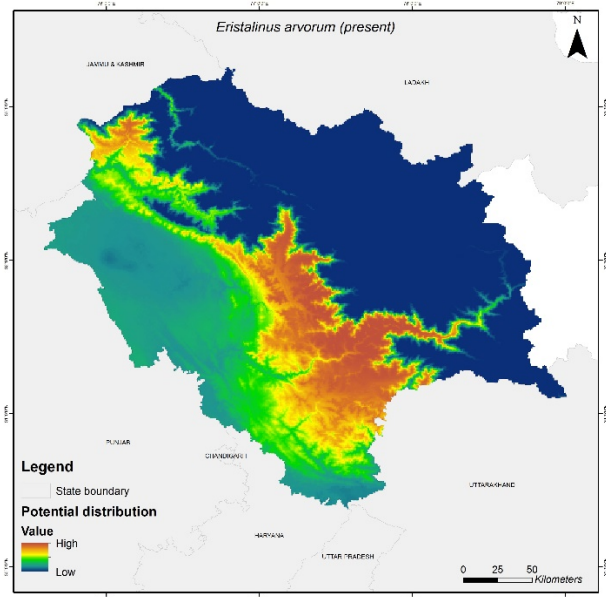
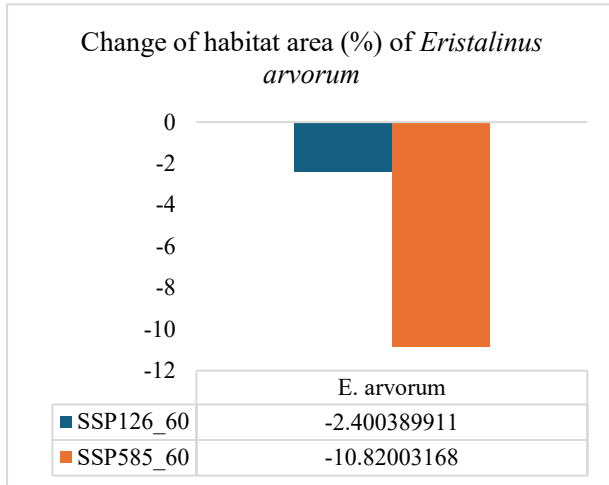
Order: Diptera

11. *Episyrphus balteatus* (De Gear, 1776)



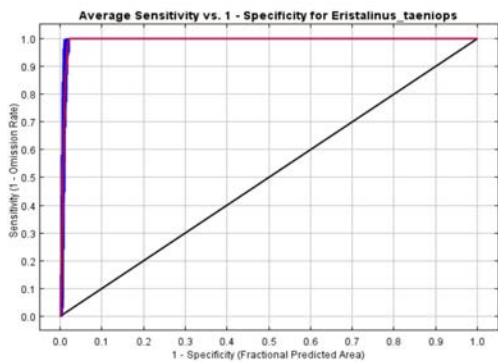
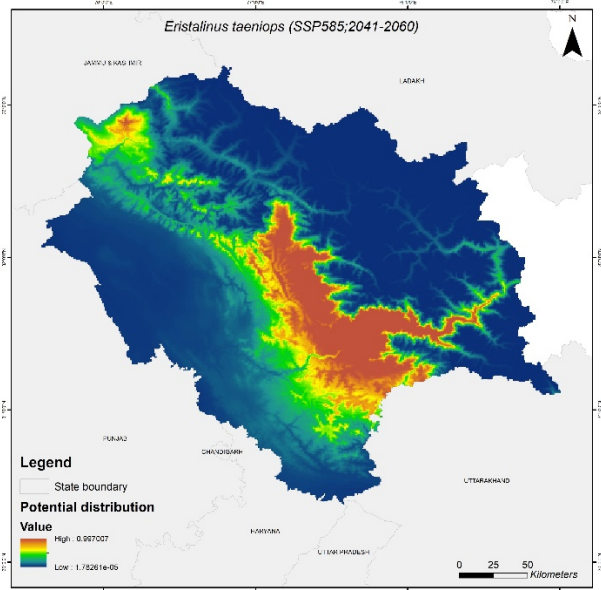
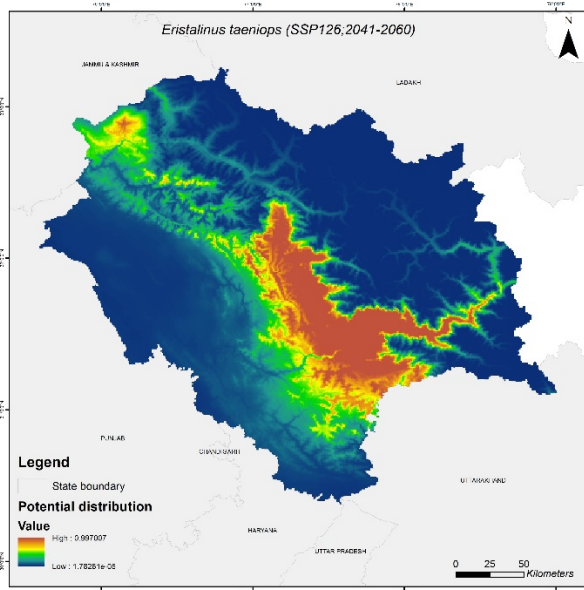
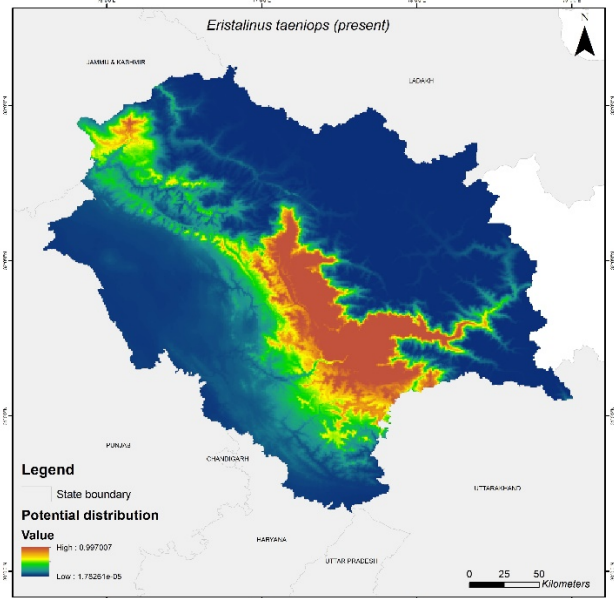
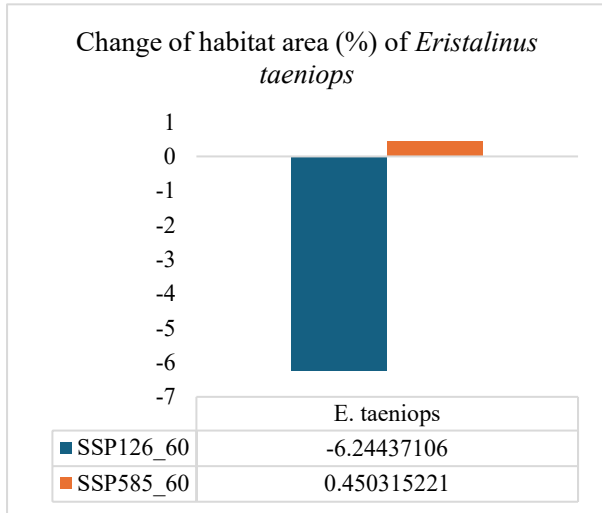
Variable	Percent contribution	Permutation importance
bio_6	38.6	32
bio_12	33.5	0
bio_4	18.7	41.5
bio_15	7.1	12.7
bio_16	1.3	2.9
dem	0.7	10.9
bio_5	0.1	0
bio_17	0	0
bio_1	0	0

12. *Eristalinus arvorum* (Fabricius, 1787)



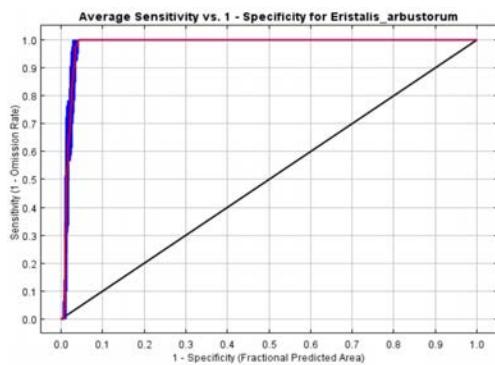
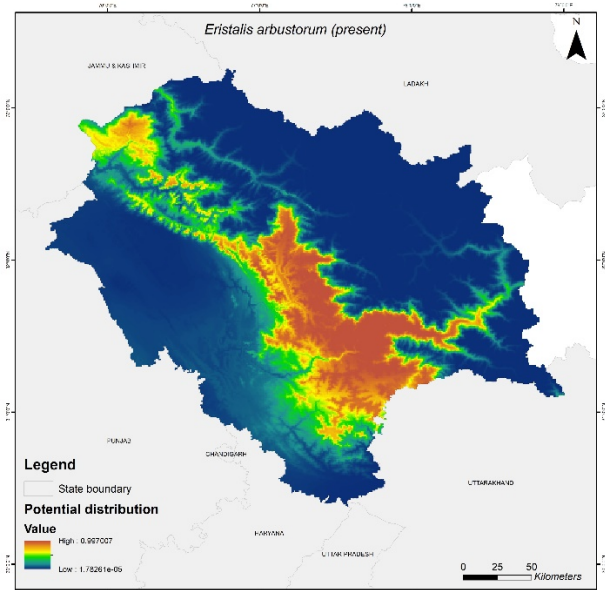
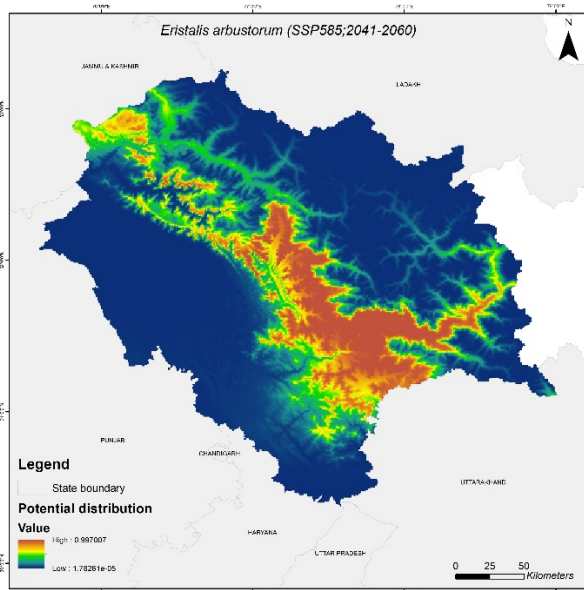
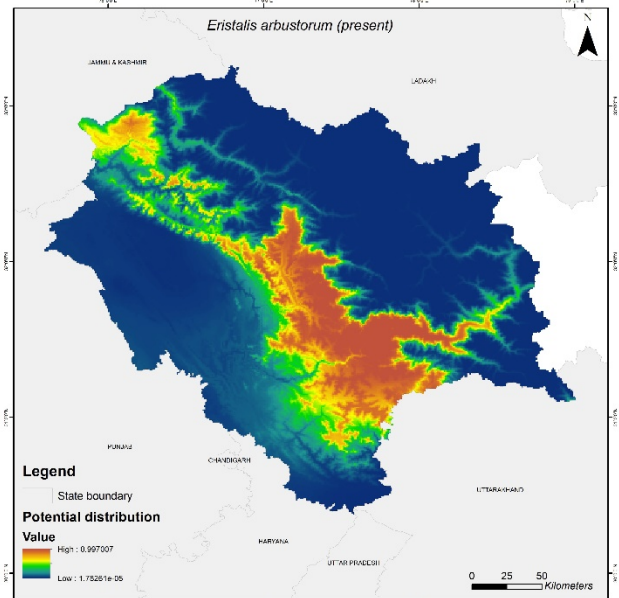
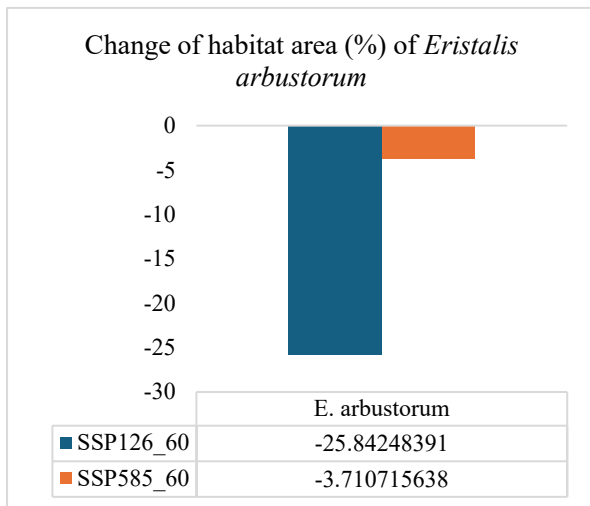
Variable	Percent contribution	Permutation importance
bio_6	82.6	68.9
bio_4	11.7	16.7
bio_15	4.3	6.9
bio_16	0.7	1.2
dem	0.6	5.2
bio_12	0.1	1.1
bio_5	0	0
bio_17	0	0
bio_1	0	0

13. *Eristalinus taeniops* (Wiedemann, 1818)



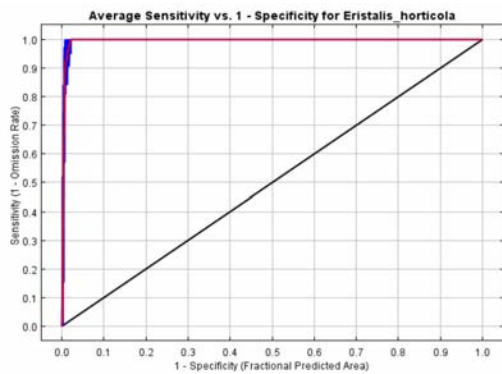
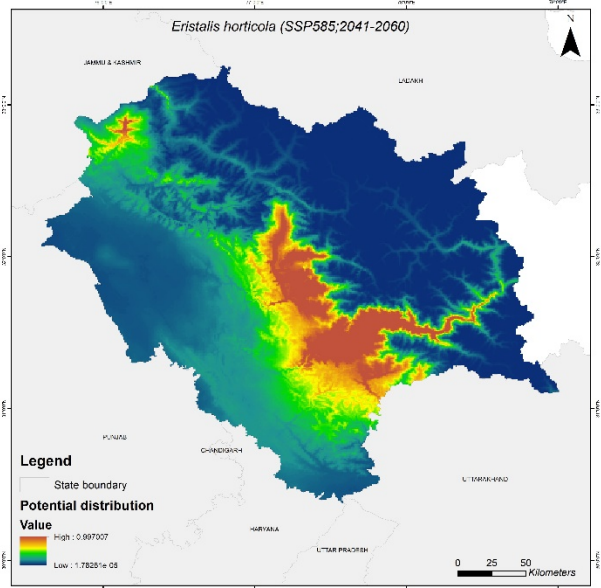
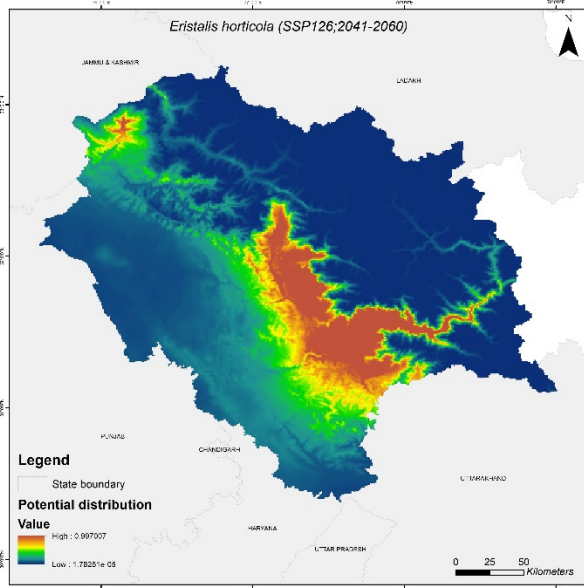
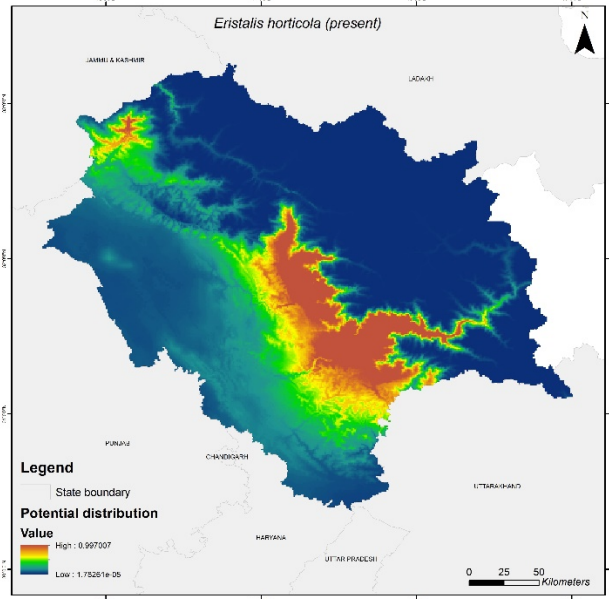
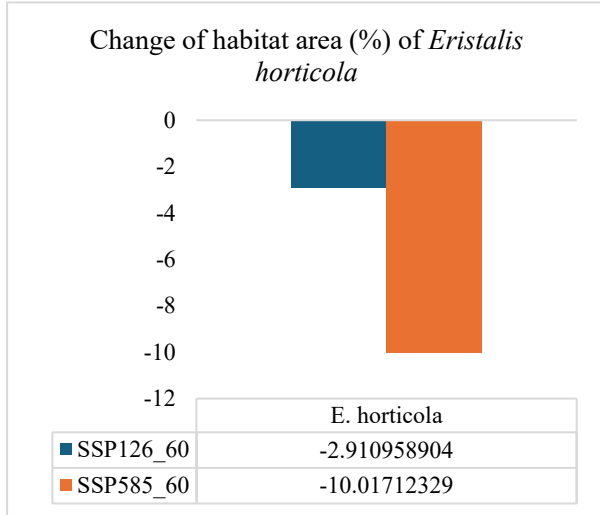
Variable	Percent contribution	Permutation importance
bio_4	32	40.5
bio_17	27.4	0.2
bio_15	23.1	31.6
bio_6	16.4	18.4
dem	0.6	4
bio_12	0.3	2
bio_16	0.1	3.3
bio_5	0	0
bio_1	0	0

14. *Eristalis arbustorum* (Linnaeus, 1758)



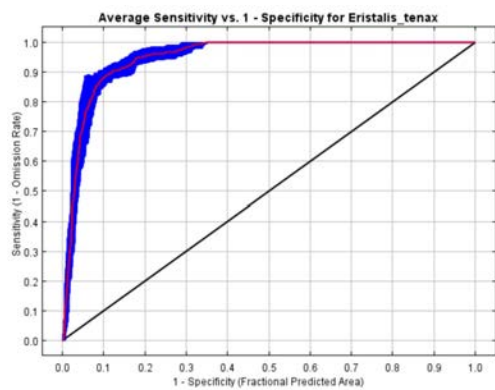
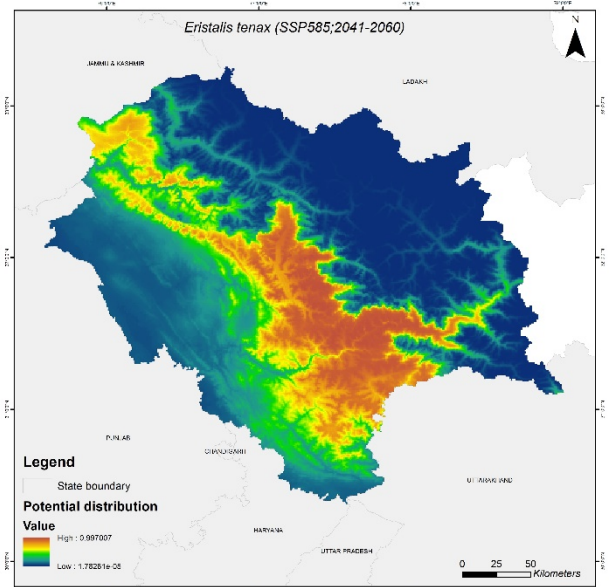
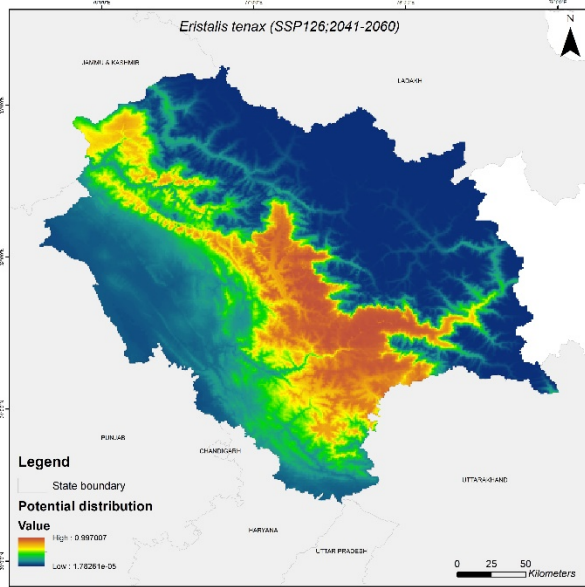
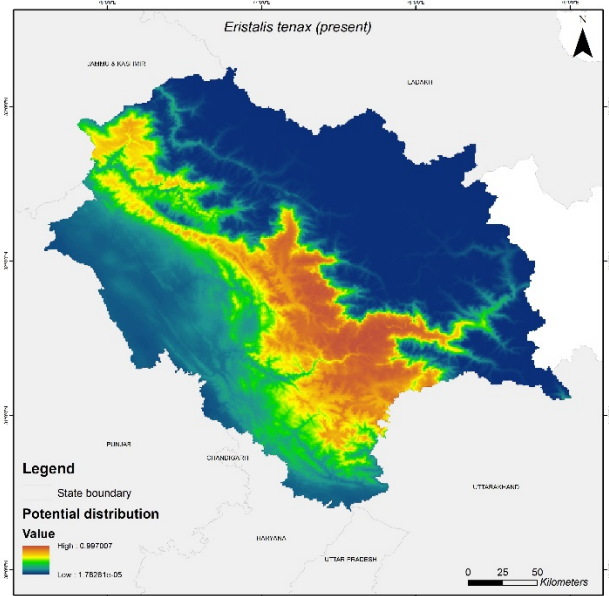
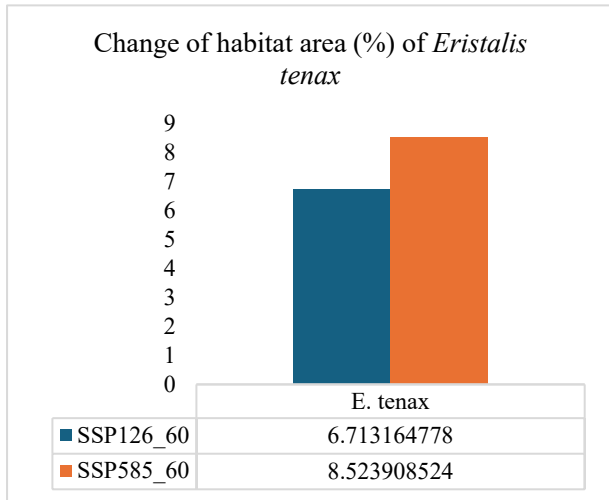
Variable	Percent contribution	Permutation importance
bio_6	63.2	46.3
bio_15	20.9	19.8
bio_4	14.6	27.1
bio_16	1.2	5.9
dem	0	0.6
bio_12	0	0.2
bio_5	0	0
bio_17	0	0
bio_1	0	0

15. *Eristalis horticola* (De Gear, 1776)



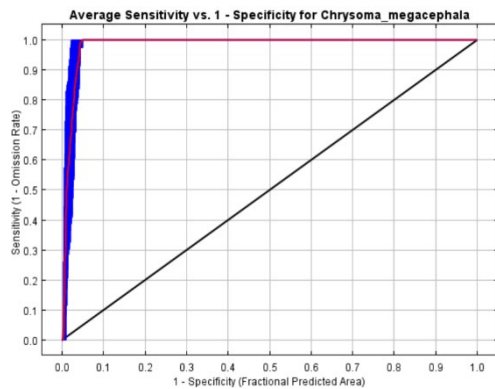
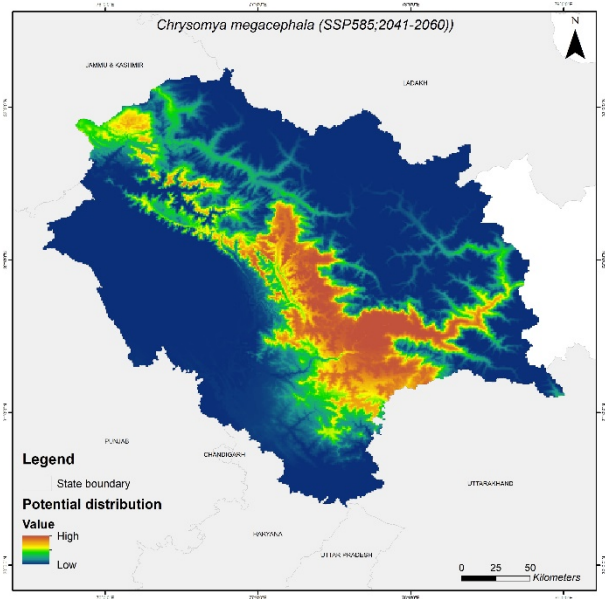
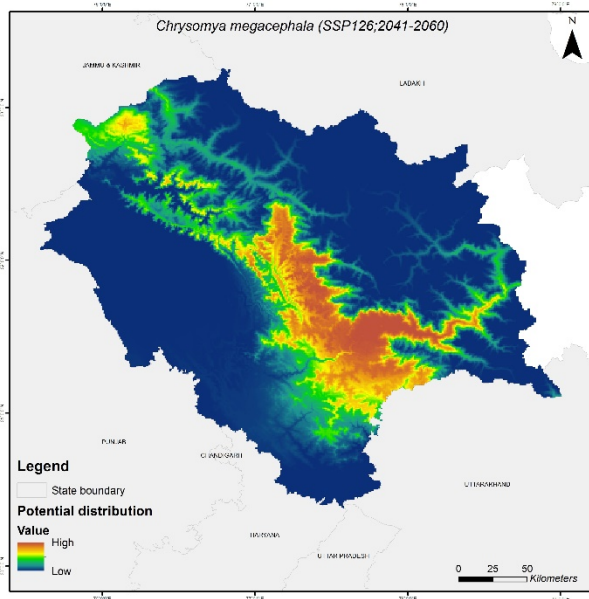
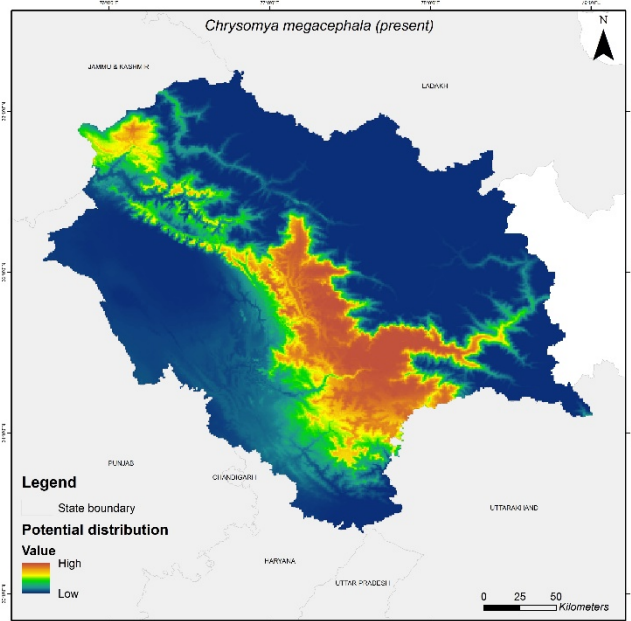
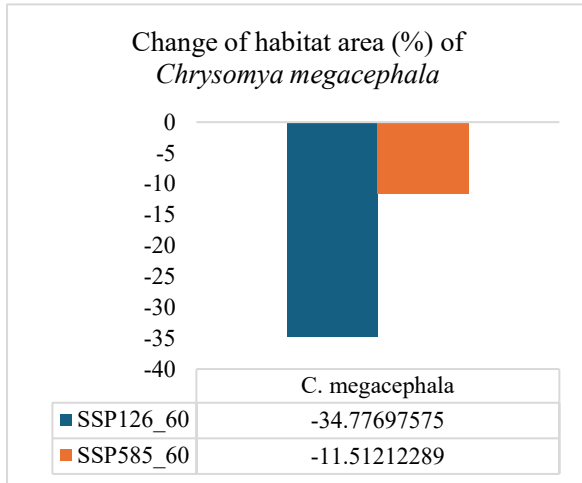
Variable	Percent contribution	Permutation importance
bio_6	51.9	48.2
bio_15	24.1	37.5
bio_4	19.7	10.3
bio_17	4.2	0
dem	0.1	3.9
bio_16	0	0
bio_5	0	0
bio_12	0	0
bio_1	0	0

16. *Eristalis tenax* (Linnaeus, 1758)



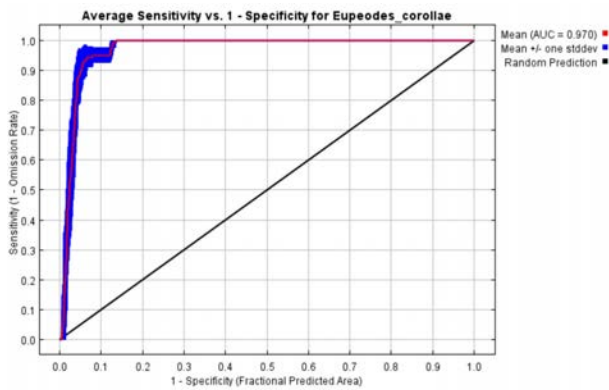
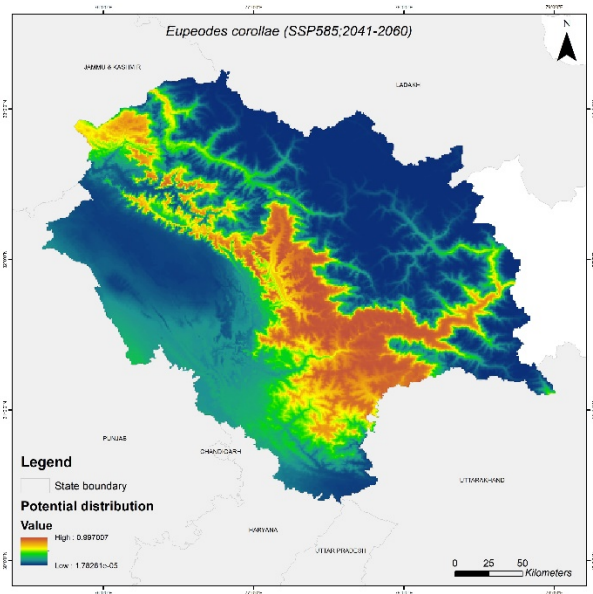
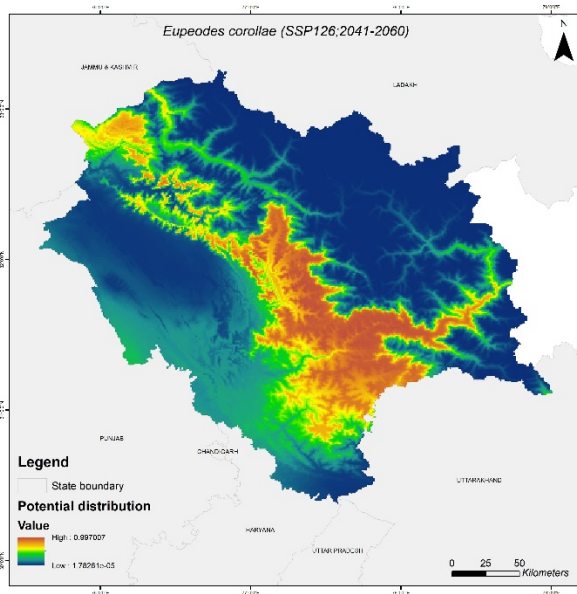
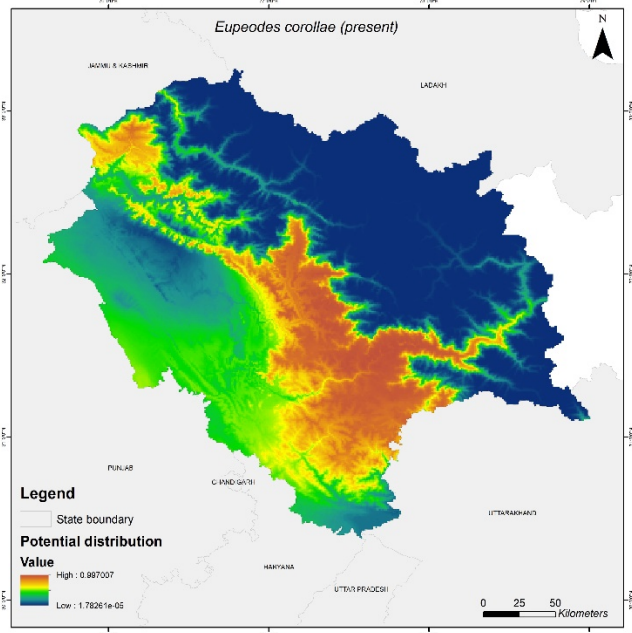
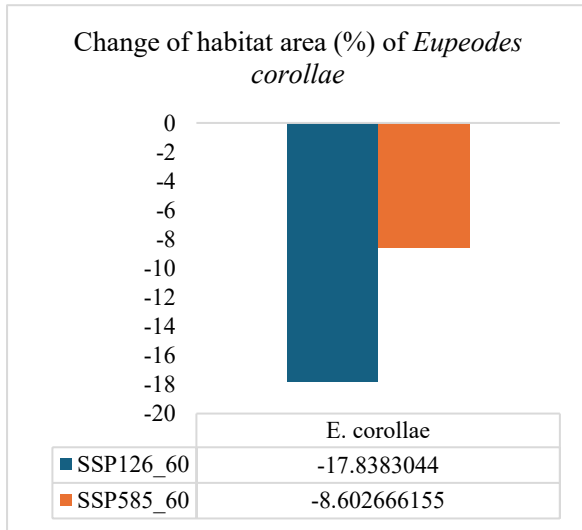
Variable	Percent contribution	Permutation importance
bio_12	36.3	1.7
bio_4	24.7	69.1
bio_17	16.9	1
bio_6	14.8	8.7
bio_15	6.1	15.6
bio_5	0.7	0
dem	0.4	3.9
bio_1	0.2	0
bio_16	0	0

17. *Chrysomya megacephala* (Fabricius, 1794)



Variable	Percent contribution	Permutation importance
bio_6	60.5	12.3
bio_15	19.5	25.9
bio_4	17.6	43.7
dem	1.6	10.8
bio_16	0.8	7.3
bio_5	0	0
bio_17	0	0
bio_12	0	0
bio_1	0	0

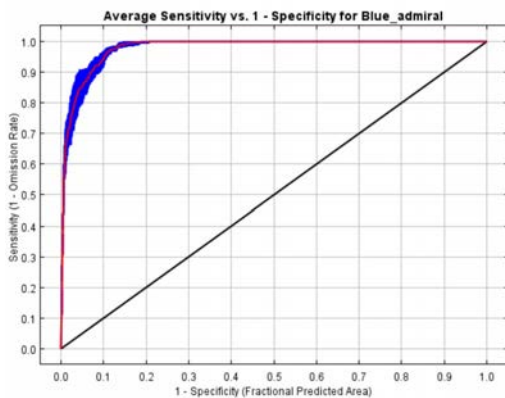
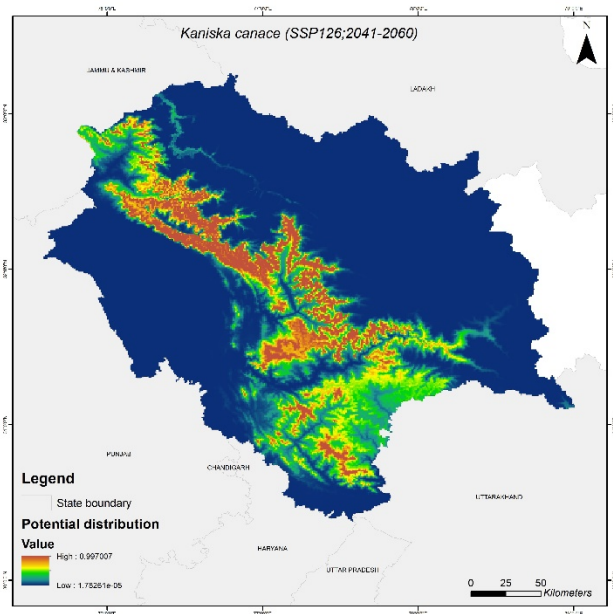
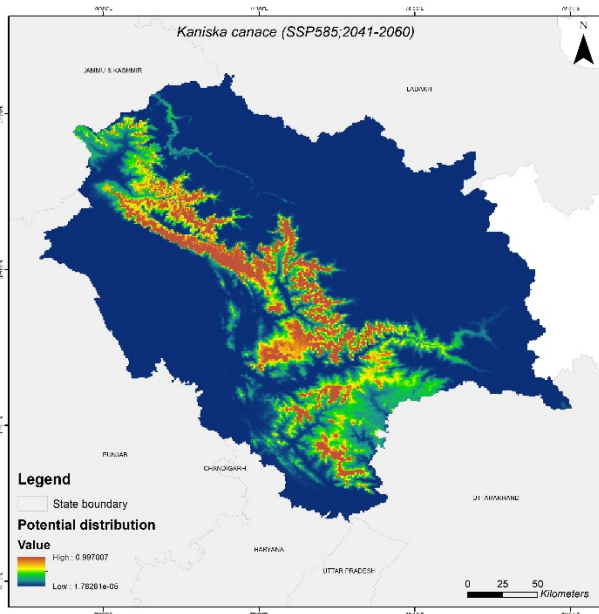
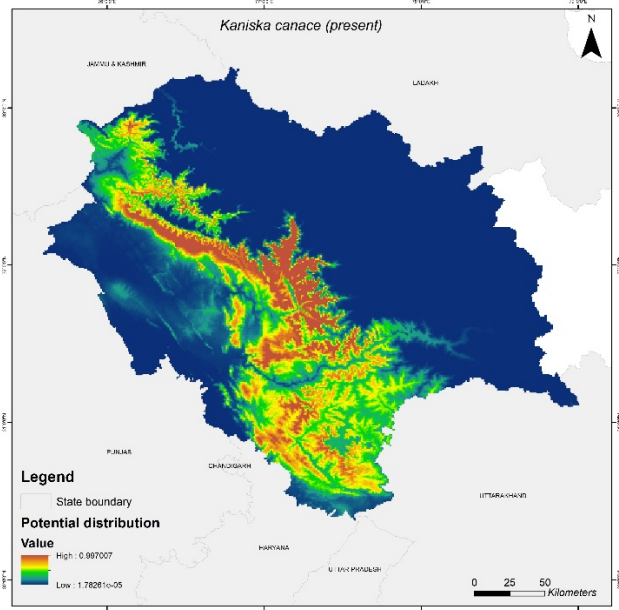
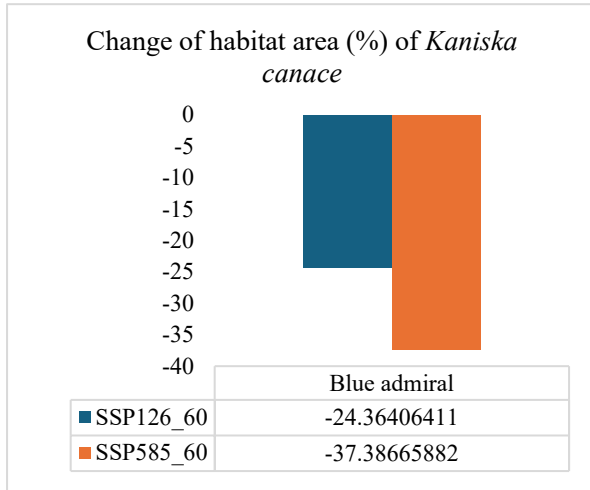
18. *Eupeodes corollae* (Fabricius, 1794)



Variable	Percent contribution	Permutation importance
bio_6	83.1	48.8
bio_4	9.4	28.3
bio_16	4.4	17.8
bio_15	3.1	2.9
dem	0.1	2.2
bio_5	0	0
bio_17	0	0
bio_12	0	0
bio_1	0	0

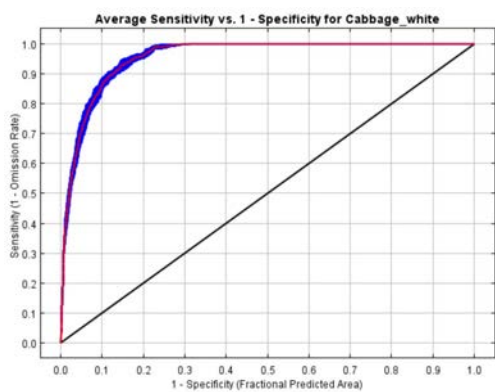
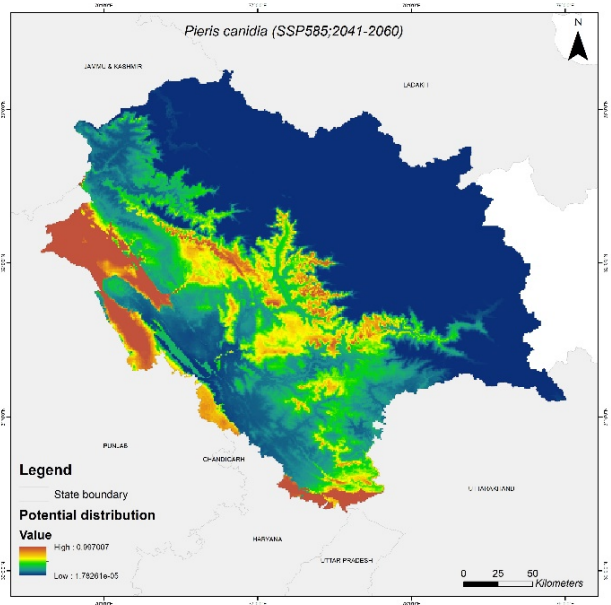
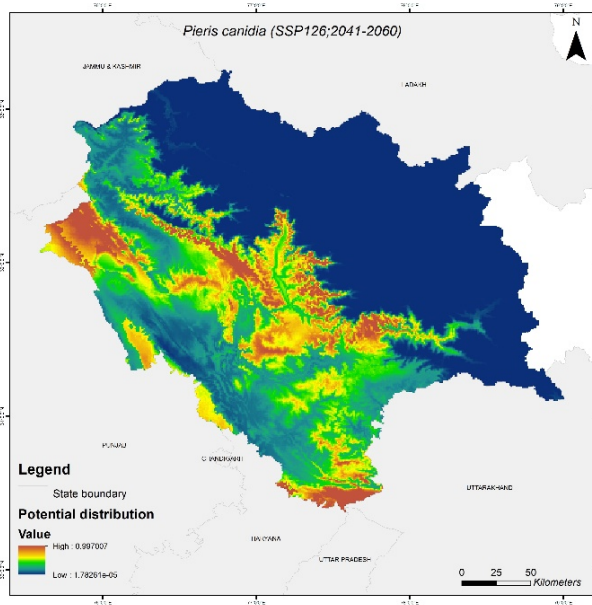
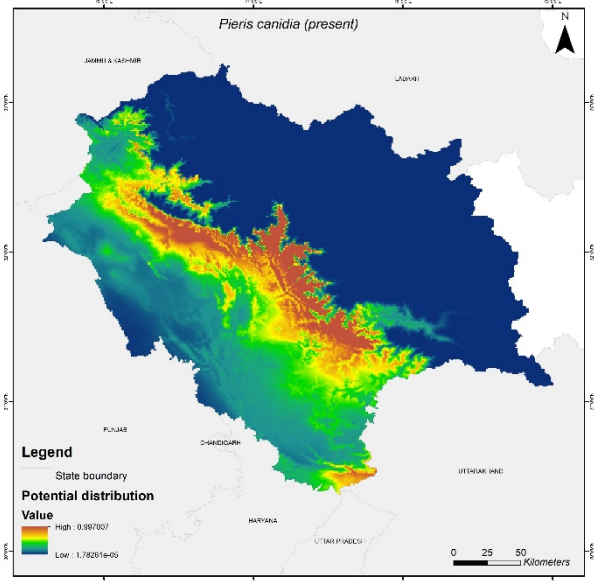
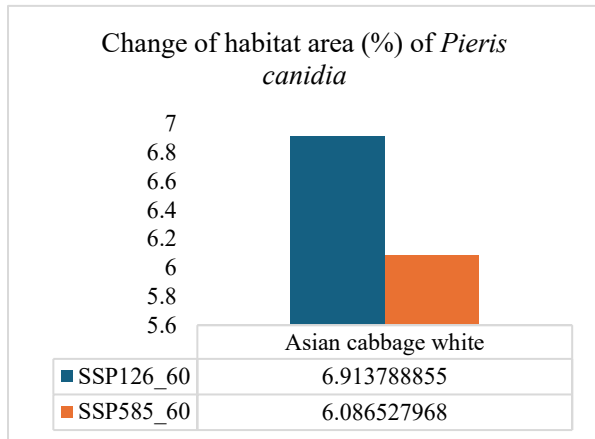
Order: Lepidoptera

19. *Kaniska canace* (Linnaeus, 1763)



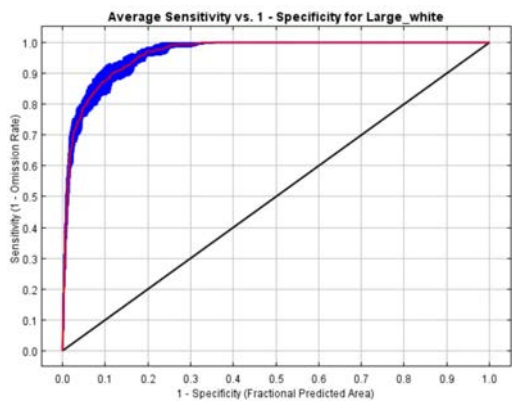
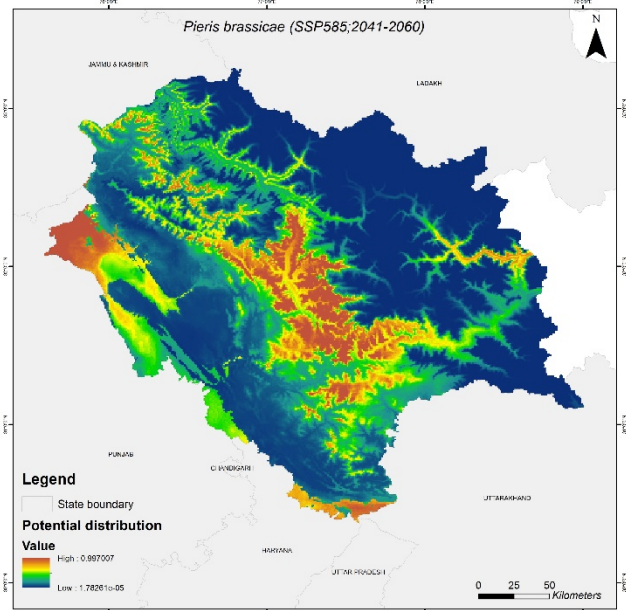
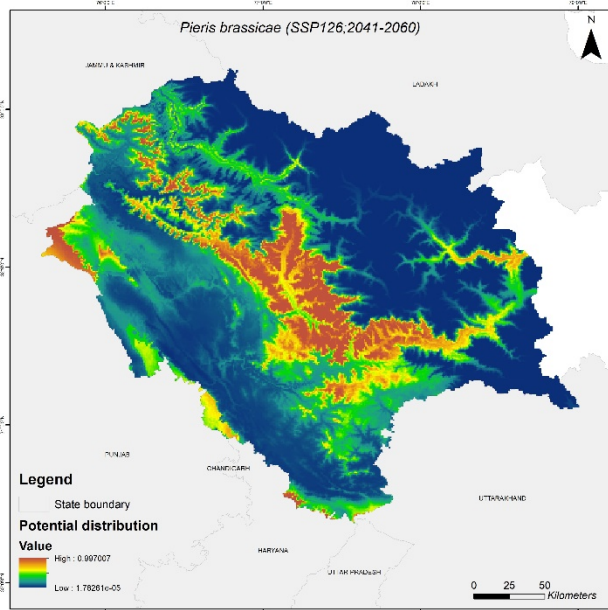
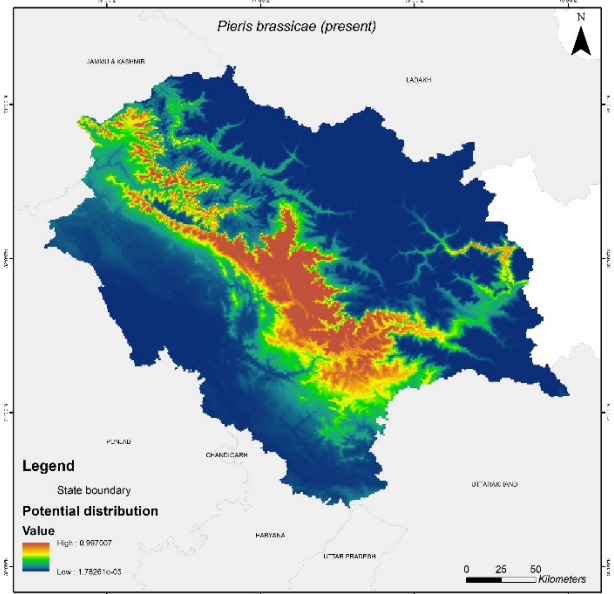
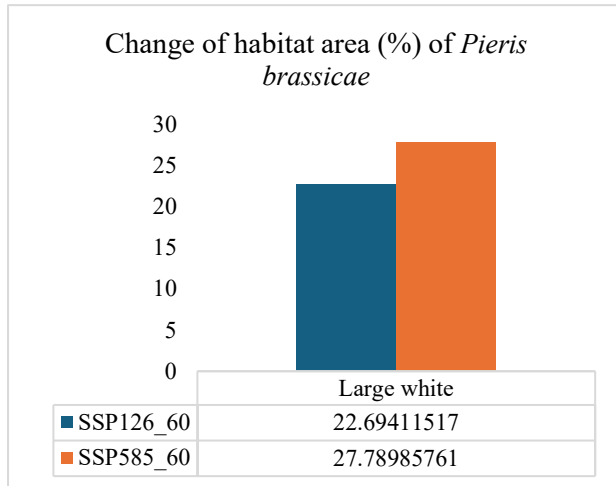
Variable	Percent contribution	Permutation importance
bio_12	51.2	42.6
bio_4	24.1	17.3
bio_6	6.5	9.2
dem	4.5	11
bio_5	4.4	5.1
bio_17	4.3	8.6
bio_15	4.1	5.6
bio_16	0.9	0.4
bio_1	0	0

20. *Pieris canidia* (Sparrman, 1768)



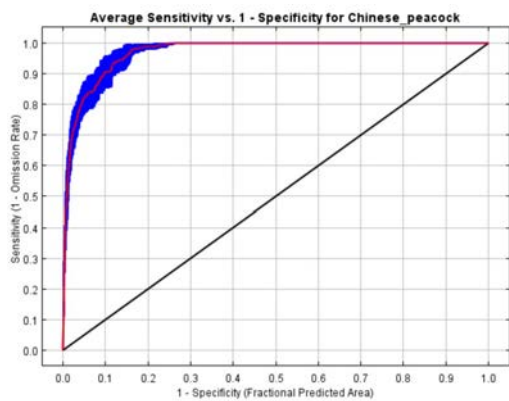
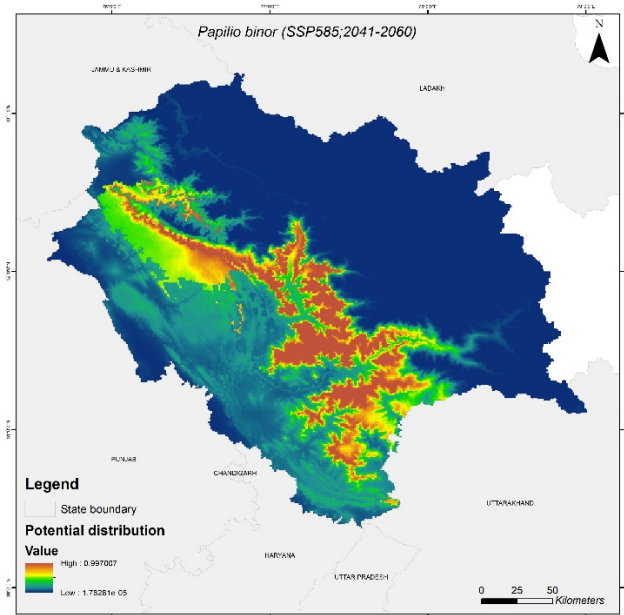
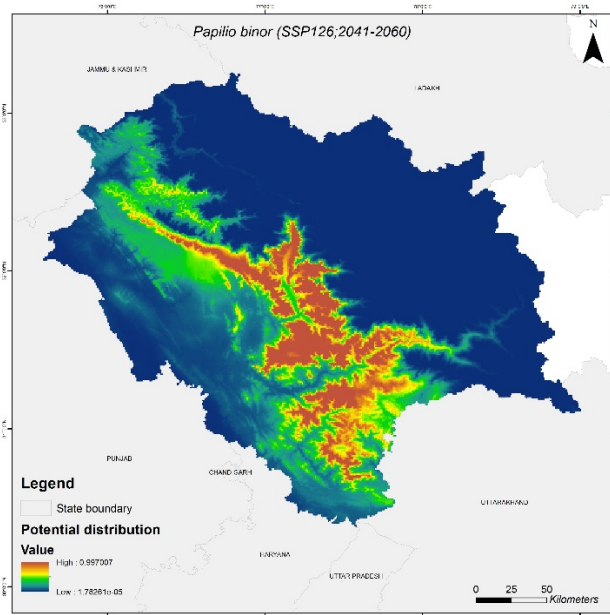
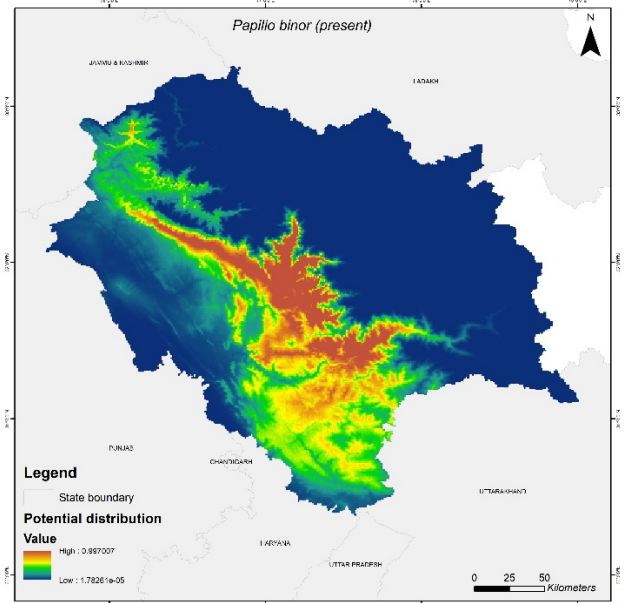
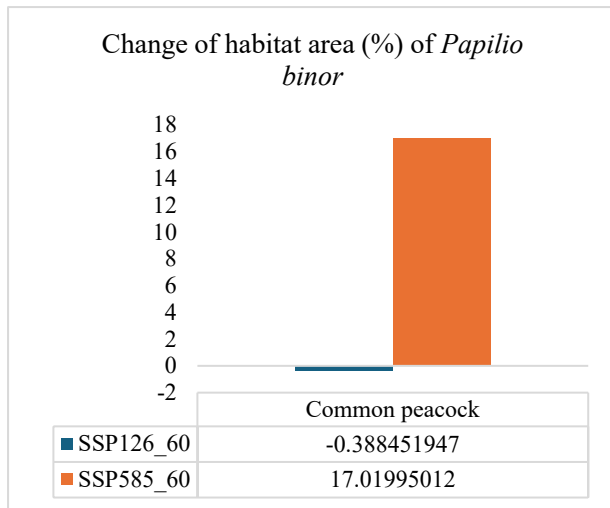
Variable	Percent contribution	Permutation importance
bio_12	62.5	26
bio_4	21.9	31
bio_15	6.8	11.1
bio_17	2.8	4.6
dem	2.1	16.1
bio_1	1.2	0.3
bio_6	1.2	5.4
bio_5	1	4.1
bio_16	0.4	1.3

21. *Pieris brassicae* (Linnaeus, 1758)



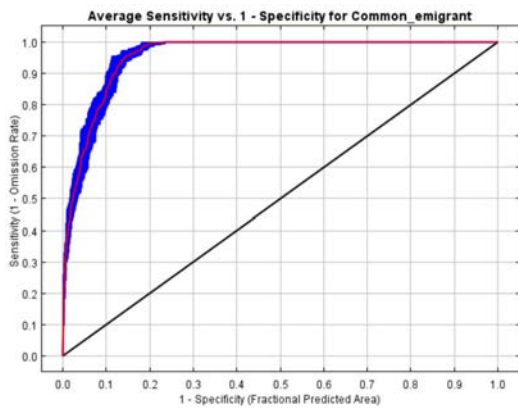
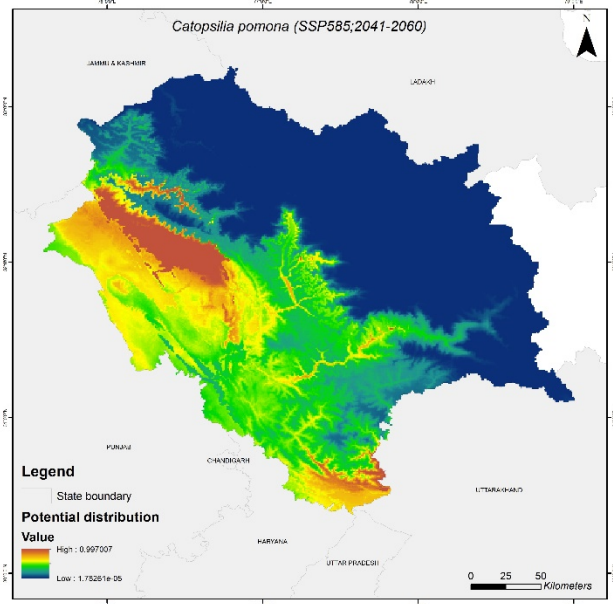
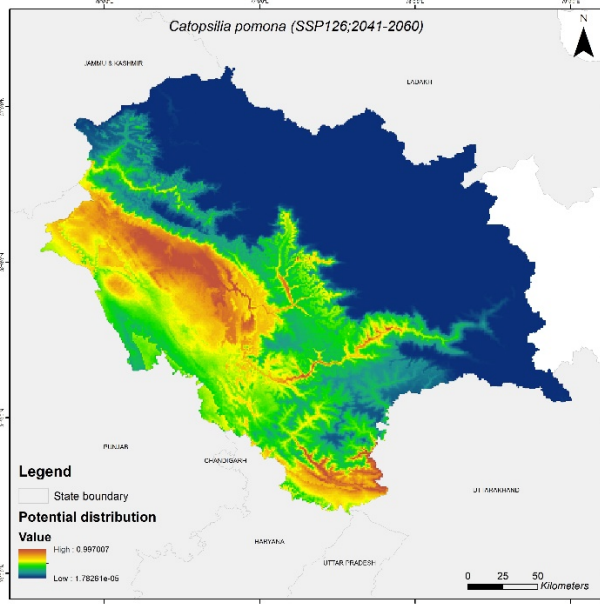
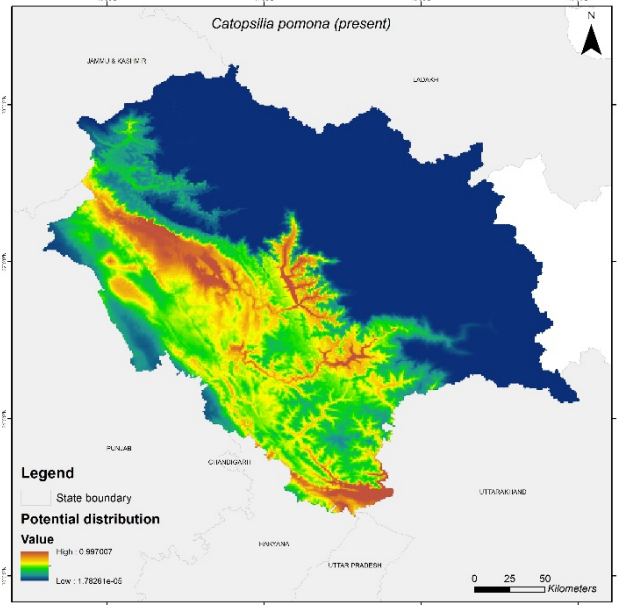
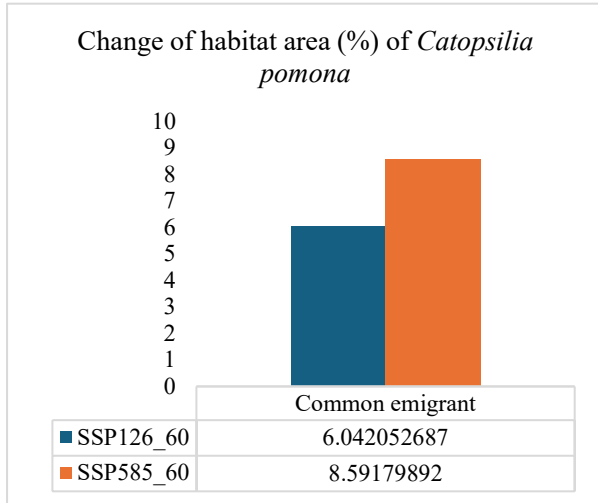
Variable	Percent contribution	Permutation importance
bio_12	42.6	11.4
bio_4	24	27.3
bio_15	12.1	19.3
bio_17	8.1	5.2
bio_1	5.4	5.8
bio_5	3.2	3
bio_6	2.1	2.5
bio_16	1.6	22.2
dem	0.9	3.4

22. *Papilio binor* (Cramer, 1777)



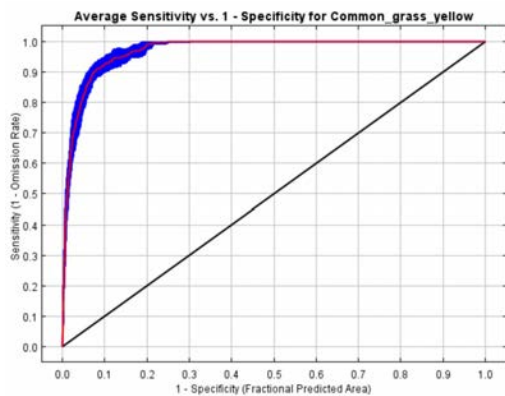
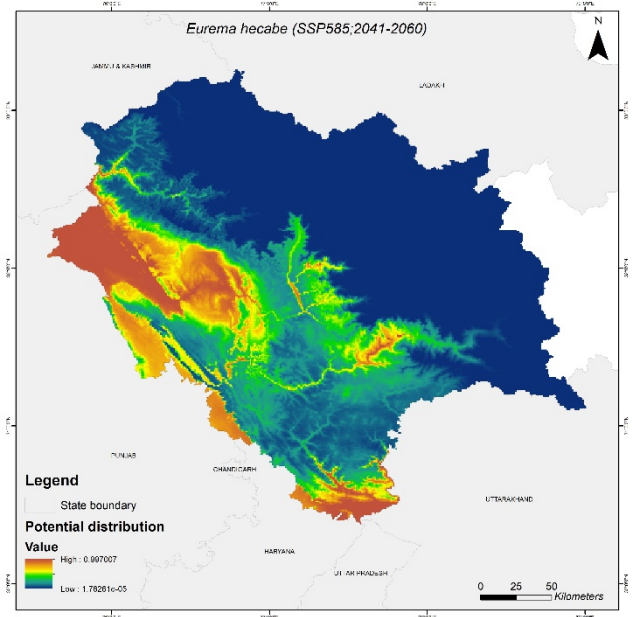
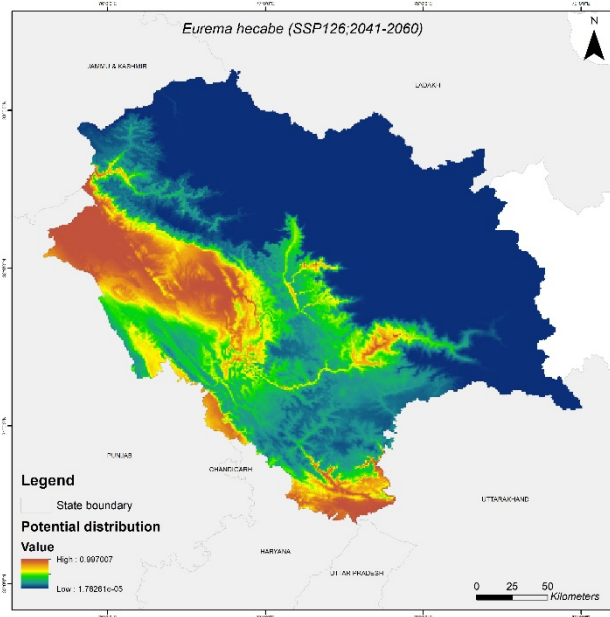
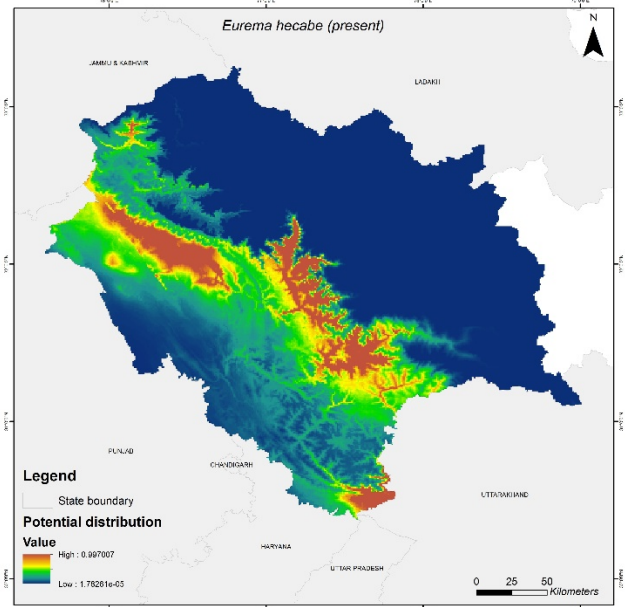
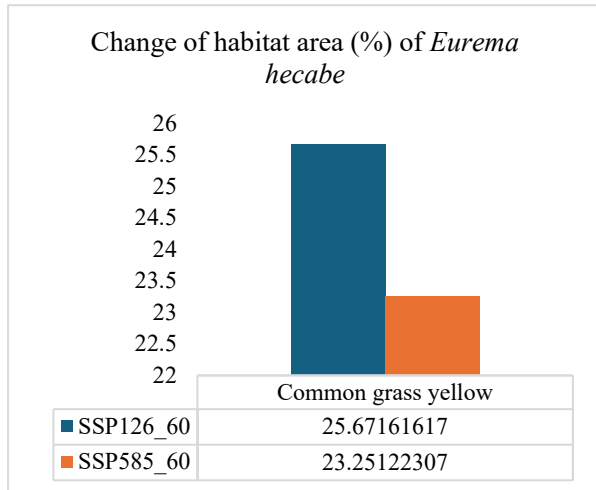
Variable	Percent contribution	Permutation importance
bio_12	40.2	27.3
bio_4	39.3	34.7
bio_6	5.3	6.2
bio_17	5.3	5.3
dem	4.6	14.9
bio_15	3.3	7.5
bio_5	1.6	3.9
bio_1	0.3	0.2
bio_16	0.1	0

23. *Catopsilia pomona* (Fabricius, 1775)



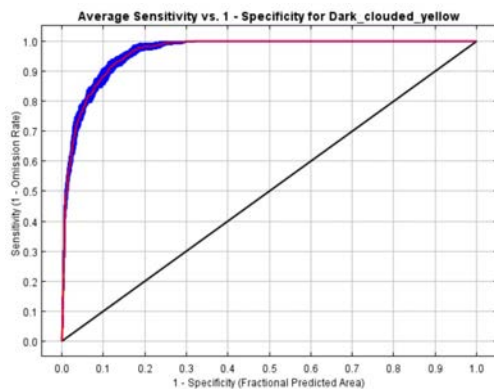
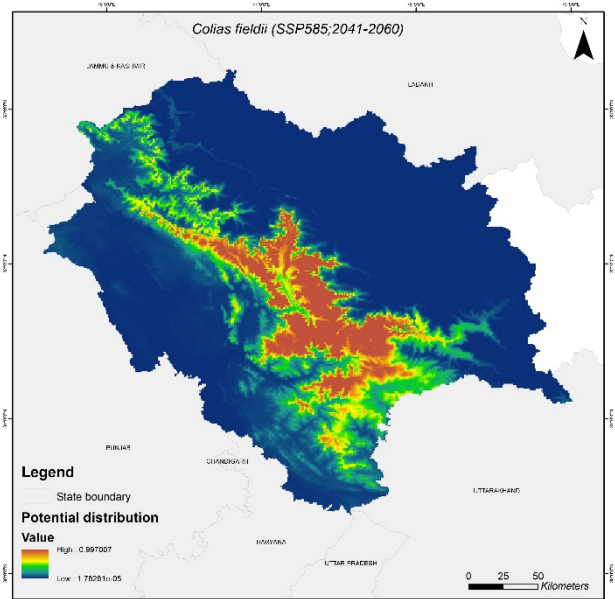
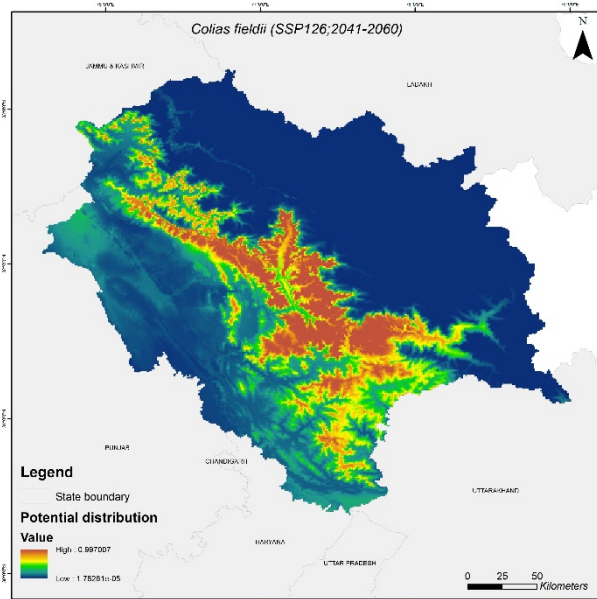
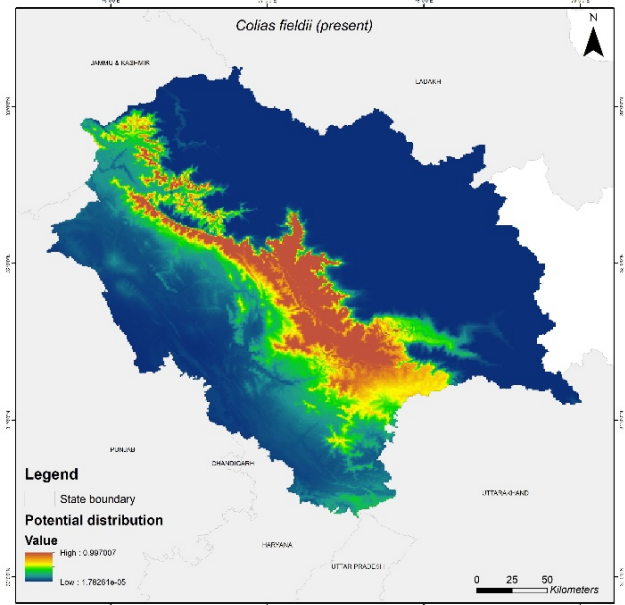
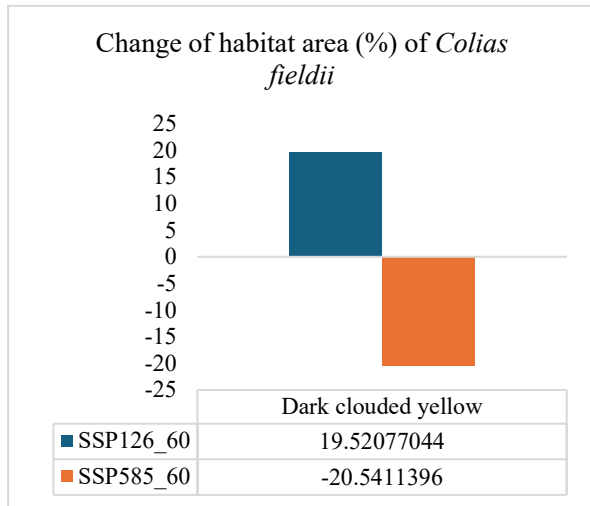
Variable	Percent contribution	Permutation importance
bio_12	34.9	6
bio_16	32	0.9
bio_15	7.6	3.9
bio_4	6.3	58.2
dem	5.7	18.1
bio_6	4.9	6.2
bio_17	3.5	3.7
bio_5	2.5	2.4
bio_1	2.5	0.6

24. *Eurema hecabe* (Linnaeus, 1758)



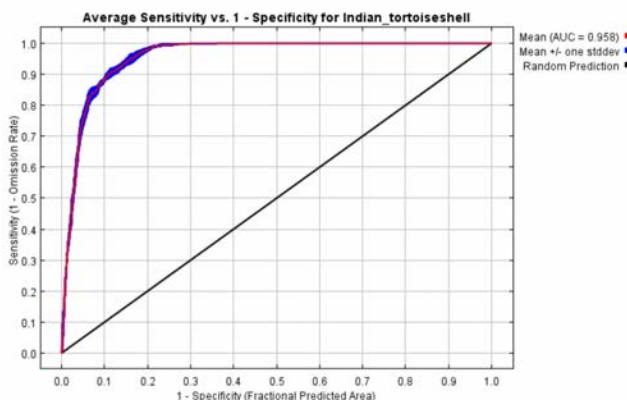
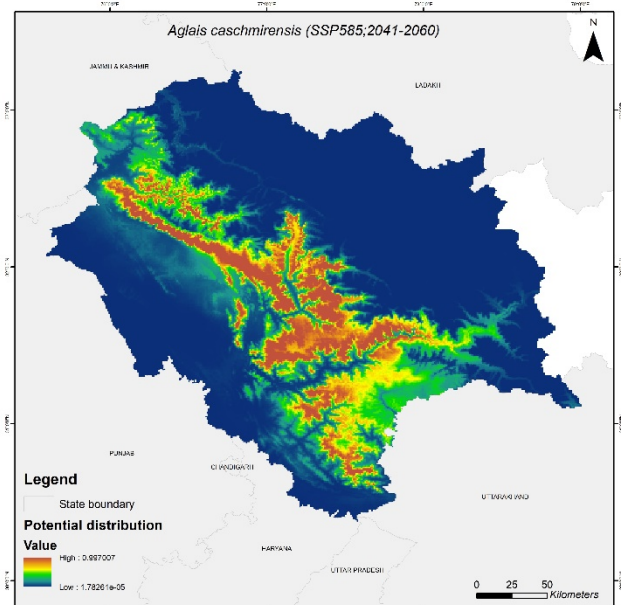
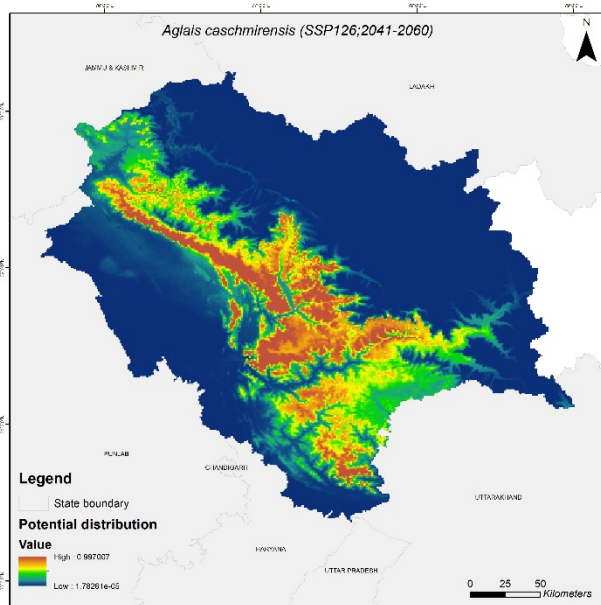
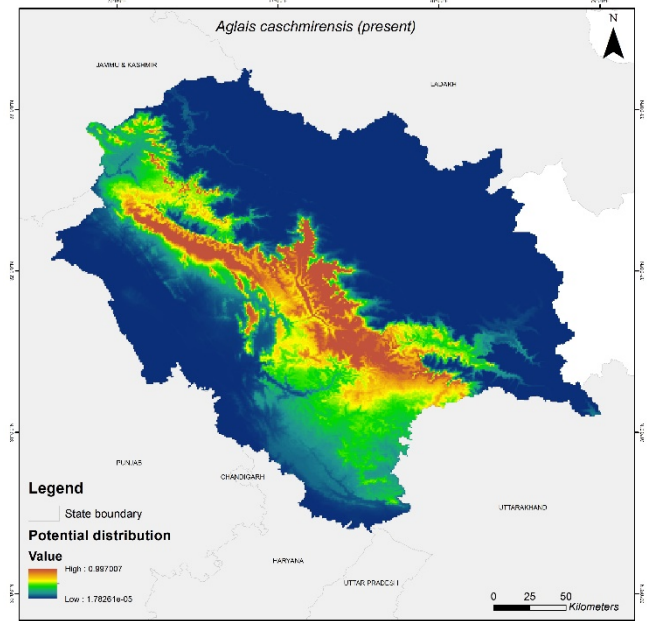
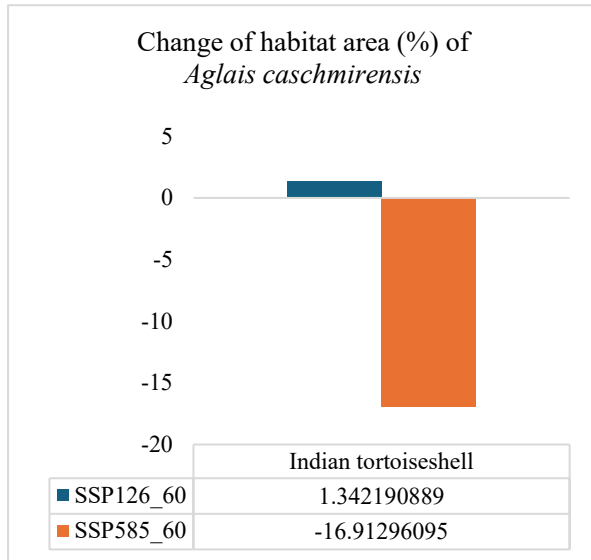
Variable	Percent contribution	Permutation importance
bio_12	48.9	17.1
bio_16	15.2	0.8
bio_4	10.7	35.2
bio_15	10.2	7.7
bio_6	4.3	3
bio_1	4	3.1
bio_17	3.2	7.7
bio_5	2	4.8
dem	1.4	20.5

25. *Colias fieldii* (Ménétriés, 1855)

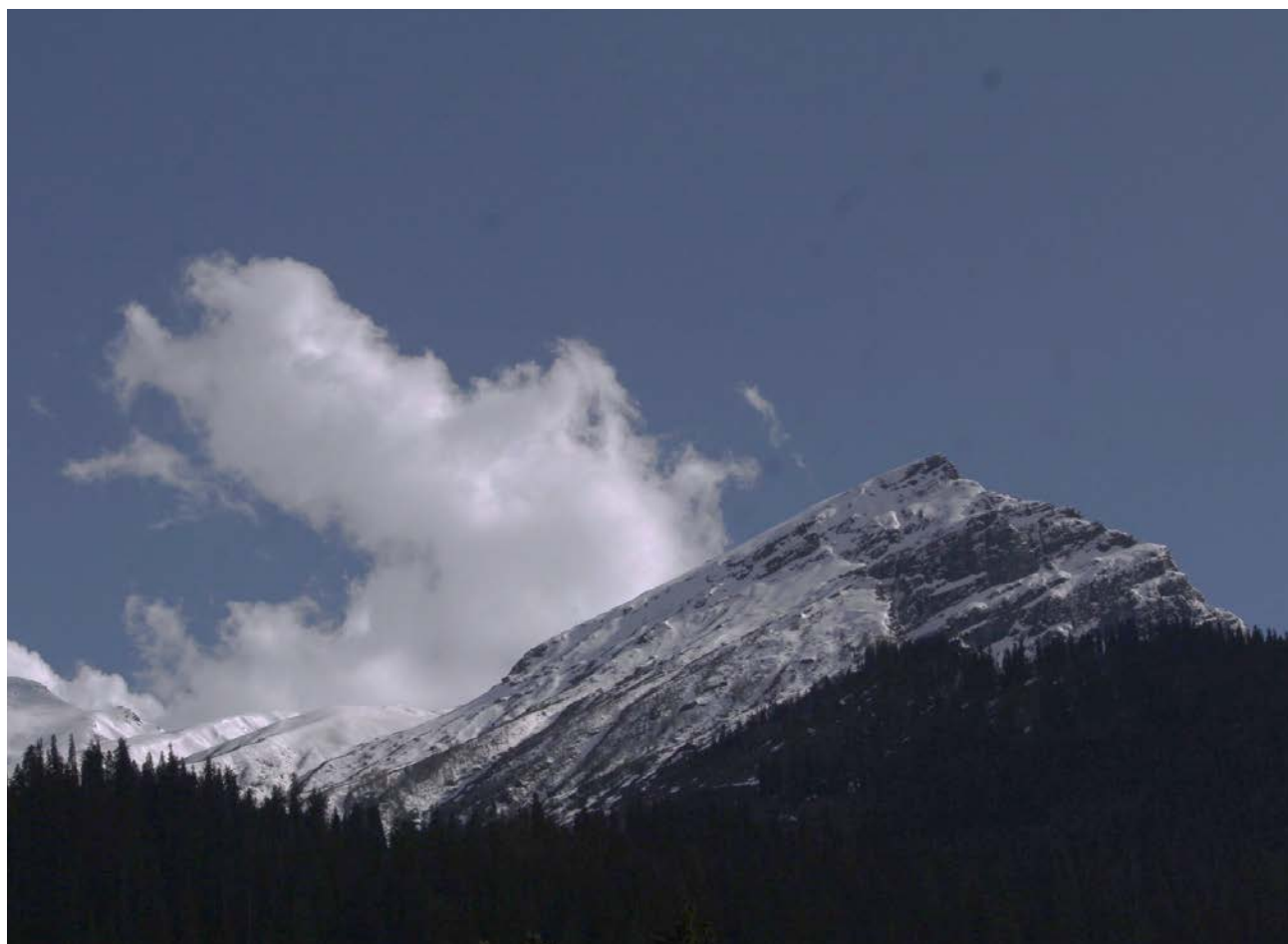


Variable	Percent contribution	Permutation importance
bio_12	50.3	26.5
bio_4	28.5	32.9
bio_15	11.2	16.4
bio_17	3.8	4.7
bio_5	2	6.8
dem	1.9	7.3
bio_6	1.5	2.6
bio_16	0.6	2.4
bio_1	0.3	0.2

26. *Aglais caschmirensis* (Kollar, 1848)



Variable	Percent contribution	Permutation importance
bio_12	30.9	19.9
bio_4	29.2	39.3
bio_17	26.2	8.3
bio_15	5.1	10.6
bio_5	4	8
dem	2.4	7.9
bio_6	1.5	4.6
bio_16	0.4	1.4
bio_1	0.3	0



Chapter 7: Syntheses and Recommendations

7.1. Syntheses

The landscape is being a part of biodiversity hotspot supports diverse array of flora and fauna in both the natural and semi natural habitats. The area is also an important commercial horticultural belt contributing significantly to local livelihood and national and global economy. Apart from this, the orchards are supported by various pollinators, particularly insect pollinators providing critical pollination services and crop yield. However, climate change and various anthropogenic disturbances has put serious threat to this landscape and the pollinators in terms of environmental alteration and LULC change leading to loss of ecosystem health and well-being of human (Chakraborty et al., 2016; Negi et al., 2017, Bhusal, 2020). Hence, it is very important to recognise the dynamics of these impacts for informed management and conservation strategies focused at preserving pollinator diversity and ecosystem functionality of a landscape.

The research highlights the rich diversity and abundance of pollinators across orchards within the study area. Although there have been several studies on pollinators in Himachal Pradesh, including the Kullu district, few have investigated how diverse land use practices impact pollinator richness, diversity, and abundance on a landscape scale. Overall, the findings of the study highlight the complex interplay between species interactions, LULC, habitat preferences, and management practices in shaping pollinator communities within orchard ecosystems. Given the mosaic-like nature of the Kullu valley, a comprehensive conservation effort aimed at preserving pollinator diversity and ecosystem functioning should consider the complex interactions between human settlements, agricultural practices, and natural habitats to sustain the habitats of pollinators in this region. The suggestion is also supported by Lindenmayer et al., 2006, which states conservation of biodiversity is guided by five key principles viz., preserving connectivity, promoting landscape diversity, maintaining complex stand structures, ensuring the integrity of aquatic ecosystems, and aligning human disturbance regimes with natural disturbance patterns. Failure to do so might result in the survival of only the more common and adaptable species in the near future, while rarer species could face extinction risks. This study lays the basis for formulating sustainable management plans and strategies for pollinator conservation in this landscape.

Additionally, it also suggests that conducting similar studies across different seasons and involving various crops could offer a more comprehensive understanding of the situation, facilitating improved management strategies. Observations made during fieldwork also

indicated that in orchards where commercial bee hives (mainly *Apis mellifera*) were present, there was a noticeable decrease in the visitation rate of wild and native pollinators. This trend has been reported earlier on other landscapes by González-Varo et al., 2009 and Page & Williams, 2022. However, a detailed investigation is needed to comprehend the impact of commercial bee hives on the visitation rate of wild and native pollinators in orchards of Kullu valley. This understanding could aid in devising more sustainable agricultural practices. Also, understanding the complex interplay between land use practices and pollination services in Kullu is crucial for sustainable development and biodiversity conservation. It calls for integrated land management approaches that prioritize biodiversity conservation, promote sustainable agriculture, and engage local communities in conservation efforts. By safeguarding pollinators and their habitats, the continued availability of pollination services crucial for ecosystem functioning and food security in the region can be ensured (Schröder et al., 2018; Bisht et al., 2020).

The analysis of land use and land cover changes in the Kullu and Tirthan valleys over the past two decades reveals dynamic shifts driven by factors such as rapid urbanization, infrastructure development, and agricultural expansion. The findings highlight the complex interplay between urban expansion, agricultural activities, and ecological processes shaping the landscape. Sustainable land management practices and conservation efforts are essential to mitigate the adverse effects of altered landscape composition on the environment and preserve the unique ecological heritage of a region (Chi, 2003; Motavalli et al., 2013). The detailed insights provided by the study can inform decision-making processes aimed at promoting sustainable development while safeguarding the unique ecological heritage of these regions. By incorporating these insights into land use planning and conservation strategies, stakeholders can work towards mitigating adverse impacts on the environment and fostering long-term sustainability and conservation of biodiversity in the study area.

The phenomena of global heating can lead to the homogenization of pollinator assemblages, reducing their resilience to future unpredictability. To counteract this trend, conservation efforts must focus on enhancing landscape connectivity and diversity (Vasiliev, & Greenwood, 2021). In this study, the future habitat suitability of hymenopteran, dipteran, and lepidopteran species under different future climate scenarios has been evaluated through the application of MaxEnt species distribution models. The reliability of the models in capturing species-environment relationships and predicting future distributions is underscored by the high AUC values (Quinn et al., 2013). The findings reveal heterogeneous responses among insect orders to changing

climatic conditions. While some species are projected to experience habitat expansion or range shifts, others face habitat loss and increased vulnerability. These responses are influenced by species-specific ecological requirements, with habitat generalists showing greater adaptability compared to habitat specialists. Notably, specialized species such as Himalayan bumble bees are particularly susceptible to habitat loss, emphasizing the need for targeted conservation efforts to protect vulnerable species and their habitats. The observed fluctuations in species' future distributions underscore the importance of considering varying degrees of climate warming and species' adaptive capacities in predictive modeling. Additionally, the study highlights the potential role of nectar host plant species in refining distribution forecasts, suggesting avenues for further research to improve predictive accuracy.

In brief, my doctoral thesis contributes valuable insights into the inventory of insect pollinators linked to significant horticultural crops across various landscape configurations in a mountainous area. Furthermore, it examines how these landscape configurations and changing climate can influence the diversity and distribution of these pollinators in the Himalayan region. Overall, the findings contribute to a better perception of the complex interactions between different land use practices, climate alterations, and pollinator diversity in this landscape. Continued monitoring and research efforts are essential to track species responses over time and development of effective conservation plans to alleviate the influences of climate change on pollinator populations and ecosystem dynamics in this ecologically diverse and vulnerable region.

7.2. Policy implications of this study

The study is in alignment with various global policies that underscore the significance of pollinators and their contributions. For instance, it supports Target 2 of the Convention on Biological Diversity (CBD), aiming to sustainably manage and enhance biodiversity benefits by 2020, with a specific focus on pollination services. Furthermore, it contributes to Sustainable Development Goal 15, emphasizing the conservation of terrestrial life. It also contributes to SDG 2, where sustaining pollination services can maintain global food security aiding in achieving zero hunger, and SDG 8, which focuses on economic growth and decent work by practices like native beekeeping and improved pollination services which can provide economic benefits through products such as wax and honey, benefiting communities economically.

To synthesize, in the Himalayas, pollinators play a critical role in sustaining mountain agriculture and horticulture, which are often practiced at subsistence levels. In India, as in many other countries, research on pollination primarily focuses on understanding pollination biology. However, agriculture and horticulture face various threats, due to the loss of pollinators and associated services as a result of excessive use of chemical pesticides, encroachment, unregulated tourism, habitat loss, land fragmentation, climate change, and altered LULC, particularly in the Himalayan region.

Based on my doctoral research, below, I outline key management strategies and recommendations for future interventions on a landscape level.

7.3. Recommendations for future intervention

- **Public awareness and community engagement**

By implementing pollinator-friendly practices, increasing awareness through educational programs, utilizing citizen science tools, and establishing a pollinator conservation resource center to provide easy access to information on native pollinators, habitat conservation guidelines, the economic significance of these pollinators, and other relevant resources can develop a sense of ownership and stewardship towards native pollinators and their services among local communities. Additionally, governmental action is essential to implement policies aimed at expanding extension facilities to educate small-scale farmers about the environmental ramifications of agrochemical usage, thereby promoting their scientific and rational application to minimize adverse environmental effects. Such initiatives would encourage the balanced use of agrochemicals, including the integration of bio-fertilizers, to enhance soil health and sustainability and organic farming.

- **Habitat improvement**

Management practices and forest cover greatly impact pollinator communities in this region. Thus, prioritizing resilient management strategies is vital, focusing on the preservation and effective management of natural habitats. Emphasizing the conservation of these habitats will help maintain and support diverse pollinator populations. By prioritizing robust management conventions, the sustainability of pollinator communities and their crucial ecosystem services can be ensured. Increased floral diversity correlates with higher diversity and relative abundance of most pollinators (Mattu & Bhagat, 2015). Hence, at a local level, planting

additional wild floral resources around orchards could help provide foraging resources for pollinators.

- **Consideration of zone of influence**

Since 1981, the Government of India has been implementing the "All India Coordinated Research Project on Honeybees and Pollinators" under the Indian Council of Agricultural Research (ICAR). This initiative aims to conserve pollinators with a focus on improving farmers' livelihoods and enhancing ecosystem services. The scheme has primarily focused on conserving pollinators within agricultural ecosystems, with less attention given to forest pollinators, especially non-bee species. It is imperative to expand such initiatives to the forested landscape for the conservation of wild pollinators to ensure their preservation.

- **PA network and conservation status**

Protected areas (PAs) are typically considered crucial for wildlife conservation, although they are primarily devised for plants and vertebrates, PAs also offer uninterrupted habitation for insect communities (Chawdhury et al., 2023) including pollinators. However, most of these insects do not benefit from this conservation because largely of their habitats often lie beyond the jurisdiction of PAs (Chawdhury et al., 2023). Since, biodiversity conservation within PAs hinges on various factors including their geographical location, management strategies, and governance structures (Carrol & Noss, 2022), it is imperative for governments to formulate comprehensive pollinator conservation policies aligned with international agreements and goals. Nevertheless, it's important to be cautious, as inadequate management within PAs can also result in the decline of insect pollinators (Rada et al., 2018). Also, evaluating the population status of key pollinators through intensive assessments across India and acknowledging their status under the IUCN's Red List or Red Data Book. This will facilitate conservation efforts beyond PAs.

- **Landscape management approach with a focus on migratory routes and stepping stones**

Recognizing that protected areas alone are insufficient for pollinator conservation, it is critical to assess the status of these pollinator species comprehensively.

Given that many of these pollinators range across the Palearctic region and exhibit migratory behavior, there is a need to investigate the migration patterns and stay-over sites of these pollinators. Detailed data on migration could assist in identifying and safeguarding pollinator corridors, ensuring their conservation during adverse weather conditions.

More diverse research efforts are necessary to unveil the habitat suitability index of pollinator species using remote sensing and geoinformatics technologies to inform the development of landscape-level management strategies. Considering that suitable habitats and conservation priorities for insects transcend international boundaries, countries sharing borders and natural habitats across the Himalayas must adopt collaborative policies aimed at restoring and protecting transboundary habitats for these pollinators, along with other wild species. Overall, fostering a shared interest in biodiversity conservation can serve as a valuable component of diplomatic strategies among Himalayan countries (Pandit, 2020).

REFERENCE

- Abrol, D.P., 2009. Bees and beekeeping in India, 2nd Kalyani publishers, Ludhiana, 720pp.
- Adamo, S.B. and Crews-Meyer, K.A., 2006. Aridity and desertification: exploring environmental hazards in Jáchal, Argentina. *Applied Geography*, 26(1), pp.61-85.
- Aguiar, A.P., Deans, A.R., Engel, M.S., Forshage, M., Huber, J.T., Jennings, J.T., Johnson, N.F., Lelej, A.S., Longino, J.T., Lohrmann, V. and Miko, I., 2013. Order Hymenoptera. In: Zhang, Z.-Q. (Ed.) Animal biodiversity: an outline of higher-level classification and survey of taxonomic richness (Addenda 2013). *Zootaxa*, 3703(1), pp.51-62.
- Aguilar, R., Ashworth, L., Galetto, L. and Aizen, M.A., 2006. Plant reproductive susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. *Ecology letters*, 9(8), pp.968-980.
- Ahmad, F, Joshi, S.R. and Gurung, M.B. 2003. The Himalayan cliff bee *Apis laboriosa* and the honey hunters of the Himalayas. Kathmandu, Nepal: ICIMOD.
- Ahmad, R., Hussain, B. and Ahmad, T., 2021. Fresh and dry fruit production in Himalayan Kashmir, sub-Himalayan Jammu and trans-himalayan Ladakh, India. *Heliyon*, 7(1).
- Airamé, S., Dugan, J.E., Lafferty, K.D., Leslie, H., McArdle, D.A. and Warner, R.R., 2003. Applying ecological criteria to marine reserve design: a case study from the California Channel Islands. *Ecological applications*, 13(sp1), pp.170-184.
- Aizen, M.A. and Feinsinger, P., 1994. Forest fragmentation, pollination, and plant reproduction in a Chaco dry forest, Argentina. *Ecology*, 75(2), pp.330-351.
- Alfred, J.R.B., Das, A.K., and Sanyal, A.K., 1998. Faunal diversity in India. Zoological Survey of India, Kolkata, pp. 495.
- Ali, H., Din, J.U., Bosso, L., Hameed, S., Kabir, M., Younas, M. and Nawaz, M.A., 2021. Expanding or shrinking? range shifts in wild ungulates under climate change in Pamir-Karakoram mountains, Pakistan. *PLoS One*, 16(12), p.e0260031.
- Alkemade, R., Bakkenes, M. and van Oorschot, M., 2009, February. Modeling impacts of global change on terrestrial biodiversity, The GLOBIO3 framework. In *IOP Conference Series. Earth and Environmental Science* (Vol. 6, No. 44). IOP Publishing.
- Allen-Wardell, G., Bernhardt, P., Bitner, R., Burquez, A., Buchmann, S., Cane, J., Cox, P.A., Dalton, V., Feinsinger, P., Ingram, M. and Inouye, D., 1998. The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conservation biology*, pp.8-17.
- Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. In *Invertebrate biodiversity as bioindicators of sustainable landscapes* (pp. 19-31). Elsevier.
- Ancillotto, L., Mori, E., Bosso, L., Agnelli, P. and Russo, D., 2019. The Balkan long-eared bat (*Plecotus kolombatovici*) occurs in Italy-first confirmed record and potential distribution. *Mammalian Biology*, 96, pp.61-67.

- Anderson, J.R., 1977. Land use and land cover changes—A framework for monitoring. *J. Res. US Geology Survey*, 5, pp.142-152.
- Anonymous. 2013. National land utilization policy: framework for land use planning and management, pp. 23. *Department of Land Resources. Ministry of Rural Development; Government of India.*
- Araújo, M.B. and Williams, P.H., 2000. Selecting areas for species persistence using occurrence data. *Biological Conservation*, 96(3), pp.331-345.
- Araujo, M.B., Pearson, R.G., Thuiller, W. and Erhard, M., 2005. Validation of species–climate impact models under climate change. *Global change biology*, 11(9), pp.1504-1513.
- Arora, G.S., 1990. Collection and preservation of animals (Lepidoptera). *Zool. Surv. Ind., Calcutta*, pp.131-138.
- Arya, M.K. and Badoni, A., 2023. Insect Pollinator Assemblage on Temperate Fruits Crops in Kumaun Himalaya. *Indian Journal of Entomology*, pp.315-321.
- Ashman, T.L., Knight, T.M., Steets, J.A., Amarasekare, P., Burd, M., Campbell, D.R., Dudash, M.R., Johnston, M.O., Mazer, S.J., Mitchell, R.J. and Morgan, M.T., 2004. Pollen limitation of plant reproduction: ecological and evolutionary causes and consequences. *Ecology*, 85(9), pp.2408-2421.
- Ashworth, L., Aguilar, R., Galetto, L. and Aizen, M.A., 2004. Why do pollination generalist and specialist plant species show similar reproductive susceptibility to habitat fragmentation? *Journal of Ecology*, pp.717-719.
- Awasthi R P (2001). Apple In: Handbook of Horticulture, Chadha, K L ed ICAR New Delhi Publication, pp 119-125.
- Baici, J. & Bowman, J., 2023. Combining community science and MaxEnt modeling to estimate Wild Turkey (*Meleagris gallopavo*) winter abundance and distribution. *Avian Conserv. Ecol.*
- Baldwin, R., 2010. Identifying Keystone Threats to Biological Diversity., pp. 17-32. https://doi.org/10.1007/978-90-481-9575-6_2.
- Basu, P., Bhattacharya, R. and Ianetta, P., 2011. A decline in pollinator dependent vegetable crop productivity in India indicates pollination limitation and consequent agro-economic crises. *Nature Precedings*, pp.1-1.
- Batra, S.W., 1998. Hornfaced bees for apple pollination. In Virginia State Horticultural Society Annual Meeting (p. 361).
- Battisti, C., Amori, G. and Luiselli, L., 2020. Toward a new generation of effective problem solvers and project-oriented applied ecologists. *Web Ecology*, 20(1), pp.11-17.
- Beaumont, L.J., Hughes, L. and Poulsen, M., 2005. Predicting species distributions: use of climatic parameters in BIOCLIM and its impact on predictions of species' current and future distributions. *Ecological modelling*, 186(2), pp.251-270.

- Beck, J., Boller, M., Erhardt, A., Schwanghart, W., 2014. Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. *Ecol. Inform.* 19, pp.10–15. <https://doi.org/10.1016/J.ECOINF.2013.11.002>
- Bhardwaj, M., Uniyal, V.P., Sanyal, A.K. and Singh, A.P., 2012. Butterfly communities along an elevational gradient in the Tons valley, Western Himalayas: Implications of rapid assessment for insect conservation. *Journal of Asia-Pacific Entomology*, 15(2), pp.207-217.
- Bhardwaj, S.K. and Sharma, S.D., 2012. Horticulture crop production in North-Western Himalayas under changing climate scenario.
- Bhattacharya, K.K., Halder, S. and Banerjee, D., 2013. New records of fruit flies (Diptera: Tephritidae) from Renuka wetland and wildlife sanctuary, Himachal Pradesh. *Records of the Zoological Survey of India*, pp.145-149.
- Bhusal, D., 2020. Insect Pollinators, Threats For Survival and Ecosystem Service: An Outlook From Hindu-Kush Himalaya Region., pp. 565-576. https://doi.org/10.1007/978-3-030-36275-1_27.
- Bhuyan, Avantika. 2019. Unseen 2019: Silence of the bees. Mint (Livemint.com) Dec.28, 2019. Retrieved from <https://www.livemint.com/mintlounge/features/unseen-2019-silenceof-the-bees-11577463902137.html>.
- Biesmeijer, J.C., Roberts, S.P., Reemer, M., Ohlemuller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R.J.M.C., Thomas, C.D. and Settele, J., 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, 313(5785), pp.351-354.
- Bisht, I., Rana, J., Yadav, R., & Ahlawat, S., 2020. Mainstreaming Agricultural Biodiversity in Traditional Production Landscapes for Sustainable Development: The Indian Scenario. Sustainability. <https://doi.org/10.3390/su122410690>.
- Borah, J., D. Wangchuk, A. Swargowari, T. Wangchuk, T. Sharma, D. Das, N. Rabha, A. Basumatari, N. Kakati, F. Ahmed et al. 2013. Tigers in the Transboundary Manas Conservation Complex: conservation implications across borders. *Parks* 19:51–62.
- Bosso, L., Smeraldo, S., Russo, D., Chiusano, M.L., Bertorelle, G., Johannesson, K., Butlin, R.K., Danovaro, R. and Raffini, F., 2022. The rise and fall of an alien: Why the successful colonizer *Littorina saxatilis* failed to invade the Mediterranean Sea. *Biological Invasions*, 24(10), pp.3169-3187.
- Brake, I., 2017. Diptera. In *The Diptera Site*. Retrieved from <http://cite.scratchpads.eu/diptera.myspecies.info/2017-09-10/Diptera.pdf>.
- Brown, J.L., 2014. SDM toolbox: a python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. *Methods in Ecology and Evolution*, 5(7), pp.694-700.
- Bulleri, F., Eriksson, B., Queirós, A., Airoidi, L., Arenas, F., Arvanitidis, C., Bouma, T., Crowe, T., Davoult, D., Guizien, K., Iveša, L., Jenkins, S., Michalet, R., Olabarria, C., Procaccini, G., Serrão, E., Wahl, M., & Benedetti-Cecchi, L., 2018. Harnessing positive species

- interactions as a tool against climate-driven loss of coastal biodiversity. *PLoS Biology*, 16. <https://doi.org/10.1371/journal.pbio.2006852>.
- Burd, M., 1994. Bateman's principle and plant reproduction: the role of pollen limitation in fruit and seed set. *The Botanical Review*, 60, pp.83-139.
- Busby, J.R., 1991. BIOCLIM—a bioclimate analysis and prediction system. In: *Margules CR, Austin MP (eds) Nature conservation: cost effective biological surveys and data analysis. CSIRO, Canberra*, pp. 64–68.
- Calderone, N.W., 2012. Insect pollinated crops, insect pollinators and US agriculture: trend analysis of aggregate data for the period 1992–2009. *PloS one*, 7(5), p.e37235.
- Cameron, S.A., Lozier, J.D., Strange, J.P., Koch, J.B., Cordes, N., Solter, L.F. and Griswold, T.L., 2011. Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences*, 108(2), pp.662-667.
- Capinera, J.L. ed., 2008. *Encyclopedia of entomology*. Springer Science & Business Media.
- Carpenter, G., Gillison, A.N. and Winter, J., 1993. DOMAIN: a flexible modelling procedure for mapping potential distributions of plants and animals. *Biodiversity & Conservation*, 2, pp.667-680.
- Carroll, C. and Noss, R.F., 2022. How percentage-protected targets can support positive biodiversity outcomes. *Conservation Biology*, 36(4), p.e13869.
- Carvalho, L., Seymour, C., Veldtman, R., & Nicolson, S., 2010. Pollination services decline with distance from natural habitat even in biodiversity-rich areas. *Journal of Applied Ecology*, 47, pp. 810-820. <https://doi.org/10.1111/J.1365-2664.2010.01829.X>.
- CCSP., 2003. Strategic Plan for the U.S. Climate Change Science Program. *Final report*.
- Chakraborty, A., Shukla, R., Sachdeva, K., Roy, P., & Joshi, P., 2016. The Climate Change Conundrum and the Himalayan Forests: The Way Forward into the Future. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, 88, pp. 837 - 847. <https://doi.org/10.1007/s40011-016-0788-x>.
- Chakrabarti, P., 1954. The insect fauna of the Nilgiris. *Annals of the Entomological Society of India*, 1(1), pp. 1-10. *Report of the Director, Zool. Surv. India, Kolkata*.
- Chand, H., Verma, S.C., Bhardwaj, S.K., Sharma, S.D., Mahajan, P.K. and Sharma, R., 2016. Effect of changing climatic conditions on chill units accumulation and productivity of apple in mid hill sub humid zone of western himalayas, India. *Current World Environment*, 11(1), pp.142-149.
- Chandra, K., 2011. Insect fauna of states and union territories in India. *ENVIS Bulletin: Wildlife & Protected Areas*, 14(1), pp.189-218.
- Chandra, K., 2011a. Insect diversity of Sikkim, India, 181-206: In *Biodiversity of Sikkim- Exploring and conserving Hotspot*, Arawatia, M.L. and Tambe, S. (eds.) Information and Public relations Department, Government of Sikkim.

- Chandra, K., Gupta, D., Gopi, K.C., Tripathy, B. and Kumar, V., 2018. Faunal Diversity of Indian Himalaya: 1-872. Published by the Director, Zool. Surv. India, Kolkata.
- Chao, A., 1984. Nonparametric estimation of the number of classes in a population. *Scandinavian Journal of statistics*, pp.265-270.
- Chapman, A.D., 2009. Numbers of living species in Australia and the world.
- Chauhan, M., Uniyal, V.P., Chandra, A., Thakur, P, and Mehrwar, V., 2021. Preliminary assessment and conservation of insect pollinators through community participation in the Lahaul and Spiti district of Himachal Pradesh, India. *Current Science* 120(5), pp.883.
- Chen, X., Vierling, L. and Deering, D. 2005. A simple and effective radiometric correction method to improve landscape change detection across sensors and across time. *Remote Sensing of Environment*, 98(1), pp.63-79.
- Chhabra, A., Geist, H., Houghton, R.A., Haberl, H., Braimoh, A.K., Vlek, P.L., Patz, J., Xu, J., Ramankutty, N., Coomes, O. and Lambin, E.F., 2006. Multiple impacts of land-use/cover change. *In Land-use and land-cover change: local processes and global impacts* (pp. 71-116). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Chi, Z., 2003. ECOLOGICAL PRINCIPLES IN FOREST MANAGEMENT. Tropical Geography. Chowdhury, S., Zalucki, M.P., Hanson, J.O., Tiatragul, S., Green, D., Watson, J.E. and Fuller, R.A., 2023. Three-quarters of insect species are insufficiently represented by protected areas. *One Earth*, 6(2), pp.139-146.
- Chowdhury, S., Jennions, M.D., Zalucki, M.P., Maron, M., Watson, J.E. and Fuller, R.A., 2023. Protected areas and the future of insect conservation. *Trends in Ecology & Evolution*, 38(1), pp.85-95.
- Cohen, J.M., Fink, D., Zuckerberg, B., 2021. Extreme winter weather disrupts bird occurrence and abundance patterns at geographic scales. *Ecography* 44 (8), pp.1143–1155.
- Cohen, W.B. and Goward, S.N., 2004. Landsat's role in ecological applications of remote sensing. *Bioscience*, 54(6), pp.535-545.
- Colwell, R.K. and Coddington, J.A., 1994. Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 345(1311), pp.101-118.
- Colwell, R.K., Mao, C.X. and Chang, J., 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. *Ecology*, 85(10), pp.2717-2727.
- Colwell, R.K., Rahbek, C. and Gotelli, N.J., 2004. The mid-domain effect and species richness patterns: what have we learned so far?. *The American Naturalist*, 163(3), pp.E1-E23.
- Connor, S. 2008. Insects will be climate change's first victims. *The independent*. Retrieved from, <https://www.independent.co.uk/news/science/insects>.
- Corbet, S.A., 1991. Applied pollination ecology.
- Corlett, R.T., 2004. Flower visitors and pollination in the Oriental (Indomalayan) Region. *Biological Reviews*, 79(3), pp.497-532.

- Correia, M.E.F. and Pinheiro, L.B.A., 1999. Monitoramento da fauna de solo sob diferentes coberturas vegetais em um sistema integrado de produção agroecológica, Seropédica (RJ).
- Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J. and Raskin, R.G., 1997. The value of the world's ecosystem services and natural capital. *nature*, 387(6630), pp.253-260.
- Crampton, G.C., 1942. Guide to the insects of Connecticut, Part VI. The Diptera or true flies of Connecticut. First Fascicle. The external morphology of the Diptera. *Bulletin of the Connecticut State Geological and Natural History Survey*, 64, pp.10-165.
- Crane, E. and Walker, P., 1984. Pollination directory for world crops. International Bee Research Association.
- Cunningham, F., Allen, J.E., Allen, J., Alvarez-Jarreta, J., Amode, M.R., Armean, I.M., Austine-Orimoloye, O., Azov, A.G., Barnes, I., Bennett, R. and Berry, A., 2022. Ensembl 2022. *Nucleic acids research*, 50(D1), pp.D988-D995.
- Daily, G.C., 2000. Management objectives for the protection of ecosystem services. *Environmental Science & Policy*, 3(6), pp.333-339.
- Das, M., Das, A. and Pandey, R., 2023. A socio-ecological and geospatial approach for evaluation of ecosystem services to communities of the Eastern Himalayan Region, India. *Environmental Science and Pollution Research*, 30(55), pp.116860-116875.
- Das, T., 2009. *Land use/Land cover change detection: An objectoriented approach, Münster, Germany* (Doctoral dissertation).
- Delaplane, K.S. and Mayer, D.F., 2000. Crop pollination by bees (pp. xv+-344).
- Dicks, L., Vaughan, M. and Lee-Mäder, E., 2016. Developing incentives for farmers to support pollinators: Contrasting approaches from Europe and the United States. In *Pollination services to agriculture* (pp. 216-234). Routledge.
- Dicks, L.V., Breeze, T.D., Ngo, H.T., Senapathi, D., An, J., Aizen, M.A., Basu, P., Buchori, D., Galetto, L., Garibaldi, L.A. and Gemmill-Herren, B., 2021. A global-scale expert assessment of drivers and risks associated with pollinator decline. *Nature Ecology & Evolution*, 5(10), pp.1453-1461.
- Dikshit, K.R., Dikshit, J.K., Dikshit, K.R. and Dikshit, J.K., 2014. Natural vegetation: forests and grasslands of North-East India. *North-East India: land, people and economy*, pp.213-255.
- District Wise Disaster Vulnerability of the State. 2018. Available at: <https://hpsdma.nic.in/index1.aspx?lsid=72&lev=2&lid=14&langid=1> Himachal Pradesh State disaster management authority.
- Doeksen, J., 1941. *Bijdrage tot de vergelijkende morphologie der Thysanoptera* (Doctoral dissertation, Veenman).
- Dormann, C., Schweiger, O., Augenstein, I., Bailey, D., Billeter, R., Blust, G., Defilippi, R., Frenzel, M., Hendrickx, F., Herzog, F., Klotz, S., Liira, J., Maelfait, J., Schmidt, T., Speelmans, M., Wingerden, W., & Zobel, M., 2007. Effects of landscape structure and

- landuse intensity on similarity of plant and animal communities. *Global Ecology and Biogeography*, 16, pp. 774-787. <https://doi.org/10.1111/J.1466-8238.2007.00344.X>.
- Easterling, D.R., Meehl, G.A., Parmesan, C., Changnon, S.A., Karl, T.R. and Mearns, L.O., 2000. Climate extremes: observations, modeling, and impacts. *Science*, 289(5487), pp.2068-2074.
- Eggleton, P., 2020. The state of the world's insects. *Ann. Rev. Environ. Resour.* 45, 61–82. <https://doi.org/10.1146/annurev-envir-on-012420-050035>.
- Elith, J. and Leathwick, J.R., 2009. Species distribution models: ecological explanation and prediction across space and time. *Annual review of ecology, evolution, and systematics*, 40, pp.677-697.
- Elith, J., Graham, C.H., Anderson, R.P., Dudík, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.M., Peterson, A.T., Phillips, S.J., Richardson, K., Scachetti-Pereira, R., Schapire, R.E., Soberon, J., Williams, S., Wisz, M.S., Zimmermann, N.E., 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29(2), PP. 129-151.
- Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E. and Yates, C.J., 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and distributions*, 17(1), pp.43-57.
- Erasu D. 2017. Remote sensing-based urban land use/land cover change detection and monitoring. *J Remote Sens & GIS*; 6 (2):1- 5.doi: 10.4172/2469-4134.1000196.
- Fagundes, C.K., Di Mare, R.A., Wink, C. and Manfio, D., 2011. Diversity of the families of Coleoptera captured with pitfall traps in five different environments in Santa Maria, RS, Brazil. *Brazilian Journal of Biology*, 71, pp.381-390.
- Fayaz, A., Shafiq, M.U., Singh, H. and Ahmed, P., 2020. Assessment of spatiotemporal changes in land use/land cover of North Kashmir Himalayas from 1992 to 2018. *Modeling Earth Systems and Environment*, 6, pp.1189-1200.
- Fearnside, P.M., 1999. Biodiversity as an environmental service in Brazil's Amazonian forests: risks, value and conservation. *Environmental conservation*, 26(4), pp.305-321.
- Ficetola, G., & Maiorano, L., 2016. Contrasting effects of temperature and precipitation change on amphibian phenology, abundance and performance. *Oecologia*, 181, pp. 683 - 693. <https://doi.org/10.1007/s00442-016-3610-9>.
- Fick, S.E. and Hijmans, R.J., 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International journal of climatology*, 37(12), pp.4302-4315.
- Fitter, A.H. and Fitter, R.S.R., 2002. Rapid changes in flowering time in British plants. *Science*, 296(5573), pp.1689-1691.
- Foster, S.W. and Jones, P.R., 1915. *The life history and habits of the pear thrips in California (No. 173)*. US Department of Agriculture.

- Franklin, J., Wiser, S.K., Drake, D.R., Burrows, L.E. and Sykes, W.R., 2006. Environment, disturbance history and rain forest composition across the islands of Tonga, Western Polynesia. *Journal of Vegetation Science*, 17(2), pp.233-244.
- Free, J. B., 1993. Insect pollination of crops. 2nd ed. *Academic Press, London*, pp. 96–104.
- Freeman, B.G., Scholer, M.N., Ruiz-Gutierrez, V. and Fitzpatrick, J.W., 2018. Climate change causes upslope shifts and mountaintop extirpations in a tropical bird community. *Proceedings of the National Academy of Sciences*, 115(47), pp.11982-11987.
- FREEP GHNP research project report., 1999. *Wildlife Institute of India, Dehradun*.
- Fürst, M.A., McMahon, D.P., Osborne, J.L., Paxton, R.J. and Brown, M.J.F., 2014. Disease associations between honeybees and bumblebees as a threat to wild pollinators. *Nature*, 506(7488), pp.364-366.
- Gallai, N., Salles, J.M., Settele, J. and Vaissière, B.E., 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological economics*, 68(3), pp.810-821.
- Ganie, M.A., Amit, K.P. and Nazeer, A., 2014. Assessment of relative abundance and diversity of native insect pollinators in apple orchards of Kashmir Himalaya. *Asian J Agri Biol*, 2(1), pp.36-37.
- Gao, J. and Liu, Y., 2010. Determination of land degradation causes in Tongyu County, Northeast China via land cover change detection. *International Journal of Applied Earth Observation and Geoinformation*, 12(1), pp.9-16.
- Gardner, J., Sinclair, J., Berkes, F. and Singh, R.B., 2002. Accelerated tourism development and its impacts in Kullu-Manali, HP, India. *Tourism Recreation Research*, 27(3), pp.9-20.
- Gardner, J.S. and Saczuk, E., 2004. Systems for hazards identification in high mountain areas: an example from the Kullu District, Western Himalaya. *Journal of Mountain Science*, 1, pp.115-127.
- Garibaldi, L.A., Carvalheiro, L.G., Vaissière, B.E., Gemmill-Herren, B., Hipólito, J., Freitas, B.M., Ngo, H.T., Azzu, N., Sáez, A., Åström, J. and An, J., 2016. Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. *Science*, 351(6271), pp.388-391.
- Garibaldi, L.A., Steffan-Dewenter, I., Kremen, C., Morales, J.M., Bommarco, R., Cunningham, S.A., Carvalheiro, L.G., Chacoff, N.P., Dudenhöffer, J.H., Greenleaf, S.S. and Holzschuh, A., 2011. Stability of pollination services decreases with isolation from natural areas despite honeybee visits. *Ecology letters*, 14(10), pp.1062-1072.
- Garwin, L. and Masood, E., 1998. The worth of the Earth. *Nature*, pp.1-4.
- Gautam, D.R., Sharma, G. and Jindal, K.K., 2003, October. Fruit setting problems of apples under changing climatic scenario of North-Western Himalayas of India. In *VII International Symposium on Temperate Zone Fruits in the Tropics and Subtropics* 662, pp. 435-441.

- Gelviz-Gelvez, S.M., Pavón, N.P., Illoldi-Rangel, P. and Ballesteros-Barrera, C., 2015. Ecological niche modeling under climate change to select shrubs for ecological restoration in Central Mexico. *Ecological Engineering*, 74, pp.302-309.
- Ghazoul, J., 2005. Buzziness as usual? Questioning the global pollination crisis. *Trends in ecology & evolution*, 20(7), pp.367-373.
- Ghisbain, G. et al., 2023. Projected decline in European bumblebee populations in the twenty first century. *Nature* [https:// doi. org/ 10.1038/ s41586- 023- 06471-0](https://doi.org/10.1038/s41586-023-06471-0).
- Gibbs, J., Elle, E., Bobiwash, K., Haapalainen, T. and Isaacs, R., 2016. Contrasting pollinators and pollination in native and non-native regions of highbush blueberry production. *PloS one*, 11(7), p.e0158937.
- Gibson, R.H., Knott, B., Eberlein, T. and Memmott, J., 2011. Sampling method influences the structure of plant–pollinator networks. *Oikos*, 120(6), pp.822-831.
- González-Varo, J., Arroyo, J., & Aparicio, A., 2009. Effects of fragmentation on pollinator assemblage, pollen limitation and seed production of Mediterranean myrtle (*Myrtus communis*). *Biological Conservation*, 142, pp. 1058-1065. <https://doi.org/10.1016/J.BIOCON.2009.01.017>.
- Goulson, D., Lye, G.C. and Darvill, B., 2008. Decline and conservation of bumble bees. *Annu. Rev. Entomol.*, 53, pp.191-208.
- Graae, B.J., Vandvik, V., Armbruster, W.S., Eiserhardt, W.L., Svenning, J.C., Hylander, K., Ehrlén, J., Speed, J.D., Klanderud, K., Bråthen, K.A. and Milbau, A., 2018. Stay or go—how topographic complexity influences alpine plant population and community responses to climate change. *Perspectives in Plant Ecology, Evolution and Systematics*, 30, pp.41-50.
- Graham, C.H, S.R. Ron, J.C. Santos, C.J. Schneider, and C. Moritz., 2004. Integrating phylogenetics and environmental niche models to explore speciation mechanisms in dendrobatid frogs. *Evolution* 58, pp.1781–1793.
- Graham, C.H. and Hijmans, R.J., 2006. A comparison of methods for mapping species ranges and species richness. *Global Ecology and biogeography*, 15(6), pp.578-587.
- Gregrio, A. and Jansen, J., 2000. Land cover classification system (LCCS); Classification concepts and user manual for software version 2.
- Grootaert, P., Pollet, M., Dekoninck, W. and van Achterberg, C., 2010. Sampling insects: general techniques, strategies and remarks. *Eymann, J., Degreef, J., Häuser, J. Monje, C., Samyn, Y. and Vanden Spiegel, D.(eds.) Manual on Field Recording Techniques and Protocols for All Taxa Biodiversity Inventories and Monitoring. Abc Taxa, Belgium*, pp.337-399.
- Gryse, J.D. and Treherne, E.C., 1924. The male genital armature of the Thysanoptera. *The Canadian Entomologist*, 56(8), pp.177-182.
- Guisan, A. and Zimmermann, N.E., 2000. Predictive habitat distribution models in ecology. *Ecological modelling*, 135(2-3), pp.147-186.

- Gupta, R., & Sharma, L., 2020. Efficacy of Spatial Land Change Modeler as a forecasting indicator for anthropogenic change dynamics over five decades: A case study of Shoolpaneshwar Wildlife Sanctuary, Gujarat, India. *Ecological Indicators*, 112, pp. 106171. <https://doi.org/10.1016/j.ecolind.2020.106171>.
- Guyon, I., Saffari, A., Dror, G. and Cawley, G., 2010. Model selection: beyond the bayesian/frequentist divide. *Journal of Machine Learning Research*, 11(1).
- Haines-Young, R., 2009. Land use and biodiversity relationships. *Land Use Policy*, 26. <https://doi.org/10.1016/J.LANDUSEPOL.2009.08.009>.
- Han, P., Long, D., Zhao, F. and Slater, L.J., 2023. Response of two glaciers in different climate settings of the Tibetan plateau to climate change through year 2100 using a hybrid modeling approach. *Water Resources Research*, 59(4), p. e2022WR033618.
- Hassan, A.A.G., 1944. The structure and mechanism of the spiracular regulatory apparatus in adult Diptera and certain other groups of insects. *Transactions of the Royal Entomological Society of London*, 94(1), pp.103-153.
- Hayden, S.H., Burrard, S.S. and Heron, A.M., 1933. *A sketch of the geography and geology of the Himalaya Mountains and Tibet*. Manager of Publications.
- Heinrich, B. and Raven, P.H., 1972. Energetics and pollination ecology: the energetics of pollinators may have wide implications in floral biology and community ecology. *Science*, 176(4035), pp.597-602.
- Heppner, J.B., 1998. Classification of Lepidoptera. Part 1. Introduction. Higgins, J.V., Bryer, M.T., Khoury, M.L. and Fitzhugh, T.W., 2005. A freshwater classification approach for biodiversity conservation planning. *Conservation Biology*, 19(2), pp.432-445.
- Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A., 2005. Very high-resolution interpolated climate surfaces for global land areas. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 25(15), pp.1965-1978.
- Holmgren P. 2006. Global land use area change matrix: input to the fourth council environmental outlook (Geo-4). Forest resource assessment, working paper-34, FAO, Rome.
- Hosmer, D.W., and S. Lemeshow., 2000. *Applied Logistic Regression*. 2nd Edition. John Wiley and Sons, New York, New York, USA.
- Hsieh, T.C., Ma, K. and Chao, A., 2016. iNEXT: an R package for rarefaction and extrapolation of species diversity (Hill numbers). *Methods in ecology and evolution*, 7(12), pp.1451-1456.
- <https://eudyan.hp.gov.in/cms/departamental-statistical-data-at-glance/kullu/>
- https://hpenvis.nic.in/Database/Horticulture_4022.aspx
- Hu, R., Gu, Y., Luo, M., Lu, Z., Wei, M. and Zhong, J., 2020. Shifts in bird ranges and conservation priorities in China under climate change. *PLoS One*, 15(10), p.e0240225.

- Hussain, A., Rahim, K., Ghffar, A., AliA., H., & Jamil, A., 2012. The hymenopterous pollinators of Himalayan foothills of Pakistan (distributional diversity). *African Journal of Biotechnology*, 11, pp. 7263-7269.
- IGARSS 2001. Scanning the Present and Resolving the Future. Proceedings. IEEE 2001. International Geoscience and Remote Sensing Symposium (Cat. No.01CH37217), 5, pp. 2230-2232 vol.5. <https://doi.org/10.1109/IGARSS.2001.977958>.
- Imbernon, J., 1999. Changes in agricultural practice and landscape over a 60-year period in North Lampung, Sumatra. *Agriculture, Ecosystems & Environment*, 76(1), pp.61-66.
- Inayatullah, M., 2012. To the knowledge of Vespidae (Hymenoptera) of Pakistan. *Zootaxa*, 3318, pp.26-50.
- Ingram, K., Knapp, E. and Robinson, J.W., 1981. Change detection technique development for improved urbanized area delineation. *NASA, Comput. Sci. Corp., Springfield, MD, CSC/TM-81/6087*.
- Ingram, M., Nabhan, G.C. and Buchmann, S.L., 1996. Impending pollination crisis threatens biodiversity and agriculture. *Tropinet*, 7.
- IPBES. 2016. The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. S.G. Potts, V. L. Imperatriz-Fonseca, and H. T. Ngo, (eds). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 552 pages.
- IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In (eds. Díaz, S. et al.). (IPBES secretariat, Bonn, Germany, 2019).
- IPCC., 2001. Climate change 2001: impacts, vulnerability and adaptation. Contribution of working group II to the third assessment report of the intergovernmental panel on climate change. IPCC working group 2. Cambridge University Press, Port Chester, New York.
- IPCC., 2014. Climate change 2014: impacts, vulnerability and adaptation. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. IPCC working group 2. Cambridge University Press, Port Chester, New York.
- IPCC., 2021: Summary for policymakers. in: Climate change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change.
- Isbell, F., Adler, P., Eisenhauer, N., Fornara, D., Kimmel, K., Kremen, C., Letourneau, D., Liebman, M., Polley, H., Quijas, S., & Scherer-Lorenzen, M., 2017. Benefits of increasing plant diversity in sustainable agroecosystems. *Journal of Ecology*, 105. <https://doi.org/10.1111/1365-2745.12789>.
- Jamwal, R. and Mattu, V.K., 2020. Pollen analysis of summer honeys from Kullu hills, Himachal Pradesh, India. *Journal of Entomological Research*, 44(4), pp.581-588.

- Jenkins, R.L., Warren, R.F. and Price, J.T., 2021. Addressing risks to biodiversity arising from a changing climate: the need for ecosystem restoration in the Tana River Basin, Kenya. *PLoS One*, 16(7), p.e0254879.
- Jensen, J.R., 1996. Introductory digital image processing: a remote sensing perspective. John Wiley, New York.
- Jones, M.C., Dye, S.R., Fernandes, J.A., Frölicher, T.L., Pinnegar, J.K., Warren, R. and Cheung, W.W., 2013. Predicting the impact of climate change on threatened species in UK waters. *PloS one*, 8(1), p.e54216.
- Jones, T., 1954. The external morphology of *Chirothrips hamatus* (Trybom)(Thysanoptera). *Transactions of the Royal Entomological Society of London*, 105(10), pp.163-187.
- Jose, V.S., Nameer, P.O., 2020. The expanding distribution of the Indian peafowl (*Pavo cristatus*) as an indicator of changing climate in Kerala, southern India: a modelling study using MaxEnt. *Ecol. Indic.* 110 <https://doi.org/10.1016/j.ecolind.2019.105930>.
- Joseph, A.N.T., 1990. Collection and preservation of animals (Diptera), Zoological Survey of India, Calcutta, pp.141-144.
- Joshi, N.C. and Joshi, P.C., 2010. Foraging behaviour of *Apis* spp. on apple flowers in a subtropical environment. *New York Science Journal*, 3(3), pp.71-76.
- Joshi, N.K., Otieno, M., Rajotte, E.G., Fleischer, S.J. and Biddinger, D.J., 2016. Proximity to woodland and landscape structure drives pollinator visitation in apple orchard ecosystem. *Frontiers in ecology and evolution*, 4, p.38.
- Kafle, S., K.C., S., Poudyal, B., & Devkota, S., 2023. Machine learning approach to detect Land Use Land Cover (LULC) change in Chure region of Sarlahi district, Nepal. *Archives of Agriculture and Environmental Science*. <https://doi.org/10.26832/24566632.2023.0802012>.
- Kapkoti, B., Joshi, R.K. and Rawal, R.S., 2016. Variations in the abundance and diversity of insects in apple orchards of Kumaun, Western Himalaya, India. *Current Science*, pp.438-443.
- Kearns, C.A., Inouye, D.W. and Waser, N.M., 1998. Endangered mutualisms: the conservation of plant-pollinator interactions. *Annual review of ecology and systematics*, 29(1), pp.83-112.
- Kehimkar, I.D., 2008. *Book of Indian butterflies*.
- Kennedy, C.M., Lonsdorf, E., Neel, M.C., Williams, N.M., Ricketts, T.H., Winfree, R., Bommarco, R., Brittain, C., Burley, A.L., Cariveau, D. and Carvalheiro, L.G., 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology letters*, 16(5), pp.584-599.
- Kevan, P.G. and Phillips, T.P., 2001. The economic impacts of pollinator declines: an approach to assessing the consequences. *Conservation ecology*, 5(1).
- Kevan, P.G., 2003. Pollination for the 21st century: integrating pollinator and plant interdependencies. In *For Nonnative Crops, Whence Pollinators of the Future?* (p. 181). Entomological Society of America.

- Khan, M.R. and Khan, M.R., 2004. The role of honeybees *Apis mellifera* L. (Hymenoptera: Apidae) in pollination of apple. *Pakistan Journal of Biological Sciences*, 7(3), pp.359-362.
- Kindt, R., 2019. Package 'BiodiversityR'. Package for community ecology and suitability analysis, 2, pp.11-12.
- Kleijn, D. and Raemakers, I., 2008. A retrospective analysis of pollen host plant use by stable and declining bumble bee species. *Ecology*, 89(7), pp.1811-1823.
- Klein, A.M., Müller, C., Hoehn, P. and Kremen, C., 2009. Understanding the role of species richness for crop pollination services. *Biodiversity, ecosystem function and human wellbeing*. New York, pp.195-208.
- Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C. and Tscharntke, T., 2007. Importance of pollinators in changing landscapes for world crops. *Proceedings of the royal society B: biological sciences*, 274(1608), pp.303-313.
- Kleinhenz, V., Milne, J., Walsh, K.B. and Midmore, D.J., 2003. A case study on the effects of irrigation and fertilization on soil water and soil nutrient status, and on growth and yield of bamboo (*Phyllostachys pubescens*) shoots. *J Bamboo Rattan*, 2(3), pp.281-293.
- Kremen, C., Williams, N.M. and Thorp, R.W., 2002. Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences*, 99(26), pp.16812-16816.
- Kremen, C., Williams, N.M., Bugg, R.L., Fay, J.P. and Thorp, R.W., 2004. The area requirements of an ecosystem service: crop pollination by native bee communities in California. *Ecology letters*, 7(11), pp.1109-1119.
- Kumar, S., Joshi, P.C., Nath, P. and Singh, V.K., 2018. Impacts of insecticides on pollinators of different food plants. *Entomol. Ornithol. Herpetol*, 7(1000211), pp.2161-0983.
- Lambin, E.F., Geist, H.J. and Lepers, E., 2003. Dynamics of land-use and land-cover change in tropical regions. *Annual review of environment and resources*, 28(1), pp.205-241.
- Larson, B.M. and Barrett, S.C., 2000. A comparative analysis of pollen limitation in flowering plants. *Biological journal of the Linnean Society*, 69(4), pp.503-520.
- Lenoir, J. and Svenning, J.C., 2015. Climate-related range shifts—a global multidimensional synthesis and new research directions. *Ecography*, 38(1), pp.15-28.
- Li, G., Liu, C., Liu, Y., Yang, J., Zhang, X. and Guo, K., 2012. Effects of climate, disturbance and soil factors on the potential distribution of Liaotung oak (*Quercus wutaishanica* Mayr) in China. *Ecological research*, 27, pp.427-436.
- Lilles and, T.M. and Kiefer, R. 1993. Remote Sensing and Image Interpretation. Fifth Edition Lindenmayer, D., Franklin, J., & Fischer, J., 2006. General management principles and a checklist of strategies to guide forest biodiversity conservation. *Biological Conservation*, 131, pp. 433-445. <https://doi.org/10.1016/J.BIOCON.2006.02.019>.
- Liu, H., Fang, C., Miao, Y., Ma, H., Zhang, Q. and Zhou, Q., 2018. Spatio-temporal evolution of population and urbanization in the countries along the Belt and Road 1950–2050. *Journal of Geographical Sciences*, 28, pp.919-936.

- Liu, Y., Zhu, G., Hai, X., Li, J., Shanguan, Z., Peng, C., & Deng, L., 2020. Long-term forest succession improves plant diversity and soil quality but not significantly increase soil microbial diversity: Evidence from the Loess Plateau. *Ecological Engineering*, 142, pp. 105631. <https://doi.org/10.1016/j.ecoleng.2019.105631>.
- Lourie, S.A. and Vincent, A.C., 2004. Using biogeography to help set priorities in marine conservation. *Conservation Biology*, 18(4), pp.1004-1020.
- Lozier, J.D., Strange, J.P. and Heraghty, S.D., 2023. Whole genome demographic models indicate divergent effective population size histories shape contemporary genetic diversity gradients in a montane bumble bee. *Ecology and Evolution*, 13(2), p.e9778.
- Lu, D., Li, G., Valladares, G.S. and Batistella, M., 2004. Mapping soil erosion risk in Rondonia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. *Land degradation & development*, 15(5), pp.499-512.
- Lu, D., Mausel, P., Brondizio, E. and Moran, E. 2004. Change detection techniques. *International Journal of Remote Sensing*, 25(12), pp.2365-2407.
- Maharjan, S.K., Sterck, F.J., Raes, N., Zhao, Y. and Poorter, L., 2023. Climate change induced elevational range shifts of Himalayan tree species. *Biotropica*, 55(1), pp.53-69.
- Mallet, J., 2007. Hybrid speciation. *Nature*, (446), pp. 279-283.
- Margules, C.R. and Pressey, R.L., 2000. Systematic conservation planning. *Nature*, 405(6783), pp.243-253.
- Marshall, S.A., 2012. Flies: the natural history & diversity of Diptera. *Firefly Books*, Richmond Hill, Ontario, Canada, pp. 616. ISSN:1210-5759.
- Matheson, A., Buchmann, S.L., O'toole, C., Westrich, P. and Williams, I.H., 1996. The conservation of bees (*Linnean Society Symposium series* 18).
- Mattu, N. and Mattu, V.K., 2010. Pollinator Diversity, Beekeeping and Sustainable Mountain Crop Productivity. In “*Advances in Entomology*”.
- Mattu, V.K. and Bhagat, T., 2015. Effect of changing landscapes on diversity, distribution and relative abundance of insect pollinators on apple crop in Northwest Himalayas. *International Journal of Science & Research*, 4(5), pp.1762-1767.
- Mattu, V.K. and Mattu, N., 2007. Conservation and management of pollinators for sustainable horticulture in Himachal Himalaya. *Institute of Integrated Himalayan Studies (UGC Centre of Excellence)*, HP Univ., Shimla, 128.
- Mattu, V.K., 2014. Role of honeybees and other pollinators in crop productivity and impacts of climate change. *Workshop on Promotion of Honey Beekeeping in Haryana, Panchkula*, pp. 56-74.
- Maurer, J.M., Schaefer, J.M., Rupper, S. and Corley, A.J.S.A., 2019. Acceleration of ice loss across the Himalayas over the past 40 years. *Science advances*, 5(6), p.eaav7266.
- Mazhar, F., & Fadia, F., 2019. A Time Series Analysis of Satellite Imageries for Land Use & Land Cover (LULC) Change Detection of Gujranwala City, Pakistan from 1999–2019.

Indian journal of science and technology, 12 pp. 01-09.
<https://doi.org/10.17485/ijst/2019/v12i46/148606>.

- McFarland, K.P., Rimmer, C.C., Goetz, J.E., Aubry, Y., Wunderle Jr, J.M., Sutton, A., Townsend, J.M., Sosa, A.L. and Kirkconnell, A., 2013. A winter distribution model for Bicknell's Thrush (*Catharus bicknelli*), a conservation tool for a threatened migratory songbird. *PloS one*, 8(1), p.e53986.
- McGregor, S.E., 1976. Insect pollination of cultivated crop plants (No. 496). *Agricultural Research Service*, US Department of Agriculture.
- Merow, C., Smith, M.J. and Silander Jr, J.A., 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography*, 36(10), pp.1058-1069.
- Meyer, W.B. and Turner, B.L., 1996. Land-use/land-cover change: challenges for geographers. *GeoJournal*, 39, pp.237-240.
- Michener, C.D., 1944. Comparative external morphology, phylogeny, and a classification of the bees (Hymenoptera). *Bulletin of the AMNH*; v. 82, article 6.
- Michener, C.D., McGinley, R.J. and Danforth, B.N., 1994. *The bee genera of North and Central America (Hymenoptera: Apoidea)* (pp. viii+-209).
- Mickoleit, E., 1961. Zur Thoraxmorphologie der Thysanoptera. *Zoologische Jahrbuecher Abteilung fuer Anatomie und Ontogenie der Tiere*, 79, 1-92.
- Mickoleit, E., 1963. *Untersuchungen zur Kopfmorphologie der Tysanoptera (Doctoral dissertation, Fischer)*.
- Misganaw, M., Mengesha, G. and Awas, T., 2017. Perception of farmers on importance of insect pollinators in Gozamin district of Amhara region, Ethiopia. *Biodiversity International Journal*, 1(5), pp.54-60.
- Misra, A. and Balaji, R., 2015. Decadal changes in the land use/land cover and shoreline along the coastal districts of southern Gujarat, India. *Environmental Monitoring and Assessment*, 187, pp.1-13.
- Mitra, B., Mukherjee, M., Banerjee, D., 2008. A checklist of hover flies (Diptera: Syrphidae) of Eastern Himalayas. *Records of the Zoological Survey of India Occasional paper*, 284, pp.1-47.
- Mitra, B., Parui, P., Banerjee, D., Mukherjee, M. and Bhattacharjee, K., 2005. A report on flies (Diptera: Insecta) as flower visitors and pollinators of Kolkata and it's adjoining areas. *Records of the Zoological Survey of India*, pp.3-20.
- Montero-Castao, A. and Vil, M. 2012. Impact of Landscape alteration and invasions on pollinators: a meta-analysis. *Journal of Ecology*, 100, pp. 884-893.
- Mooney, H., Larigauderie, A., Cesario, M., Elmquist, T., Hoegh-Guldberg, O., Lavorel, S., Mace, G.M., Palmer, M., Scholes, R., Yahara, T., 2009. Biodiversity, climate change, and ecosystem services. In: *Current Opinion in Environmental Sustainability*, 1. <https://doi.org/10.1016/j.cosust.2009.07.006>. Issue 1.

- Morales, C.L. and Traveset, A., 2009. A meta-analysis of impacts of alien vs. native plants on pollinator visitation and reproductive success of co-flowering native plants. *Ecology letters*, 12(7), pp.716-728.
- Moritz, C., Richardson, K.S., Ferrier, S., Monteith, G.B., Stanistic, J., Williams, S.E. and Whiffin, T., 2001. Biogeographical concordance and efficiency of taxon indicators for establishing conservation priority in a tropical rainforest biota. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 268(1479), pp.1875-1881.
- Morse, J., & Hoddle, M., 2006. Invasion biology of thrips. *Annual review of entomology*, 51, pp. 67-89. <https://doi.org/10.1146/ANNUREV.ENTO.51.110104.151044>.
- Motavalli, P., Nelson, K., Udawatta, R., Jose, S., & Bardhan, S., 2013. Global achievements in sustainable land management. *International Soil and Water Conservation Research*, 1, pp. 1-10. [https://doi.org/10.1016/S2095-6339\(15\)30044-7](https://doi.org/10.1016/S2095-6339(15)30044-7).
- Mouflis, G.D., Gitas, I.Z., Iliadou, S. and Mitri, G.H., 2008. Assessment of the visual impact of marble quarry expansion (1984–2000) on the landscape of Thasos Island, NE Greece. *Landscape and urban planning*, 86(1), pp.92-102.
- Mountain Research Initiative EDW Working Group., 2015. Elevation-dependent warming in mountain regions of the world. *Nat. Clim. Change* 5, 424–430. <https://doi.org/10.1038/nclimate2563>.
- Munroe, D.K., Croissant, C. and York, A.M., 2005. Land use policy and landscape fragmentation in an urbanizing region: Assessing the impact of zoning. *Applied Geography*, 25(2), pp.121-141.
- Murienne, J., Guilbert, E., Grandcolas, P., 2009. Species' diversity in the New Caledonian endemic genera *Cephalidiosus* and *Nobarnus* Insecta: Heteroptera: Tingidae, an approach using phylogeny and species' distribution modelling. *Bot. J. Linn. Soc.* 97, pp.177-184.
- Mustard, J.F., Defries, R.S., Fisher, T. and Moran, E., 2012. Land-use and land-cover change pathways and impacts. In *Land change science: Observing, monitoring and understanding trajectories of change on the earth's surface* (pp. 411-429). Dordrecht: Springer Netherlands.
- Nabhan, G.P. and Buchmann, S.L., 1997. Services provided by pollinators. *Nature's Services: societal dependence on natural ecosystems*, pp.133-150.
- Nagendra, H., Pareeth, S. and Ghate, R., 2006. People within parks—forest villages, land-cover change and landscape fragmentation in the TadobaAndhari Tiger Reserve, India. *Applied Geography*, 26(2), pp.96-112.
- NAP. 2008 Earth Observation from Space. www.nap.edu.
- National Research Council, 2007. Status of pollinators in North America. National Academies Press.
- Nayak, R.K., Rana, K., Sharma, H.K., Rana, V.S. and Thakur, M., 2019. Influence of bumble bee pollination on quantitative and qualitative parameters of kiwifruit. *Indian Journal of Horticulture*, 76(2), pp.294-299.

- Neff, F., Blüthgen, N., Chisté, M., Simons, N., Steckel, J., Weisser, W., Westphal, C., Pellissier, L., & Gossner, M., 2019. Cross-scale effects of land use on the functional composition of herbivorous insect communities. *Landscape Ecology*, 34, pp. 2001 - 2015. <https://doi.org/10.1007/s10980-019-00872-1>.
- Negi, V. and Irfan, M. 2022. Land Use/Cover Mapping and Change Detection Using Remote Sensing Techniques: A Case of Upper Kullu Valley, Himachal Pradesh. *Current World Environment*. 17(2), pp.417-426.
- Negi, V., Maikhuri, R., Pharswan, D., Thakur, S., & Dhyani, P., 2017. Climate change impact in the Western Himalaya: people's perception and adaptive strategies. *Journal of Mountain Science*, 14, pp. 403-416. <https://doi.org/10.1007/s11629-015-3814-1>.
- Nelder, J.A. and Wedderburn, R.W., 1972. Generalized linear models. *Journal of the Royal Statistical Society Series A: Statistics in Society*, 135(3), pp.370-384.
- Nelson, R.F., 1983. Detecting forest canopy change due to insect activity using Landsat MSS. *Photogrammetric Engineering and Remote Sensing*, 49(9), pp.1303-1314.
- Newsome, T., Alamgir, M., Crist, E., Galetti, M., Laurance, W., Mahmoud, M., Ripple, W. and Wolf, C., 2017. World Scientists' Warning to Humanity: A Second Notice.
- Nieto, A, Roberts, S P M, Kemp, J, Rasmont, P, Kuhlmann, M, García Criado, M, Biesmeijer, J C, Bogusch, P, Dathe, H H, De la Rúa, P, De Meulemeester, T, Dehon, M, Dewulf, A, Ortiz-Sánchez, F J, Lhomme, P, Pauly, A, Potts, S G, Praz, C, Quaranta, M, Radchenko, V G, Scheuchl, E, Smit, J, Straka, J, Terzo, M, Tomozii, B, Window, J and Michez, D., 2014. European Red List of Bees. *Publication Office of the European Union*, Luxembourg.
- Oksanen, J., 2016. Design decisions and implementation details in vegan. *Vignette of the package vegan. R package version*, 2016, pp.2-4.
- Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Wagner, H. and Oksanen, M.J., 2022. *Package 'vegan'. Community ecology package*, version, 2(3).
- Oldroyd, B.P., 2007. What's killing American honey bees?. *PLoS biology*, 5(6), p.e168.
- Oliver, T., Smithers, R., Beale, C., & Watts, K., 2016. Are existing biodiversity conservation strategies appropriate in a changing climate. *Biological Conservation*, 193, pp. 17-26. <https://doi.org/10.1016/J.BIOCON.2015.10.024>.
- Ollerton, J., Winfree, R., & Tarrant, S., 2011. How many flowering plants are pollinated by animals. *Oikos*, 120, pp. 321-326. <https://doi.org/10.1111/J.1600-0706.2010.18644.X>.
- Orford, K.A., Vaughan, I.P. and Memmott, J., 2015. The forgotten flies: the importance of non-syrphid Diptera as pollinators. *Proceedings of the royal society B: biological sciences*, 282(1805), p.20142934.
- Ortega-Huerta, M.A. and Peterson, A.T., 2004. Modelling spatial patterns of biodiversity for conservation prioritization in north-eastern Mexico. *Diversity and Distributions*, 10(1), pp.39-54.

- Osten-Sacken, C.R., 1884. *An essay of comparative chaetotaxy, or the arrangement of characteristic bristles of Diptera*.
- Page, M., & Williams, N., 2022. Honeybee introductions displace native bees and decrease pollination of a native wildflower. *Ecology*, pp. e3939. <https://doi.org/10.1002/ecy.3939>.
- Palmer, M., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., Gold, B., Jacobson, R., Kingsland, S., Kranz, R. and Mappin, M., 2004. Ecology for a crowded planet. *Science*, 304(5675), pp.1251-1252.
- Pandit, M. K., 2013. The Himalayas must be protected. *Nature* 501, pp.283–283.
- Pandit, M.K. and Grumbine, R.E., 2012. Potential effects of ongoing and proposed hydropower development on terrestrial biological diversity in the Indian Himalaya. *Conservation Biology*, 26(6), pp.1061-1071.
- Pandit, M.K., 2020. The Himalaya should be a nature reserve. *Nature*, 583(7814), pp.9-9.
- Pandit, M.K., Sodhi, N.S., Koh, L.P., Bhaskar, A. and Brook, B.W., 2007. Unreported yet massive deforestation driving loss of endemic biodiversity in Indian Himalaya. *Biodiversity and Conservation*, 16, pp.153-163.
- Panetta, A.M., Stanton, M.L. and Harte, J., 2018. Climate warming drives local extinction: Evidence from observation and experimentation. *Science advances*, 4(2), p.eaaq1819.
- Partap, T., 2011. Hill agriculture: challenges and opportunities. *Indian Journal of Agricultural Economics*, 66(1), pp.33-52.
- Partap, U., 1999. Conservation of endangered Himalayan honeybee, *Apis cerena* for crop pollination. *Asia Bee Journal*, 1, pp. 44-49.
- Partap, U., 1999. Pollination management of mountain crops through beekeeping. *ICMOD, Kathmandu, Nepal*. Pp. 117.
- Partap, U. 2010a. Honeybees and ecosystem services in the Himalayas. In *Spehn, EM; Rudmann-Maurer, K; Körner, C; Maselli, D (eds), Mountain biodiversity and global change*, pp. 21-21. Basel, Switzerland: Global Mountain Biodiversity Assessment (GMBA) of DIVERSITAS.
- Partap, U. and Partap, T., 1997. Managed crop pollination: the missing dimension of mountain productivity. *International Centre for Integrated Mountain Development (ICIMOD): Discussion paper series*.
- Partap, U. and Partap, T., 2002. Warning signals from Apple Valleys of the HKH region: productivity concerns and pollination problems. *ICIMOD: Kathmandu, Nepal*.
- Partap, U., 2010. The pollination role of honeybees. In *Honeybees of Asia* (pp. 227-255). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Partap, U., 2010b. Innovations in revival strategies for declining pollinators with particular reference to the indigenous honeybees: experiences of ICIMOD's initiatives in the Hindu Kush- imalayan region. *Pest Management and Economic Zoology*, 18(1/2), pp.85-95.

- Partap, U., 2011. The pollination role of honeybees. In *Honeybees of Asia* (pp. 227-255). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Partap, U.P. and Partap, T.P., 2001. Declining apple production and worried Himalayan farmers: promotion of honey bees for pollination.
- Paul, S., Sarkar, D., Patil, A., Ghosh, T., Talukdar, G., Kumar, M., Habib, B., Nigam, P., Mohan, D., Pandav, B. and Mondol, S., 2020. Assessment of endemic northern swamp deer (*Rucervus duvaucelii duvaucelii*) distribution and identification of priority conservation areas through modeling and field surveys across north India. *Global Ecology and Conservation*, 24, p.e01263.
- Peitsch, D., Fietz, A., Hertel, H., de Souza, J., Ventura, D.F. and Menzel, R., 1992. The spectral input systems of hymenopteran insects and their receptor-based colour vision. *Journal of Comparative Physiology A*, 170, pp.23-40.
- Pelorosso, R., Leone, A. and Boccia, L., 2009. Land cover and land use change in the Italian central Apennines: A comparison of assessment methods. *Applied geography*, 29(1), pp.35-48.
- Peterson, A.T., 2006. Uses and requirements of ecological niche models and related distributional models. *Biodiversity informatics*, 3.
- Peterson, A.T., Kumar, R.S., Nair, M.V., Talukdar, G., 2018. Digital accessible knowledge of the birds of India. *Current Science*. 115 (1), pp.35–42.
- Peterson, A.T., Soberón, J., Pearson, R.G., Anderson, R.P., Martínez-Meyer, E., Nakamura, M. and Araújo, M.B., 2011. Ecological niches and geographic distributions (MPB-49). In *Ecological Niches and Geographic Distributions (MPB-49)*. Princeton University Press.
- Phillips, S.J. and Dudík, M., 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, 31(2), pp.161-175.
- Phillips, S.J., Anderson, R.P. and Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. *Ecological modelling*, 190(3-4), pp.231-259.
- Phillips, S.J., Dudík, M., Schapire, R.E., 2019. Maxent Software for Modeling Species Niches and Distributions (version 3.4.1). Available from url. http://biodiversityinformatics.amnh.org/open_source/maxent/.
- Phillips, S.J., M. Dud'ík, and R.E. Schapire., 2004. A maximum entropy approach to species distribution modeling. In *Proceedings of the 21st International Conference on Machine Learning. ACM Press, New York, New York, USA*. pp. 655–662.
- Pitkin, B.R., 1972. A revision of the Australian genus *Odontothripella bagnali*, with descriptions of fourteen new species (Thysanoptera: Thripidae). *Australian Journal of Entomology*, 11(4), pp.265-289.
- Poppy, G.M., Chiotha, S., Eigenbrod, F., Harvey, C.A., Honzák, M., Hudson, M.D., Jarvis, A., Madise, N.J., Schreckenberg, K., Shackleton, C.M. and Villa, F., 2014. Food security in a perfect storm: using the ecosystem services framework to increase understanding.

- Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1639), p.20120288
- Porto, R.G., De Almeida, R.F., Cruz-Neto, O., Tabarelli, M., Viana, B.F., Peres, C.A. and Lopes, A.V., 2020. Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. *Food Security*, 12(6), pp.1425-1442.
- Potts, S., Imperatriz-Fonseca, V., Ngo, H., Aizen, M., Biesmeijer, J., Breeze, T., Dicks, L., Garibaldi, L., Hill, R., Settele, J., & Vanbergen, A., 2016. Safeguarding pollinators and their values to human well-being. *Nature*, 540, pp. 220-229. <https://doi.org/10.1038/nature20588>.
- Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O. and Kunin, W.E., 2010. Global pollinator declines: trends, impacts and drivers. *Trends in ecology & evolution*, 25(6), pp.345-353.
- Pounds, J.A., Fogden, M.P. and Campbell, J.H., 1999. Biological response to climate change on a tropical mountain. *Nature*, 398(6728), pp.611-615.
- Quinn, S.A., Gibbs, J.P., Hall, M.H. and Petokas, P.J., 2013. Multiscale factors influencing distribution of the eastern hellbender salamander (*Cryptobranchus alleganiensis alleganiensis*) in the northern segment of its range. *Journal of Herpetology*, 47(1), pp.78-84.
- R Core Team., 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing Vienna, Austria. URL <https://www.R-project.org/>.
- Rada, S., Schweiger, O., Harpke, A., Kühn, E., Kuras, T., Settele, J. and Musche, M., 2019. Protected areas do not mitigate biodiversity declines: A case study on butterflies. *Diversity and Distributions*, 25(2), pp.217-224.
- Rader, R., Bartomeus, I., Garibaldi, L.A., Garratt, M.P., Howlett, B.G., Winfree, R., Cunningham, S.A., Mayfield, M.M., Arthur, A.D., Andersson, G.K. and Bommarco, R., 2016. Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences*, 113(1), pp.146-151.
- Rader, R., Bartomeus, I., Tylianakis, J.M. and Laliberté, E., 2014. The winners and losers of land use intensification: Pollinator community disassembly is non-random and alters functional diversity. *Diversity and Distributions*, 20(8), pp.908-917.
- Rader, R., Cunningham, S., Howlett, B. and Inouye, D., 2020. Non-Bee Insects as Visitors and Pollinators of Crops: Biology, Ecology and Management. *Annual review of entomology* <https://doi.org/10.1146/annurev-ento-011019-025055>.
- Radosavljevic, A. and Anderson, R.P., 2014. Making better Maxent models of species distributions: complexity, overfitting and evaluation. *Journal of biogeography*, 41(4), pp.629-643.
- Raj, H., Mattu, V.K. and Thakur, M.L., 2012. Pollinator diversity and relative abundance of insect visitors on apple crop in Shimla hills of western Himalaya, India. *International Journal of Science and Nature* 3 (3), pp.507-513.

- Rajabi, A., Shabanlou, S., Yosefvand, F., & Kiani, A., 2021. Exploring the sample size and replications scenarios effect on spatial prediction of flood, using MARS and MaxEnt methods case study: saliantape catchment, Golestan, Iran. *Natural Hazards*, 109, pp. 871 - 901. [tps://doi.org/10.1007/s11069-021-04860-0](https://doi.org/10.1007/s11069-021-04860-0).
- Rajesh, S. and Gupta, J.K., 2010. Effect of changing landscapes on the density and diversity of insect pollinators on apple crop in Kullu valley of Himachal Pradesh. *Pest Management and Economic Zoology*, 18(1/2), pp.277-280.
- Raman, R. and Punia, M., 2012. Land use dynamics and landscape fragmentation in higher Garhwal Himalaya, India. *Asian Journal of Geoinformatics*, 12(1).
- Ramesh, K., Sathyakumar, S. and Rawat, G.S., 1999. Ecology and conservation status of the pheasants of Great Himalayan National Park, Western Himalaya. *Wildlife Institute of India, Dehradun*.
- Rana, S. R., Bhagat, R.M., Kalia, V., Lal, H. and Dubash, N.K., 2009. Impact of climate change on shift of apple belt in himachal Pradesh. Impact of climate change on agriculture. *Panigrahy, S.; Ray, SS and Parihar, S. J.(eds.). Ahmedabad, India. Int. Soc. Photogram. Remote Sens*, pp.131-137.
- Range, A., Reserve, F., Price, J., Forstenhaeusler, N., Graham, E., Warren, R., Vanderwal, J., Atkinson, I., Baird, D., Lawry, P., 2019. Report on Observed Climate, Projected Climate and Biodiversity Changes for April.
- Rani, S., Kumar, R. and Maharana, P., 2022. Climate change, its impacts, and sustainability issues in the Indian Himalaya: an introduction. In *Climate Change: Impacts, Responses and Sustainability in the Indian Himalaya* (pp. 1-27). Cham: Springer International Publishing.
- Rashid, I., Romshoo, S., Chaturvedi, R., Ravindranath, N., Sukumar, R., Jayaraman, M., Lakshmi, T., & Sharma, J., 2015. Projected climate change impacts on vegetation distribution over Kashmir Himalayas. *Climatic Change*, 132, pp. 601-613. <https://doi.org/10.1007/s10584-015-1456-5>.
- Rawat, J.S. and Kumar, M., 2015. Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science*, 18(1), pp.77-84.
- Reyne, A., 1947. Notes on the Biology of *Comperiella unifasciata* Ishil and its Host *Aspidiotus destructor rigidus* nov. subsp.
- Rice, J., Gjerde, K.M., Ardron, J., Arico, S., Cresswell, I., Escobar, E., Grant, S. and Vierros, M., 2011. Policy relevance of biogeographic classification for conservation and management of marine biodiversity beyond national jurisdiction, and the GOODS biogeographic classification. *Ocean & coastal management*, 54(2), pp.110-122.
- Richards, K.W., 1997. Potential of the alfalfa leafcutter bee, *Megachile rotundata* (F.) (Hym., Megachilidae) to pollinate hairy and winter vetches (*Vicia* spp.). *Journal of Applied Entomology*, 121(1-5), pp.225-229.
- Richardson, D.M., and R.J. Whitaker. 2010. Conservation biogeography - foundations, concepts and challenges. *Diversity and Distributions* 16:313–320.

- Ricketts, T.H., Regetz, J., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Bogdanski, A., Gemmill-Herren, B., Greenleaf, S.S., Klein, A.M., Mayfield, M.M. and Morandin, L.A., 2008. Landscape effects on crop pollination services: are there general patterns?. *Ecology letters*, 11(5), pp.499-515.
- Riebsame, W.E., Meyer, W.B. and Turner, B.L., 1994. Modeling land use and cover as part of global environmental change. *Climatic change*, 28(1), pp.45-64.
- Risler, H., 1957. Der Kopf von Thrips physapus L.(Thysanoptera, Terebrantia). *Zool. Jahrb. Anat*, 76, pp.251-302.
- Rissler, L.J. and Apodaca, J.J., 2007. Adding more ecology into species delimitation: ecological niche models and phylogeography help define cryptic species in the black salamander (*Aneides flavipunctatus*). *Systematic biology*, 56(6), pp.924-942.
- Rissler, L.J., Hijmans, R.J., Graham, C.H., Moritz, C. and Wake, D.B., 2006. Phylogeographic lineages and species comparisons in conservation analyses: a case study of California herpetofauna. *The American Naturalist*, 167(5), pp.655-666.
- Rodgers, W.A. and Panwar, H.S., 1988. Planning a wildlife protected area network in India.
- Roig-Alsina, A., 1990. *Coelioxoides* Cresson, a parasitic genus of Tetrapediini (Hymenoptera: Apoidea). *Journal of the Kansas Entomological Society*, pp.279-287.
- Ross, H.H., 1936. The ancestry and wing venation of the Hymenoptera. *Annals of the Entomological Society of America*, 29(1), pp.99-111.
- Roubik, D.W. ed., 1995. Pollination of cultivated plants in the tropics (Vol. 118). Food & Agriculture Org.
- Rushton, S.P., Ormerod, S.J. and Kerby, G., 2004. New paradigms for modelling species distributions?. *Journal of applied ecology*, 41(2), pp.193-200.
- Saczuk, E.A., 2001. Has the Kullu district experienced an increase in natural hazard activity over the past 27 years? A case study in risk and land use/cover change. *GIS@ Development. GIS Development*, 5(10), pp.34-44.
- Sah, M.P. and Mazari, R.K., 2007. An overview of the geoenvironmental status of the Kullu Valley, Himachal Pradesh, India. *Journal of Mountain Science*, 4, pp.003-023.
- Sala, E., Aburto-Oropeza, O., Paredes, G., Parra, I., Barrera, J.C. and Dayton, P.K., 2002. A general model for designing networks of marine reserves. *Science*, 298(5600), pp.1991-1993.
- Schmid-Hempel, R., Eckhardt, M., Goulson, D., Heinzmann, D., Lange, C., Plischuk, S., Escudero, L.R., Salathé, R., Scriven, J.J. and Schmid-Hempel, P., 2014. The invasion of southern South America by imported bumblebees and associated parasites. *Journal of Animal Ecology*, 83(4), pp.823-837.
- Schröder, P., Beckers, B., Daniels, S., Gnädinger, F., Maestri, E., Marmiroli, N., Mench, M., Millán, R., Obermeier, M., Oustrière, N., Persson, T., Poschenrieder, C., Rineau, F., Rutkowska, B., Schmid, T., Szulc, W., Witters, N., & Sæbø, A., 2018. Intensify production, transform biomass to energy and novel goods and protect soils in Europe-A vision how to

- mobilize marginal lands. *The Science of the total environment*, 616-617, pp. 1101-1123. <https://doi.org/10.1016/j.scitotenv.2017.10.209>.
- Schulz, J.J., Cayuela, L., Echeverria, C., Salas, J. and Benayas, J.M.R., 2010. Monitoring land cover change of the dryland forest landscape of Central Chile (1975–2008). *Applied Geography*, 30(3), pp.436-447.
- Sengupta, J., Naskar, A., Homechaudhuri, S. and Banerjee, D., 2020. A Taxonomic Account of Hover Flies (Insecta: Diptera: Syrphidae) with 2 New Records from Mid Hill Zone of Himachal Pradesh, India. *International Journal of Advancement in Life Sciences Research*, pp.30-49.
- Sengupta, J., Naskar, A., Maity, A., Hazra, S. and Banerjee, D., 2016. New distributional records and annotated keys of hover flies (Insecta: Diptera: Syrphidae) from Himachal Pradesh, India. *J. Adv. Zool*, 37(1), pp.31-54.
- Serra, P., Pons, X. and Saurí, D., 2008. Land-cover and land-use change in a Mediterranean landscape: a spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography*, 28(3), pp.189-209.
- Shah, S. and Sharma, D.P., 2015. Land use change detection in Solan forest division, Himachal Pradesh, India. *Forest Ecosystems*, 2, pp.1-12.
- Shalaby, A. and Tateishi, R., 2007. Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the Northwestern coastal zone of Egypt. *Applied Geography*, 27(1), pp.28-41.
- Shannon, C.E. and Weaver, W., 1963. *The mathematical theory of communication*. Urbana: University of Illinois Press.
- Shannon, C.E., 1948. A mathematical theory of communication. *The Bell system technical journal*, 27(3), pp.379-423.
- Sharma, H.K., Bakshi, N., Thakur, R.K. and Devi, M., 2016. Diversity and density of insect pollinators on sweet cherry (*Prunus avium* L.) in temperate region of Kullu valley of Himachal Pradesh. *Journal of Entomological Research* 40(2), pp.123-128.
- Sharma, H.K., Gupta, J.K., Suman, V. and Belavadi, V.V., 2015. Studies on flowering phenology, pollinator diversity, supplemented pollination and their impact on fruit set in apple under changing climatic scenario in Kullu valley of Himachal Pradesh. *International Journal of Farm Sciences*, 5(4), pp.156-164.
- Sharma, H.R. and Chauhan, S.K., 2013. Agricultural transformation in Trans Himalayan region of Himachal Pradesh: cropping pattern, technology adoption and emerging challenges. *Agricultural Economics Research Review*, 26, pp.173-179.
- Sharma, L.K. and Rana, R.K., 2015. Effect of top working to improve pollination in apple (*Malus x domestica* Borkh.) orchards under mid hill conditions of Kullu district. *Himachal Journal of Agricultural Research*, 41(1), pp.89-92.

- Sharma, R. and Gupta, J.K., 2010. Effect of changing landscapes on the density and diversity of insect pollinators on apple crop in Kullu valley of Himachal Pradesh. *Pest Management and Economic Zoology*, 18(1/2), pp.277-280.
- Sharma, R.M. and Mitra, B., 2011. A preliminary study on insect pollinators of temperate fruit crops in Himachal Pradesh. *Records of the Zoological Survey of India*, pp.103-110.
- Shipley, B., Laughlin, D., Sonnier, G., & Otfinowski, R., 2011. A strong test of a maximum entropy model of trait-based community assembly. *Ecology*, 92 2, pp. 507-17. <https://doi.org/10.1890/10-0394.1>.
- Simpson, E.H., 1949. Measurement of diversity. *Nature*, 163(4148), pp.688-688.
- Singh, A., 1984. *Tropical forest monitoring using digital Landsat data in Northeastern India* (Doctoral dissertation, University of Reading).
- Singh, A.P. and Sondhi, S., 2016. Butterflies of Garhwal, Uttarakhand, western Himalaya, India. *Journal of Threatened Taxa*, 8(4), pp.8666-8697.
- Singh, A.P., Chandra, A., De, K., Uniyal, V.P. and Sathyakumar, S., 2023. Decreasing potential suitable habitat of bumble bees in the Great Himalayan National Park Conservation area. *Oriental Insects*, 57(1), pp.36-53.
- Singh, A.P., De, K., Uniyal, V.P. and Sathyakumar, S., 2024. Unveiling of climate change driven decline of suitable habitat for Himalayan bumblebees. *Scientific Reports*, 14(1), p.4983.
- Singh, M., and Sharma, J., 2014. Climate resilient apple production in Kullu valley of Himachal Pradesh. *International Journal of Farm Sciences*, 3, pp. 91-98.
- Singh, R.B., 1998. Land use/cover changes, extreme events and ecohydrological responses in the Himalayan region. *Hydrological Processes*, 12(13-14), pp.2043-2055.
- Singh, S.K., Chandel, V., Kumar, H. and Gupta, H., 2014. RS & GIS based urban land use change and site suitability analysis for future urban expansion of Parwanoo planning area, Solan, Himachal Pradesh (India). *International Journal of Development Research*, 4(8), pp.1491-1503.
- Sinha, S., Sharma, L.K. and Nathawat, M.S., 2015. Improved land-use/land-cover classification of semi-arid deciduous forest landscape using thermal remote sensing. *The Egyptian Journal of Remote Sensing and Space Science*, 18(2), pp.217-233.
- Skendžić, S., Zovko, M., Živković, I.P., Lešić, V. and Lemić, D., 2021. The impact of climate change on agricultural insect pests. *Insects*, 12(5), p.440.
- Skorupski, P., Döring, T.F. and Chittka, L., 2007. Photoreceptor spectral sensitivity in island and mainland populations of the bumblebee, *Bombus terrestris*. *Journal of Comparative Physiology A*, 193, pp.485-494.
- Slariya, M.K., 2014. Shifting from traditional food cropping to cash cropping. Livelihood Security in Northwestern Himalaya: Case Studies from Changing Socio-economic Environments in Himachal Pradesh, India, pp.83-92.

- Slifer, E.H. and Sekhon, S.S., 1974. Sense organs on the antennae of two species of thrips (Thysanoptera, Insecta). *Journal of morphology*, 143(4), pp.445-455.
- Smith, R.A., 1971. The effect of unequal group size on Tukey's HSD procedure. *Psychometrika*, 36, pp.31-34.
- Snodgrass, R.E., 1909. *The thorax of insects and the articulation of the wings (Vol. 36)*. US Government Printing Office.
- Somerville, D.C., 1999. Honeybees (*Apis mellifera* L.) increase yields of faba beans (*Vicia faba* L.) in New South Wales while maintaining adequate protein requirements from faba bean pollen. *Australian Journal of Experimental Agriculture*, 39(8), pp.1001-1005.
- Song, C., Woodcock, C., & Li, X., 2001. Manifestation of forest succession in optical imagery.
- Sritongchuay, T., Hughes, A., Memmott, J., & Bumrungsri, S., 2019. Forest proximity and lowland mosaic increase robustness of tropical pollination networks in mixed fruit orchards. *Landscape and Urban Planning*. <https://doi.org/10.1016/j.landurbplan.2019.103646>.
- St, L. and Wold, S., 1989. Analysis of variance (ANOVA). *Chemometrics and intelligent laboratory systems*, 6(4), pp.259-272.
- Steffan-Dewenter, I., Münzenberg, U., Bürger, C., Thies, C. and Tschardtke, T., 2002. Scale-dependent effects of landscape context on three pollinator guilds. *Ecology*, 83(5), pp.1421-1432.
- Steffan-Dewenter, I., Potts, S.G. and Packer, L., 2005. Pollinator diversity and crop pollination services are at risk. *Trends in ecology & evolution*, 20(12), pp.651-652.
- Steinbauer, M.J., Grytnes, J.A., Jurasinski, G., Kulonen, A., Lenoir, J., Pauli, H., Rixen, C., Winkler, M., Bardy-Durchhalter, M., Barni, E. and Bjorkman, A.D., 2018. Accelerated increase in plant species richness on mountain summits is linked to warming. *Nature*, 556(7700), pp.231-234.
- Stockwell, D., 1999. The GARP modelling system: problems and solutions to automated spatial prediction. *International journal of geographical information science*, 13(2), pp.143-158.
- Stockwell, D.R., Peterson, A.T., 2002. Effects of sample size on accuracy of species distribution models. *Ecol. Model.* 148 (1), pp.1–13.
- Student, 1908. The probable error of a mean. *Biometrika*, pp.1-25.
- Telwala, Y., Brook, B., Manish, K., & Pandit, M., 2013. Climate-Induced Elevational Range Shifts and Increase in Plant Species Richness in a Himalayan Biodiversity Epicentre. *PLoS ONE*, 8. <https://doi.org/10.1371/journal.pone.0057103>.
- Thakur N, Rishi M, Keesari T, Sharma DA, Singh R. 2018. Assessment of changes in land use and land cover patterns using RS and GIS: a case study of upper Beas Basin of Kullu Valley in Western Himalayas, India. *Anusandhan*, 7(14), pp.1-10. doi: 10.29070/AUJ-AN.
- Thakur, B. and Mattu, V.K., 2014. Diversity and distribution of pollinators of temperate fruit crops of Shimla hills in Himachal Pradesh. *Asian Journal of Advanced Basic Sciences*, 3(1), pp.151-163.

- Theodoridis, S., Patsiou, T., Randin, C., & Conti, E., 2018. Forecasting range shifts of a cold adapted species under climate change: are genomic and ecological diversity within species crucial for future resilience?. *Ecography*, 41, pp. 1357–1369. <https://doi.org/10.1111/ecog.03346>.
- Tingley, M., Koo, M., Moritz, C., Rush, A., & Beissinger, S., 2012. The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. *Global Change Biology*, 18. <https://doi.org/10.1111/j.1365-2486.2012.02784.x>.
- Tiwari, P., 2008. Land use changes in Himalaya and their impacts on environment, society and economy: A study of the Lake Region in Kumaon Himalaya, India. *Advances in Atmospheric Sciences*, 25, pp.1029-1042.
- Tscharntke, T., Tylianakis, J., Rand, T., Didham, R., Fahrig, L., Batáry, P., Bengtsson, J., Clough, Y., Crist, T., Dormann, C., Ewers, R., Fründ, J., Holt, R., Holzschuh, A., Klein, A., Kleijn, D., Kremen, C., Landis, D., Laurance, W., Lindenmayer, D., Scherber, C., Sodhi, N., Steffan-Dewenter, I., Thies, C., Putten, W., & Westphal, C., 2012. Landscape moderation of biodiversity patterns and processes - eight hypotheses. *Biological Reviews*, 87. <https://doi.org/10.1111/j.1469-185X.2011.00216.x>.
- Tukey, J., 1953. Multiple comparisons. *Journal of the American Statistical Association*, 48(263), pp.624-625.
- Turner, B., Meyer, W.B. and Skole, D.L., 1994. Global land-use/land-cover change: towards an integrated study. *Ambio. Stockholm*, 23(1), pp.91-95.
- Ulyshen, M., Urban-Mead, K.R., Dorey, J.B. and Rivers, J.W., 2023. Forests are critically important to global pollinator diversity and enhance pollination in adjacent crops. *Biological Reviews*, 98(4), pp.1118-1141.
- Uma Partap, U.P. and Tej Partap, T.P., 2001. Declining apple production and worried Himalayan farmers: promotion of honey bees for pollination.
- Uma Partap, U.P. and Tej Partap, T.P., 2002. *Warning signals from the apple valleys of the Hindu Kush-Himalayas: productivity concerns and pollination problems* (pp. 104-pp).
- V.M. Uys & R.P., 2006. Urban (Eds.): "How to Collect and Preserve Insects and Arachnids". Pretoria. pp.112 p. ISBN 1-86849-311-3.
- Vaidya, P., Bhardwaj, S.K. and Sood, S., 2018. Land use and land cover changes in Kullu valley of Himachal Pradesh. *Indian Journal of Agricultural Sciences*, 88(6), pp.902-906.
- Valavi, R., Elith, J., Lahoz-Monfort, J.J. and Guillera-Arroita, G., 2023. Flexible species distribution modelling methods perform well on spatially separated testing data. *Global Ecology and Biogeography*, 32(3), pp.369-383.
- Van Nieuwerkerken, E., 2011. Order lepidoptera Linnaeus, 1758.
- Vanbergen, A., 2014. Landscape alteration and habitat modification: impacts on plant pollinator systems. *urrent opinion in insect science*, 5 pp. -49. <https://doi.org/10.1016/J.COIS.2014.09.004>.

- Vanbergen, A.J. and Initiative, T.I.P., 2013. Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment*, 11(5), pp.251-259.
- Vasiliev, D., & Greenwood, S., 2021. The role of climate change in pollinator decline across the Northern Hemisphere is underestimated. *The Science of the total environment*, 775, pp. 145788. <https://doi.org/10.1016/j.scitotenv.2021.145788>.
- Verma, L.R. and Partap, U., 1993. The Asian hive bee, *Apis cerena*, as a pollinator in vegetable seed production. *International Centre for Integrated Mountain Development (ICIMOD)*.
- Verma, M.K., Ahmed, N., Singh, A.K. and Awasthi, O.P., 2010. Temperate tree fruits and nuts in India. *Chronica Horticulture* 50(4), pp.43-48.
- Viana, B.F., Boscolo, D., Lopes, L., Lopes, A., Ferreira, P., Pigozzo, C.M. and Primo, L., 2012. How well do we understand landscape effects on pollinators and pollination services? *Journal of Pollination Ecology*, 7.
- Viette, P.E., 1948. *Catalogue of the Heterocerous Lepidoptera from French Oceania*.
- Vishwa, B.S., Kaur, B.K. and Simrit, K., 2013. Land use/cover change and its implications for Kullu district of Himachal Pradesh, India. *International journal of geomatics and geosciences*, 3(3), pp.538-551.
- Visser, M.E. and Both, C., 2005. Shifts in phenology due to global climate change: the need for a yardstick. *Proceedings of the Royal Society B: Biological Sciences*, 272(1581), pp.2561-2569.
- Vivekananda, G.N., Swathi, R. and Sujith, A.V.L.N., 2021. Multi-temporal image analysis for LULC classification and change detection. *European journal of remote sensing*, 54(sup2), pp.189-199.
- Vos, C., Berry, P., Opdam, P., Baveco, H., Nijhof, B., O'Hanley, J., Bell, C., & Kuipers, H., 2008. Adapting landscapes to climate change: examples of climate-proof ecosystem networks and priority adaptation zones. *Journal of Applied Ecology*, 45, pp. 1722-1731. <https://doi.org/10.1111/J.1365-2664.2008.01569.X>.
- Wambulwa, M.C., Milne, R., Wu, Z.Y., Spicer, R.A., Provan, J., Luo, Y.H., Zhu, G.F., Wang, W.T., Wang, H., Gao, L.M. and Li, D.Z., 2021. Spatiotemporal maintenance of flora in the Himalaya biodiversity hotspot: current knowledge and future perspectives. *Ecology and Evolution*, 11(16), pp.10794-10812.
- Warren, R., VanDerWal, J., Price, J., Welbergen, J.A., Atkinson, I., Ramirez-Villegas, J., Osborn, T.J., Jarvis, A., Shoo, L.P., Williams, S.E. and Lowe, J., 2013. Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. *Nature Climate Change*, 3(7), pp.678-682.
- Weber, H., 1933. *Lehrbuch der entomologie*.
- Wenzel, A., Grass, I., Belavadi, V., & Tschardtke, T., 2020. How urbanization is driving pollinator diversity and pollination – A systematic review. *Biological Conservation*, 241, pp. 108321. <https://doi.org/10.1016/j.biocon.2019.108321>.

- Westerkamp, C. and Gottsberger, G., 2000. Diversity pays in crop pollination. *Crop science*, 40(5), pp.1209-1222.
- Westphal, C., Bommarco, R., Carré, G., Lamborn, E., Morison, N., Petanidou, T., Potts, S.G., Roberts, S.P., Szentgyörgyi, H., Tscheulin, T. and Vaissière, B.E., 2008. Measuring bee diversity in different European habitats and biogeographical regions. *Ecological monographs*, 78(4), pp.653-671.
- Whitney, H.M., Kolle, M., Andrew, P., Chittka, L., Steiner, U. and Glover, B.J., 2009. Floral iridescence, produced by diffractive optics, acts as a cue for animal pollinators. *Science*, 323(5910), pp.130-133.
- Whittaker, R.J., Araújo, M.B., Jepson, P., Ladle, R.J., Watson, J.E. and Willis, K.J., 2005. Conservation biogeography: assessment and prospect. *Diversity and distributions*, 11(1), pp.3- 23.
- Wickham, H., Chang, W. and Wickham, M.H., 2016. Package ‘ggplot2’. *Create elegant data visualisations using the grammar of graphics*. Version, 2(1), pp.1-189.
- Williams, I.H., 1994. The dependence of crop production within the European Union on pollination by honeybees. *Agricultural Science Reviews*, 6, pp.229-257.
- Williams, P.H. and Osborne, J.L., 2009. Bumblebee vulnerability and conservation world-wide. *Apidologie*, 40(3), pp.367-387.
- Winfree, R., Aguilar, R., Vázquez, D.P., LeBuhn, G. and Aizen, M.A., 2009. A meta-analysis of bees' responses to anthropogenic disturbance. *Ecology*, 90(8), pp.2068-2076.
- Winfree, R., Williams, N.M., Dushoff, J. and Kremen, C., 2007. Native bees provide insurance against ongoing honeybee losses. *Ecology letters*, 10(11), pp.1105-1113.
- Wisz, M.S., Hijmans, R.J., Li, J., Peterson, A.T., Graham, C.H., Guisan, A. and NCEAS Predicting Species Distributions Working Group, 2008. Effects of sample size on the performance of species distribution models. *Diversity and distributions*, 14(5), pp.763-773.
- Wu, Q., Li, H.Q., Wang, R.S., Paulussen, J., He, Y., Wang, M., Wang, B.H. and Wang, Z., 2006. Monitoring and predicting land use change in Beijing using remote sensing and GIS. *Landscape and urban planning*, 78(4), pp.322-333.
- Wyman, M.S. and Stein, T.V., 2010. Modeling social and land-use/land-cover change data to assess drivers of smallholder deforestation in Belize. *Applied Geography*, 30(3), pp.329-342.
- Xiao, Y., Li, X., Cao, Y. and Dong, M., 2016. The diverse effects of habitat fragmentation on plant–pollinator interactions. *Plant Ecology*, 217, pp.857-868.
- Yang XQ, Kushwaha SPS, Saran S, Xu J, Roy PS (2013). MaxEnt modeling for predicting the potential distribution of medicinal plant *Justicia adhatoda* L. in Lesser Himalayan foothills. *Ecol Eng* 51, pp.83–87.
- Yang, X. and Lo, C.P., 2002. Using a time series of satellite imagery to detect land use and land cover changes in the Atlanta, Georgia metropolitan area. *International Journal of Remote Sensing*, 23(9), pp.1775-1798.

- Yuan, H., Wei, Y., & Wang, X., 2015. Maxent modeling for predicting the potential distribution of Sanghuang, an important group of medicinal fungi in China. *Fungal Ecology*, 17, pp. 140-145. <https://doi.org/10.1016/J.FUNECO.2015.06.001>.
- Zai, X., Qin, P., Wan, S., Zhao, F., Wang, G. and Yan, D., 2009. The application of beach plum (*Prunus maritima*) to wasteland vegetation recovery in Jiangsu Province, China: seedling cloning and transplantation. *Ecological engineering*, 35(4), pp.591-596.
- Zhao, X., Zheng, Y., Wang, W., Wang, Z., Zhang, Q., Liu, J., & Zhang, C., 2023. Habitat Suitability Evaluation of Different Forest Species in Lvliang Mountain by Combining Prior Knowledge and MaxEnt Model. *Forests*. <https://doi.org/10.3390/f14020438>.
- Zheng B, Duan J, Jia J, Liu F, Yan Y. Assessment of ecosystem services of Lugu Lake watershed., 2008. *The International Journal of Sustainable Development and World Ecology*. 15(1):62-70.
- Zoological Survey of India., 1995. Fauna of conservation areas 2: Fauna of Western Himalaya (UP). Eds. Director Zoological Survey of India, Kolkata, India, 288 pp.

Annexure 1: External morphological characteristics of Hymenoptera, Diptera, Lepidoptera, Coleoptera and Thysanoptera for taxonomic identification

Order: Hymenoptera

Head: The head of hymenopteran insects is typically mobile and distinct from the thorax, often varying in shape with the longitudinal axis predominant. While the cranial capsule is consolidated, the clypeus and labrum are typically distinct, with a well-developed and trilobed epipharynx in higher forms. Acute vision is a hallmark of the order, with large compound eyes being the norm, sometimes strongly convergent or holoptic in males. However, in certain ant species like *Dorylus* and *Eciton*, the eyes may be reduced or atrophied. Although three ocelli are common, they can be aborted in some species like *Bembicini* and certain ant workers. Antennae exhibit significant variability, being longer in males and often showing sexual dimorphism, especially in Proctotrupoids and Chalcidoidea, where they may be filiform, clavate, pectinate, branched, or verticillate. Segment count in antennae varies widely among superfamilies, from as low as 14 to as high as 70 in Ichneumonidae, while in groups like Sphecoidea, Vespoidea, and Apoidea, segment count is more consistent, typically 13 in males and 12 in females (figure 2,3).

Mouthparts: Mouthparts of Hymenoptera range from generalized biting types in Symphyta to highly specialized sucking types in bees like *Apis* and *Euglossa*. Mandibles are present in all members but are mainly used for tasks like cutting cocoons or gathering materials rather than feeding, except in predacious Tenthredinidae. The mouthparts undergo various degrees of specialization, with reductions in the number of segments in maxillary and labial palpi, particularly in Chalcidoidea. In certain superfamilies, like Apoidea, mouthparts elongate to form a proboscis, essential for feeding on nectar from deep flowers (figure 4).

Thorax: The thorax of Hymenoptera is characterized by the fusion of the first abdominal segment with the metathorax, forming the propodeum. The pronotum attaches to the front of the mesothorax, while the mesonotum consists of distinct plates, the scutum and scutellum. Additionally, the metanotum is typically reduced to a single plate carrying the hind wings, and the metapostnotum merges with the propodeum in higher taxa (figure 5).

Wings: Wings in Hymenoptera are highly modified, with extensive fusion of veins and transverse orientation of branches. Ross's (1936) venational scheme, based on comparisons with *Sialis*, and Cresson's alternative terminology are commonly referenced. Specialization in wing structure, marked by reduction and fusion, is prominent in Apocrita, particularly seen in Evaniidae and Chalcidoidea with solitary compound veins and sometimes veinless hind wings. Interlocking wings are facilitated by hamuli along the costal margin of the hind wings, with

reduction observed in certain groups like Chalcids and Mymaridae. Apterous forms are prevalent in Hymenoptera, notably among ants' workers, Mutillidae, and certain Proctotrupoids, Ichneumonidae, and Braconidae species (figure 6).

Legs: Legs in hymenopteran insects display adaptations for various functions, including parasitism, preening, digging, running, and pollen-carrying. In parasitic groups, trochanters are often two-segmented, while in Apoidea, the posterior legs are specialized for pollen collection, featuring a corbicula or pollen basket formed by a modified tibia and basitarsus. Generally, Hymenopteran tarsi are 5-segmented with an arolium between the claws (figure 7,8).

Abdomen: The abdomen typically starts from the second segment, with the first abdominal segment forming the propodeum which is fused with the metathorax, and the gaster or metasoma. The number of discernible abdominal segments varies widely across species, with the higher groups typically having six exposed segments in females and seven or eight in males. The 1st abdominal segment forms a petiole in Apocrita, which varies from highly attenuated to nearly absent, while Symphyta lack this modification. The ovipositor is well-developed, with three pairs of gonapophyses involved in various functions such as sawing, boring, piercing, or stinging, depending on the group. Additionally, males possess complex genitalia, including a basal ring, forceps, volsella, and penis valves, whose homologies are subject to debate among morphologists (figure 9-12).

Diagrammatic representation of external morphology and body parts of an adult bee

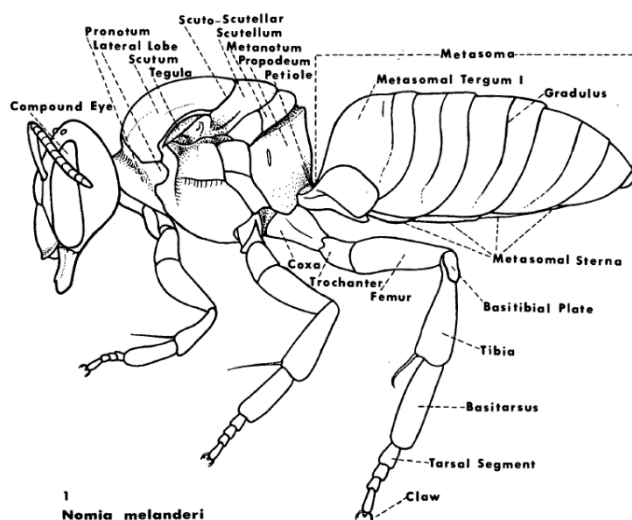


Figure 1: Lateral view of *Nomia melanderi* female

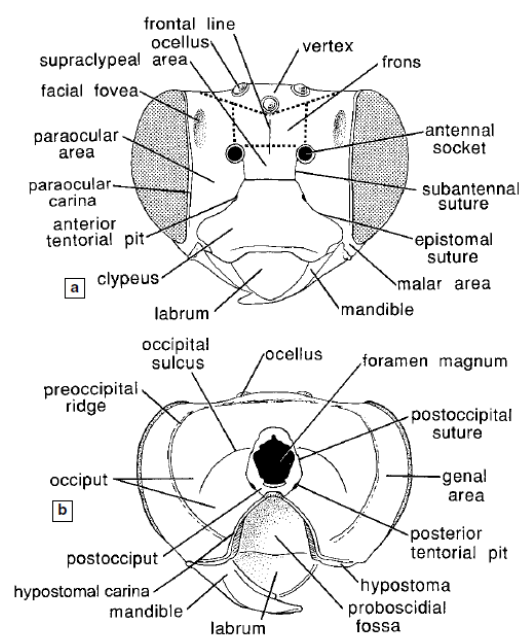


Figure 2: Diagrams of a bee's head, showing major structures. a, Anterior view; b, Posterior view. (From Michener, McGinley, and Danforth, 1994).

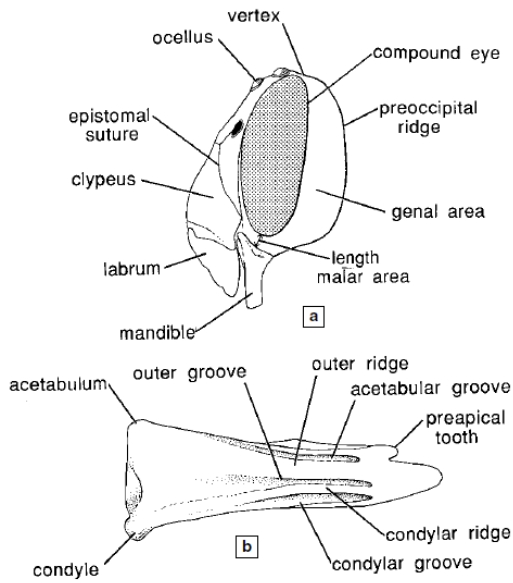


Figure 3: a, Diagrammatic lateral view of a bee's head; b, Outer surface of mandible (From Michener, McGinley, and Danforth, 1994).

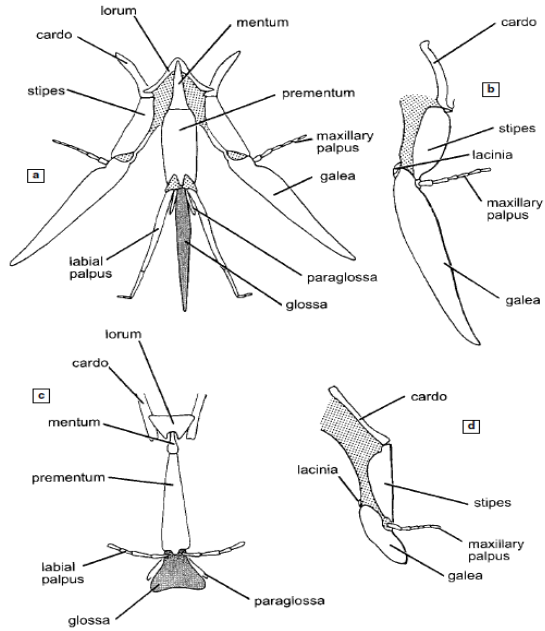


Figure 4: Diagrams of pro-boscides of bees. a, Spread proboscis of a long-tongued bee; b, Maxilla of the same; c, Labium of a short-tongued, in this case colletid, bee, showing portions of maxillary cardines at the base; d, Maxilla of the same (From Michener, McGinley, and Danforth, 1994).

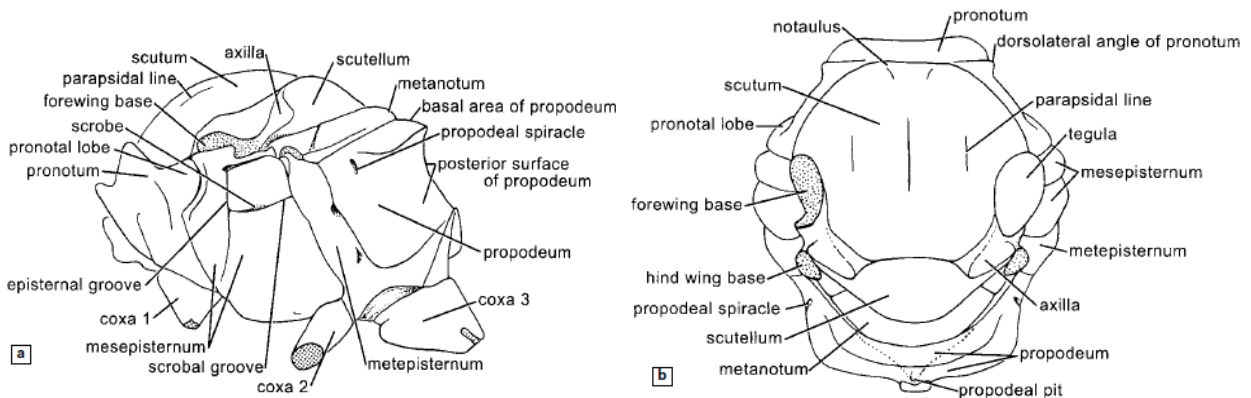


Figure 5: Diagrams of a bee's thorax. a, Lateral view; b, Dorsal view. (The tegula is omitted in a and the left side of b. The propodeal triangle is indicated by dotted lines in b) (From Michener, McGinley, and Danforth, 1994).

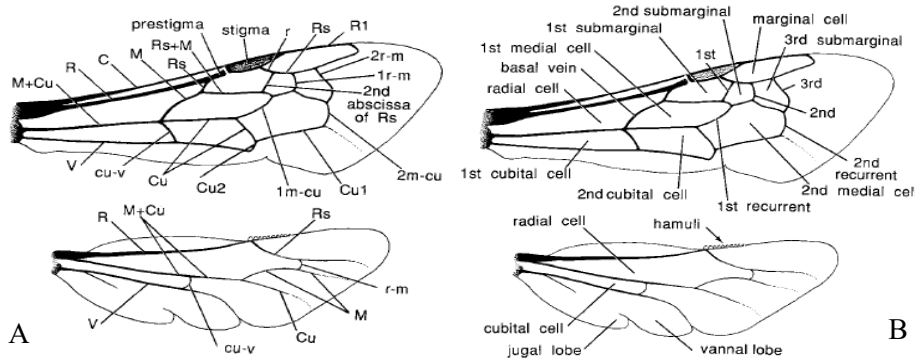


Figure 6: A, Diagram of fore wings of a bee, showing the venation terminology of Michener (1944). B, Diagram of the wings of a bee, showing frie terminology of cells and morphologically noncommittal terms for certain veins. From Michener, McGinley, and Danforth, 1994).

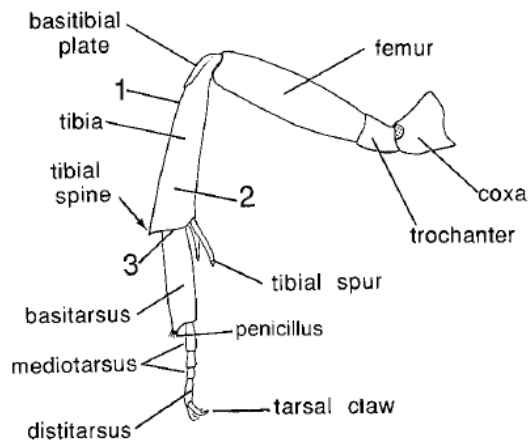


Figure 7: Hind leg of a female bee, hairs omitted except those that form the penicillus. The numeral indicates the posterior or upper margin of the tibia; 2, the outer surface; and 3, the distal or apical margin. Modified from Michener, McGinley, and Danforth, 1994.

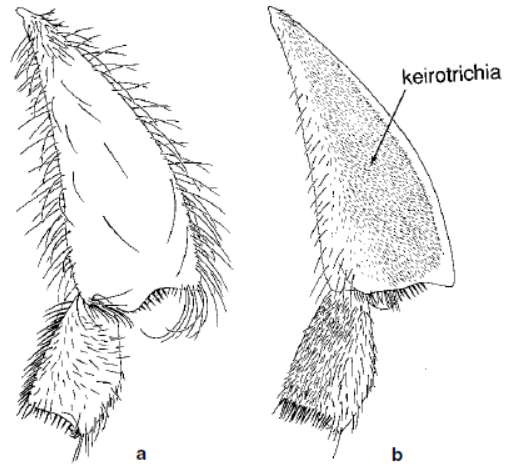


Figure 8: Hind tibia and basitarsus of a worker of *Plebeia frontalis* (Friese). a, Outer surfaces, showing the scopa reduced to fringes around the smooth and largely hairless tibial corbicula; b, Inner surfaces (Michener, McGinley, and Danforth, 1994).

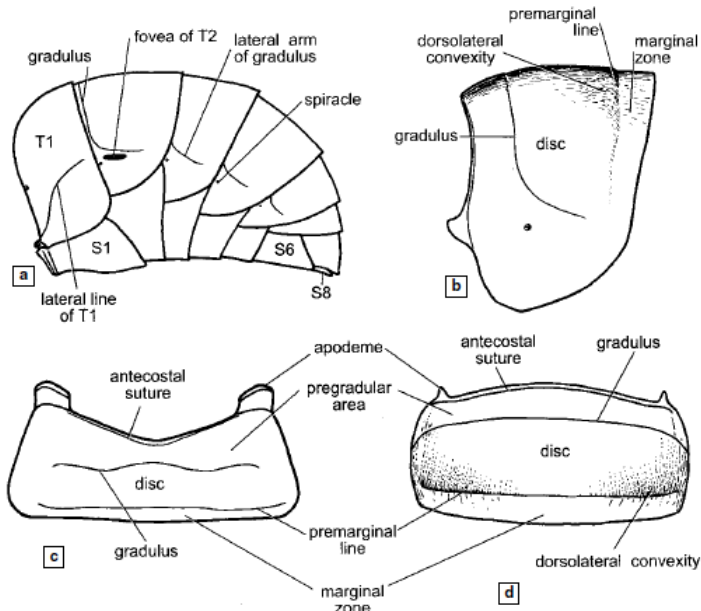


Figure 9: Metasomal structures of a male bee. a, Diagrammatic lateral view of the metasoma; b, Lateral view of T3; c, of S; d, Dorsal view of T3. a, b, and c, modified from Michener, 1944.

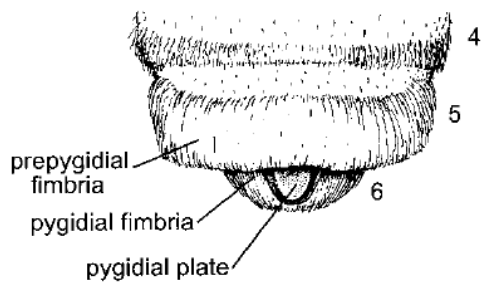


Figure 10: Diagram of apex of metasoma of a female bee, such as a eucerine, The tergal numbers are indicated on the righthand side.

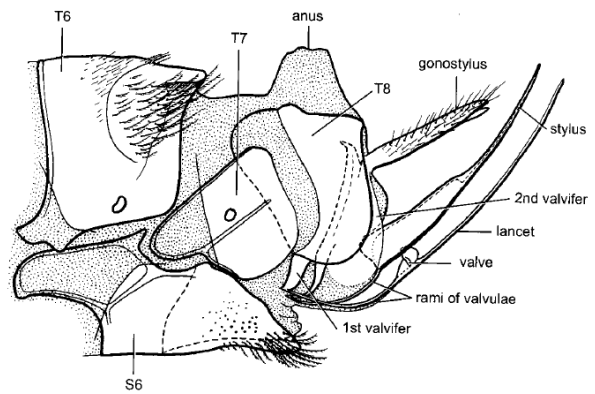


Figure 11: Apex of meta soma of a female *Halictus farinosus* Smith, the sting apparatus artificially extruded (Michener, 1944).

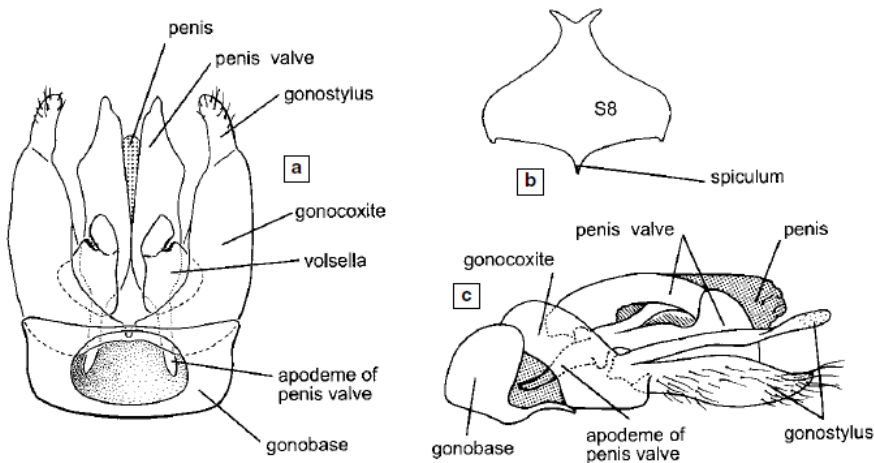


Figure 12: Terminal structures of male bees.

a, Diagram of ventral view of genitalia; *b*, Diagram of S8; *c*, Lateral view of male genitalia of *Coelioxoides exulans* (Holmberg), showing upper and lower gonostyli. *a*, *b*, modified from Michener, McGinley, and Danforth, 1994; *c*, from Roig-Alsina, 1990.

Order: Diptera

Head: Crampton's work (1942) serves as a comprehensive introduction to Diptera external anatomy, particularly highlighting the remarkable mobility and relatively large size of the head. Compound eyes, often larger in males, exhibit holoptic or dichoptic configurations, with occasional holoptic condition in females. Ocelli, typically forming a triangular arrangement, may be absent in some families. Terminology for head regions, though varied and sometimes confusing, includes descriptors such as "front," frontal triangle, and ocellar triangle. The face, demarcated by the frontal suture, is flanked laterally by facial ridges and terminates distally at the epistoma, with vibrissal angles housing vibrissae at its lower ends. The antennae, in Diptera play a significant role in classification, showcasing notable variations across different groups. In Nematocera, the flagellum typically comprises cylindrical segments, while in Brachycera, it consists of fewer, dissimilar elements with basal segments carrying a terminal appendage, often termed a style or arista. Cyclorrhapha feature antennae with three basal segments, the third being the largest and most complex, carrying the arista. The morphology of the arista, whether bare, plumose, or pectinate, provides valuable classificatory insights. Additionally, Cyclorrhapha possess a frontal sac or ptilinum, indicated externally by the arched frontal or ptilinal suture, aiding in puparium rupture during emergence (figure 13).

Mouthparts: The mouthparts, of Diptera display considerable structural diversity, adapted to various feeding habits. The labrum is typically well-sclerotized dorsally but more membranous ventrally, while mandibles are often reduced except in blood-sucking forms. Maxillae exhibit variability, with maxillary palpi serving classificatory purposes. The labium forms a proboscis, usually with expanded distal lobes or labella. Hypopharynx, likely universally present, varies in form. Blood-sucking Diptera show specialized trophi, with well-developed mandibles in

females. The proboscis morphology varies extensively, with adaptations for piercing and sucking in different families. The tentorium, characterized by three pairs of arms and reduced body, persists in modified forms, aiding in cranial support (figure 14).

Thorax: Dipteran thoracic anatomy highlights the well-developed second segment housing wings, with anterior and posterior regions reduced to supportive bands. Pronotal reduction is pronounced in higher Diptera, while the mesonotum, divisible into prescutum, scutum, and scutellum, features lateral swellings known as calli. Pleural interpretation, especially in Cyclorrhapha, requires precise definitions aided by Osten-Sacken's terminology based on sutures like the notopleural and sternopleural (figure 15).

Legs: The legs typically have five-segmented tarsi, with notable features including preapical bristles on tibiae in Acalyptratae and variations in foot pads such as pulvilli and arolium among different fly families.

Wings: Wing types varies among Diptera, with some species being apterous or sub-apterous, notably in maritime and parasitic genera. The venation of wings in primitive dipterans closely resembles a hypothetical primitive type, with variations including the atrophy of certain veins and the presence of accessory lobes like the alula and squamae. Halteres, modified from hind wings, are universally present except in a few apterous forms. These structures function as gyroscopic organs during flight, aiding in the control of the fly's movement, as demonstrated by experiments on their role in flight stability when partially or fully amputated (figure 16).

Chaetotaxy: Chaetotaxy, studied by Osten-Sacken (1884), focuses on the arrangement of bristles in flies, crucial for Diptera classification. Important macrochaetae include cephalic, thoracic, and abdominal bristles, aiding in systematic analysis of fly species. Key bristles include orbital, notopleural, dorsocentral, and marginal, offering valuable insights into fly morphology.

Abdomen: The first abdominal segment in Diptera is typically reduced, with *Tipula* species possessing segments 2 through 11, while Cyclorrhapha often exhibit only 4 or 5 visible segments. *Dacus* species display 11 segments, with the first represented by a reduced sternum. In female *Musca*, segments 2 to 5 are visible, while segments 6 to 10 form a retractile ovipositor. The male genitalia, often forming the hypopygium with segments 9 and 10, can exhibit a 180° twist (hypopygium inversum). Some families have a circumverse hypopygium, like Dolichophodidae. Genitalia include claspers and an aedeagus with accessory structures. Thoracic and abdominal spiracles vary in number and position, with regulation mechanisms discussed by Hassan (1944).

Diagrammatic representation of external morphology and body parts of an adult fly

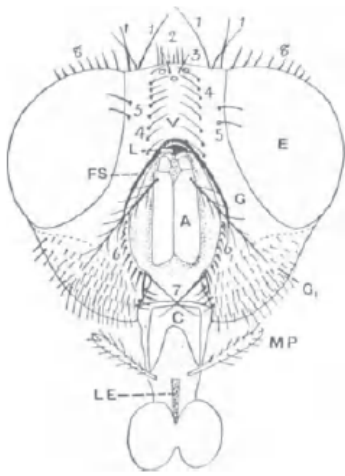


Figure 13: Frontal view Of head Of a Cyclorrhaphous fly (Schizophora). A, antenna; C, clypeus; E, eye; FS, frontal suture; G, gena and lower portion GI or jowl; L, lunule; LE, labrum; MP, maxillary palp; V, vertex. The numerals refer to the chaetotaxy.

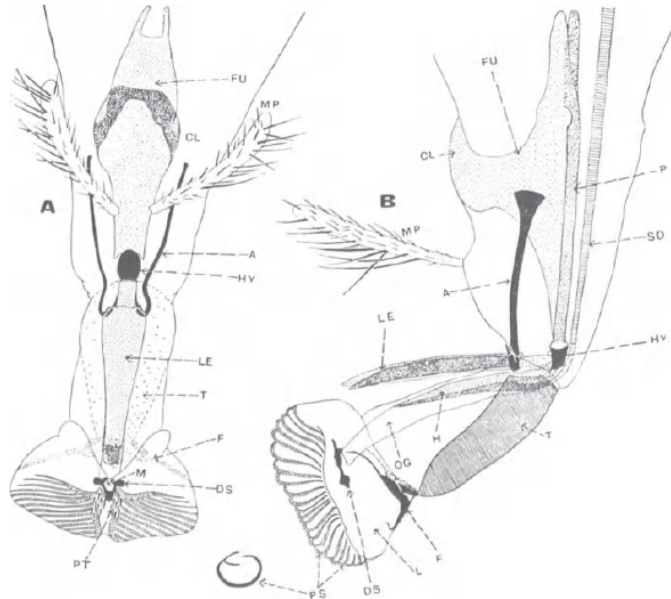


Figure 14: Proboscis of Calliphora. A, frontal; B, lateral view A, apodeme (stipes); CL, clypeus; DS, discal sclerite; F, furca; FU, furculum; H, hypopharynx; HY, theca; L, labellum; LE, labrum; M, mouth; MP, maxillary palpi; OG, oral groove; P, course of pharynx; PS, pseudotracheae; PT, prestomal teeth; T, prementum.

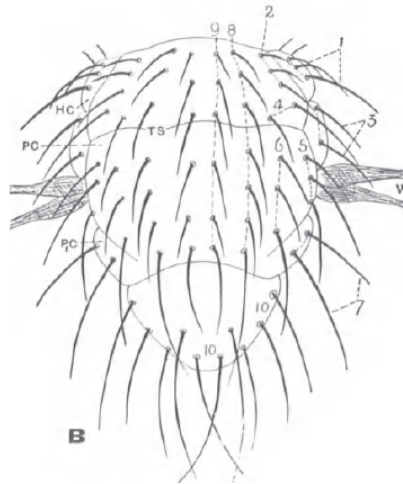
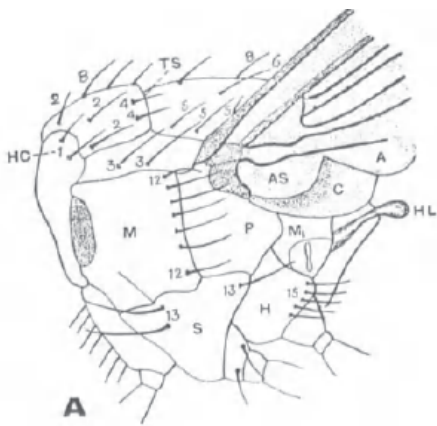


Figure 15: Thorax of A, *Lucilia caesar*; B, *Compsilura concinnata*, dorsal view (A, alula; AS, antisquama; C, calyptera; H, hypopleuron; HC, humeral callus; haltere; M, mesopleuron; MI, metapleuron; P, pteropleuron; PC, prealar callus; P1C, postalar callus; S, sternopleuron; TS, transverse suture; W, wing—base. The numerals refer to the chaetotaxy) Adapted from Surcouf and Gonzalez-Rincones.

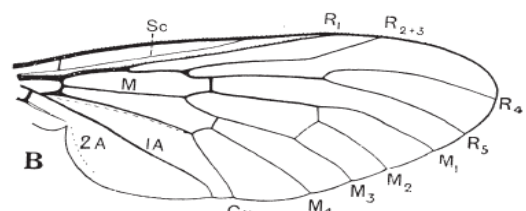
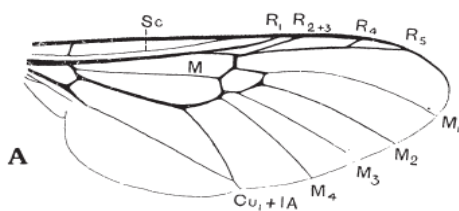


Figure 16: Venation of Brachycera. A, *Geosargus* (Stratiomyidae); B, *Rhagio*

Order: Lepidoptera

Head: The head of Lepidoptera, primarily comprises the frontoclypeus and large compound eyes. Behind the eyes lie two ocelli, often concealed by scales or seemingly absent. Some families feature chaetosemata sensory organs. The frontoclypeus, often delimited dorsally by a transfrontal sulcus, occupies the anterior region of the head. The labrum varies in shape, being narrow and pointed in some species and transversely plate-like in others. The antennae, composed of numerous segments, exhibit varying lengths and structures, with males typically displaying more pronounced development than females, notably in Saturniidae (figure 17A).

Mouthparts: The mouthparts in Lepidoptera are highly modified, with mandibles typically absent and maxillae forming a suctorial proboscis composed of elongated galeae for liquid feeding. Maxillary palpi are often reduced or absent, while labial palpi vary in size and structure. The proboscis, when fully developed, is spirally coiled and equipped with sclerotized rings and sensory papillae. Some species exhibit reduced or non-functional proboscis, while others retain primitive mandibulate mouthparts, as seen in *Sabatinca*, with functional dentate mandibles and elongated galeae. Tegicula maxillae show sexual dimorphism, with elongated inner lobes in females for pollen retention, potentially corresponding to greatly elongated palpifers (figure 17B).

Thorax: In Lepidoptera, the thorax exhibits a compressed and reduced prothorax, resembling a collar in higher families. The mesothorax is prominent, featuring a narrow prescutum, a large scutum, and a well-developed scutellum, often accompanied by distinct tegulae. The metathorax is relatively small, sometimes resembling the mesothorax, with a concealed postnotum and roughened areas engaging with the fore wings (figure 18).

Legs: The legs typically have limited mobility at the coxae, with primary movement occurring at the coxa-trochanter articulation. Certain species feature peculiar lamellate spurs on the inner surface of the anterior tibiae, while mid and hind tibiae usually bear one or two pairs of spurs.

Wings: Wings play significant role in identification of lepidoptera. The wings are covered by flattened scales derived from modified macrotrichia, transitioning into broader scales, with microtrichia present on wing membranes except in most Ditrysia. Innervation studies reveal three nerve branches supplying each wing, with various sensory organs present, possibly tactile or for orientation. Scales are secreted by enlarged ectodermal cells, exhibiting intricate structure and development, often ornamented with ridges and striae for rigidity and coloration. Specialized scales, like androconia in males, serve as scent organs, while wing venation demonstrates atrophy or coalescence rather than addition, with specialized wing-coupling

mechanisms ranging from frenate to amplexiform types. Flightless conditions in certain female Lepidoptera species are linked to reduced or absent wings, possibly as an adaptation to environmental factors or reproductive strategies (figure 19,20).

Abdomen: The abdomen of Lepidoptera comprises ten segments, with the 1st reduced and the 9th and 10th greatly modified for genitalia. The presence of a tympanum, mainly in larger nocturnal species, aids in detecting bat echolocation signals. Male genitalia, including the tegumen, claspers, uncus, and aedeagus, exhibit complex structures with taxonomic significance, while females may have telescoped terminal segments serving as an ovipositor, often with an exserted oviscap in certain groups (figure 21).

Diagrammatic representation of external morphology and body parts of an adult butterfly

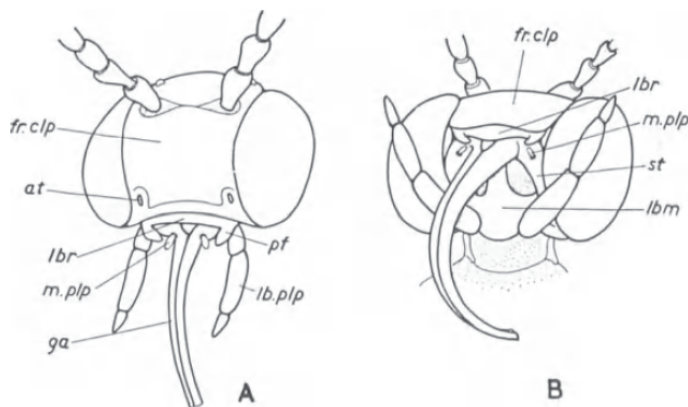


Figure 17: Head and mouthparts of Lepidoptera. A. Frontal view (Snodgrass, 1935). B. Ventral view (Weber, 1933).

a.t, anterior tentorial pit; fr.clp, fronto-clypeus; ga, galea; lbr, labrum; lb.plp, labial palp; m.plp, maxillary palp; pf, pilifer; st, stipes.

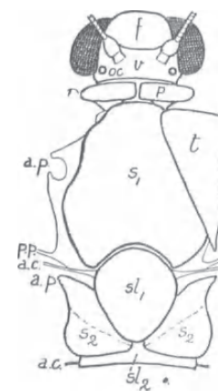


Figure 18: Dorsal view of head and thorax of *Nactua pronuba* (left tegula removed)

a.c, axillary cord; a.p, anterior wing process; oc, ocellus; p, patagium; pp, posterior wing process; st, mesoscutum; sli, mesoscutellum; s2, metascutum; sl2, postnotum; t, tegula.

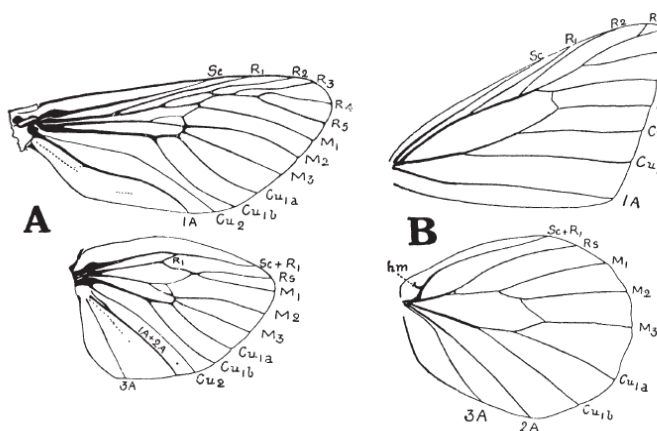


Figure 19: Venation of Ditrysia. A, *Prionoxystus robiniae* (Cossidae). After Comstock, lettering modified. B, *Pieris brassicae* (Pieridae). Original



Figure 20: Androconia of male butterflies (Comstock after Kellogg).

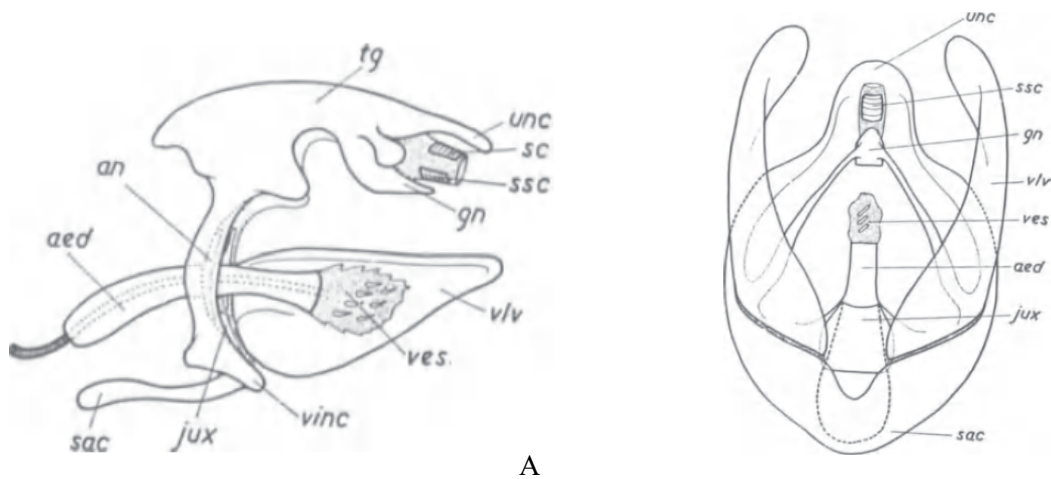


Figure 21: A - lateral view of male genitalia of *Lepidoptera*, left valve removed and B - ventral view of male genitalia of *Lepidoptera* (Viette, 1948).

aed, aedeagus; *an*, anellus; *gn*, gnathos; *jux*, juxta; *sac*, saccus; *sc*, scaphium; *ssc*, subscaphium; *tg*, tegumen; *unc*, uncus; *ves*, vesica; *vinc*, vinculum; *vlv*, valve.

Order: Coleoptera

Head: The head in beetles is heavily sclerotized, and while an epicranial sulcus is probably absent, some Hydrophilidae exhibit a Y-shaped sulcus, though it may be secondary. In many Curculionidae species and a few others, the frons and vertex extend anteriorly to form a rostrum, housing the mouthparts and antennae. Eyes vary greatly, from absent in certain species to large and contiguous in male Lampyridae. Eyeless Coleoptera are met with among cavernicolous species and in certain subterranean forms, including those living beneath boulders. Ocelli are rare, found in select Staphylinidae and other beetles. The clypeus typically consists of anteclypeus and postclypeus, with the latter often fused with the frons (figure 22,23).

Mouthparts: The labrum is very variably developed but is present in nearly all the families. Antennae vary widely in segments, from 1 to over 27. In Lucanidae males, mandibles can grow exceptionally large, sometimes surpassing the body length, and may branch like antlers. Weevils of Curculionidae exhibit vertical mandible movement due to dorsal condyle position. Mandibular scars in some Curculionid subfamilies support provisional mandibles shed after emergence. Maxillae typically have full development, with various specializations such as reduction in some groups like Corylophidae. Labium features a large mentum, variable ligula, and typically 3-segmented palps, though exceptions exist in certain beetle families (figure 22,28).

Thorax: The prothorax, often the largest thoracic segment, is typically freely movable, a notable trait of the order. Pronotum consists of a single sclerite, fully visible from above. Pleuron may lack division into sclerites, with absence of notopleural sulcus in Polyphaga. In some groups like Curculionoidea, prothoracic sclerites fuse into a single band. Coxal cavities may be entire or open, their significance in Adephaga classification is discussed. Meso- and metathorax are fused, with metathorax often well-developed; both segments typically covered by elytra, while furca details in metathorax aid in classification. The arms of the furca provide attachments for the leg muscles and are best developed in species which actively use their legs (figure 24).

Legs: Beetle legs are typically adapted for walking or running but are modified for various functions such as burrowing, swimming, or jumping in different families. Coxal form and tarsal segment count are crucial for classification. Adephaga and many Polyphaga exhibit primitive 5-segmented tarsi, while Chrysomeloidea and Curculionoidea show fusion of 4th and 5th segments. Specialized tarsal structures, particularly in males, are notable in groups like Dytiscidae and Staphylinoidea.

Wings (Elytra): In Coleoptera, elytra, modified mesothoracic wings, develop simultaneously with hind wings, but in certain families like Carabidae, Curculionidae, and Ptinidae, hind wings may be absent and elytra firmly united. Some Dytiscidae species exhibit varied wing reductions, including dimorphism with winged and brachypterous forms. In Scolytinae, female wing muscles may degenerate during oviposition and regenerate later. Elytra's hard texture results from thick cuticle layers and trabeculae connections. Elytra cavities contain blood, nerves, tracheae, and gland cells. Venation studies reveal distinct types: Adephagid with complete veins and oblongum cell, Staphylinid with vanished cross-veins, and Cantharid with M and Cu fusion forming a loop (figure 25,26).

Abdomen: The abdominal region in Coleoptera typically comprises eight externally visible tergites, with the 9th and 10th plates invaginated. The number of sternites varies, with five to seven visible externally, exhibiting four main types: Adephagid with fused hind coxae, haplogastrous with partial 2nd sternite, symphiogastrous with fused pleurites, and hologastrous with distinct 2nd sternite. Female terminal segments may be retractile and tubular for oviposition, while male genitalia, concealed within the abdomen, aid in classification based on tubular evagination and associated sclerites (figure 27).

Stridulating Organs: Stridulating organs are widespread in Coleoptera, varying in structure and location, often arising from friction between adjacent exoskeletal parts. Notably developed in Scarabaeoids, with file-like areas on the head or prosternum in certain families.

Cerambycidae exhibit diverse stridulatory mechanisms, while remarkable structures occur in larvae of Lucanidae, Passalidae, and Geotrupes, featuring ridges on middle coxae and modified hind legs for rasping. In Curculionidae, files on elytra or abdomen enable sound production through tubercle friction.

Diagrammatic representation of external morphology and body parts of an adult beetle



Figure 22: *Hydrophilus piceus*, dorsal view of head (A, vertex; B, clypeus; C, labrum; D, mandible; E, maxilla and F, its palp; G, antenna). Adapted from Newport.

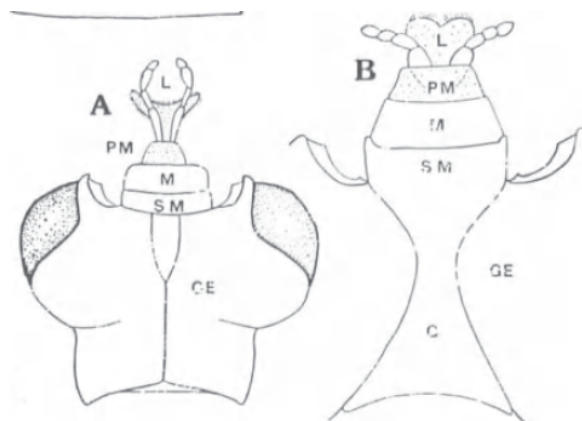


Figure 23: A, *Nicrophorus interruptus* (Silphidae), ventral aspect of Head. B, *Xylodrepa quadripunctata* (Silphidae), median ventral region of head.

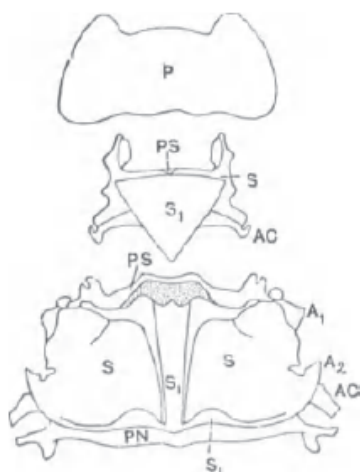


Figure 24: *Hydrophilus*, dorsal aspect of thorax with the segments disarticulated. A₁, anterior wing process; A₂, posterior do.; AC, axillary cord; P, pronotum; PN, postnotum; PS, prescutum; S, scutum; S₁, scutellum (Snodgrass, Proc. U.S. nat. Mus., 36).

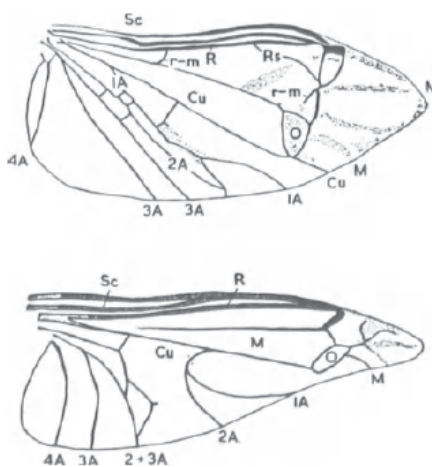


Figure 25: Adepagid type of wing. Above, Cupedidae (after Forbes). Below, Carabidae (original). O - oblongum.

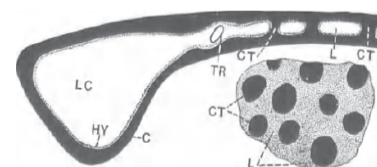


Figure 26: Transverse section. of a portion of an elytron of *Dytiscus* passing through the outer margin: below, a small area of an elytron seen in surface view (diagrammatic) C, cuticle; CT, trabeculae; HY, epidermis; L, lacunae; LC, lateral blood channel; TR, trachea.

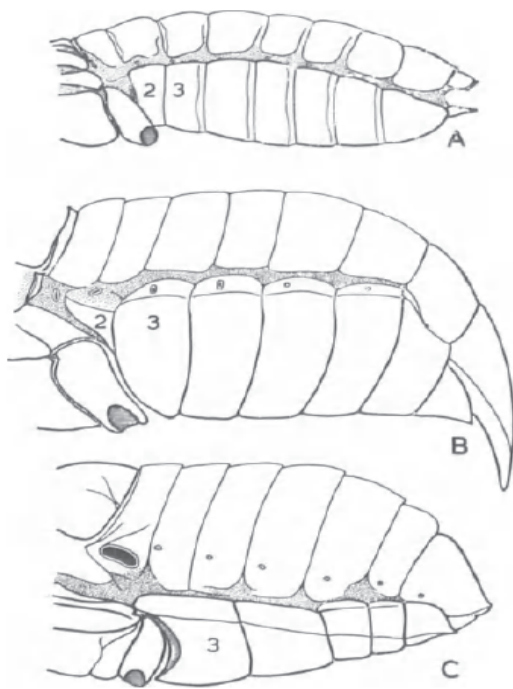


Figure 27: Three types of abdomens in Coleoptera. A, Hologastran (*Rhagonycha limbata*, Cantharidae). B, Haplogastran (*Melolontha melolontha*, Scarabaeidae). C, Symphiogastran (*Hylobius abietis*, Curculionidae). 2, 3: 2nd and 3rd abdominal sterna.

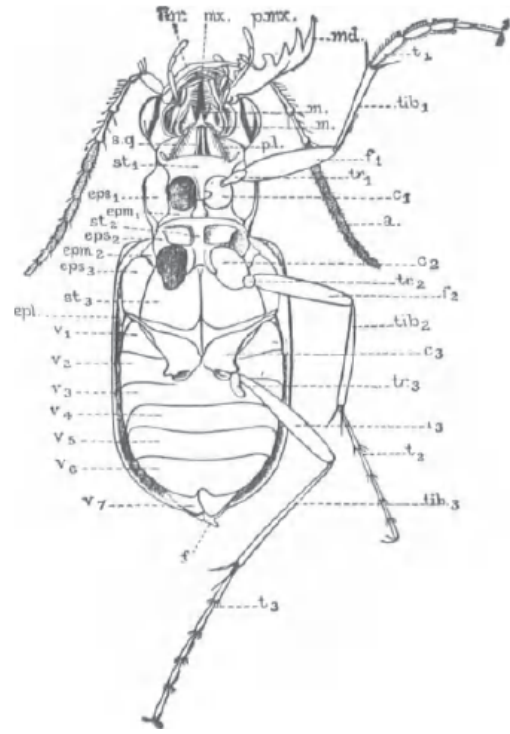


Figure 28: *Cicindela*, ventral aspect: male. lbr; anterior margin of labrum; md, mandible; mx, maxilla and p.m.x, palp; m, m, mentum; p.l, labial palp; s.g, gular sutures; st₁–st₃, thoracic sterna; eps₁–eps₃ episterna; epm₁–epm₂, epimera; epl, epipleuron; V₁–V₃, visible abdominal segments; f, aedeagus; c₁–c₃, coxae; tr₁–tr₃, trochanters; f₁–f₃, femora; tib₁–tib₃, tibiae; t₁–t₃, tarsi. From Fowler (F.B.I.), after Ganglbauer

Order: Thysanoptera

Doeksen (1941), and Jones (1954) have offered detailed insights into the external morphology of thrips species (figure 29).

Head: The head (Risler, 1957; Mickoleit, 1963) typically displays a somewhat quadrangular shape with small yet prominent compound eyes characterized by large, convex facets. Winged forms feature three ocelli on the vertex, while apterous ones lack them. Most head sclerites are closely fused, with barely discernible sulci, and the tentorium is greatly reduced. Antennae, typically 6 to 10-segmented, are closely positioned near the front and adorned with setae and chemoreceptor sensilla (Slifer & Sekhon, 1974) (figure 30).

Mouthparts: Reyne (1927) extensively studied mouthpart structure and development, informing the interpretation presented here. Mouthparts are adapted for piercing and suction, with structures modified as stylets enclosed within a short cone projecting downward from the ventral head surface (see Fig. 348). Among Terebrantia, the left mandible is a strong sclerotized

stylet, while the right is absent in postembryonic stages. Maxillae consist of palpbearing plates with associated stylets, forming the mouth-cone's side walls. The palps are composed of 2-8 segments among different genera. Differences in mouthparts among Tubulifera include mandibular articulation and maxillary stylet connections with the head capsule (figure 30).

Thorax: The prothorax is distinct, while the meso- and metathorax are compactly united (Mickoleit, 1961). Legs exhibit typical components, with tarsi, often 1- or 2-segmented, featuring weak claws and a protrusible vesicle aiding in surface adhesion. Wings are narrow and strap-shaped, often lacking veins or possessing few, with long setae and occasional spines along veins. Wing development variations are common among species.

Abdomen: The abdomen, consisting of 11 segments, features modifications in terminal segments related to external genitalia. Tubulifera lack an ovipositor, with a long, cylindrical tenth segment. Terebrantia have a small tenth segment and a conspicuous serrated ovipositor derived from eighth and ninth abdominal segment appendages. Males in both suborders possess an eversible aedeagus flanked by one or two pairs of parameres, the taxonomic significance of which varies (De Gryse & Treherne, 1924; Pitkin, 1972).

Diagrammatic representation of external morphology and body parts of an adult Thrip

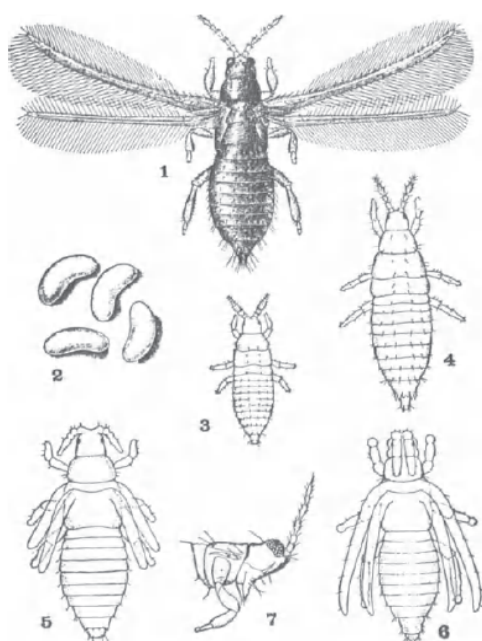


Figure 29: The Pear Thrips (*Taeniothrips inconsequens*) 1, Adult; 2, eggs; 3, 1st instar nymph; 4, fully-grown nymph; 5, prepupa; 6, pupa; 7, lateral view of head of adult (Foster and Jones, U.S. Dept. Agric. Bull., 173).

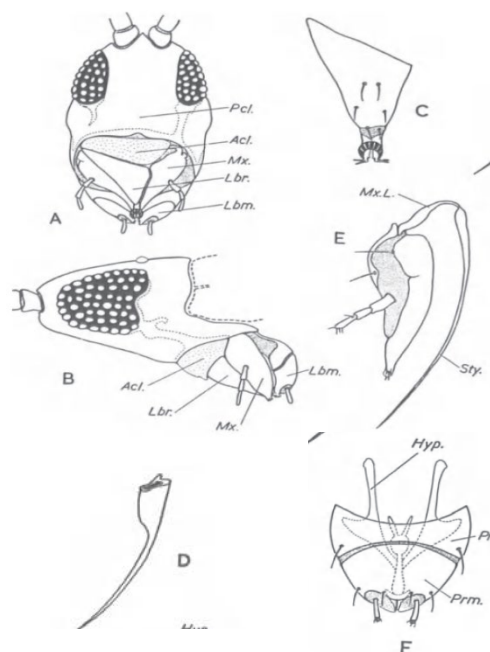


Figure 30: Head and mouthparts of *Chirothrips hamatus* (after Jones, 1954). A. Frontal view of head. B. Lateral view of head. C. Labrum. D. Left mandible. E. Maxilla. F. Labium and hypopharynx (Acl, anteclypeus; Hyp, hypopharynx; Lbm, labium; Lbr, labrum; Mx, maxilla; Mx.L, maxillary lever; Pcl, postclypeus; Pm, postmentum; Pym, prementum).

Annexure 2: List of insect visitors of apple and plum orchards recorded from Kullu valley

Order: Hymenoptera					
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank
1. Andrenidae	1	<i>Andrena</i> sp.1	11	0.17	28
	2	<i>Andrena</i> sp.2	2	0.03	32
	3	<i>Andrena</i> sp.3	32	0.51	16
	4	<i>Andrena</i> sp.4	17	0.27	22
	5	<i>Andrena</i> sp.6	18	0.29	21
2. Apidae	6	<i>Amegilla zonata</i> (Fabricius,1775)	84	1.34	6
	7	<i>Anthophora</i> sp.	15	0.24	24
	8	<i>Apis cerena indica</i> (Fabricius, 1798)	422	6.71	1
	9	<i>Apis dorsata</i> (Fabricius, 1793)	15	0.24	24
	10	<i>Apis laboriosa</i> (Smith,1871)	16	0.25	23
	11	<i>Apis mellifera</i> (Linnaeus,1758)	249	3.96	2
	12	<i>Bombus haemorrhoidalis</i> (Smith,1852)	94	1.5	5
	13	<i>Bombus lucorum</i> (Linnaeus,1761)	3	0.05	31
	14	<i>Bombus tunicatus</i> (Smith,1852)	14	0.22	25
	15	<i>Ceratina braynti</i> (Cockerell, 1919)	30	0.48	18
	16	<i>Ceratina cognata</i> (Smith, 1879)	8	0.13	29
	17	<i>Ceratina muscatella</i> (Nurse, 1902)	38	0.6	15
	18	<i>Ceratina smaragdula</i> (Fabricius,1787)	75	1.19	8
	19	<i>Ceratina</i> sp (Smith,1854)	5	0.08	30
	20	<i>Xylocopa dejeanii</i> (Ma, 1938)	30	0.48	18
	21	<i>Xylocopa fenestrata</i> (Fabricius,1798)	14	0.22	25

	22	<i>Xylocopa latipes</i> (Drury,1773)	67	1.07	10	
	23	<i>Xylocopa aestuans</i> (Linnaeus,1758)	2	0.03	32	
	24	<i>Xylocopa</i> sp. (Fabricius, 1793)	2	0.03	32	
3.	Crabonidae	25	<i>Astata</i> sp.	23	0.37	19
4.	Halictidae	26	<i>Halictus</i> sp.	17	0.27	22
		27	<i>Nomia elliotii</i> (Smith 1875)	43	0.68	13
		28	<i>Nomia</i> sp.	19	0.3	20
5.	Megachilidae	29	<i>Megachilae lanata</i> (Fabricius, 1775)	140	2.23	3
		30	<i>Megachilae</i> sp. (Linnaeus,1758)	34	0.54	16
		31	<i>Osmia caerulescens</i> (Linnaeus,1758)	95	1.51	4
6.	Scoliidae	32	<i>Campsomeris sauteri</i> (Betrem,1928)	77	1.22	7
7.	Sphecidae	33	<i>Ammophila</i> sp.	46	0.73	12
		34	<i>Chalybion bengalense</i> (Dahlbom, 1845)	39	0.62	14
8.	Vespidae	35	<i>Eumenes</i> sp. (Nurse, 1903)	3	0.05	31
		36	<i>Polistes stigma</i> (Fabricius, 1793)	70	1.11	9
		37	<i>Polistes dorsalis</i> (Fabricius,1775)	64	1.02	11
		38	<i>Vespa auraria</i> (Smith,1852)	13	0.21	26
		39	<i>Vespa tropica</i> (Linnaeus,1758)	2	0.03	32
		40	<i>Vespa velutina</i> (Lepeletier, 1836)	12	0.19	27
		41	<i>Vespula flaviceps</i> (Smith 1870)	18	0.29	21
Order: Diptera						
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank	
1.	Bibionidae	1	<i>Biblio</i> sp.	50	0.8	20
		2	<i>Plecia</i> sp.	57	0.91	18
2.	Calliphoridae	3	<i>Lucilia sericata</i> (Meigen, 1826)	44	0.7	21

	4	<i>Chrysoma megacephala</i> (Fabricius, 1794)	202	3.21	2
	5	<i>Calliphora</i> sp. (Robineau-Desvoidy, 1830)	83	1.32	13
3. Conopidae	6	<i>Conops</i> sp. (Linnaeus, 1758)	30	0.48	30
4. Muscidae	7	<i>Musca</i> sp.	26	0.41	28
5. Sarcophagidae	8	<i>Sarcophaga</i> sp.	38	0.6	23
6. Scathophagidae	9	<i>Scathophaga</i> sp.1 (Meigen, 1803)	28	0.45	27
	10	<i>Scathophaga</i> sp.2 (Meigen, 1803)	25	0.4	29
7. Sepsidae	11	<i>Sepsis</i> sp.	12	0.19	33
8. Syrphidae	12	<i>Eristalis tenax</i> (Linnaeus, 1758)	241	3.83	1
	13	<i>Meliscaeva cinctella</i> (Zetterstedt, 1843)	169	2.69	5
	14	<i>Scaeva pyrastris</i> (Linnaeus, 1758)	63	1	17
	15	<i>Sphaerophoria Indiana</i> (Bigot, 1880)	130	2.07	8
	16	<i>Eupeodes latifasciatus</i> (Macqvert, 1829)	132	2.1	6
	17	<i>Eristalinus taeniops</i> (Wiedemann, 1818)	88	1.4	10
	18	<i>Eristalis arbustorum</i> (Linnaeus, 1758)	85	1.35	12
	19	<i>Mesembrius bengalensis</i> (Wiedemann, 1819)	65	1.03	16
	20	<i>Episyrphus balteatus</i> (De Gear, 1776)	173	2.75	3
	21	<i>Ischiodon scutellaris</i> (Fabricius, 1805)	86	1.37	11
	22	<i>Sphaerophoria scripta</i> (Linnaeus, 1758)	74	1.18	14
	23	<i>Eristalis similis</i> (Fallén, 1817)	131	2.08	7
	24	<i>Eristalis horticola</i> (De Gear, 1776)	95	1.51	9
	25	<i>Eupeodes corollae</i> (Fabricius, 1794)	172	2.74	4

	26	<i>Eristalis himalayensis</i> (Brunetti, 1908)	51	0.81	19
	27	<i>Eristalinus arvorum</i> (Fabricius, 1787)	88	1.4	10
	28	<i>Syrphus ribesii</i> (Linnaeus, 1758)	70	1.11	15
	29	<i>Eupeodes</i> sp.1 (Ostensacken, 1877)	26	0.41	28
	30	<i>Eristalinus paria</i> (Bigot, 1880)	40	0.64	22
	31	<i>Eupeodes</i> sp.2	8	0.13	34
	32	<i>Melanostoma orientale</i> (Wiedemann, 1824)	37	0.59	24
	33	<i>Eristalis</i> sp.	17	0.27	30
	34	<i>Scaeva latimaculata</i> (Brunetti, 1923)	38	0.6	23
	35	<i>Episyrphus</i> sp.	29	0.46	26
	36	<i>Syrphus</i> sp. (Fabricius, 1775)	12	0.19	33
	37	<i>Eristalis cerealis</i> (Fabricius, 1805)	14	0.22	31
	38	<i>Betasyrphus</i> sp.	13	0.21	32
9. Tipulidae	39	<i>Nephrotoma</i> sp.	40	0.64	22
Order: Lepidoptera					
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank
1. Lycaenidae	1	<i>Pseudozizeeria maha</i> (Kollar, 1844)	88	1.4	8
	2	<i>Lycaena phlaeas</i> (Linnaeus, 1761)	101	1.61	6
2. Noctuidae	3	<i>Helicoverpa armigera</i> (Hübner, 1808)	3	0.05	17
	4	<i>Mythimna separata</i> (Walker, 1865)	1	0.02	18
3. Nymphalidae	5	<i>Kaniska canace</i> (Linnaeus, 1763)	90	1.43	7
	6	<i>Vanessa indica</i> (Herbst, 1794)	19	0.3	13
	7	<i>Aglais caschmirensis</i> (Kollar, 1848)	246	3.91	1
	8	<i>Neptis hylas</i> (Linnaeus, 1758)	34	0.54	10
	9	<i>Phalanta phalantha</i> (Dury, 1773)	16	0.25	15
	10	<i>Junonia</i> sp.	18	0.29	14

4.	Papilionidae	11	<i>Papilio bianor</i> (Cramer, 1777)	38	0.6	9
		12	<i>Byasa polyeuctes</i> (Doublyday, 1842)	29	0.46	12
5.	Pieridae	13	<i>Pieris brassicae</i> (Linnaeus, 1758)	197	3.13	3
		14	<i>Pieris canidia</i> (Sparrman, 1768)	141	2.24	5
		15	<i>Colias fieldii fieldii</i> (Ménétriés, 1855)	232	3.69	2
		16	<i>Eurema hecabe</i> (Linnaeus, 1758)	146	2.32	4
		17	<i>Catopsilia pomona</i> (Fabricius, 1775)	32	0.51	11
		18	<i>Gonepteryx rhamni</i> (Linnaeus, 1758)	4	0.06	16
Order: Coleoptera						
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank	
1. Coccinellidae	1	<i>Coccnella septempunctata</i> (Linnaeus, 1758)	10	0.16	1	
	2	<i>Menochilus sexmaculata</i> (Fabricius, 1781)	3	0.05	3	
	3	<i>Priscibrumus uropygialis</i> (Mulsant, 1853)	2	0.03	4	
2. Chrysomelidae	3	<i>Altia cyanea</i> (Weber, 1801)	6	0.1	2	
3. Scarabaeidae	4	<i>Maladera</i> sp.	2	0.03	4	
4. Carabidae	6	<i>Amara</i> sp.	2	0.03	4	
	7	<i>Calosoma aruoupunctatum</i> (Herbst, 1784)	1	0.02	5	
Order: Thysanoptera						
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank	
<i>Thripidae</i>	1	<i>Thrips hawaiiensis</i> (Morgan, 1913)	20	0.23	3	
	2	<i>Thrips florum</i> (Schmutz, 1913)	25	0.4	1	
	3	<i>Thrips palmi</i> (Karny, 1925)	21	0.33	2	

Annexure 3: List of insect visitors of apple and plum orchards recorded from Tirthan valley

Order: Hymenoptera					
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank
1. Andrenidae	1	<i>Andrena</i> sp.3	4	0.13	21
	2	<i>Andrena</i> sp.4	11	0.37	19
	3	<i>Andrena</i> sp.5	14	0.47	17
2. Apidae	4	<i>Amegilla zonata</i> (Fabricius,1775)	52	1.73	7
	5	<i>Anthophora</i> sp.	21	0.7	14
	6	<i>Apis laboriosa</i> (Smith,1871)	187	6.22	2
	7	<i>Apis mellifera</i> (Linnaeus,1758)	11	0.37	19
	8	<i>Apis cerena cerena indica</i> (Fabricius, 1798)	289	9.62	1
	9	<i>Bombus haemorrhoidalis</i> (Smith,1852)	62	2.06	4
	10	<i>Bombus lucorum</i> (Linnaeus,1761)	8	0.27	20
	11	<i>Bombus tunicatus</i> (Smith,1852)	11	0.37	19
	12	<i>Ceratina (neoceratina) dentipes</i> (Friese, 1914)	25	0.83	12
	13	<i>Ceratina cognata</i> (Smith, 1879)	34	1.13	11
	14	<i>Ceratina muscatella</i> (Nurse, 1902)	42	1.4	8
	15	<i>Ceratina smaragdula</i> (Fabricius,1787)	25	0.83	12
	16	<i>Xylocopa dejeanii</i> (Ma, 1938)	18	0.6	15
	17	<i>Xylocopa latipes</i> (Drury,1773)	61	2.03	5
3. Halictidae	18	<i>Nomia elliotii</i> (Smith 1875)	16	0.53	16
	19	<i>Nomia</i> sp.	3	0.1	22
	20	<i>Lasioglossum</i> sp.1	18	0.6	15
	21	<i>Lasioglossum</i> sp.2	37	1.23	10
	22	<i>Lasioglossum</i> sp.3	16	0.53	16

4. Megachilidae	23	<i>Megachile lanata</i> (Fabricius, 1775)	58	1.93	6
	24	<i>Osmia caerulescens</i> (Linnaeus, 1758)	22	0.73	13
5. Scoliidae	25	<i>Campsomeris sauteri</i> (Betrem, 1928)	8	0.27	20
6. Sphecidae	26	<i>Chalybion bengalense</i> (Dahlbom, 1845)	13	0.43	18
7. Vespidae	27	<i>Polistes dorsalis</i> (Fabricius, 1775)	41	1.36	9
	28	<i>Polistes stigma</i> (Fabricius, 1793)	81	2.7	3
	29	<i>Vespula flaviceps</i> (Smith 1870)	25	0.83	12
8. Pompilidae	30	<i>Anoplius</i> sp.	21	0.7	14
Order: Diptera					
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank
1. Bibionidae	1	<i>Biblio</i> sp.	51	1.7	9
2. Calliphoridae	2	<i>Chrysoma megacephala</i> (Fabricius, 1794)	84	2.8	3
	3	<i>Calliphora</i> sp.	25	0.83	16
	4	<i>Lucilia sericata</i> (Meigen, 1826)	11	0.37	20
3. Conopidae	5	<i>Conops</i> sp.	8	0.27	22
4. Syrphidae	6	<i>Scaeva latimaculata</i> (Brunetti 1923)	46	1.53	12
	7	<i>Scaeva pyrastris</i> (Linnaeus, 1758)	42	1.4	13
	8	<i>Scaeva</i> sp.	13	0.43	19
	9	<i>Sphaerophoria Indiana</i> (Bigot, 1880)	47	1.56	11
	10	<i>Sphaerophoria scripta</i> (Linnaeus, 1758)	10	0.33	21
	11	<i>Eristalinus arvorum</i> (Fabricius, 1787)	48	1.6	10
	12	<i>Eristalinus taeniops</i> (Wiedemann, 1818)	14	0.47	18
	13	<i>Eupeodes corollae</i> (Fabricius, 1794)	52	1.73	8
	14	<i>Eupeodes latifasciatus</i> (Macqvert, 1829)	68	2.26	6
15	<i>Meliscaeva cinctella</i> (Zetterstedt, 1843)	84	2.8	3	

	16	<i>Mesembrius bengalensis</i> (Wiedemann, 1819)	33	1.1	15
	17	<i>Eristalis arbustorum</i> (Linnaeus, 1758)	96	3.19	2
	18	<i>Eristalis cerealis</i> (Fabricius, 1805)	11	0.37	20
	19	<i>Eristalis himalayensis</i> (Brunetti, 1908)	11	0.37	20
	20	<i>Eristalis horticola</i> (De Gear, 1776)	34	1.13	14
	21	<i>Eristalis similis</i> (Fallén, 1817)	76	2.53	4
	22	<i>Eristalis</i> sp.	10	0.33	21
	23	<i>Eristalis tenax</i> (Linnaeus, 1758)	71	2.36	5
	24	<i>Episyrphus balteatus</i> (De Gear, 1776)	115	3.83	1
	25	<i>Syrphus ribesii</i> (Linnaeus, 1758)	19	0.63	17
	26	<i>Ischiodon scutellaris</i> (Fabricius, 1805)	60	2	7
Order: Lepidoptera					
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank
1. Nymphalidae	1	<i>Aglais caschmirensis</i> (Kollar, 1848)	92	3.06	1
	2	<i>Kaniska canace</i> (Linnaeus, 1763)	3	0.1	13
	3	<i>Vanessa cardui</i> (Linnaeus, 1758)	27	0.9	10
	4	<i>Neptis hylas</i> (Linnaeus, 1758)	51	1.7	5
	5	<i>Phalanta phalantha</i> (Dury, 1773)	3	0.1	13
2. Lycaenidae	6	<i>Lycaena phlaeas</i> (Linnaeus, 1761)	40	1.33	7
	7	<i>Pseudozizeeria maha</i> (Kollar, 1844)	44	1.46	6
	8	<i>Aricia agestis nazira</i> (Moore, 1865)	1	0.01	14
	9	<i>Heliophorus moorei</i> <i>coruscans</i> (Moore, 1882)	40	1.33	7
3. Papilionidae	10	<i>Papilio bianor</i>	3	0.1	13

		(Cramer, 1777)			
	11	<i>Byasa polyeuctes</i> (Doublyday, 1842)	36	1.2	8
4. Pieridae	12	<i>Pieris brassicae</i> (Linnaeus, 1758)	84	2.8	2
	13	<i>Pieris canidia</i> (Sparman, 1768)	66	2.2	3
	14	<i>Eurema andersoni</i> (Moore, 1886)	32	1.06	9
	15	<i>Colias fieldii fieldii</i> (Ménétriés, 1855)	56	1.86	4
	16	<i>Delias belladonna</i> (Fabricius, 1793)	7	0.23	11
	17	<i>Belenois aurota</i> (Fabricius, 1793)	5	0.17	12
Order: Coleoptera					
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank
1. Coccinellidae	1	<i>Coccinella septempunctata</i> (Linnaeus, 1758)	9	0.3	1
	2	<i>Menochilus sexmaculata</i> (Fabricius, 1781)	7	0.23	2
Order: Thysanoptera					
Family	S. No.	Species	Number of individuals	Relative abundance (%)	Rank
1. Thripidae	1	<i>Thrips hawaiiensis</i> (Morgan, 1913)	27	0.9	1

Annexure 4: Questionnaire survey sheet**Questionnaire for orchard owners/managers**

1. Grid reference:

2. Location/address of orchard:

3. Owner name:

4. Contact number:

5. Age:

6. Gender:

7. Family members:

8. Dependent members:

9. Earning members:

10. Dependency percentage:

11. Other occupation:

12. Size of orchard (ha/sqm/bigha):

13. Fruit crop: Apple plum

14. Types of varieties:

15. No of trees:

16. Approx. age of trees:

17. Orchard floor management?

Unmanaged	Mown
Entirely scrubbed over	Neglected
Mixed farming of vegetable	Deadwood retained on ground
Cattle grazed	Natural grass only

18. If managed orchard,

Traditional	Modern	Both
Traditional	Modern	Both

19. If mixed farming of vegetable, what are the crop sown?

20. What are the other fruit crops cultivated?

21. Management of trees?

Standing dead trees left	Deadwood retained in canopy	Tree replacements or additions	Regularly pruned	Obvious livestock damage to trees
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22. Season of crop harvesting?

May-June-July

July-Aug-Sept

Sept-Oct-Nov

23. Any change in fruit plantation: Y / N

23. If Yes, why?

24. What is the yearly yield of the orchard (*How many crates and how much weight per crate?*)?

25. Has the yield of orchard increased or decreased in the last 5 years? Y / N / No change

26. Decreased then what is the reason? / If increased then what is the reason?

27. What is the monetary benefit (total income) from your orchard? (*One crate for how much?*)

28. How the cropping practices changed over years?

Traditional to Modern	
Monoculture to Mixed culture	
Mixed culture to mono culture	
No change (Always monoculture / Always mixed culture)	

29. What are the Insecticides/Pesticides/Fungicides used? (*Intensity of use?*)

- A. Danitol:
- B. Dimethoate:
- C. Durmet:
- D. Chlorpyrifos;
- E. Imidacloprid:
- F. Horticultural mineral oil (HMO):
- G. Bordo (Bordeaux) mixture:
- H. Carbendazim:
- I. Bavistin:
- J. Mancozeb M45:
- K. Any other?

30. Any micronutrient used? (*Composition and intensity of use?*)

31. What are used for increasing soil fertility? (*Intensity of use?*)

32. Any other use of orchard (bee rearing by you or others for honey /poultry/cattle): Y / N

33. If Yes, What?

34. Do you keep bee hives for pollination? Y / N
35. Are the boxes owned by you or / are they placed by some other source or / hired?
36. If **hired**, how much do you pay?
37. If placed by others then do, they pay you for it? Y / N
38. If **Yes**, how much do they pay?
39. If **No**, then what do you get?
40. Which season (month) do you put the boxes?
41. If the boxes are owned by you then do you sell Honey? Y / N
42. If **Yes**, Yearly yield of honey?
43. Seasonal market price of honey?
44. Do you produce anything else other than honey? Y / N
45. If **Yes**, what?
46. Type of insects visit flowers: Butterflies Flies Bugs Beetles Wasp
47. Do you leave old trees in your farm? Y / N
48. If **Yes**, then what age trees do you leave?
49. Do you have any source of water in and around the orchard? Y / N
50. If **Yes**, then what?
51. Any variation in pollinator visitation rate (in last 5/10 years)?
 Increase /decrease /no change
52. If change, reason of change?
53. Other comment

Filled by:

date:

Influence of Different Landscape Configurations on Insect Pollinators of Important Horticultural Crops in A Western Himalayan Landscape

Pollinators play critical roles in ecosystem stability and agricultural productivity, and their decline has become a global concern. One of the main reasons for pollinators decline is changing landscape configuration. We conducted this study in Kullu Valley of Himachal Pradesh, India to evaluate impact of varied landscape configuration on the diversity, richness, and abundance of insect pollinators in apple and plum orchards. Five different landscape configurations were considered for the study. The survey spanned 28 orchards across the valley during the blooming periods of 2021 and 2022. Standard sampling protocols were used to collect the pollinator specimen. Authors recorded a total of 108 insect species across 66 genera, 27 families and five orders (Hymenoptera, Lepidoptera, Diptera, Coleoptera, and Thysanoptera) from different orchards. Hymenoptera and Diptera were the most abundant pollinators in the study area. Pollinator richness and diversity were higher in orchards located within 1-km distance of natural forests and in lower elevations (>1500 meters). Orchards near large settlements, agricultural lands and complete modernised management practice showed comparative less pollinator diversity, richness, and abundance. This study demonstrates the influence of diverse land-use practices on pollinators on a landscape scale and provides insights for developing effective conservation strategies in the Himalaya.

Key words: Pollination, Himachal Pradesh, Landscape, Conservation strategies

Introduction

Pollinators play a crucial role in ecosystems by maintaining biodiversity, sustaining natural habitats, and supporting agricultural productivity (Misganaw *et al.*, 2017). Beyond their ecological significance, pollinators contribute immensely to global food production, ensuring the growth of many crops for human and animal sustenance (Klein *et al.*, 2007). Their economic contribution to global agriculture has been estimated at 153 billion pounds (€) annually (Gallai *et al.*, 2009). Apart from bees, there are various non-bee pollinators such as flies, moths, butterflies, beetles, ants, wasps, birds, and bats, who play a crucial role in pollination by providing 39% of crop pollination visits (Rader *et al.*, 2016, 2020). Studies have recorded that 84% of total pollen is carried by non-syrphid dipteran flies (Orford *et al.*, 2015). However, their contribution is little explored.

In recent years, there has been a significant decline in both the abundance and diversity of insect pollinators (Ghazoul, 2005; Steffan-Dewenter *et al.*, 2005; Biesmeijer *et al.*, 2006; Williams and Osborne, 2009). While much attention has been given to the decline of managed honeybee populations due to Colony Collapse Disorder (Oldroyd, 2007), several wild bee species have also experienced sharp declines and, in many cases, have disappeared from their historic natural ranges (Biesmeijer *et al.*, 2006; National Research Council, 2007; Potts *et al.*, 2010; Cameron *et al.*, 2011)

In the past few years, a disturbance in crop pollination services due to

*Study reveals
landscape
configuration impacts
pollinator diversity in
Kullu Valley's
orchards, with higher
richness near forests
and lower elevations,
and less diversity near
settlements and
agricultural lands.*

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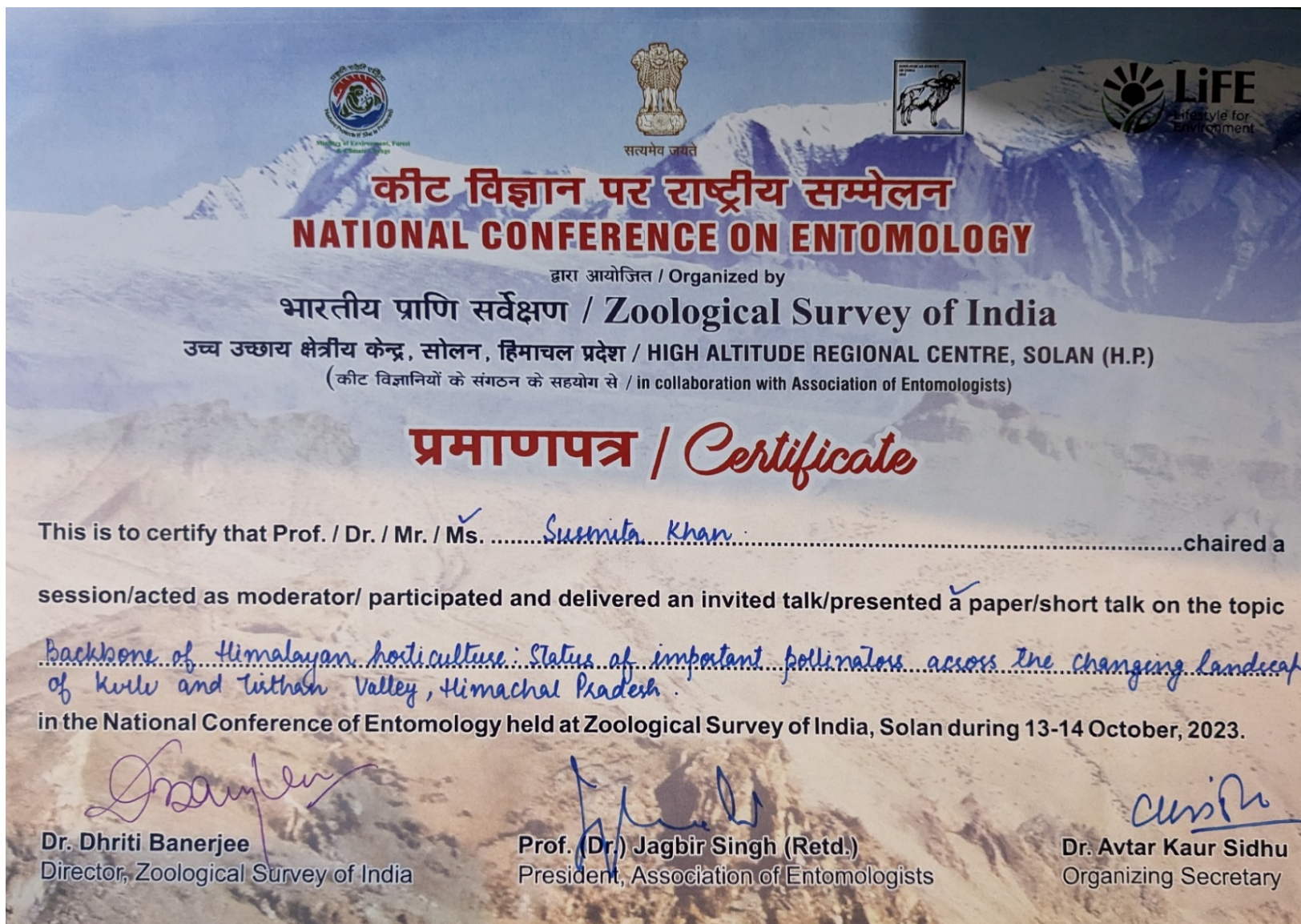
Conference Presentation

1. Presented a talk on “Assessment of wild pollinators in apple and plum orchards of Kullu Valley, Himachal Pradesh, India” in 3rd International conference on Bee Pollination and Conservation on occasion of World Bee Day, 2023 organized by University of Agriculture, Multan, Pakistan.



Conference Presentation

- Presented a talk on "Backbone of Himalayan horticulture: status of important pollinators across the changing landscape of Kullu and Tirthan valley, Himachal Pradesh" in National conference on entomology organized by Zoological Survey of India, high altitude regional centre, Solan during 13-14 October 2023.



Conference Presentation

3. Presented a talk on “Predicting the Distribution of Important Insect Pollinators in a Western Himalayan Landscape under Future Climate Scenarios” in SILVA/IUFRO Div. 3 PhD conference held in Swedish University of Agricultural Sciences (SLU), Umea, Sweden from 16-20th June 2024.



Certificate

Susmita Khan

*has participated in the SILVA/IUFRO Div. 3 PhD student conference,
held in Umeå, Sweden, 16-20th June 2024*

*The conferences consisted of two days of oral research presentations by the
PhD students, and two days of field excursions on forests and forestry in
Sweden.*

A handwritten signature in blue ink, appearing to read 'Ola Lindroos', is written over a horizontal line.

Ola Lindroos
IUFRO and SLU

A handwritten signature in blue ink, appearing to read 'Dimitris Athanassiadis', is written over a horizontal line.

Dimitris Athanassiadis
SLU's Research school SILVA

