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Assessing the economic and nutritional value of pollination services in Nepal

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Pollination is a key ecosystem service crucial for supporting agricultural production, economic growth, social inclusion, and environmental protection. Understanding the economic value of pollination and its impact on human health and nutrition is essential for effective pollinator conservation and management. This study evaluates the economic and nutritional value of pollination services in Nepal and quantifies historic changes in pollinator reliance. Using public data on agricultural production and commodity prices, in combination with published nutritional composition values, we employ the dependency-ratio method to quantify economic and nutritional value across different regions of the country and through time. We conservatively estimate the annual economic value of pollination services in Nepal at US $477 million, representing 9% of total agricultural revenue. Pollinator-dependent crops, particularly fruits and vegetables are the source of essential nutrients; 40% of plant-based vitamin A and 14% of vitamin C are directly attributable to insect pollination. The cultivated area of these pollinator-dependent crops has increased by 91% in Nepal over 20 years – 3.7 times faster than equivalent increases in non-pollinator-dependent crops. The decline in wild pollinators during the same time period poses a threat, leading to potential pollination deficits and crop losses. Our study underscores the importance of conserving and managing pollinators to ensure sustainable agriculture, food security, and nutrition. Targeted efforts, including policy interventions and conservation strategies, are needed to safeguard pollinator populations and enhance pollination services.

Pollination is a crucial ecosystem service that supports sustainable crop production, benefiting around 105 widely cultivated crops, including many of the world's most popular fruit, vegetable, and nut commodities. These are consumed worldwide to varying extents and are dependent on pollinators for their production[1,2]. This service contributes more than US$800 billion in gross economic value, highlighting its importance for global food security and economic prosperity[3]. While cereals, which contribute the highest volume of production, depend primarily on wind pollination, a significant proportion of other crops, including vegetables, fruits, nuts and seeds require insect pollination to ensure a high quantity and quality of yield[1]. These pollinator-dependent crops are generally more nutritious and economically valuable, providing a major source of economic income and key dietary micronutrients to populations around the world[4,5].

Among pollinators, bees play a significant role in the pollination of many agricultural crops[6,7], although non-bee pollinators, including flies, beetles, moths, butterflies, birds, and bats, among others, are also vital for the process[8]. However, the global decline in both wild and managed pollinators is a growing concern, driven by multiple anthropogenic stressors[6,9]. Agriculture intensification, habitat loss, fragmentation, and climate change are the primary contributors to this decline, causing a reduction in the abundance and diversity of wild pollinators and creating a mismatch between pollination supply and demand in agricultural fields[6,9,10]. As such, the decline in pollinator populations is alarming and has severe economic and nutritional consequences globally, emphasizing the urgent need for action to protect and promote pollinator populations for sustainable crop production and food security.

In order to generate both political and public support for pollinator conservation, it is important to provide an empirical assessment of the value that they provide to humanity. Various methods have been used to assess the value of pollination services, spanning a range of different spatial scales and levels of complexity[11,12]. The most widely-used of these are production-function methods which typically apply pollinator dependence

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ratios to estimate crop production losses in the absence of pollinators. This method has recorded values for pollination services ranging from € 153 billion at a global level in 2005[13] to $12 billion in Brazil[14], £ 430 million in UK[15], $ 106.08 billion in China[16], $ 84.57 billion in India[17]. An alternative approach is the use of replacement costs which capture the value of pollination services through the cost of providing technological replacements (often through hiring managed pollinators; (e.g[18]). Stated preferences can also be used to estimate the value of pollination through public surveys on willingness to pay for ecosystem services (e.g[19]). Meanwhile, surplus models evaluate the economic impact of yield losses on crop prices and the subsequent effects on producer profits and consumer income (e.g[20]). Most valuation studies – particularly those using the dependency ratio method - restrict their assessments to the level of the producer and ignore the effects on other participants within the food system[11,12]. For example, pollinator declines are also likely to impact consumers through higher food prices[21] and reduced availability of key micronutrients derived from pollinator-dependent crops[5,22]. Considering these broader measures of value is particularly important in countries with large numbers of smallholder farmers, whose participation in the market economy is limited, but whose livelihoods and access to nutritious food will nevertheless be impacted by pollinator declines[23].

Around 83% of the global agricultural population, equivalent to more than 2 billion people, rely on smallholder agriculture[24]. Many of the crops grown on these smallholder farms are highly pollinator dependent, and the families that run them are thus heavily reliant on insect pollinators for their livelihoods and food security[25]. In this context, it is particularly crucial for smallholders to understand the contribution of insect pollinators to their crop production. However, evidence suggests that farmer knowledge about the economic benefits of pollinators is limited in many regions[26].

In Nepal, agriculture is the main source of livelihood, household income, and food security for two thirds of the population[27]. Agriculture accounts for 27% of the gross domestic product and two-thirds of export earnings, making it a key sector for sustainable development[28]. Moreover, Nepalese agriculture exhibits a high level of diversification in terms of climatic and geographic variations, further emphasizing the importance of understanding the role of pollination in this sector[23,27].

Numerous studies have investigated the economic value of pollination services at a global and national scale[9,19,26]. Nevertheless, in Nepal, a significant gap remains in comprehending the value of pollination services for supporting agricultural production and human nutrition. It is very clear that if pollinator declines continue, levels of poverty and malnutrition in Nepal will worsen, further exacerbating the existing pressures on natural resources and biodiversity[25]. Using public data on agricultural production and commodity prices, in combination with published nutritional composition values, we employ the dependency-ratio method to quantify the economic and nutritional value of pollination services in seven provinces of Nepal and assess the changing reliance upon pollination services over the last 18 years. We address this aim via the following three objectives: (i) Quantify the value of insect pollination for human consumption in Nepal and identify specific crops and regions of the country with high vulnerability to pollinator declines. (ii) Quantify the contribution of pollination services to the supply of each key dietary nutrient in Nepal and identify specific nutrients and regions of the country with high vulnerability to pollinator declines. (iii) Asses the trend in pollinator-dependent crop production over the last 18 years in Nepal, comparing these with trends in non-pollinator-dependent crops to assess the changing vulnerability of Nepal to pollinator declines. Although the dependency ratio method does not capture the full economic value of pollination services, it is a widely-used approach which provides a useful indication of the direct economic value of pollination services to farmers, a metric which can be readily compared amongst regions and countries. Together with our nutritional assessment of pollination services, these two measures provide a clear indication of the direct value of pollinators to the livelihoods and food security of smallholder farmers.

Methods

Data collection on cultivated area, production and market value of crops

We sourced data on the cultivated area and total production of 75 major cultivated crops in Nepal from the Ministry of Agriculture and Livestock Development (MOALD)[29,30]. Market value data was retrieved from Food and Agriculture Organization of the United Nations (FAO)[31] datasets. Some of the data missing in FAO datasets were obtained from the Kalimati Fruits and Vegetable Market Development Board, Ministry of Agriculture and Livestock Development and Ministry of Industry, Commerce and Supplies. The cultivated area and production data were disaggregated to the seven provinces of Nepal (Fig. 1), allowing us to assess trends and vulnerability in each province separately.

The cultivated crops were classified into five groups based on their pollinator dependency ratios (DR) classified by[1]. They were: (i) essential, where crop production would be reduced by over 90% in the absence of animal pollinators; (ii) great, where reduction would range between 40 and 90%; (iii) modest, where reduction would range between 10 and 40%; (iv) little, where reduction would range between 0 and 10%; and (v) pollinator-independent crops for which the pollinator dependence is either not know, zero, or only relevant for seed production. To estimate the Economic Value of Insect Pollination (EVIP) services in crop production, we multiplied the Total Value of each Crop (TVC) by its Pollinator Dependency Ratio (Di) for crop production following[11,12]. The Total Value of each Crop (TVC), as defined in our study, is the product of the quantity (Qi) and market price (Pi) of crop I to the producer, ignoring any values to the consumer, or non-market values (see[11,12]). The Di ratio is the contribution of insect pollination to food production and corresponds to the quantitative relative loss of agricultural production that would result from the disappearance of pollinators[1]. The crop pollinator dependency ratio (Di) is calculated according to the following equation:

$$Di = 1 - \frac{fpe}{fop}$$

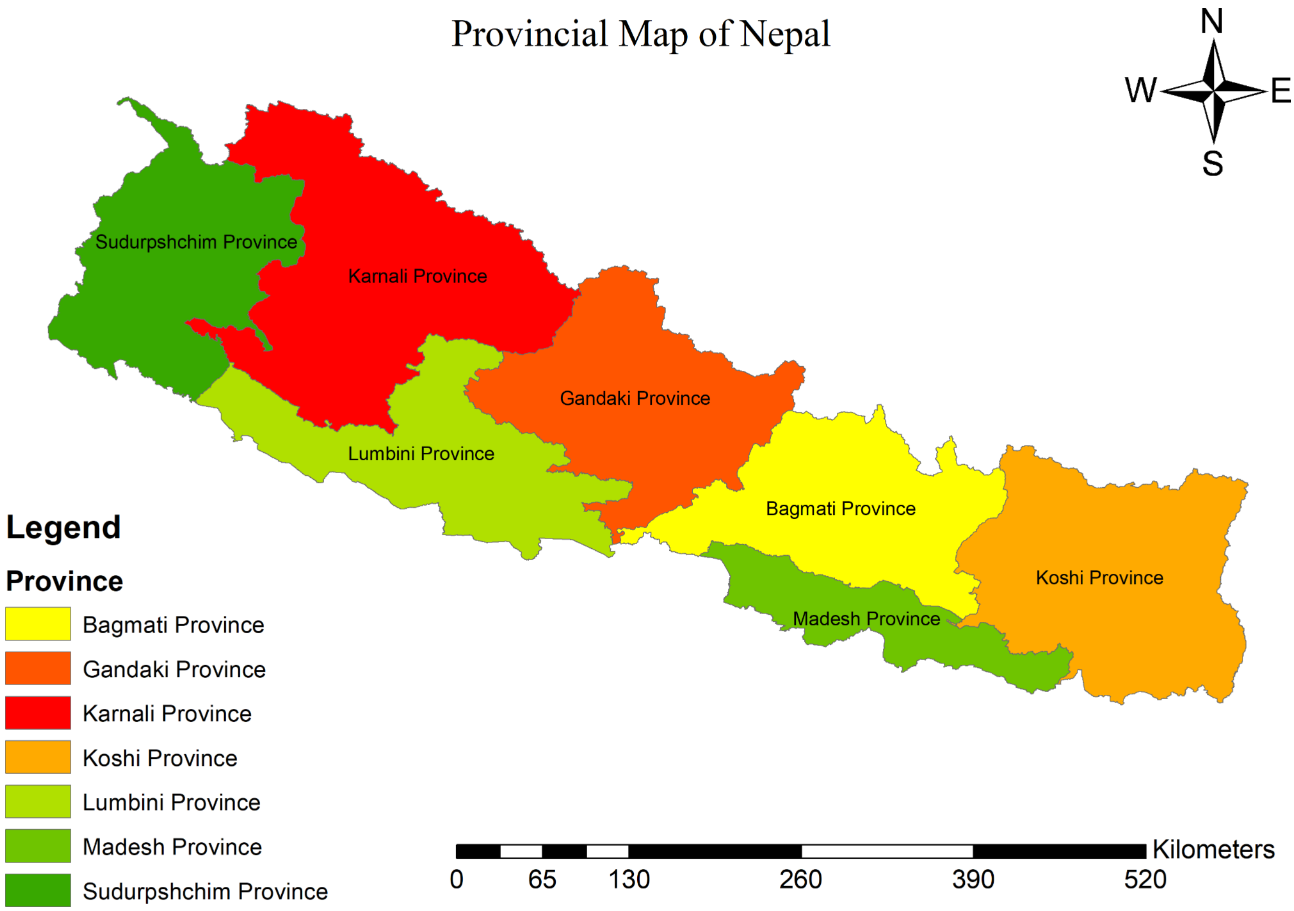

Fig. 1. Map of Nepal showing the seven provinces.

where fpe = fruit set of commodities under pollinator exclusion conditions; fop = fruit set of commodities under open pollination conditions.

In addition to calculating the Economic Value of Insect Pollination (EVIP) services at the national level – as outlined above – we also calculated these same values at the provincial level to investigate variation amongst different provinces. To ensure consistency, the price of agricultural commodities was considered to be the same across all seven provinces. Although this is a simplifying assumption, our goal was to assess the relative importance of pollination services in the different provinces, not differences in their economic context; thus it was more appropriate to assume standard commodity prices across the country. It should be noted however that this assumption is likely to increase the error margins on our estimates of absolute economic value in each province.

We also calculated the Ratio of Vulnerability (RV) of the agricultural output to pollinator loss, which provides a measure of the potential relative production loss attributable solely to the lack of insect pollination. To calculate the Ratio of Vulnerability to pollinator losses (RV), we divided Economic Value of Insect Pollination (EVIP) by Total Value of Crop (TVC) according to the equation shown below:

$$RV = \frac{EVIP}{TVC}$$

Trends in crop area and production from 2000 to 2018

We used MOALD and FAO datasets to gather data on the cultivated area and production of the major agricultural crops cultivated in Nepal from 2001 to 2018 to assess the trend in pollinator-dependent crop production during this 18-year time period. For each category of pollinator dependence (essential, great, modest, little and none) the total area of cultivation and total crop production were plotted over time to visualize the trend in pollinator dependence. The annual growth in the cultivated area and production of pollinator-dependent crops (i.e. those which require insect pollinators for the fruit or seed set) and non-dependent crops (i.e. the crops that are self-pollinated or cultivated solely for roots, tubers, leaves, stem etc.) was calculated as the ratio of the previous year to the current year between 2001 and 2018. The pollinator dependent crops were categorized according to their degree of pollinator dependence (little, modest, great and essential) as classified by[1,11].

Assessing the nutritional value of crop pollination services in Nepal

The nutritional values for each crop were taken from food composition tables compiled from multiple sources, including the United States Department of Agriculture (2013), McCance and Widdowson's The Composition of Foods Integrated Dataset (2015), the Bangladesh food composition Table (2013), the Nepal food composition Table (2012) and other peer-reviewed published sources for rare items. We recorded the availability per 100 g of each crop of 14 key nutrients which are widely recognised as essential for human health and which can be obtained from plants (not just animal products)[19]. These were: Calcium, Energy, Fat, Folate, Iron, Niacin (B3), Protein, Riboflavin (B2), Thiamin (B1), Vitamin B6, Vitamin C, Vitamin E, Vitamin A and Zinc. These nutrient values were multiplied by the total production of each crop in each province to give the total grams of nutrient produced at a province level. For each crop, the nutrient values were multiplied by the pollinator dependence ratio of the crop to show the proportion of each nutrient attributable to insect pollination at both a national and a province level. This enabled us to identify nutrients and regions of the country which are particularly vulnerable to pollinator loss. In this analysis, we made the simplifying assumption that the nutritional value of each crop remains the same across the country, regardless of the region, the agricultural practices used, or the cultivar grown. This was necessary, given the lack of data on nutritional values for different regions and different local cultivars. Whilst this assumption is likely to increase the margin of error in our estimates of nutritional value, we do not expect it to alter the relative importance of pollination services to nutrient production across the country – our question of primary interest.

Data analysis

To gain insights into the clustering patterns of different provinces based on their Ratio of Vulnerability (RV) values, we used a hierarchical analysis which provides a systematic approach for quantifying the similarity in a given variable (in this case RV values) between different categories (in this case provinces). We utilized the commonly used Manhattan distance measure to calculate the dissimilarity or similarity between rows or columns of data, which involves computing the absolute differences between the values of two points in the same dimension and summing them up across all dimensions. The hierarchical clustering algorithm used this distance metric to group similar regions together and create clusters based on their similarity level. We used the unweighted pair group method with arithmetic mean (UPGMA, average linkage) as the grouping method, which effectively captures the average distance between each point in one cluster and every point in the other cluster. These dissimilarity measures were then visualised using clustered heatmaps in the package *pheatmap*[32].

Results

Objective 1: economic value of crop pollination services

There are over 75 different crops cultivated in Nepal, of which 53 (70%) rely at least to some degree on insect pollination for their production whereas the remaining 22 crops (ca. 30%) did not depend on pollinators for production. However, five of these 22 crops (broccoli, cabbage, cauliflower, carrot and radish) still rely on visitation by insects to set viable seeds for use the following year, even though their edible portion is not dependent on pollinators. The remaining 17 crops (23%) show no dependence at all on insect pollinators.

The economic value of insect pollination (EVIP) for human-consumed crop production in Nepal was estimated at US $477 million which represents ca. 9% of total agricultural revenue (estimated at $5.9 billion). Among the 9 crop categories, the contribution of insect pollination was highest for vegetables ($255 million) followed by fruits ($140 million) and oilseed ($58 million), as shown in Table 1; Fig. 2A. We found that gourd crops (bitter gourd, bottle gourd, sponge gourd etc.) had the highest pollination economic value ($73 million) followed by mango ($70 million), mustard ($49 million), citrus ($24 million) and apple ($14 million).

We found that Madesh Province (10%) showed the highest economic vulnerability to pollinator loss followed by Bagmati Province (9%), Karnali Province (8.6%), Sudurpaschim Province (7.4%), Gandaki Province (7.3%), Lumbini Province (6.9%) and least in Koshi Province (6.7%). Fruit crops had the highest vulnerability to pollinator decline (34%), followed by vegetables (30%) and oilseed (24%) as shown in (Fig. 2B). Similarly, we found that the total economic value of crops was four times higher for the non-pollinator dependent crops than

Crop category	Total value of crops (million US dollars)	Economic value of insect pollination (million US dollars)	Ratio of vulnerability
Cereal	2707	3	0.12
Fruit	425	140	33
Oilseed	240	58	24
Pulses	290	9	3
Spices	215	12	5
Stimulant crop	118	0.001	0.16
Treenut	7	0.05	5
Vegetable	859	255	30
Non-edible cash crops	1091	0.02	Negligible

Table 1. The economic value of different crop types grown in Nepal measured as millions of US dollars gained in revenue each year. Shown alongside the total value of crop production (TVC) is the value of insect pollination (EVIP) as well as the ratio of vulnerability (EVIP/TVC). Crops are grouped into categories following[11].

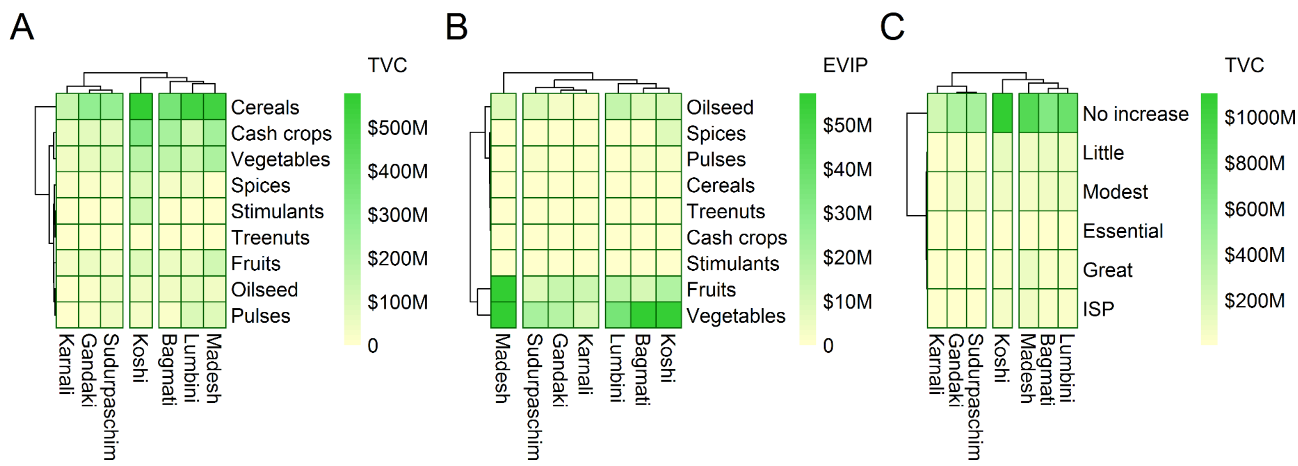

Fig. 2. Clustered heat map that displays the Total value of Crop (TVC) across provinces in columns and crop category in rows. **B** Clustered heat map that displays the Economic value of Insect Pollination (EVIP) across provinces in columns and crop category in rows. **C** Clustered heat map that displays the Total value of Crop (TVC) across provinces in columns and Pollination dependence in rows. The hierarchical cluster analysis utilized the UPGMA method and Euclidean distance measurement following the standardization of the average scores (using the decostand function with the range method in R).

for pollinator dependent crops. Among the pollinator dependent crops TVC of the crops classified as modest pollinator dependent crops was found higher (34%) followed by essential (33%), little (25%) and great (8%) as shown in Fig. 2C.

Objective 2: nutritional value of crop pollination service

Nutrients varied substantially in their proportion of pollinator-dependence, with 40% of plant-based Vitamin A production directly reliant on animal pollinators, but only 2% of plant-based energy (i.e., calories) reliant on pollinators (Fig. 3). Vitamin C (14%), Vitamin E (13%), Fat (8%) and Folate (8%) also showed a relatively high dependence on insect pollinators for their production. Most nutrients were produced in Madesh province (Fig. 4) where many fruits and vegetables are grown. This province also showed the greatest vulnerability to pollinator declines, with 56% of total Vitamin A production expected to be lost in the absence of insect pollination. This pattern differed slightly amongst nutrients however, with some nutrients (like Vitamin C, Calcium and Folate) showing a greater vulnerability to pollinator declines in other provinces, including Karnali, Gandaki and Bagmati (Fig. 5).

Objective 3: Trends in pollinator-dependent crop production

The area cultivated with pollinator-dependent crops (all categories of pollinator dependence combined) expanded by 91.3% during the period from 2001 to 2018, whereas the area cultivated with pollinator-independent crops increased by only 24.8% during this same time period. This represents a 3.7 times greater rate of increase in pollinator dependent crops and thus an increasing relative reliance on pollinators. Most categories of pollinator dependence (great, modest and little) showed a marked increase in cultivation area and total production between 2001 and 2018 as shown in Fig. 6. However, for the crops where pollination was essential, production showed a sharp decline in the year of 2015. This was driven by a fall in the production of certain crops due to the earthquake[33]. Following this decline, the production of crops for which pollination is essential, continued their steady increase.

Discussion

Our study examined the economic and nutritional value of pollination services in Nepal where most farmers are smallholders and highly reliant on pollination services for their livelihoods and food production. Our results show that pollination services contributed US $477 million in the year 2018 to Nepalese agricultural revenue, most of which is derived from vegetable and fruit production. This figure reflects only the producer-focused market value, whereas the real value of pollination services (including non-market values to the consumer) is likely to be substantially higher[11,12]. We found that 70% of the 75 different crops cultivated in Nepal rely to some degree on insect pollination for the quantity and quality of their yield. Many of these crops are highly nutritious and up to 40% of some important micronutrients (e.g., Vitamin A) and 20% Vitamin C are entirely dependent on insect pollination for their production. Overall, the cultivated area of pollinator dependent crops has increased by 91%, more than three times faster than the rate of increase in non-pollinator dependent crops, representing an increasing reliance on pollinators in Nepal. In the following sections, we discuss the wide-reaching benefits of pollinators for the livelihoods and food and nutrition security of Nepalese farmers and suggest appropriate actions to conserve and enhance pollination services in Nepal.

Smallholder farmers are known to be highly dependent on the services provided by pollinating insects for their crop production[23] and insufficient pollination is known to result in substantial yield gaps (pollination

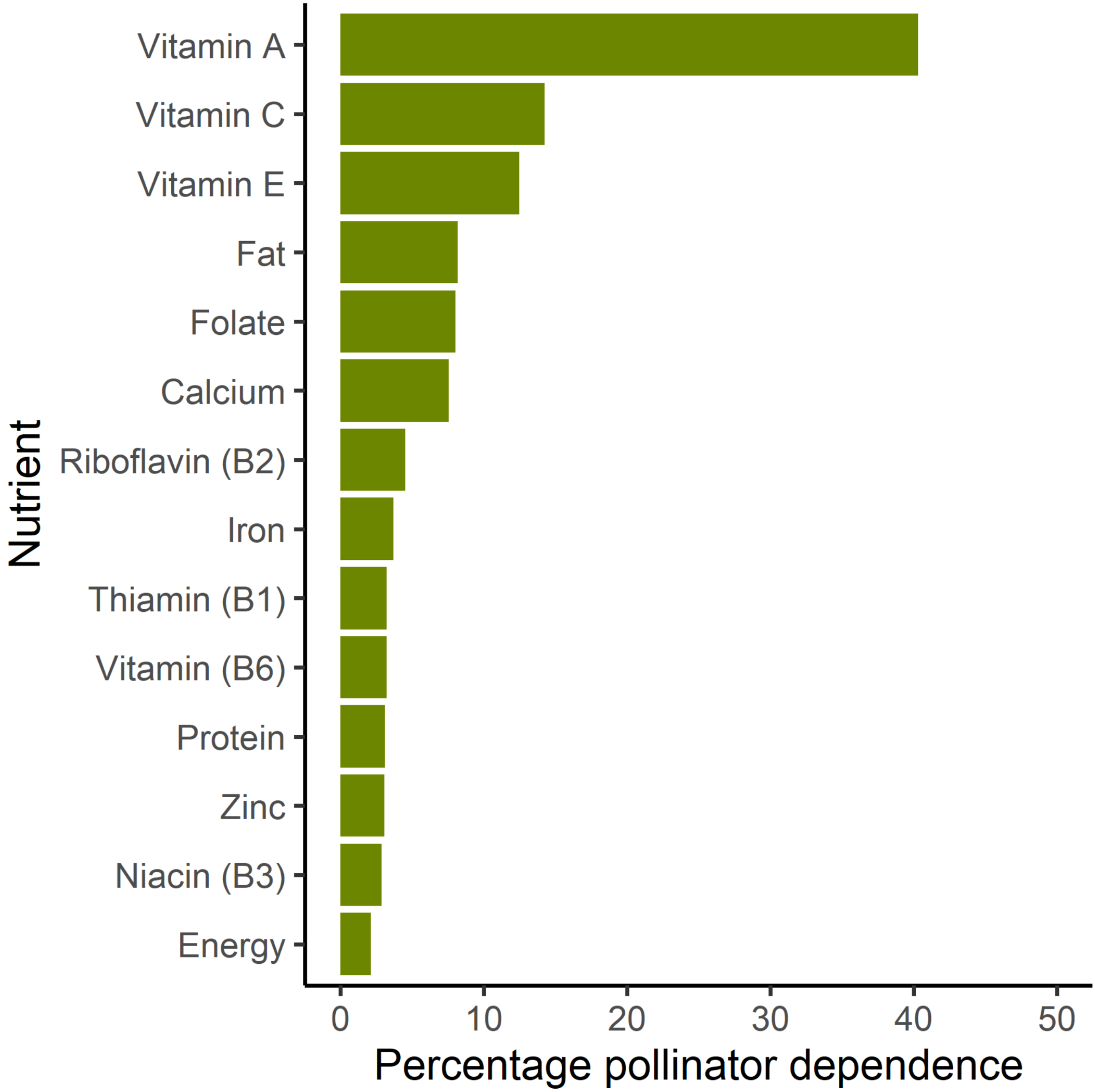

Fig. 3. Percentage of total plant-based nutrient production attributable to animal pollination for each of 14 key dietary nutrients derived from crops grown in Nepal.

deficits) for these farmers[27]. Our study shines a light on some of the commercial crops which are at greatest risk of pollination deficits in Nepal and which may lose farmers the most income if pollinators were to decline. We found that the production of fruits, vegetables and oilseeds are particularly dependent on insect pollination in Nepal, similar to other regions of the world including China, USA and Europe[16,34]. In Nepal, the economic value of insect pollination has increased by more than five-fold since 2005 ($ 80 million), reflecting a similar trend found by[11]. The rise in economic value of insect pollination can be attributed to shifting agricultural patterns in Nepal, driven by the national government's strong promotion of highly pollinator-dependent cash crops such as apples, citrus, cardamom, and various vegetables. As a result, these crops have expanded their cultivated areas across the country, as highlighted in the Prime Minister Agriculture Modernisation Project (PMAMP)[35]. However, the increasing dominance of cash crop monocultures creates a growing demand for concentrated pollination services, placing additional pressure on pollinator biodiversity and contributing to the decline of pollinators[36]. Addressing this issue and ensuring the pollination needs of crops are met sustainably will require strong efforts at both a policy and practitioner level.

The economic value of crop pollination services are not distributed evenly across the country, but are instead concentrated in regions of high fruit and vegetable production such as Madesh province. Farmers in these regions

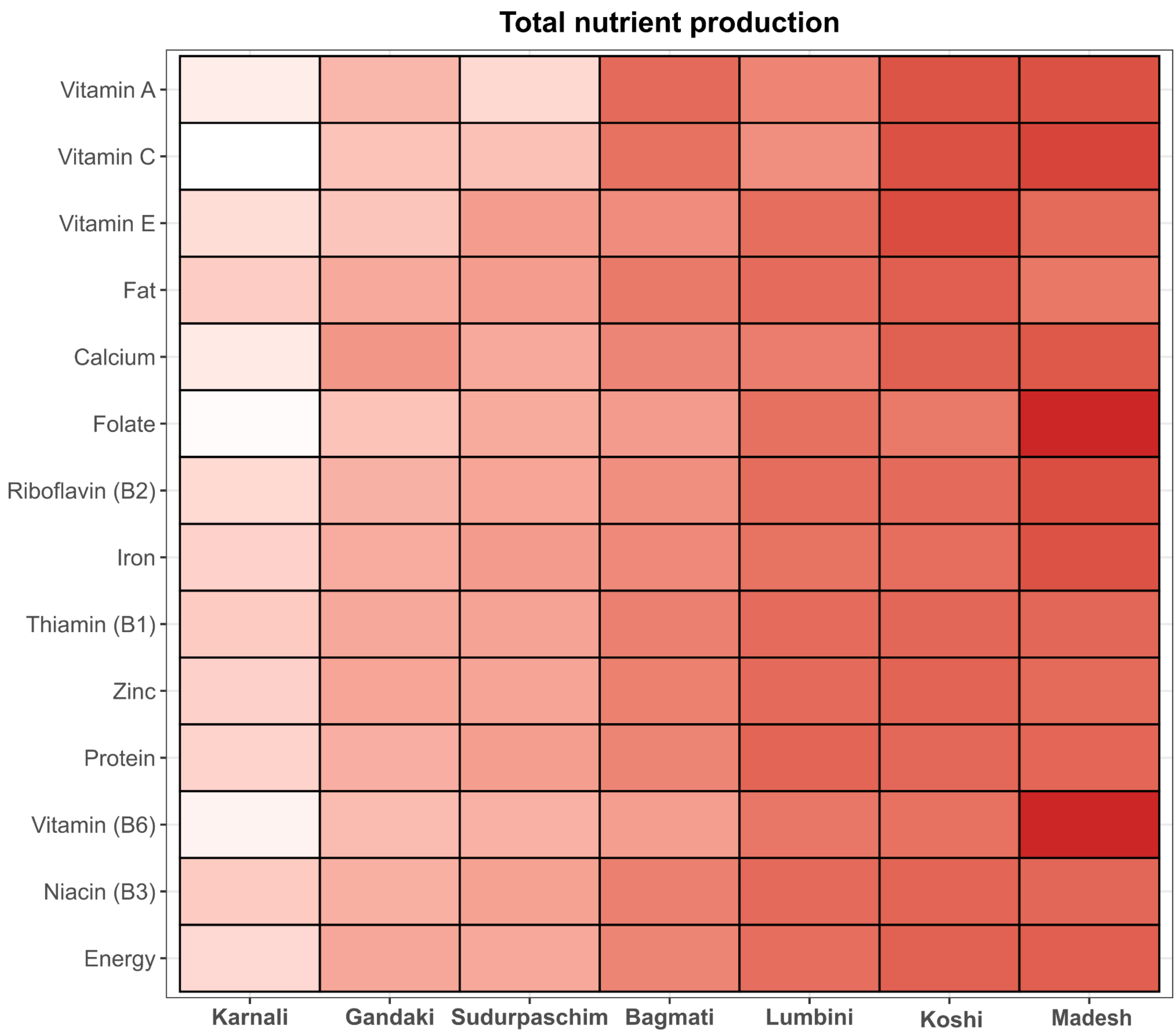

Fig. 4. Heatmap showing the proportion of each key nutrient produced in each of the seven provinces. Provinces are ordered from lowest (left) to highest (right) total nutrient production.

– particularly those specializing on highly pollinator-dependent fruits and vegetable crops such as mango or squash, are likely to be most at risk of pollinator decline. The conservation of wild bees and commercialization of native honey bees in these regions are crucial to meet the pollination demands of crop production[16]. Likewise, conservation and education efforts should thus be targeted in these regions to achieve the maximum impact. A recent modelling study showed that farmers in Nepal have substantial opportunities to increase their crop yields and resulting income by enhancing pollination services. Closing pollination related yield gaps (pollination deficits) in Nepal was predicted to increase the economic income of individual farmers by 31%[37].

The high pollinator dependence of certain essential nutrients, such as vitamin A and vitamin C, results from their high concentrations in pollinator-dependent fruit and vegetable crops. Examples of such crops include mango, citrus, squash, gourds, and tomatoes. The high dependence on pollinators for these nutrients raises concerns, particularly considering the limited access of subsistence farming communities to alternative high-density nutrient sources like meat and animal products, which are often scarce or unaffordable. Vitamin A is crucial for maintaining vision, boosting the immune system, and supporting growth and development[31]. In Nepal, where vitamin A deficiency is prevalent and leads to issues like night blindness and increased vulnerability to infections, ensuring an adequate intake of this nutrient is essential for improving overall health and well-being[38,39].

The potential loss of pollination services and the resulting decline in vitamin A production, as well as other nutrients such as folate and vitamin C, is predicted to drive a number of negative health impacts in Nepal and across the world[22]. Conversely, improved management of pollination services and the resulting increase in yields of nutritious crops can be expected to bring substantial health benefits to the population of Nepal. Over the last 18 years (2000 to 2018), there has been a 91% percent increase in the cultivated area and 107% increase in the

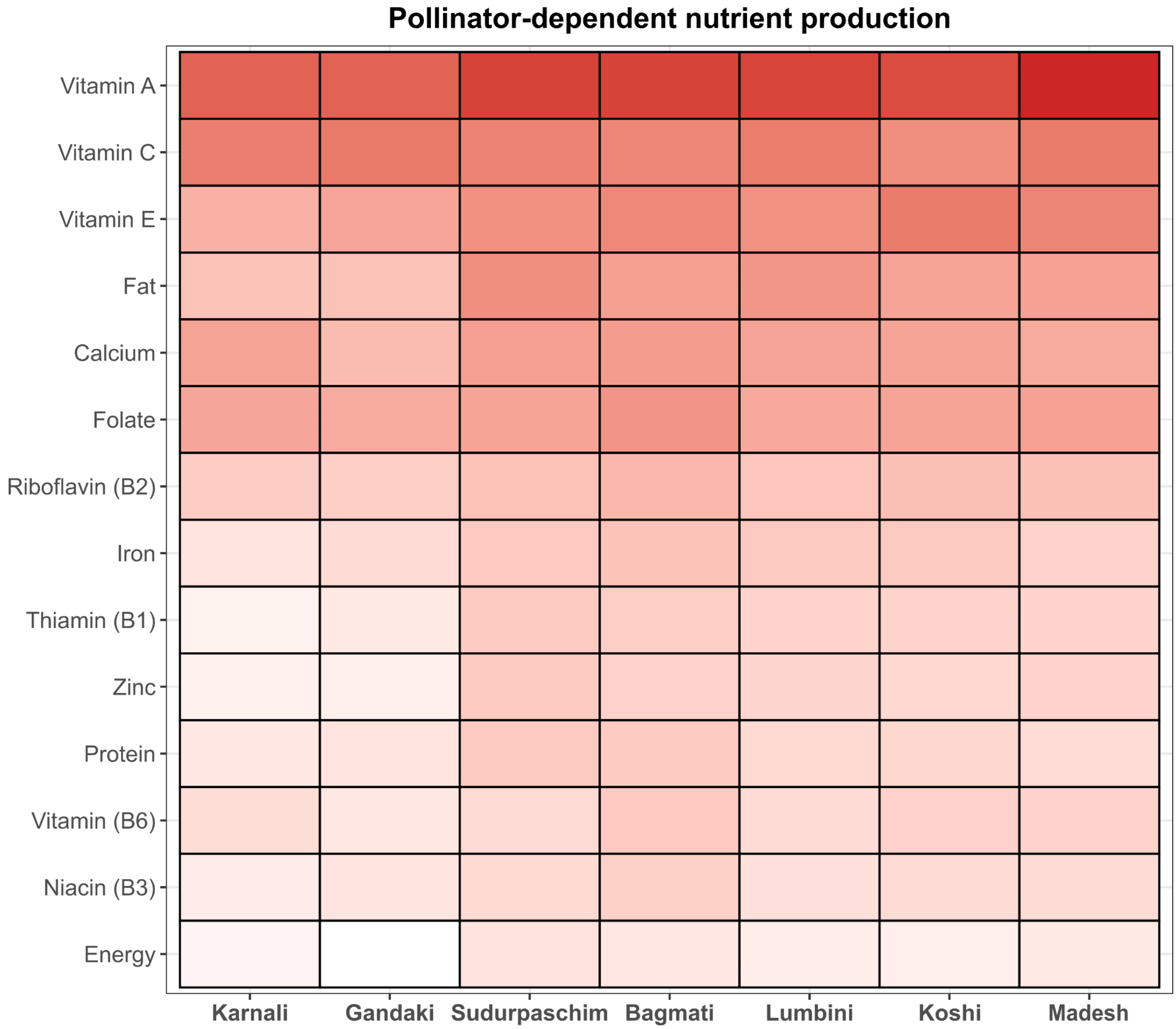

Fig. 5. Heatmap showing the vulnerability of each key nutrient to pollinator loss, separated by province. Nutrients are ordered from highest (top) to lowest (bottom) pollinator dependence.

production of pollinated-dependent crops in Nepal. This trend of increasing area and production of pollinator-dependent crops is consistent with the global pattern observed[25,40]. However, the figures reported from Nepal surpass the growth rates observed in China, where the increase in both area and production reached 22%[16] as well as global context, with a growth rate of 40%[20,41].

The notable expansion of pollinator-dependent crops contrasts strongly with the rates of decline observed in wild and managed pollinators across the world. The mismatch between increasing demand for pollination services and declining pollinator populations has resulted in documented pollination deficits in cereal, vegetable, and oilseed production both in Nepal, and elsewhere[42–45]. Therefore, this data underscores the growing significance of pollinator-dependent crops and the subsequent challenges posed by the decline of wild pollinators. The decline of insect pollinator populations in developing countries like Nepal poses substantial risks to food systems, sustainable livelihoods and nutrition[23]. It highlights the urgent need for sustainable management strategies to address the pollination deficits in vital crop sectors such as fruits, vegetables, and oilseeds, in order to ensure their continued production and contribution to food and nutrition security in Nepal.

Our result shows that the ratio of crop vulnerability, attributable to the loss of pollinators, was approximately 9% at a national scale, ranging from 10% in Madesh Province to 7% in Koshi Province which is strongly related to the cropping practices of the high-value fruits like mango and vegetables[46]. The dominance of pollinator dependent crops in these regions, combined with a low abundance and diversity of insect pollinators resulting from agriculture intensification, may result in the decline of crop production and yield[44]. An understanding of the economic and nutritional value of pollination services across different regions of the country is crucial for devising a targeted plan for the conservation and management of pollinators for sustainable agricultural production[47]. We found that the overall production of fruit crops will reduce by 34% in the absence of insect

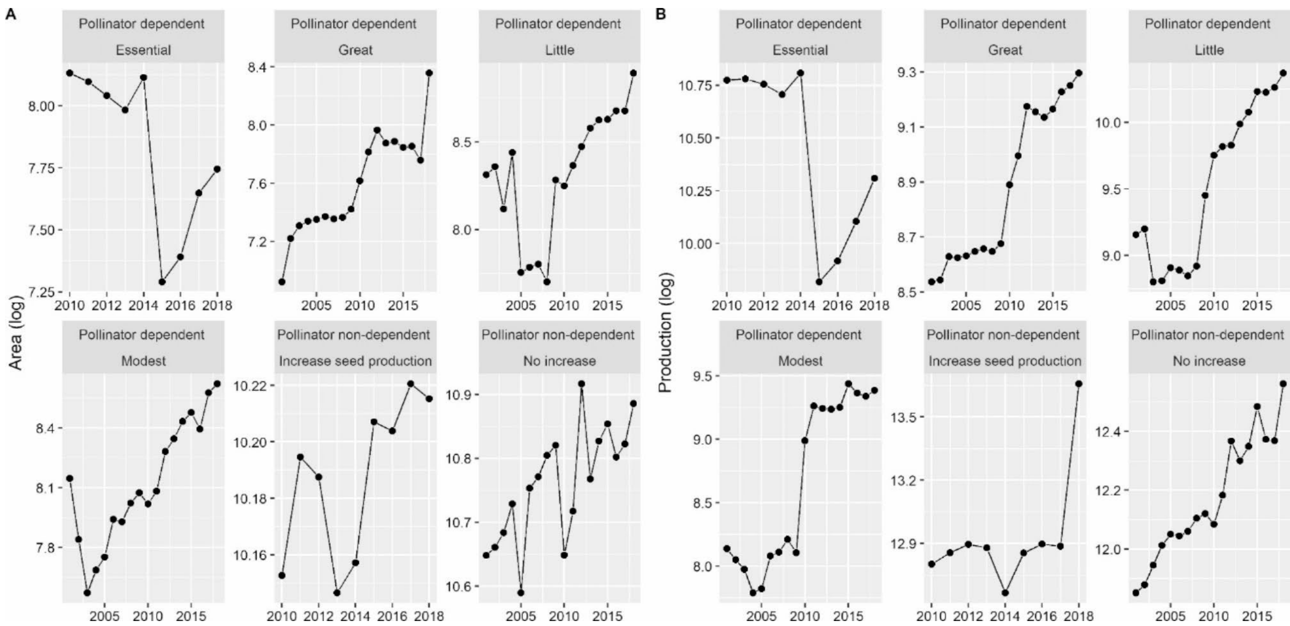

Fig. 6. Historical trends in (a) cultivated area and (b) production of crops in Nepal. Crops are divided into categories depending on their degree of pollinator dependence.

pollinators, followed by a 30% and 24% decline in vegetables and oilseed production, respectively. As well as impacting the yield of fruits and vegetables, pollinator declines may also alter the quality and nutritional value of these crops, potentially leading to even greater economic and nutritional losses[5,19,47,48]. Moreover, the production of many pollinator-dependent crops including fruits, vegetables, oilseeds, tree nuts, spices and other cash crops represent the main source of income for farmers and present great importance for the province's economy and food security[34].

Given the growing economic value of insect pollination, the conservation and management of wild pollinators is more crucial than ever for supporting and enhancing local economies and farmer livelihoods[49]. However, pollinators are instead subjected to increasing threats from agricultural intensification, habitat loss, pesticide use and climate change[6,50]. Addressing these threats and promoting the widespread uptake of pollinator-friendly farming methods will be crucial for maintaining livelihoods and human health whilst simultaneously benefitting biodiversity. The management of pollination services is of particular importance for smallholder farmers in developing countries like Nepal. These populations often lack the flexibility to change their farming practices or diets and are therefore highly vulnerable to the loss of pollination services both at a local, province and national level. If pollinator declines persist in the current manner, vulnerable populations are likely to experience increased rates of malnutrition and poor health, resulting in reduced productivity and perpetuating the intergenerational cycle of persistent poverty[5,22,51]. Thus, to ensure economic growth, social inclusion, and environmental protection, the conservation and management of pollinators should be a central priority in sustainable development initiatives. Achieving this will require a combination of bottom-up approaches such as pollinator awareness programs for farmers and the promotion of pollination management practices; as well as top down approaches including pesticide regulation, enabling policies and improved agricultural support systems[52,53]. In the short term, farmers can safeguard and enhance pollination services on their farms through simple, low-cost management actions such as sustainable native beekeeping, planting wildflower margins and hedgerows to provide food for pollinators, ensuring sufficient nesting sites and reducing pesticide use[49]. Overall, we emphasize the value of sustaining local crop, pollinator, and wild plant diversity in order to promote long-term stability and resilience in food production and livelihoods for smallholder farmers.

Conclusion

Sustainable agricultural development is essential for achieving the Sustainable Development Goals of poverty alleviation, zero hunger and nutrition and food security in developing countries. In this regard, pollination is one of the key agroecosystem services which ensures sustainable agriculture production and integrates economic growth, food and nutrition security, and environmental protection[9]. Our findings – the high economic value of pollination and its importance for human livelihoods and nutrition has important policy implications regarding pollinator conservation and management for sustainable agriculture production at both the federal and provincial levels in Nepal. It should be noted that our economic valuation approach represents only the direct value of pollination services to producers (i.e. farmers) and the full economic value to society will be substantially higher. Nevertheless, we provide the first baseline measure of pollination service value in Nepal and we hope that future studies extend this to include other important measures of value, including values to the consumer and values derived through non-crop pollination services such as medicinal plants and ecosystem functioning. Despite its limited scope, our study presents compelling evidence for the substantial contribution of pollination to crop production and human nutrition. Given these substantial values to society, we highlight the crucial importance of safeguarding pollination services in Nepal and the opportunities for enhancing livelihoods and nutrition by managing pollinators as a key agricultural input. Although our study focuses on Nepal, the findings may serve as a relevant example for other countries and governments aiming to improve livelihoods and nutritional outcomes whilst conserving biodiversity.

Data availability

Data will be available upon request via email to the corresponding authors Dr. Kedar Devkota on kdevkota@afu.edu.np.

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Author contributions

KD planned the questions and the sampling design. KD and ABF conducted and validated the dataset. KD, CFS and TT organized and structured datasets for statistical analysis. CFS and TT executed the data analysis. All the authors contributed to the developemnt of concept and writing the manuscript. All the authors wrote the original draft, discussed the scope, and reviewed the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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