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Investigating pollinator dynamics and regional variations in Doda, J&K, INDİA: challenges, monitoring and conservation perspectives

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Abstract

This study explores the plant-pollinator network in district Doda, Jammu & Kashmir, India, a Himalayan region with limited research on biodiversity and pollination ecology. Pollinators like bees, butterflies, and beetles are vital for ecosystem health and agricultural productivity, yet Doda lacks comprehensive data on its pollinator species and interactions, unlike the Kashmir Valley and Jammu region. Drawing insights from similar regions such as Kashmir, Himachal Pradesh, and Uttarakhand, this research highlights the ecological role of pollinators and emphasizes the need for extensive field exploration in Doda. The study advocates for an interdisciplinary approach combining ecological, agricultural, and local knowledge, recommending detailed surveys, long-term monitoring, and socio-economic studies to understand pollination's impact on agriculture. It calls for collaborative efforts among researchers, agricultural departments, and conservationists to gather baseline data, promote biodiversity preservation, and enhance agricultural sustainability. These efforts are crucial for supporting local livelihoods and establishing a foundation for future research and conservation initiatives in Doda's unique ecological networks.

Keywords: pollinator networks, biodiversity conservation, plant-ınsect ınteractions, agricultural sustainability, environmental ımpacts

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Doda, J&K, HİNDİSTAN'da tozlayıcı dinamiklerinin ve bölgesel farklılıkların araştırılması: zorluklar, izleme ve koruma perspektifleri

Özet

Bu çalışma, biyolojik çeşitlilik ve tozlaşma ekolojisi üzerine sınırlı araştırmalara sahip bir Himalaya bölgesi olan Hindistan'ın Jammu ve Keşmir, Doda bölgesindeki bitki tozlayıcı ağını araştırıyor. Arılar, kelebekler ve böcekler gibi tozlaştırıcılar, ekosistem sağlığı ve tarımsal üretkenlik açısından hayati önem taşıyor; ancak Keşmir Vadisi ve Jammu bölgesinin aksine Doda, tozlayıcı türleri ve etkileşimleri hakkında kapsamlı verilere sahip değil. Keşmir, Himaşal Pradeş ve Uttarakhand gibi benzer bölgelerden bilgiler alan bu araştırma, tozlayıcıların ekolojik rolünü vurguluyor ve Doda'da kapsamlı saha araştırmalarının gerekliliğini vurguluyor. Çalışma, ekolojik, tarımsal ve yerel bilgileri birleştiren disiplinler arası bir yaklaşımı savunuyor; tozlaşmanın tarım üzerindeki etkisini anlamak için ayrıntılı araştırmalar, uzun vadeli izleme ve sosyo-ekonomik çalışmalar öneriyor. Temel verileri toplamak, biyolojik çeşitliliğin korunmasını teşvik etmek ve tarımsal sürdürülebilirliği geliştirmek için araştırmacılar, tarım departmanları ve korumacılar arasında işbirlikçi çabalar çağrısında bulunuyor. Bu çabalar, yerel geçim kaynaklarının desteklenmesi ve Doda'nın benzersiz ekolojik ağlarında gelecekteki araştırma ve koruma girişimleri için bir temel oluşturulması açısından çok önemlidir.

Anahtar kelimeler: tozlayıcı ağları, biyolojik çeşitliliğin korunması, bitki-böcek etkileşimleri, tarımsal sürdürülebilirlik, çevresel etkiler

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1. Introduction

Pollination is a critical ecological service, essential for the reproduction of many flowering plants and the production of a significant portion of the world's food crops [1]. In agricultural ecosystems, pollinators play a pivotal role in enhancing crop yields and quality, thereby supporting both food security and economic stability [2]. Among the most vital pollinators are insects, including bees, butterflies, beetles, and others, which facilitate the transfer of pollen from one flower to another, enabling fertilization and seed production [3]. Plant-insect pollinator networks represent complex and dynamic interactions between plant species and their pollinators [4]. These networks are crucial for maintaining biodiversity and ecosystem health, as they ensure the survival and proliferation of both plants and pollinators [5]. In recent years, there has been growing recognition of the importance of understanding these networks, particularly in the context of environmental changes such as habitat loss, climate change, and pesticide use, which threaten pollinator populations globally [6].

The Kashmir Valley, known for its rich biodiversity and unique agro-climatic conditions, has been a focal point for ecological and agricultural research in India [7]. However, the region of Doda, located within Jammu and Kashmir, remains comparatively under-researched. Despite its similar climatic and ecological characteristics, Doda's plant-pollinator interactions have not been studied extensively, leaving a gap in our understanding of the region's ecological networks. The primary objective of this review is to bring attention to the underexplored plant-insect pollinator networks in Doda, J&K, India, and to articulate the ecological and agricultural significance of these networks. While the Kashmir Valley has been easily accessed by researchers and government policy framework for ecological research, Doda's unique sub-temperate environment remains unexplored and unobserved, particularly concerning its pollination systems. This review aims to fill this gap by synthesizing existing literature from similar climatic regions and providing a comparative analysis with the well-documented Kashmir Valley. Furthermore, the review seeks to identify the key pollinator species within these networks and their roles in local agriculture, thus laying the groundwork for future research. Additionally, this review aims to highlight the critical need for establishing baseline data on pollinator species and their interactions with native and cultivated plants in district Doda. This review will also address the challenges and gaps in current research, such as the impact of environmental changes and anthropogenic activities on pollinator populations. Ultimately, this review proposes a framework for future interdisciplinary research, combining ecological, agricultural, and socio-economic studies. This approach is essential for developing targeted conservation strategies and promoting sustainable agricultural practices in the region. By encouraging collaboration between local researchers, agricultural departments, and conservationists, the review seeks to foster a more comprehensive understanding of the ecological dynamics in district Doda and support the resilience of its agricultural systems..

2. Materials and methods

2.1 Literature search strategy

This review synthesized research on plant-insect pollinator networks with a specific focus on the understudied region of Doda, Jammu & Kashmir, India. A comprehensive literature search was conducted across various scientific databases, including Google Scholar, PubMed, and Web of Science, using keywords such as "pollinator networks," "plant-pollinator interactions," "biodiversity conservation," "Himalayan pollinators," and "agricultural pollination." Studies conducted in similar sub-temperate and temperate regions, like the Kashmir Valley, Himachal Pradesh, and Uttarakhand, were also included to provide comparative insights.

2.2 Topography of the region

The Doda District, situated in the eastern part of the Jammu Region (33°08'N, 75°3'E) within the outer Himalayan Range, has an average elevation of 1,107 meters above sea level [8]. This district was selected for study due to its critical role in temperate fruit production in the state of Jammu and Kashmir, based on both the area cultivated and the yield. While the focus for temperate fruit cultivation predominantly is in the Kashmir valley, the Doda district shares similar agro-climatic conditions, making it a suitable region for growing high-value fruit crops as done in Kashmir. Currently, the district is engaged in the cultivation of significant temperate fruit species, including *Malus domestica* (apple), *Pyrus* (pear), *Prunus armeniaca* (apricot), *Prunus persica* (peach), *Prunus domestica* (plum), *Olea europaea* (olive), *Juglans regia* (walnut), *Carya illinoinensis* (pecan), and *Prunus dulcis* (almond) (https://hortikashmir.gov.in/Area%20Production%20data.html). However, no studies on plant-insect pollinators or pollination ecology have been reported from the area. Further the described area has the potential to become a fruit and vegetable region, but the locals seems having no information about economic importance of these fruits and its produce. So there is a communication lacunae between horticulture department of J&K and locals of District Doda.

2.3 Comparative regional analysis

To draw parallels with Doda's ecological conditions, we compared data from neighboring regions with similar agro-climatic conditions, such as Himachal Pradesh and Uttarakhand. Comparative analysis involved evaluating existing pollinator species lists, documented interaction patterns, and identified threats to pollinators. This approach provided a broader understanding of Doda's potential pollinator diversity and network structure, allowing us to infer likely challenges and conservation needs.

2.4 Network structure and pollinator ecology

The review included studies utilizing network analysis to assess the structure of plant-pollinator interactions, particularly metrics such as network modularity, nestedness, and connectance. These parameters, as reported in relevant studies, were used to compare network stability and resilience in Himalayan pollinator networks. The synthesis involved summarizing findings on dominant pollinator groups, interaction patterns, and implications for ecosystem stability.

2.5 Conservation, socio-economic perspectives, data extraction and synthesis

A section of the review was dedicated to examining socio-economic studies that assessed pollinator impact on agriculture in similar regions. These studies provided insights into how pollination services benefit local communities economically, emphasizing the need for pollinator conservation in sustaining agricultural productivity. Additionally, this review analyzed the effectiveness of conservation initiatives from neighboring regions to propose potential frameworks for Doda.For each selected article, data on pollinator species, interaction types, environmental threats, and conservation strategies were extracted and organized thematically. Key findings were synthesized into comparative summaries and tables to highlight regional differences and similarities in pollinator diversity, network dynamics, and conservation challenges.This review aims to consolidate the available knowledge on Doda's pollinator networks and underscore gaps in research, encouraging further studies and conservation efforts in this understudied Himalayan region.

3. Results

3.1 Area and production of fruit crops in Doda

Based on the data available from Directorate of Horticulture, Jammu and Kashmir (https://hortikashmir.gov.in/Area%20Production%20data.html), the area under fruit cultivation in district Doda has shown fluctuations over the years. It started at 13,052 hectares in 2015-2016 and peaked at 15,064 hectares in 2018-2019. The lowest recorded area was 12,054 hectares in 2020-2021. On the contrary, the production of fruits, measured in metric tonnes, also shows significant variability. The highest production was in 2015-2016 with 43,321 metric tonnes, while the lowest was in 2017-2018 at 18,372 metric tonnes. There is a notable increase in production in 2018-2019, reaching 35,916 metric tonnes, after which it dropped again. This suggests that factors such as climatic conditions, agricultural practices, or market conditions might have influenced production levels. While the area under cultivation and production levels generally move in tandem, this is not always the case. For instance, despite a relatively high area in 2019-2020, the production was lower compared to 2018-2019, indicating that other factors beyond just the area might affect production yields (Figure 1).

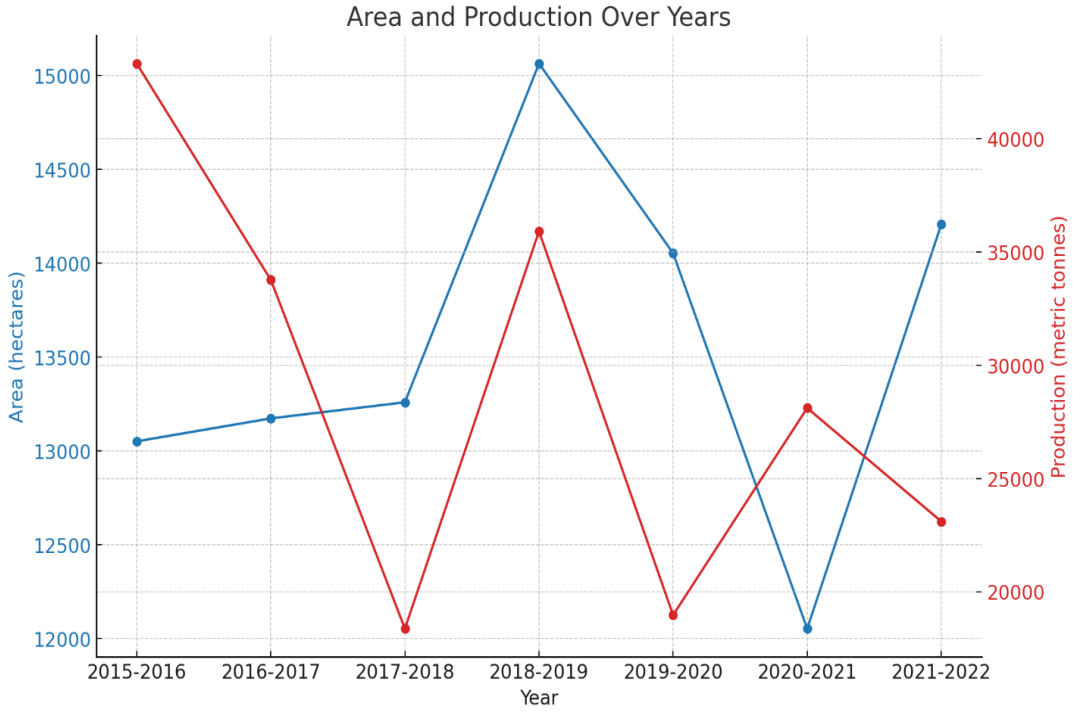

Figure 1. Area under fruit crop and production of fruit crops in district Doda from 2015-2022

3.2 Comparative analysis between Doda and Srinagar Districts

The comparative analysis between Districts Doda and Srinagar from 2015-2022 reveals significant differences in agricultural area and production. Doda has a larger agricultural area, ranging from 12,054 to 15,064 hectares, but its production fluctuates, peaking at 43,321 metric tonnes in 2015-2016 and dipping to 18,372 metric tonnes in 2017-2018. In contrast, Srinagar, with a smaller and more stable agricultural area (around 3,000 to 3,354 hectares), shows a steady increase in production, reaching a high of 31,266 metric tonnes in 2021-2022. This disparity suggests varying factors influencing productivity, such as crop types, soil quality, or agricultural practices, emphasizing the need for tailored strategies to optimize agricultural output in each district. Overall, the District Srinagar shows a promising trend in fruit crop production, with increasing outputs despite relatively stable cultivation areas. This highlights the potential for further optimization and development in the region's agricultural practices.

The observed fluctuations in agricultural yields in District Doda, compared to the more stable outputs in Srinagar, may stem from several critical factors (Figure 2). One key issue is the limited understanding of pollinator dynamics in Doda, as no comprehensive studies have been conducted to assess their role in supporting agricultural productivity. Pollinators are vital for the reproductive success of many crops, and insufficient pollinator activity due to habitat loss, pesticide use, or climate variability could be a significant factor behind Doda's fluctuating yields. Additionally, land use patterns in Doda, characterized by fragmented agricultural plots and limited irrigation infrastructure, may restrict farming efficiency and reduce crop resilience. Climatic variability in the region further exacerbates these issues, disrupting both crop cycles and pollinator activity. By comparison, Srinagar benefits from more stable climatic conditions, better-managed agricultural practices, and potentially healthier pollinator populations, which contribute to consistent agricultural outputs. To address these disparities, targeted research on pollinator dynamics, habitat restoration, reduction of pesticide use, and the adoption of integrated pest and land management practices in Doda are necessary to enhance pollination services, stabilize yields, and improve overall agricultural sustainability.

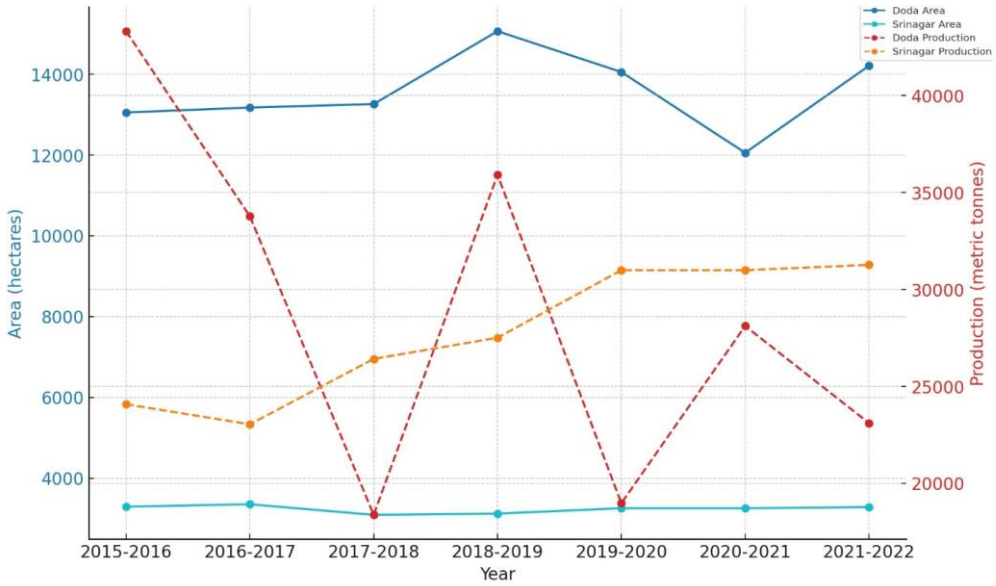

Figure 2**.** Comparative Analysis of Area under fruit crops and fruit Production between Districts Doda and Srinagar

3.3 Plant-insect pollinator networks in Kashmir division

The Kashmir Himalaya, located in the northwestern part of the Himalayas, is famous for its natural landscape, which features a diverse and unique biodiversity [9]. Despite this rich biodiversity, there have been relatively few research studies focused on the diversity of flowering plants and their insect visitors in this region. In the study conducted by Rather *et al.* (2017), a comprehensive survey of the Kashmir Himalaya's flora revealed 227 plant species spanning 182 genera and 58 families, identified as key foraging sources for various pollinators. The research indicated that annual herbaceous plants were the predominant contributors of pollen and nectar, followed by perennial herbs, shrubs, trees, and biennial herbs. The family Asteraceae emerged as the leading family in terms of pollen and nectar production. The study documented 70 species of flower visitors from 43 genera and 23 families, with Apidae being the most dominant family. A significant diversity in floral traits was noted, including variations in floral display size, inflorescence architecture, and flower shape. These traits were found to significantly influence pollinator attraction and visitation rates, with larger and more conspicuous floral displays attracting more pollinators. Actinomorphic flowers, which are symmetrical and accessible to a wide range of pollinators, were more prevalent compared to zygomorphic flowers, which are more specialized. The study identified *Xylocopa valga*, along with *Apis mellifera* and *Apis cerana*, as highly effective pollinators in terms of pollen deposition, with *Xylocopa valga* being particularly noted for its efficiency. The analysis highlighted a predominance of generalized plant-pollinator interactions, with a substantial number of plant species being visited by multiple pollinator species. This generalist strategy indicates a resilient plant-pollinator network capable of sustaining biodiversity under varying environmental conditions.

A further study by Rather *et al.* (2023) investigated a plant-pollinator meta-network in the Kashmir Himalaya, highlighting its structure and stability. This research documented interactions between 230 plant species and 80 pollinator species, with Malus domestica and Apis bees being particularly influential. The network showed significant modularity, including eight distinct modules comprising both native and alien species, indicating a well-integrated community. Notably, alien species contributed to 40% of the interactions. Extinction simulations revealed that the network is more vulnerable to the loss of key pollinators than plants, emphasizing the critical role of pollinators in maintaining ecological stability [10]. A detailed list of plat-Insect pollinators associated with different agro-horticultural crops of Kashmir Valley is discuused in Table 1.

3.4 Plant-insect pollinator networks in Jammu division

Shankar *et al.* (2017) conducted a study in the Jammu region to examine the species composition of pollinators on *Pongamia pinnata* L., a perennial flowering plant commonly used as an avenue tree. The study identified 21 pollinator species from the orders Hymenoptera, Diptera, Thysanoptera, and Lepidoptera, as well as birds. Among these, megachilid bees were the most abundant, constituting over 55% of the insect visitors. The foraging activity of these pollinators peaked between 10:00 and 12:00 hours. The study suggests that Pongamia flowers could be important floral sources, providing a reservoir for pollinators during hot summers [16]. Ganai *et al.* (2017) studied the insect pests, pollinators, and natural enemies associated with marigold crops in the Jammu division and recorded several pollinators visiting marigold flowers, including *Apis mellifera*, *Apis dorsata*, *Pieris brassicae*, and the thistle butterfly (*Vanessa cardui*). Among natural enemies, the syrphid fly (*Syrphus spp*.), ladybird beetle (*Coccinella septumpunctata*), spider (*Oxyopes javanus*), and big-eyed bug (*Geocoris spp.*) were noted [17].

Table 1. Insect pollinators associated with different agro-horticultural crops of Kashmir Valley

Order	Species	References
Hymenoptera	*Bombus funerarius*	[10, 11, 12, 13, 14, 15]
	Thyreus nitidulus	
	Melissodes bimaculata	
	Lasioglossum moroi	
	Ceratina calcarata	
	Ceratina hieroglyphica	
	Halictus confuses	
	Polistes maculipennis	
	Vespa auraria	
	Andrena gravida	
	Pison punctifrons	
	Athalia proxima	
	Megascolia haemorrhoidalis	
	Eusaphyga verticalis	
	Anthophora sp.	
	Polistes sp.	
	Odynerus sp.	
	Pimpla sp.	
	Megachile sp.	
	Osmia sp.	
	Pepsis sp.	
	Rhynchium sp.	
	Xylocopa valga	
	Xylocopa violacea	
	Bombus simillmus	
	Bombus tunicatus	
	Andrena patella	
	Andrena cineraria	
	Sphecodes tantalus	
	Sphecodes lasimensis	
	Lasioglossum himalayense	
	Lasioglossum nursei	
Diptera	*Sphaerophoria bengalensis*	
	Metasyrphus bucculatus	
	Episyrphus balteatus	
	Eristalodes paria	
	Eristalis tenax	
	Eoseristalis cerealis	
	Eristalis soliatus	
	Didea fasciata	
	Scaeva pyrastri	
	Syrphus balteatus	
	Syritt orientalis	
	Eristalis tenax	
	Eristalis arbustorum	
	Sphaerophoria scripta	
	Hermetia illucens	
	Helophilus trivittatus	
	Bombylus major	
	Musca domestica	
	Dryomyza flaveola	
	Eristalinus sp.	

Table 1. Continued

	Syritt sp.
	Sphaerophoria sp.
	Eristalis sp.
	Bibio sp.
	Chrysomyia sp.
	Pseudopyrellia sp.
	Bombylidae sp.
	Machinus sp.
	Fanna sp.
	Sarcophaga sp.
Lepidoptera	*Pieris brassicae*
	Cynthia cordui
	Colias romonovi
Coleoptera	*Coccinella septumpunctata*
	Hippodamia variegate
	Altica cyanea
Odonata	*Ischnura pumilio*
	Libellula quadrimaculata

3.5 Plant-insect pollinator networks in Jammu division

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Jamwal *et al.* (2019) conducted a study in the Jammu division to investigate the diversity of insect pollinators on citrus flowers. The study identified 44 insect species across 5 orders and 16 families. The distribution of these species included 15 from Hymenoptera, 13 from Diptera, 6 from Lepidoptera, 8 from Coleoptera, and 2 from Hemiptera. Among the hymenopterans, the Indian honeybee, *Apis cerana*, was the most abundant, accounting for 33.07% of insect visitors to citrus crops [18]. Kumari & Sidhu (2020) studied the grasslands in Jammu, part of the union territory of Jammu and Kashmir, highlighting their ecological importance as habitats for diverse species, including Hymenoptera. These insects are crucial pollinators in grassland ecosystems and help control pest populations, thus maintaining ecological balance. Over two years, the researchers identified 13 species of Apoidea from 6 genera and 9 subgenera, with two species newly recorded for the region. The study underscores the role of Hymenoptera in pollination and the ecological significance of grasslands [19]. Mondal *et al.* (2022) investigated the diversity of bumblebee species across sub-tropical, intermediate, and temperate regions in the Jammu division, adjacent to District Doda. The study, conducted over two years (2016-2017), recorded varying species distributions across different altitudes. In the sub-tropical zone, two species, *Bombus haemorrhoidalis* and *Bombus trifasciatus*, were identified. The intermediate zone hosted three species: *B. haemorrhoidalis*, *Bombus simillimus*, and *Bombus tunicatus*. The temperate zone, ranging from 1000 m to 2214 m above mean sea level, supported five species, including the aforementioned three and *Bombus pyrosoma*. Overall, seven bumblebee species were documented, highlighting a greater diversity in higher altitude regions [20].

Abrol & Chatterjee (2022) documented a diverse range of Megachilid bees in the Jammu division of Jammu and Kashmir, India, many of which were newly recorded for the region. The study identified sixteen morpho-species, with most found in plains and foothills, and one species in both hilly and plain regions. These bees showed peak foraging activity in the forenoon and were efficient pollinators, suggesting their importance in sustainable agriculture. The species included ten morpho-species of Megachile, three of *Osmia*, two of *Coelioxys*, and one of *Anthidium*, highlighting the rich biodiversity of the area [21]. Shankar & Mukhtar (2022) conducted a two-year study on the diversity and foraging behavior of pollinators on Sesamum indicum L. flowers across different altitudes in Jammu. They identified 26 native pollinator species from the families Apidae, Megachilidae, Halictidae, and Sphingidae. The dominant pollinators, in descending order, were Megachilid bees, Honeybees, Halictid bees, Ceratina bees, Amegilla bees, *Xylocopa* bees, and Bumblebees. Pollinator abundance followed a polynomial distribution, suggesting an even

distribution among groups, with some dominant in flower visitation. The study found that Megachilid and Honeybees had longer foraging bouts compared to other pollinators [22].

3.6 Existing research from similar regions

Sub-temperate regions such as Himachal Pradesh and Uttarakhand have been the focus of numerous studies on plant-insect pollinator networks due to their rich biodiversity and significant agricultural landscapes [23]. These areas are characterized by diverse ecosystems ranging from alpine forests to subtropical woodlands, each supporting a unique assemblage of pollinator species [24]. The research conducted in these regions has been pivotal in understanding the complex interactions between plants and their pollinators, offering valuable insights into the functioning of these ecosystems [25]. In Himachal Pradesh, extensive studies have been conducted recently on the role of native bee species, particularly in apple orchards, which are a major agricultural crop in the region [26]. These studies have shown that native bees, including various species of solitary bees and bumblebees, are crucial for pollination, contributing to fruit set and quality. The research also highlights the importance of maintaining natural habitats adjacent to agricultural lands, as these areas provide nesting sites and floral resources for pollinators throughout the year. Uttarakhand, with its diverse topography and climate, offers a wide range of habitats for pollinators. Research in these localities has focused on both managed pollinators, such as the Indian honey bee (*Apis cerana*), and wild pollinators, including a variety of butterflies, moths, and beetles [27]. Studies have documented the critical role these insects play in pollinating a wide range of crops, from traditional staples like millets and pulses to horticultural crops such as tomatoes and cucumbers [28]. Additionally, Uttarakhand's forests support a rich variety of flowering plants that rely on insect pollination, further underscoring the ecological importance of these networks.

3.7 Implications for Pollinator montioring in Doda Based on regional studies

The studies conducted in neighbouring districts of Doda in both Jammu and Kashmir divisions, Himachal Pradesh, Uttarakhand, and other sub-temperate regions offer valuable insights and lessons that can be directly applied to understanding and managing plant-insect pollinator networks in Doda, J&K, India.One of the key takeaways from the research in these regions is the critical need for comprehensive baseline data on pollinator species and their interactions with plants [29]. In Doda, similar efforts are necessary to catalog the diversity and abundance of pollinators and to identify the plant species they pollinate. This baseline data is crucial for understanding the ecological roles of different pollinators, assessing their contributions to crop production, and establishing conservation priorities [30]. Moreover, In Doda, conducting preliminary field studies is crucial for gathering baseline data on the diversity and behavior of pollinator species, as well as their interactions with local flora [31]. Suggested methods include direct observation, where researchers systematically observe pollinator activities and behaviors; net sampling, which involves capturing pollinators to accurately identify and study them; and photographic documentation, which serves as a visual record for later analysis and species identification (Figure 3). These methods provide essential data that can help establish a foundational understanding of the pollination dynamics in Doda, informing both conservation strategies and agricultural practices. The research in neighbouring localities of Doda has highlighted the significant role that native pollinators, such as solitary bees and bumblebees, play in pollinating crops and wild plants. For Doda, this underscores the importance of identifying and conserving native pollinator species, which may be adapted to local environmental conditions and plant species. Protecting these native pollinators can enhance crop yields and biodiversity, particularly in a region with diverse agricultural practices and natural habitats [32]. Studies from these regions have demonstrated how environmental changes, including habitat loss, pesticide use, and climate change, can negatively affect pollinator populations [33]. In Doda, similar threats are likely present, and the lessons learned from these other regions emphasize the need for sustainable agricultural practices and habitat conservation. For instance, reducing pesticide use, planting diverse floral resources, and preserving natural habitats can help mitigate the impacts of environmental changes on pollinator health and diversity [34].

Research in neighbouring localities of Doda has shown that involving local communities in conservation efforts is crucial for the success of pollinator protection strategies. In Doda, community education and involvement can be equally important. Raising awareness about the importance of pollinators, promoting practices that protect these species and encouraging local participation in monitoring and conservation efforts can lead to more sustainable outcomes [35]. Community-based initiatives, such as establishing pollinator-friendly gardens or reducing pesticide use, can play a vital role in supporting pollinator populations. For Doda, adopting a similar interdisciplinary approach can help address the complex challenges related to pollinator conservation and agricultural productivity. Collaboration between researchers, agricultural extension services, local farmers, and conservation organizations can lead to more holistic and effective strategies for managing pollinator networks. The experiences from neighbouring localities of district Doda suggest that policies supporting sustainable agricultural practices and habitat conservation are essential for protecting pollinator networks. Moreover, advocating for policies that promote the use of pollinator-friendly practices, protect natural habitats, and support research and education initiatives can help ensure the long-term health of pollinator populations and the ecosystems they support. By applying these insights and lessons to Doda, stakeholders can develop targeted

conservation strategies that protect pollinator diversity, enhance agricultural sustainability, and support the overall health of the region's ecosystems.

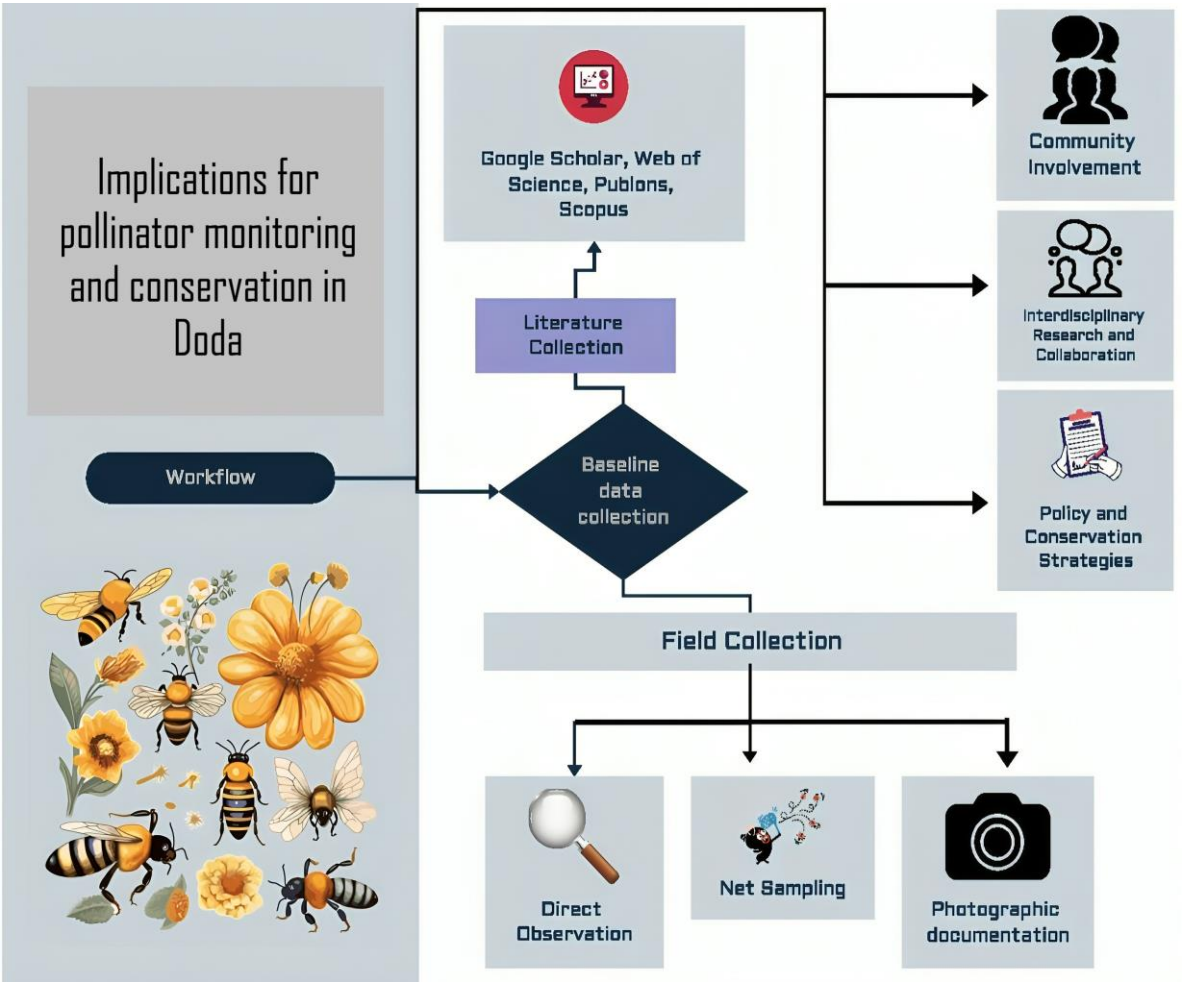

Figure 3. A workflow of implications for pollinator monitoring in district Doda on regional studies

4. Conclusions and discussions

The proposed research framework emphasizes the importance of interdisciplinary approaches in studying plant-insect pollinator networks. Integrating perspectives from ecology, agriculture, and local knowledge is crucial for developing a comprehensive understanding of these networks in Doda. Ecological studies can provide insights into the biodiversity and behavior of pollinator species, while agricultural research can explore the implications of pollinator activity on crop yields and quality. Local knowledge, including traditional practices and observations from farmers and indigenous communities, can offer valuable context and enhance the relevance and applicability of research findings. To address the gaps in current knowledge and support the conservation and management of pollinator networks in Doda, the following studies and surveys are proposed:

4.1. Detailed surveys and long-term monitoring

Conducting detailed surveys to document the diversity and abundance of pollinator species in various habitats across Doda is essential. These surveys should include the identification of key pollinator species and their interactions with native and cultivated plants. Long-term monitoring is also crucial to track changes in pollinator populations and behaviors over time, providing data on the effects of environmental changes, habitat loss, and climate change.

4.2. Socio-economic studies

Pollination has significant socio-economic implications, particularly in agricultural regions. Studies should investigate the impact of pollination services on local agriculture, including crop yields, quality, and economic benefits to farmers. These studies can also explore the socio-economic factors that influence pollinator health, such as land use

practices, pesticide application, and conservation attitudes. Understanding these factors can help develop targeted interventions and policies that support both pollinator conservation and agricultural sustainability. By combining ecological, agricultural, and socio-economic research, this proposed framework aims to create a robust foundation for understanding and enhancing pollinator networks in Doda. Such an integrated approach will not only contribute to the conservation of biodiversity but also support sustainable agricultural practices and improve the livelihoods of local communities.

This review synthesizes findings from regions with similar sub-temperate climates, such as neighbouring districts, and states like Himachal Pradesh and Uttarakhand, highlighting the rich diversity of plant-insect pollinator networks and their critical roles in both natural ecosystems and agricultural systems. These studies emphasize the importance of native pollinators, the impact of environmental changes, and the benefits of community involvement in conservation efforts. By applying these insights to Doda, it becomes evident that there is a significant gap in baseline data and understanding of local pollinator species and their interactions with plants. The applicability of these findings to Doda suggests that similar ecological patterns and challenges are likely present, underscoring the need for comprehensive research and targeted conservation strategies.

Given the critical role of pollinators in maintaining biodiversity and supporting agricultural productivity, there is an urgent need for focused research and conservation efforts in Doda. Establishing baseline data on pollinator species, conducting detailed ecological and socio-economic studies, and monitoring environmental impacts are essential steps toward understanding and protecting these vital networks. Additionally, fostering collaboration between local researchers, agricultural departments, and conservationists is crucial. Such partnerships can facilitate the sharing of knowledge, resources, and expertise, leading to more effective conservation strategies and sustainable agricultural practices. By engaging with local communities and integrating traditional knowledge, these efforts can be further strengthened, ensuring the resilience and health of Doda's ecosystems and agricultural systems. This collective approach is not only beneficial for biodiversity conservation but also vital for the long-term sustainability of local livelihoods dependent on agriculture.

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References

[1] Porto, R. G., De Almeida, R. F., Cruz-Neto, O., Tabarelli, M., Viana, B. F., Peres, C. A., & Lopes, A. V. (2020). Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. *Food Security*, *12*(6), 1425-1442. https://doi.org/10.1007/s12571-020-01043-w

[2] Rehman, A., Farooq, M., Lee, D. J., & Siddique, K. H. (2022). Sustainable agricultural practices for food security and ecosystem services. *Environmental Science and Pollution Research*, *29*(56), 84076-84095. https://doi.org/10.1007/s11356-022-23635-z

[3] Zariman, N. A., Omar, N. A., & Huda, A. N. (2022). Plant attractants and rewards for pollinators: their significant to successful crop pollination. *International Journal of Life Sciences and Biotechnology*, *5*(2), 270-293. https://doi.org/10.38001/ijlsb.1069254

[4] Adedoja, O. A., Kehinde, T., & Samways, M. J. (2018). Insect-flower interaction networks vary among endemic pollinator taxa over an elevation gradient. *PLoS One*, *13*(11), e0207453. https://doi.org/10.1371/journal.pone.0207453

[5] Fufa, D., & Getu, E. (2023). The Hidden World of Insect-Plant Interactions: a review. *SINET: Ethiopian Journal of Science*, *46*(3), 356-384. https://doi.org/10.4314/sinet.v46i3.12

[6] Decourtye, A., Alaux, C., Le Conte, Y., & Henry, M. (2019). Toward the protection of bees and pollination under global change: present and future perspectives in a challenging applied science. *Current opinion in insect science*, *35*, 123-131. https://doi.org/10.1016/j.cois.2019.07.008

[7] Ahmad, S., Mir, N., Bhat, S., & Singh, J. (2018). High altitude pasturelands of Kashmir Himalaya: Current status, issues and future strategies in a changing climatic scenario. *Current Journal of Applied Science and Technology*, *27*(2), 1-10. https://doi.org/10.9734/CJAST/2018/40695

[8] Nain, M. S., & Chandel, S. S. (2013). Knowledge vis a vis Adoption of Agrithorti System in Doda District of Jammu & Kashmir State. *Indian Journal of Extension Education*, *49*(1&2), 105-109.

[9] Riyaz, M. (2022). Butterfly fauna (Lepidoptera: Rhopalocera) in and around Hirpora Wildlife Sanctuary, Shopian Kashmir, J&K UT, India. *Biological Diversity and Conservation*, 15(3), 273-279. http://dx.doi.org/10.46309/biodicon.2022.1207812

[10] Rather, Z. A., Ollerton, J., Parey, S. H., Ara, S., Watts, S., Paray, M. A., & Khuroo, A. A. (2023). Plant-pollinator meta-network of the Kashmir Himalaya: Structure, modularity, integration of alien species and extinction simulation. *Flora*, *298*, 152197. https://doi.org/10.1016/j.flora.2022.152197

[11] Dar, S. A., Wani, A. R., & Sofi, M. A. (2018a). Diversity and abundance of insect pollinators of sweet cherry Prunus avium in Kashmir valley. *Indian Journal of Entomology*, 80(3), 725-736. https://doi.org/10.5958/0974-8172.2018.00231.6

[12] Riyaz, M., Mathew, P., Paulraja, G., & Ignacimuthu, S. (2018). Entomophily of Apple ecosystem in Kashmir valley, India: A review. *International Journal of Scientific Research in Biological Sciences* 5(5), 146-154. http://dx.doi.org/10.26438/ijsrbs/v5i5.146154

[13] Ganie, M. A., Pal, A. K., & Ahmad, N. (2013). Native insect pollinators in apple orchards under different management practices in the Kashmir Valley. *Turkish Journal of Agriculture-Food Science and Technology*, 1(1), 29-36. https://doi.org/10.24925/turjaf.v1i1.29-36.12

[14] Akhter, F., Khanday, A. L., & Ahmad, S. T. (2016). Pollination potential: A comparative study of various hymenopteran insects pollinating some economically important crops in Kashmir. *International Journal of Advanced Research in Biological Sciences*, *3*(9), 50-59. https://doi.org/10.22192/ijarbs.2016.03.09.007

[15] Saini, M. S., Raina, R. H., & Khan, Z. H. (2012). Species Diversity of Bumblebees (Hymenoptera: Apidae) from Different Mountain Regions of Kashmir Himalayas. *Journal of Scientific Research*, 4(1), 263-272. https://doi.org/10.3329/jsr.v4i1.8815

[16] Shankar, U., Abrol, D. P., & Singh, A. K. (2017). Plants for bees Pongamia pinnata (L.) Pierre. *Journal of Palynology*, 53, 133-137.

[17] Ganai, S. A., Ahmad, H., Sharma, D., Sharma, S., Khaliq, N., & Norboo, T. (2017). Diversity of arthropod fauna associated with marigold (Tagetes erecta L.) in Jammu. *Journal of Entomology and Zoology Studies*, 5(5), 1940-1943.

[18] Jamwal, K. S., Jamwal, K. S., & Thakur, M. S. (2019). Diversity, distribution and relative abundance of different insect pollinators on citrus crops. *Journal of Entomological Research*, 43(4), 513-518. https://doi.org/10.5958/0974-4576.2019.00090.2

[19] Kumari, P., & Sidhu, A. K. (2020). Diversity of apoidea (Hymenoptera) from Grassland ecosystem of Jammu (UT of Jammu and Kashmir). *Journal of Entomology and Zoology Studies*, 8(4), 424-427.

[20] Mondal, A., Abrol, D. P., & Sharma, P. (2022). Diversity of bumblebees under different agro climatic condition of Jammu, India. *Environment and Ecology*, 40, (4C), 2573-2585.

[21] Abrol, D. P., & Chatterjee, D. A. D. (2022). Plant-Pollinator Interaction and Diversity of Megachilid Bees in Different Landscapes of Jammu, India. *Journal of Palynology* Vol, 58, 15-21.

[22] Shankar, U., & Mukhtar, Y. (2022). Diversity and foraging behaviour of pollinators on Sesamum indicum L. *Indian Journal of Ecology*, 49(5), 1984-1988.

[23] Sharma, R. M., & Mitra, B. (2011). A preliminary study on insect pollinators of temperate fruit crops in Himachal Pradesh. *Records of the Zoological Survey of India*, 103-110. https://doi.org/10.26515/rzsi/v111/i3/2011/158857

[24] Ahmad, F., & Goparaju, L. (2018). Climate change and its impact on forest fire in the state of Himachal Pradesh and Uttarakhand states of India: Remote sensing and GIS analysis. *Contemporary Trends in Geoscience*, *7*(2), 229-246. https://doi.org/10.2478/ctg-2018-0016

[25] Chauhan, D. S., Negi, G. C. S., & Joshi, R. (2024). Effect of Honey Bee (Apia cerana) Dominated Insect Pollination on Yield and Quality of Mustard, Buckwheat and Plum in a Central Himalayan Agro-Ecosystem. *International Journal of Ecology and Environmental Sciences*, *50*(4), 543-556. https://doi.org/10.55863/ijees.2024.0069

[26] Arya, M. K., & Badoni, A. (2023). Insect Pollinator Assemblage on Temperate Fruits Crops in Kumaun Himalaya. *Indian Journal of Entomology*, 315-321. https://doi.org/10.55446/IJE.2022.594

[27] Luthra, A., Scholar, F. N. S., & Allington, G. (2023). Pollinator Landscapes in the Himalayas. *Focus On Geography*, *66*, 1-1. https://doi.org/10.21690/foge/2023.66.4p

[28] Bhusal, D. R. (2020). Insect pollinators, threats for Survival and ecosystem service: an outlook from hindu-kush Himalaya region. *Hindu Kush-Himalaya watersheds Downhill: landscape ecology and conservation perspectives*, 565-576.

[29] Paschapur, A. U., Bhat, S., Subbanna, A. R., Choudhary, G., Hedau, N. K., Mishra, K. K., & Kant, L. (2022). Role of Entomophily and Artificial Pollination in Enhancing Quality and Yield of Seed Onion (L.) in Indian Himalayas. *Journal of Apicultural Science*, *66*(2), 133-147. https://doi.org/10.2478/jas-2022-0008

[30] Negi, G. C. S. (2022). Trees, forests and people: The Central Himalayan case of forest ecosystem services. *Trees, Forests and People*, *8*, 100222. https://doi.org/10.1016/j.tfp.2022.100222

[31] Otto, C. R., O'Dell, S., Bryant, R. B., Euliss Jr, N. H., Bush, R. M., & Smart, M. D. (2017). Using publicly available data to quantify plant–pollinator interactions and evaluate conservation seeding mixes in the northern Great Plains. *Environmental entomology*, *46*(3), 565-578. https://doi.org/10.1093/ee/nvx070

[32] Archer, C. R., Pirk, C. W. W., Carvalheiro, L. G., & Nicolson, S. W. (2014). Economic and ecological implications of geographic bias in pollinator ecology in the light of pollinator declines. *Oikos*, *123*(4), 401-407. https://doi.org/10.1111/j.1600-0706.2013.00949.x

[33] Pelayo, R. C., Llambí, L. D., Gámez, L. E., Barrios, Y. C., Ramirez, L. A., Torres, J. E., & Cuesta, F. (2021). Plant phenology dynamics and pollination networks in summits of the High Tropical Andes: A baseline for monitoring climate change impacts. *Frontiers in Ecology and Evolution*, *9*, 679045. https://doi.org/10.3389/fevo.2021.679045

[34] Garibaldi, L. A., Carvalheiro, L. G., Leonhardt, S. D., Aizen, M. A., Blaauw, B. R., Isaacs, R., ... & Winfree, R. (2014). From research to action: enhancing crop yield through wild pollinators. *Frontiers in Ecology and the Environment*, *12*(8), 439-447. https://doi.org/10.1890/130330

[35] Stout, J. C., & Dicks, L. V. (2022). From science to society: implementing effective strategies to improve wild pollinator health. *Philosophical Transactions of the Royal Society B*, *377*(1853), 20210165. https://doi.org/10.1098/rstb.2021.0165