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Decline in Honeybees and Its Consequences for Beekeepers and Crop Pollination in Western Nepal

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Simple Summary: Beekeeping provides numerous economic, cultural, and crop pollination benefits to communities around the world, including in Nepal, where traditional beekeeping has been practiced for centuries. Anecdotal reports suggest that the native Asian honeybee *Apis cerana* is declining across Asia, but few studies have measured the extent of these declines or their implications for beekeepers and farmers. Working in the Jumla District of Western Nepal, our aims were to investigate population trends of the native honeybee *Apis cerana cerana* and assess its importance for livelihoods and crop pollination. Interviews with 116 local beekeepers revealed a 44% decline in the number of occupied beehives and a 50% decline in honey production per hive from the years 2012 to 2022. Beekeepers reported climatic changes and the loss of flowers as the main drivers of this decline. These declines pose a major threat to local communities, as sales of honey contribute 16% of total household income for beekeepers, and *Apis cerana cerana* is a key pollinator of many important crops. Our study provides a warning signal of potential declines in all insect pollinators across the region and calls for actions by farmers, beekeepers, researchers and policy-makers to work together in addressing this socio-ecological crisis.

Abstract: In understudied regions of the world, beekeeper records can provide valuable insights into changes in pollinator population trends. We conducted a questionnaire survey of 116 beekeepers in a mountainous area of Western Nepal, where the native honeybee *Apis cerana cerana* is kept as a managed bee. We complemented the survey with field data on insect–crop visitation, a household income survey, and an interview with a local lead beekeeper. In total, 76% of beekeepers reported declines in honeybees, while 86% and 78% reported declines in honey yield and number of beehives, respectively. Honey yield per hive fell by 50% between 2012 and 2022, whilst the number of occupied hives decreased by 44%. Beekeepers ranked climate change and declining flower abundance as the most important drivers of the decline. This raises concern for the future food and economic security of this region, where honey sales contribute to 16% of total household income, and where *Apis cerana cerana* plays a major role in crop pollination, contributing more than 50% of all flower visits to apple, cucumber, and pumpkin. To mitigate further declines, we promote native habitat and wildflower preservation, and using well-insulated log hives to buffer bees against the increasingly extreme temperature fluctuations.

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1. Introduction

Insect pollination enhances the yields and quality of 75% of global crop plants [1], but pollination services are severely threatened globally [2]. Declines in insect pollinators have been reported across most regions of the world where historic data and monitoring programs enable such assessments [3–6]. These declines are thought to be driven by a combination of anthropogenic factors including agricultural intensification, habitat loss, disease, pesticide use and climate change [7–10]. The threats facing pollinators likely differ amongst regions of the world and the impact of pollinator declines on food security is potentially the most severe for smallholder farmers in low-income countries. These farmers strongly rely on local pollination services for their food and nutrition security, as well as their income [11,12]. Despite the immense importance of pollination services to smallholder farmers, we know almost nothing about the population trends of insect pollinators in regions of the world where smallholder farming systems predominate [13]. This makes it challenging to assess the degree of risk and identify likely drivers and mitigation strategies.

The lack of historic data and formal monitoring schemes for insect populations in most low-income countries currently poses a major barrier to understanding global pollinator statuses and trends and the ability to tailor conservation efforts accordingly. In the absence of long-term quantitative data on insect population trends in understudied regions, other forms of data may prove useful, including the records and perceptions of local beekeepers. Given the strong reliance on bees for their livelihoods, food, and medicinal needs, beekeepers typically have a strong awareness of the health and well-being of their bees and the environment in which they forage [14]. This should make beekeepers ideal witnesses for reporting on the population status of the bees they keep, along with the environmental stressors affecting them. However, despite their wealth of local knowledge, the perceptions, records and experience of indigenous beekeepers are rarely considered [2].

Beekeeping is practiced widely across the world, predominantly using two species of managed honeybees, *Apis mellifera* Linnaeus (1758) and *Apis cerana* Fabricius (1793), but also various stingless bees such as *Trigona* spp. and *Melipona* spp. [15]. Beekeeping has immense cultural and economic importance across the world [16], particularly for smallholder farmers, as it requires only a small amount of land and minimal investment whilst providing a significant source of income [17]. In addition to producing valuable products such as honey, beeswax, pollen, and propolis, managed bees can play a crucial role in crop pollination, substantially enhancing agricultural yields [18,19]. In Nepal, where this study is based, traditional beekeeping of the native *Apis cerana* has been practiced for many centuries. Bees were traditionally kept in wooden log hives, but commercial beekeeping with the rearing of *A. cerana* in modern beehives began in the 1980s [20]. After the introduction of *Apis mellifera* in 1992, commercial and migratory beekeeping was taken up in the plains and mid-hills of Nepal [18].

The introduction of *A. mellifera* in Nepal reflects a broader trend of the introduction and replacement of *A. cerana* across South Asia, resulting in widespread reports of *A. cerana* population decline [21]. Here, we focus on *Apis cerana cerana* Fabricius (1793), a subspecies of *A. cerana* native to the western high hills and mountains of Nepal, where it occurs both as a wild and semi-domesticated pollinator. Although the honey production of *Apis cerana cerana* is relatively low compared to the western honeybee *Apis mellifera*, *Apis cerana cerana* is an efficient pollinator in harsh, high-altitude mountain environments such as in the Jumla District of Western Nepal [22]. In the Jumla District, *Apis cerana cerana* was identified as the most important pollinator in both subsistence and commercial cash crop farming systems [23], consistent with the high importance of *Apis* spp. honeybees

worldwide [1,24]. Moreover, *Apis cerana cerana* requires relatively low maintenance and management costs, and beekeepers possess indigenous technical knowledge on their forage and management [25], making the species highly suitable for remote subsistence-farming communities with limited access to funds and technology [17,22].

The main objective of this study is to shed light on the management practices, population trends and conservation status of *Apis cerana cerana* for Jumla District—a remote mountainous region of Western Nepal and understudied region of the world. The population status of *Apis cerana cerana* is unclear in Nepal since local-level population assessments are lacking. Moreover, the implications of potential changes in bee pollinators for local crop production and beekeeper livelihoods are unknown and have not been previously investigated. Here, we address the ecological and economic importance of *Apis cerana cerana* for beekepers in Jumla, using a combination of different approaches. We asked the three following questions: (1) Have beekeepers experienced a change in the population size of *Apis cerana cerana*? (2) Has the honey yield per beehive and the number of beehives per beekeeper changed between the years 2012 and 2022? (3) What are the drivers of *Apis cerana cerana* population change, and what consequences might this have for crop production and beekeeper livelihoods?

2. Materials and Methods

2.1. Study Site and Sampling Methods

The main beekeeper study was conducted in 10 smallholder farming villages at 2400–3000 m above sea level in Patarasi Rural Municipality, Jumla District, Mid-Western Nepal (Appendix A, Figures A1 and A2 and Table A1). Jumla is a remote mountainous district, situated in the Karnali Province of Nepal. Rates of poverty, food insecurity and malnutrition are particularly high in this region, and 80% of the population is directly dependent on smallholder agriculture [26]. More than 50 crops are grown in this region, including many pollinator-dependent species such as apples, beans, pumpkins, cucumber, mustard, and buckwheat. Beekeeping with traditional log hives has been practiced in Jumla for centuries, with many households keeping hives of the native *Apis cerana cerana* in and around their homesteads [25]. Despite efforts to test and introduce improved, modern beehives in the 1990s [25], most beekeepers keep their bees in hollowed-out log hives, which prevent combs from being inspected without permanently damaging them. *Apis cerana cerana* is the only bee subspecies that is widely kept in this region, as it is higher-yielding and less likely to abscond than other subspecies such as *Apis cerana himalaya* and *Apis cerana indica*. To avoid the spread of disease, the non-native *Apis mellifera* is not currently kept in this region. The honey produced by *Apis cerana cerana* hives is either sold for income or retained for household consumption, medicine, and use in religious ceremonies. Since honey production is one of the few sources of cash income for local farmers in the region, beekeeping is an important activity for sustainable livelihoods. Beehives are generally situated near houses, surrounded by small vegetable gardens and livestock paddocks. Village areas also include small arable fields, apple orchards and large areas of steep, heavily grazed grassland pasture and native coniferous forest (Appendix A, Figure A2).

2.2. Questionnaire Survey and Interview

We conducted questionnaire surveys on a total of 116 beekeepers in the 10 study villages to explore the status of honeybee populations (*Apis cerana cerana*) in Jumla. On average, 11 beekeepers were interviewed per village, which represented the majority of the core beekeeping population in the smaller villages and about half for the bigger villages (see Appendix A, Table A1, for the exact number of beekeepers per village). The questionnaire was designed to reveal temporal changes in honey yield per hive and number of (occupied) hives per beekeeper currently (i.e., in the year 2022) and in the past (years: 2021, 2019, 2017, 2012, and before 2012). To better understand the potential drivers behind any changes, we asked the beekeepers to rank the main causes for changes in number of honeybees, beehives and honey yield. Similarly, to gain insights into the potential consequences for

their livelihood, we asked the beekeepers to rank the main impacts of honeybee declines on their livelihood. The questions and reply options are shown in Appendix B. Interviews were conducted in the Nepali language by a trained data collector in the presence of the lead author and answers were recorded on Android tablets using a custom-built data collection app in CommCare Version 2.48.3 (http://www.commcarehq.org/home/; accessed on 30 August 2022), a cloud-based data collection platform. All interviews were performed by the same individual to avoid any variation due to interviewer effects.

To test for temporal trends in honey yield per hive and number of beehives per beekeeper, we fit two generalised linear models (GLMs) relating honey yield (in kg) and number of occupied hives to year. Because of right-sided skewness in the data, we used a log link function in both cases. Honey yield was modeled using an identity (Gaussian) link function and the number of beehives using a log (Poisson) link function. One was added to the observed values to account for zeros. Predictions were back-transformed to the original scale for easier interpretation. Assuming that the log-linear relationships may continue in the future, we predicted future changes in honey yields and number of beehives up to the year 2030. The regressions were performed using base R, version 4.3.0 [27], and data visualizations using ggplot [28].

To gain a more general and in-depth understanding of the status of honeybee populations in the Jumla District and the drivers of population change, we conducted an in-depth interview with one carefully selected local, lead beekeeper who comes from a household which has kept large numbers of traditional beehives for many generations. The lead beekeeper worked in the Jumla veterinary office for many years and is also one of the few people who uses the improved Jumla top-bar hive to manage bee colonies. Because of this, he has better technical knowledge of beekeeping than most beekeepers in the district (see Appendix C for a transcription and translation of the interview from Nepali to English). In the interview, the same questions were asked as in the questionnaire survey, but the lead beekeeper was encouraged to elaborate on his replies.

2.3. Economic Importance of Honeybees in Jumla District

To assess the prevalence of beekeeping and its importance as a livelihood strategy across the wider Jumla District, we conducted a series of brief structured questionnaires with the lead farmer of 920 households across all eight municipalities of Jumla District (Chandannath, Kankasundari, Sinja, Hima, Tila, Guthichaur, Tatopani and Patarasi). Approximately four respondents were randomly selected from each village in each of the eight municipalities during a series of farmer consultation meetings. As far as possible, the gender ratio of the respondents was balanced to ensure roughly equal participation in the study. Each respondent was asked a simple binary question of whether or not they kept bees. If they answered yes to this question, the participant was then asked how many occupied beehives they had and how much income they derived in the previous year from selling honey. Finally, the respondent was asked to list all of the crops they grow and report their total annual household income from the sale of all agricultural produce. These data enabled us to assess the prevalence of beekeeping in the region and to calculate the proportional contribution of honey sales to total agricultural revenue and determine the relative value of beekeeping as a livelihood strategy. These wider household surveys were conducted by eight trained data collectors (one in each municipality) and answers were recorded in the open-source data collection platform Open Data Kit (ODK; (https://getodk.org/; accessed on 12 Novenber 2022).

Written informed consent was obtained from all participants in the beekeeper and household surveys, and from the lead beekeeper, to publish the information obtained through the interviews conducted in this study.

2.4. Crop Dependency on Apis cerana cerana

To investigate the Asian honeybee's importance as a crop pollinator in Jumla, we analyzed an insect visitation dataset collected in the 10 villages in Jumla during the same time

period as the beekeeper survey was conducted. Insect visitation sampling was conducted every two weeks from 18 April to 4 November 2021 (spring to autumn) in a 600 × 600 m sampling area centered on the midpoint of each study village. This area was divided into three habitat categories: village, crop, and semi-natural vegetation (Appendix A, Figure A2). In each of these habitats, we randomly located three replicate fixed survey plots of 60 × 60 m (9 plots per village). Every two weeks, a 40 min. plant-pollinator visitation survey was conducted in each plot to record the interactions between plants (both crop and non-crop species) and flower-visiting insects. Insects were captured, pinned and identified to species or morphospecies (see acknowledgements). For full details on the insect visitation sampling, see Appendix D.1 and [23].

For each crop in each village, we calculated the proportion of all visits to each crop that were made by *Apis cerana cerana*. Restricting our analysis to pollinator-dependent crops only, we ranked crops from the highest to the lowest proportion of visits made by honeybees, thereby identifying crops which are most reliant on honeybees and therefore most likely to be impacted by honeybee declines.

As well as making a large number of visits to crops, honeybees might be especially important pollinators because they carry large amounts of pollen. To test this, we calculated the pollen carrying capacity of *Apis cerana* and compared it with that of other insect taxa recorded visiting crop flowers in this study region. Pollen carrying capacity was recorded by swabbing a total of 1928 insect specimens (representing 136 unique crop flower-visiting taxa) with glycerine jelly and counting the total number of pollen grains on each insect using light microscopy; pollen in the corbicula was not included in the sampling as this is not available for pollination. For each of the 136 insect taxa that were sampled, we calculated a mean pollen carrying capacity value across all replicate specimens and compared these values amongst taxa to identify the best transporters of pollen (see Appendix D.2 for further details).

3. Results

The district-wide household survey of 920 farming households across all eight municipalities of Jumla revealed that 12.5% of all farming households keep at least one beehive. For those households which kept bees, the mean number of hives per household was 3.4 (±0.3 SE). The average number of beehives for the 116 selected beekeeper respondents of this study decreased from 10.5 in 2012 to 5.3 in 2022.

3.1. Temporal Changes in Honey Yield and Beehives

Across all villages, beekeepers report a significant ($p < 0.0001$) decline in honey yield from (before) 2012 to 2021 (Figure 1a). Specifically, the honey yield declined by 55% over this 10-year period (see Table 1 for glm coefficients). Declines were consistent across all 10 villages (Figure 2), but were only statistically significant in two villages marked with an asterisk in Figure 2.

Table 1. Coefficients (β) and p-values for generalised linear models with a log link function relating honey yield or number of occupied beehives against year. Honey yield was modeled with an identity (Gaussian) link function while beehives were modeled with a log (Poisson) link function. One was added to the observed values to account for zeros.

	Honey Yield		**Beehives**	
Term	β	p**-Value**	β	p**-Value**
Intercept	90.11	<0.001	112.3	<0.001
Slope	−0.044	<0.001	−0.055	<0.001
McFadden's pseudo-R^2	0.010		0.048	

While we record a few instances of very high honey yields (>15 kg per hive), these are likely to represent recall errors by the respondents rather than true values, possibly

because respondents provided a high guess instead of stating that they did not recall the honey yields for a given year. However, as these high values tend to occur in the more recent years (in 2017 or later), they are unlikely to have influenced the overall trend in the detected honey decline.

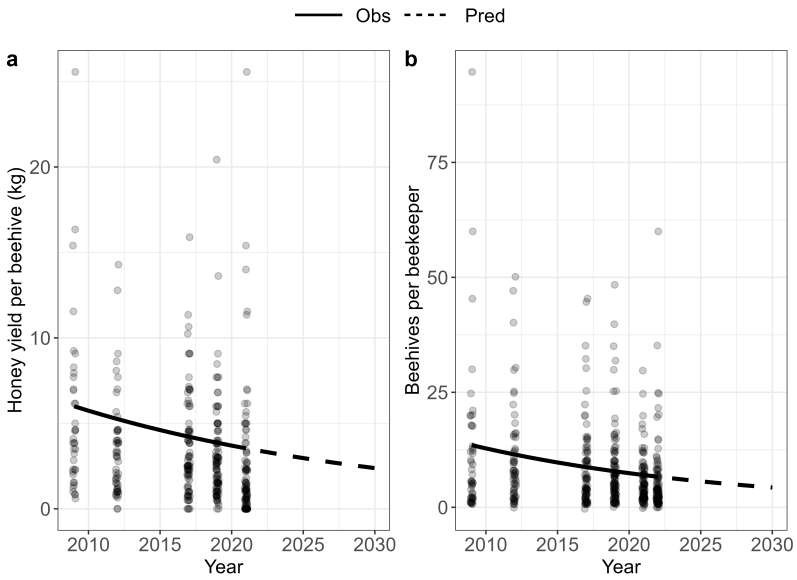

Figure 1. Change in (**a**) honey yield per hive (kg) for the period before 2012 to 2022 and (**b**) number of beehives per beekeeper for the period before 2012 to 2021 across all villages (Obs), with stippled prediction lines (Pred) until year 2030. The analyses are based on 116 beekeeper respondents.

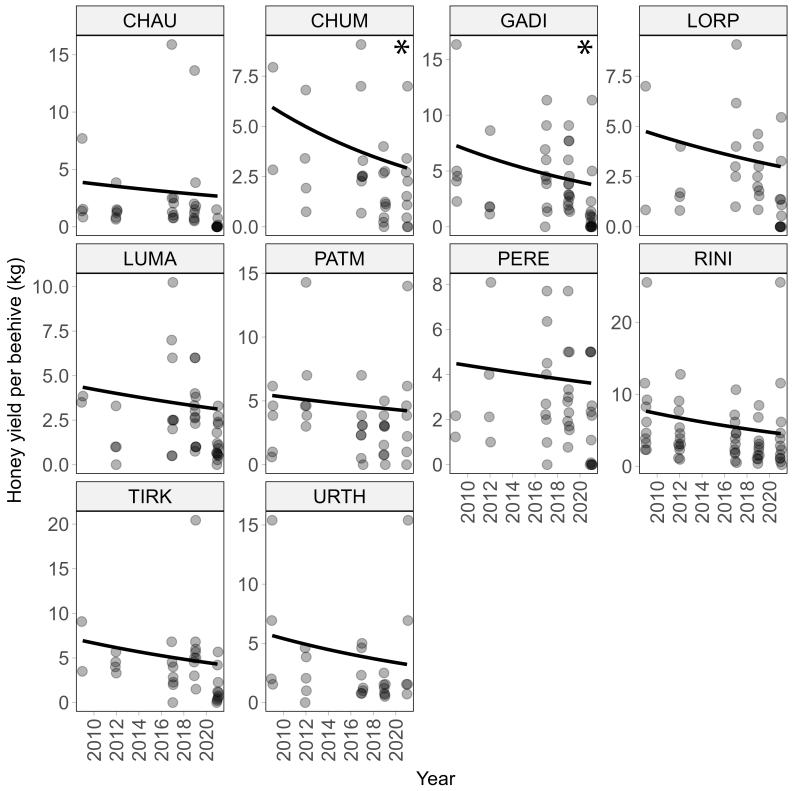

Figure 2. Changes in honey yield per beehive for the 10 villages (on average 11 respondents per village) for the period before 2012 to 2021. The decline in honey yield was consistent across villages but only statistically significant ($p < 0.05$) for two villages (Chuma and Gadigaun) marked with an asterisk in the panels upper right corner. Darker points in the panels are due to overlap in values.

Across villages, beekeepers also reported a significant ($p < 0.0001$) decline in the number of (occupied) beehives per beekeeper during the period from (before) 2012 to 2022 (Figure 1b), corresponding to a total decline of 44% during this 10-year period (Table 1). The decline in beehives per beekeeper varied between villages and was statistically significant in Chaura, Chuma, Lorpa, Patmara, and Urthu (Figure 3). The significant decline in beehives in Patmara is especially notable, as this village used to be a hub for beekeeping in the Jumla District in the 1990s and beekeepers there had a rich knowledge of *Apis cerana cerana* and traditional ways to manage them [25].

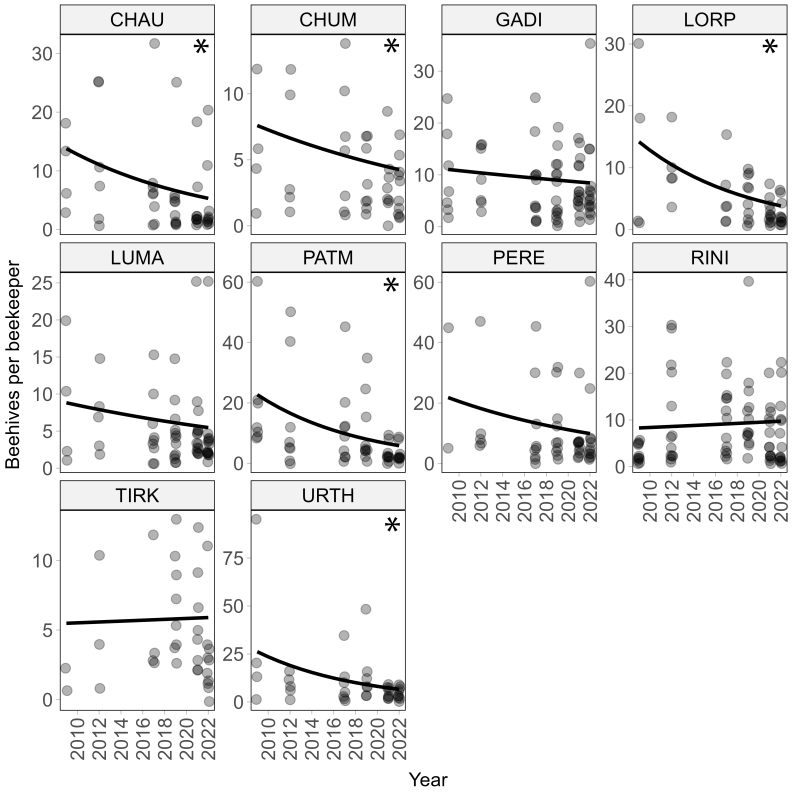

Figure 3. Changes in the number of beehives per beekeeper for the 10 villages (on average, 11 respondents per village). The decline in beehives per beekeepers was statistically significant ($p < 0.05$) for five villages (Chaura, Chuma, Lorpa, Patmara and Urthu) marked with an asterisk in the panels upper right corner. Darker points in the panels are due to overlaps in values.

3.2. Reasons for the Decline in Honeybees

According to the beekeepers' responses to the questionnaire, the four main causes for the decline in honeybees in the Jumla District are (1) climate change (listed as a major driver by 59% of respondents), (2) reduced availability of flowers (55% of respondents), (3) insecticide/herbicide use (48% of respondents), and (4) bee diseases (37% of respondents) (Figure 4). When asked in more detail about the characteristics of the changes in the climate, the beekeepers reported (1) heavier monsoon, (2) more unpredictable weather patterns, and (3) drier weather (see Appendix E, Figure A3). While heavier monsoon (rain) and drier weather may initially seem contradictory, the issue here is shifts in the timing of these events, which may influence the timing of flowering plants and insect activity, potentially causing mismatches between the two. When asked in more detail about the characteristics of lower flower availability, the beekeepers reported (1) cutting of the forest, (2) fewer flowering crops, (3) overgrazing, and (4) wetter weather as the main causes for the decline in flower abundances (see Appendix E, Figure A4). Some respondents also mentioned the destruction of the deciduous flowering shrub known as 'Dhatelo' (*Prinsepia utilis*) as a significant factor in reducing flower availability. 'Dhatelo' shrubs bloom early in the season when few other plants are in flower. Thus, their removal is likely to increase food scarcity

for honeybees early in the season with negative impacts. The decline in Dhatalo is complex and was attributed to a number of reasons by the respondents. Traditionally, Dhatalo was used as a fence in crop fields, especially in fields growing leguminous plants often found on sloping areas near forests, to protect them from domestic and wild animals. However, the accessibility of modern iron fences have made them a more convenient alternative to Dhatalo (which is a thorny plant) and therefore the plants have been removed from the fields. The general conversion of semi-natural lands to farming land might also have been destroying Dhatelo. Moreover, the need of Dhatalo for household purposes (Dhatelo seed oil) has decreased due to the availability of commercial alternatives such as sunflower and soybean oil, yet another reason why the plants have been removed.

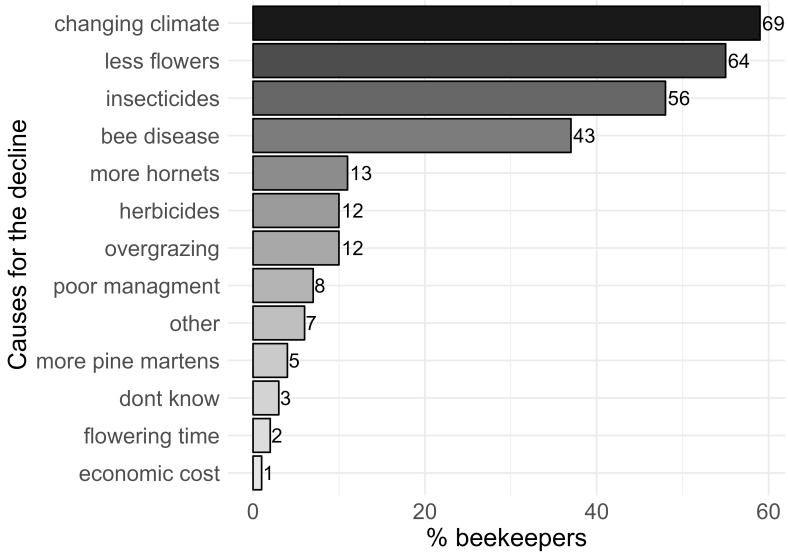

Figure 4. Ranking of the causes for the decline in honeybees according to beekeepers' perceptions. Bar lengths are proportional to the percentage (*x*-axis) of beekeepers who listed a driver as a potential cause for the honeybee decline. The corresponding numbers of beekeepers are placed next to the bars. The top four causes for the decline perceived by the beekeepers are (1) climate change, (2) fewer flowers, (3) insecticides, and (4) bee disease.

3.3. Importance of Apis cerana to Agriculture

Out of all the pollinator-dependent crops grown in this study region, apple *Malus domestica* is the most dependent on honeybees (67% of all visits to flowers of this crop were made by *A. cerana cerana*) followed by cucumber *Cucumis sativus* (52%), pumpkin *Cucurbita maxima* (50%), mustard seed *Brassica alba* (42%), and chilli *Capsicum* sp. (33%). These crops are all important to local farmers and are widely grown in the region. Particularly important are chilli, apple, and pumpkin, which are grown by more than 80% of all farmers (Figure 5).

In addition to the high number of visits made by honeybees to important crops, the bees also carry a relatively large amount of pollen per individual bee. This means they can potentially deposit many pollen grains per visit, which can be important for full pollination of fruits such as apples. Honeybees carried, on average, 96 (±6.8 SE) pollen grains per individual, compared to a mean of 57 (±7.7 SE) and a median of 18 grains across all taxa sampled. Although there were 29 other insect taxa (out of a total of 135) which carried more pollen than honeybees (mostly bumblebee and solitary bee species), honeybees were nevertheless within the top 20% of pollen-carrying taxa (see Appendix D for how the pollen data were collected). The high visitation rates of honeybees to a range of important crops, combined with their relatively high pollen transport capacity, suggests that *Apis cerana cerana* is amongst the most important crop pollinators in this region. The relatively low number of visits from honeybees to buckwheat in our study (7% of all buckwheat visits were made by honeybees) may be surprising, as honeybees are often dominant visitors to buckwheat at lower elevations [29]. However, the buckwheat fields in our study region

are typically located on the hills above villages and therefore at relatively high elevations (>2500 m), where flies are more dominant than honeybees [11].

Apples are the most economically important crop in this region, and their high dependence on honeybees suggests their production may be heavily impacted by the observed honeybee declines. Consistent with this prediction, when asked about changes in apple yield quality and quantity, 55% and 42% of the beekeepers responded that they experienced a decrease in apple yield and change in quality, respectively, whereas only 8.6% and 2.6% experienced an increase, respectively (see Appendix E, Figure A5).

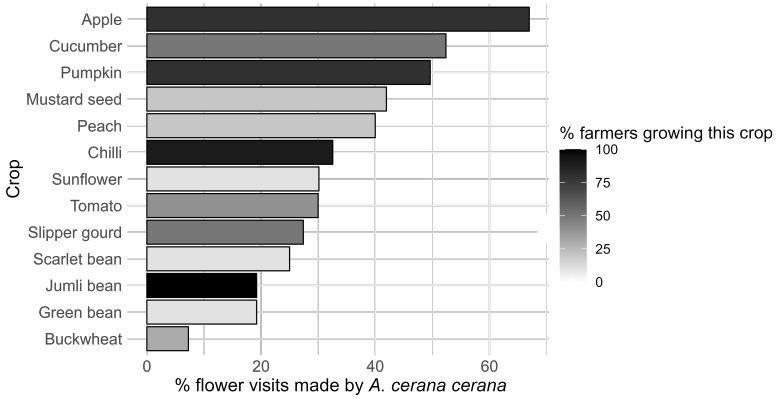

Figure 5. Percentage of visits from honeybees to the most important crop plants in the Jumla District. The color shading shows the percentage of farmers growing the crop.

3.4. Effects on Beekeepers' Livelihoods

Half of the beekeepers (51%) reported impacts to their livelihood due to loss of honeybees, 42% reported no change and 7% did not know (see Appendix E, Figure A6). For the beekeepers that experienced a negative impact on their livelihood, the main features were loss of income and less, or no, honey for their own consumption. In a follow-up question, the 42% of the respondents who reported no impact replied that they have other income from high-value crops such as apples (see Appendix E, Figure A6).

A wider survey of 920 farming households across all eight municipalities of the Jumla District revealed that the mean annual household income from the sale of honey was NPR (Nepalese rupees) 5493 (±1015 SE), or USD 41.23, representing 16% of total household farming income (mean NPR 34,567, or USD 260). Given the rate of decline in honey yield reported in this study (Figure 1), we estimate that beekeepers have lost approximately 14% of their household income from agriculture over the last ten years as a result of these changes. This ignores any loss of income as a result of crop yield declines, which may be even more substantial. Interestingly, despite the heavy reliance on crop pollination services by farmers in this region, only 17% of respondents in the wider household survey were aware that honeybees play an important role in crop production through their provision of pollination services.

3.5. Summary of In-Depth Interview with Key Informant

The key informant beekeeper (local expert) confirmed the decline in honey yield indicated by the beekeepers of the survey. The total amount of honey harvested from all of his hives combined has declined from 50–100 kg (from 25–35 hives) per year to only 3 kg (nine hives) over the past 5 to 10 years. He mentioned that the amount of honey produced was not even sufficient for keeping his bee colonies alive during the winter. He further stated that the bees are starving. The two most important drivers for the decline in honeybees that he mentioned were climate change and pesticide use. In particular, he stated that there is a huge effect of climatic change on bees: "It rains when is should not, and it does not rain when it should". Similar descriptions were given by several beekeepers during the survey. For example, when bees start to become active in April and May, it rains

heavily when it should not be raining. According to the key informant's perception, the heavy rainfall will wash away the nectar which, combined with fewer flowers, decreases the resource availability for the bees. Moreover, he said that climate change induces shifts in flowering seasons and behavior. Plants flower earlier and the season is shorter. He believed that this is why bees do not have enough food and die. According to him, there is no problem of livestock overgrazing in Jumla. In terms of pollination services, the key informant stated that apple quantity and quality has diminished compared to the past. When asked about how the decline in honeybees has affected his livelihood, he confirmed that the decline in honeybees has affected his livelihood negatively due to loss of income and loss of honey for household consumption. He also said that farmers are not prioritizing beekeeping as much as in the past. According to him, the farmers are unaware of the importance of bees for crop pollination and food production, which may explain why they do not prioritize beekeeping.

4. Discussion

According to the beekeepers in our study, the honeybee *Apis cerana cerana* is declining in Western Nepal. The reported honeybee decline is likely indicative of a regional trend, consistent with previous reports of declining *Apis cerana* populations in Nepal and throughout Asia [21,30]. Because of declining bee populations, honey yields and the number of occupied beehives are also decreasing. Changing climate and unpredictable weather patterns and reduced flower availability are the major drivers for the declines as perceived by the beekeepers. Locally, the decline in bees is associated with loss of income from honey sales and poorer crop pollination, especially for apples. This poses a risk to the livelihoods and food security of beekeepers and smallholder farmers in the region.

4.1. Are Honeybees Starving in Western Nepal?

Across the world, pollinating insects are threatened by a range of anthropogenic pressures such as agricultural intensification, habitat loss, climate change and pesticide use [7–9]. All of these pressures are known to reduce the availability of food (pollen and nectar) for insects [31], a resource which is considered the most important factor limiting pollinator populations [32,33]. Honeybees are generalist foragers whose accumulation of honey is largely determined by the quantity and quality of floral resources present in the landscape, as well as local climatic conditions which influence their ability to forage [34]. The declining honey yields reported by beekeepers in our study region therefore indicate a reduction in floral resource availability or a reduced ability to freely forage and collect these resources, for example due to unfavorable weather conditions. Weather conditions are a key factor influencing the foraging activity of both managed honeybees and wild bees [35,36] and this may be particularly relevant in our study region where weather patterns have changed dramatically as reported by beekeepers and confirmed by empirical data [37,38]. In particular, beekeepers report that heavier and more erratic rainfall events—often coinciding with important stages of the colony life cycle—are impacting the ability of bees to forage and accumulate honey reserves.

Fewer flowers and reduced foraging ability equate to less food for bees and will result in honeybees collecting less pollen and nectar for their brood—thus reducing the size of colonies and limiting the honey stored for the winter, which ultimately risks starvation of the bee colonies. In the case of our study region, where beekeepers report climate change and reduced flower availability as the two most important drivers of bee and honey declines, it is likely that these two factors are interacting. For example, climate change can alter the distribution, quantity and quality of the flowers on which insects depend for food [39]. Moreover, warming can lead to unpredictable seasonal weather patterns which cause phenological mismatches between plants and pollinators [40]. As insects are ectotherms, changes in temperature can also have a direct influence on their physiology and behavior and thus change their foraging range [41]. For bees, the outcome of such direct and indirect effects on behavior and physiology can influence a colony's ability to

store sufficient honey to survive the winter. Our key informant remarked that honey yields are increasingly becoming too low to even keep colonies alive throughout the winter.

As a factor contributing to reductions in honey yields, reduced flower availability may force bees to forage over greater distances. A recent study using an agent-based model showed that flower abundance is a major driver of foraging distances with decreasing floral abundance, leading to larger foraging distances [42]. Evidence also shows that honey bees produce less honey if they need to forage at greater distances [41,43,44]. Moreover, the breeding rate of a colony partly depends upon the quantity of incoming forage [45]. In other words, if incoming foraging decreases, the colonies decline. Larger foraging distances may also put honeybees at greater risk of exposure to unpredictable weather regimes, increasing the chances of being caught in bad weather. Beekeepers, including the lead beekeeper in our survey, repeatedly stated that bees are often caught in weather conditions with heavy rainfall during flights and therefore do not return to their hives. Increasingly unpredictable weather patterns as predicted for the Himalayan region [38] could worsen the situation for honeybees and other wild pollinators.

4.2. Honeybee Decline and Its Consequences for Crop Pollination

Apis cerana cerana honeybees are one of the most important crop pollinators in this region, both because of the large number of visits they make to key crops and because of the large amount of pollen they carry per individual [23]. In the unlikely event of total honeybee loss, farmers stand to lose approximately 45% of all crop pollen transport and as much as 73% in the case of apple [23]. Red Delicious apples, the major cash crop in the region, are almost entirely pollinator-dependent and may already be showing signs of decline in honeybee pollination, as beekeepers in our survey generally report reductions in apple quality (e.g., shape and size) and quantity.

In addition to cash crops, honeybees are important pollinators for a range of other nutritionally important crop plants [23] such as mustard seeds, pumpkins, and chilies, which may all experience decreased pollination as a result of honeybee declines. In smallholder farming villages where most people depend upon local food production for survival, these declines have the potential to seriously impact their food and nutrition security, as well as their livelihoods. Surprisingly, only 17% of respondents were aware of the value of honeybees or other pollinators to crop production, which is in line with the key informant's perception. This lack of pollination awareness amongst smallholder farmers may result from their limited scientific education on concepts such as plant reproductive biology and insect ecology. Thus, although their local knowledge of plants and insects is very high, they do not recognize or understand the importance of these insects in transporting microscopic pollen grains between flowers. This limited awareness may also explain why only half of the respondents reported a negative impact of bee declines on their livelihood, as they only consider the loss of income from reductions in honey production and ignore the importance of bees for crop production and hence agricultural income.

4.3. Are Wild Insect Pollinators also Declining in Jumla?

It is likely that honeybees are not the only insects declining in Jumla. Many of the mechanisms that are reported to be driving honeybee decline in Jumla, such as fewer flower resources, unpredictable climatic patterns, phenological mismatches, and agrochemical use, are also known to cause declines in other pollinating insects [2,7,9,10]. Honey yields are known to serve as a convenient bio-indicator of floral resource availability and foraging conditions, so consistent declines in honey yields point towards strong floral resource limitation and resulting population declines for all pollinators in this region [34].

Indeed, many wild pollinators are likely to be affected even more severely than honeybees as they do not retain honey reserves to help them through sparse periods of the year and their food supply is not supplemented by beekeepers, as is sometimes the case for honeybees. Moreover, their foraging ranges are shorter than honeybees making it more challenging for them to reach distant resources. This prediction is consistent with

studies from other regions of the world which indicate that declines in wild pollinators are generally steeper than those for honeybees [46–48]. The increasingly erratic weather patterns reported by beekeepers in this region are also likely to be having severe impacts on the wild pollinator community, as weather patterns are known to be one of the most important factors influencing wild insect populations [10]. In regions of the world where honeybees have experienced declines from Colony Collapse Disorder (generally linked to honeybee-specific diseases), wild pollinators have been shown to provide effective insurance against honeybee losses [49]. However, in our study region, where the reported drivers of honeybee decline are stressors which also impact wild pollinators (loss of flowers, changing weather patterns and pesticides), it is unlikely that wild pollinators will be able to compensate for declines in the pollination services provided by honeybees. This increases the potential vulnerability of pollination services in this region and further emphasizes the importance of mitigating these declines.

4.4. Knowledge Gaps, Future Prospects and Management Advice

To mitigate further declines in *Apis cerana cerana* and wild pollinators in this region, farmers should be made aware of the value of these insects for their crop production, and encouraged to incorporate pollinator-friendly management practices into their farming. Pollinator-friendly management may include the increased provision of floral resources, reduced insecticide and herbicide use, and the maintenance of crop diversity and natural habitat areas on their farms. Floral resources can be enhanced by incorporating native flowering shrubs such as *Cotoneaster microphyllus*, *Prinsepia utilis*, and *Rosa sericea* into hedgerows and adding flower-rich field margins to farmland [23]. These should ideally be provided in close proximity to hives and crops so that bees do not have to travel far and run the risk of getting caught during bad weather. A previous study from Nepal shows that comb building in *A. cerana* colonies accelerated in the vicinity of mustard *Brassica* spp. and buckwheat *Fagopyrum esculentum*, two mass-flowering crop species grown in Jumla [22]. It is also important to ensure adequate nesting sites for both wild-nesting honeybee colonies and other wild pollinators; these may include old trees and logs, piles of sticks, and bare sloping earth banks. Due to the increasing occurrence of unpredictable weather, which is likely to become more common in the future under climate change, beekeepers may benefit from using well-insulated log hives or modified log top-bar hives which buffer colonies from extreme temperature fluctuations and are resistant to attack by pine martens. We discourage the use of all chemical pesticides, especially during the flowering season. Additionally, it is essential that beekeeping efforts in this region utilize the native *Apis cerana* species and avoid the import of *Apis mellifera*, which might exacerbate the decline in the native bees and pollinators through the spread of disease and competition for diminishing floral resources [21,50].

The household survey and our key informant interview indicated that beekeepers have limited knowledge about the importance of bees for crop production. Thus, an important priority in the region should be to increase public awareness of the importance of insect pollination through a widespread education and outreach program. Moveover, a training and extension program to promote the management of bee colonies in movable comb hives would be of great value and could build on past successes with the Jumla top-bar hive—an adapted form of the traditional log hive. We know that *Apis cerana cerana* has been negatively affected by the brood diseases (e.g., Thai sacbrood and European foulbrood) since the 1990s [51] and it is likely that more recent agrochemical use in Jumla is exacerbating this. However, the current prevalence of diseases and agroechemical use is unknown, and the contribution of these factors to bee decline is not clear, therefore an expert assessment of bee disease prevalence and the relative contribution of pesticide poisoning as well as bee disease in this region should be undertaken.

5. Conclusions

Our study indicates that the native and semi-domesticated honeybee *Apis cerana cerana* is declining in Western Nepal. The exact reasons for the decline are unknown, but the respondents of our survey point to climate change, unpredictable weather patterns and reduced floral food resources as the main drivers. Further studies should be conducted to clarify the reasons for the decline, as well as the magnitude and extent of it. Based on the perceptions of respondents, the decline may have already impacted crop production in the region, as well as reducing revenue from honey production. Moreover, it is likely that the reported declines in honeybee populations and honey yields are indicative of a wider decline in wild pollinators in the region, especially if the causes of the decline are connected to climate change and reduced floral resource availability. To mitigate further declines in the honeybees and wild pollinators, we strongly advocate for the promotion of beekeeping with the indigenous *Apis cerana cerana* and the use of flowering hedgerows and field margins in proximity to crop fields and beehives, aswell as the maintenance native habitat areas to enhance food supplies and nesting sites for pollinators. We also recommend the use of well-insulated log or top-bar log hives to buffer bees against extreme temperature fluctuations, which are expected to worsen with climate change.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Study Area

The study was conducted in 10 smallholder farming villages in Patarasi Rural Municipality, Jumla District, Nepal (2400–3000 m altitude; Table A1, Figure A1). Each study village comprised a cluster of 100–400 closely spaced households surrounded by small vegetable gardens and livestock paddocks (Figure A2). The area surrounding each village includes many small (0.01–0.3 ha) arable fields and apple orchards as well as large areas of steep, heavily grazed grassland pasture and native coniferous forest (Figure A2). The high altitude, steep slopes, and challenging climate (cold and relatively dry) mean that agricultural productivity is lower here than in many other regions, resulting in high rates of poverty, food insecurity and malnutrition [26]. With limited access to markets and services, reliance on locally grown agricultural produce is high, and 80–100% of households in each village identify as subsistence farmers, whose main purpose for farming is to feed the family. Although remittances from family members outside of the district provide an important source of economic income to these villages, the food and nutrition security

of most households is still heavily reliant on subsistence farming and the ecosystem services that support it. A wide range of crops are grown in each village, including many pollinator-dependent species such as apples, beans, buckwheat, mustard, slipper gourd and pumpkins, which contribute important income and nutrients to farming households.

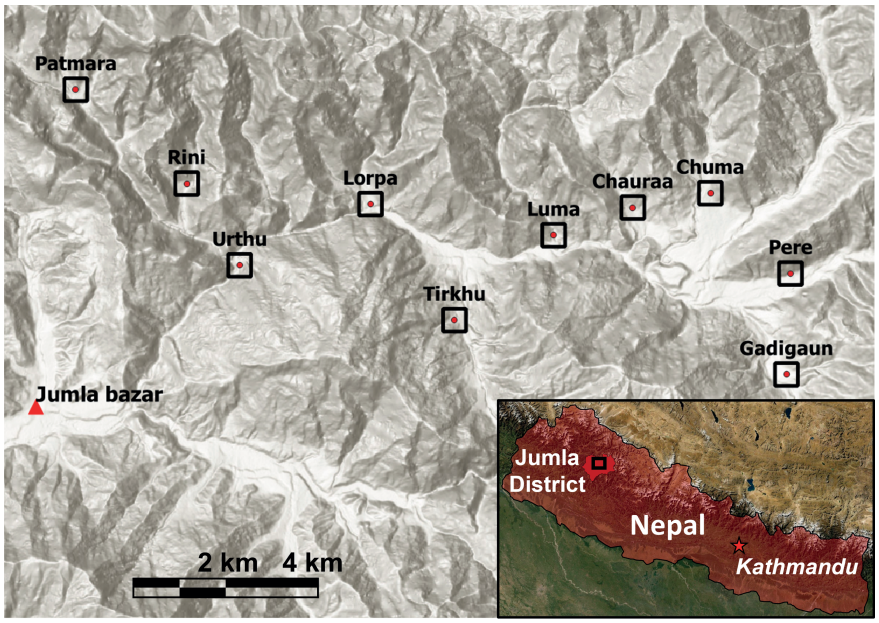

Figure A1. Study villages shown within the Jumla District of Western Nepal. Jumla bazar is the districts headquarter.

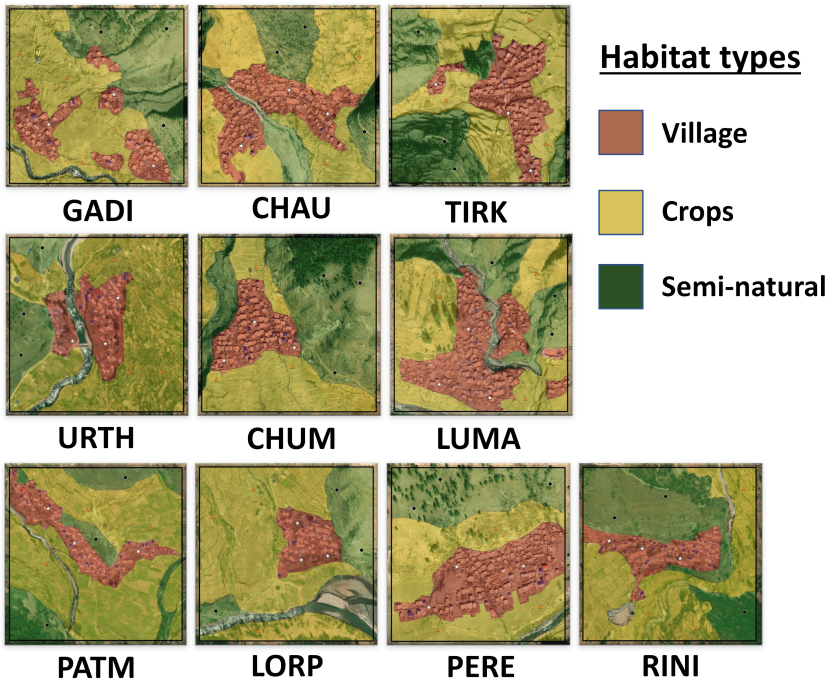

Figure A2. Maps showing the distribution of habitats within each of the study villages. Village ID codes are the first four letters of each village name (see Table A1).

Table A1. Names and details of each study village where sampling took place. All villages are located in Patarasi RM.

Village	Abbreviation	Number	Location	Altitude (m)	Households	Population	GPS Lat.	GPS Long.
Chaura	Chau	10	Ward 3	2713	200	1223	29°18′57″ N	82°19′17″ E
Chuma	Chum	10	Ward 3	2790	171	1026	29°19′7″ N	82°20′24″ E
Gadigaun	Gadi	15	Ward 1	2739	225	1350	29°16′54″ N	82°21′24″ E
Lorpa	Lorp	11	Ward 5	2459	230	1380	29°18′52″ N	82°15′36″ E
Luma	Luma	15	Ward 4	2567	374	1545	29°18′34″ N	82°18′9″ E
Patmara	Patm	10	Ward 7	2986	180	1080	29°20′24″ N	82°11′22″ E
Pere	Pere	12	Ward 2	2657	312	1240	29°18′4″ N	82°21′36″ E
Rini	Rini	14	Ward 7	2663	180	1080	29°19′2″ N	82°12′54″ E
Tirkhu	Tirk	10	Ward 4	2636	298	1788	29°17′34″ N	82°16′52″ E
Urthu	Urth	9	Ward 6	2411	120	720	29°18′18″ N	82°13′45″ E

Appendix B

Questionnaire Questions and Possible Answers

1. **Which study site (village) are you recording in this survey?**
   Chaura, Chuma, Gadigaun, Lorpa, Luma, Pere, Rini, Tirkhu, Urthu, Patmara, Huri, or Mahuri.
2. **Record the location of this interview**: latitude, longitude, altitude.
3. **How many years have you been keeping bees for?**
4. How many **occupied hives** (colonies) do you currently manage?
5. How many **unoccupied hives** (empty hives) do you currently have?
6. **Has the number of occupied beehives that you manage changed over the past years?**
   - Yes, an **increase** in occupied colonies.
   - Yes, a **decrease** in occupied colonies.
   - Number of beehives **remained the same**.
   - Don't know.
7. How many **occupied hives** did you manage:
   (a) **Last year.**
   (b) Approximately **3 years ago**.
   (c) Approximately **5 years ago**.
   (d) Approximately **10 years ago**.
   (e) **More than 10 years ago.**
8. **How much honey did you produce last year from *one individual hive* (per hive on average)?** Consider only the final product (pressed honey), rather than honey comb. Record in decimals if needed. Answer 999 if you don't know.
   (a) What **units** are you recording this in?
   Kilogram or liters or Manna or Dharni.
   (b) Honey yield converted to kilograms.
9. **What type of beehives do you have?** Choose all that apply:
   - Log hive (round or square type opening at the end).
   - Log hive (rectangular opening at the back).
   - Wall hive (rectangular opening at the back, built into the wall of the house).
   - Top bar hive (where combs are on sticks that can be taken out and replaced).
   - Newton hive (modern beehive) made of thin planks of wood.
   - Straw hive.
   - Other type of hive.
10. **Did the number of bees (bee population) *per hive* change over the past years?**
    - Yes, a **decrease** in bees per hive (go to question 12).
    - Yes, an **increase** in bees per hive (go to question 13).
    - Bee population **remained the same**.
    - Don't know.

11. **How many years ago did this change start?**
12. **Why do you think the bee population has declined?** Read out the options and choose multiple if needed. Then, please choose the **3 most important reasons** for the decline in bee populations.
    - Fewer flowers (go to question 14).
    - Bee disease (go to question 17).
    - Herbicides (go to question 16).
    - Insecticides (go to question 16).
    - Changing climate/weather patterns (go to question 15).
    - Grazing by livestock.
    - Changes in flowering time of flowers.
    - More pine martens.
    - Poor beehive management.
    - More hornets.
    - Economic costs of beekeeping.
    - Other.
    - Don't know.
13. **Please select all of the reasons why you think the bee population has increased.** Read out the options and choose multiple if needed. Then, please choose the **3 most important reasons** for the increase in bee populations.
    - Less herbicides.
    - Less insecticides.
    - More flowers.
    - Less disease among bees.
    - Changing climate/weather patterns.
    - Less grazing of flowers by livestock.
    - Organic farming.
    - Less pine martens.
    - Better beehive management.
    - Less hornets.
    - New wildflowers or crops.
    - Other.
    - Don't know.
14. You stated that bees are declining because of fewer flowers. **Why do you think flowers are decreasing?**
    - Forests being cleared.
    - Overgrazing by livestock.
    - Fewer flowering crops.
    - More fires.
    - Drier weather.
    - Wetter weather.
    - Hotter weather.
    - Colder weather.
    - Late frost in April/May.
    - Over-harvesting of herbs.
    - Other (state the other reason why flowers have decreased).
    - Don't know
15. You stated that bees are declining because of changes in climate/weather patterns. Please **specify which changes you think are causing this decline**:
    - Colder.
    - Wetter.
    - Warmer.
    - Drier.
    - More unpredictable weather.
    - Earlier monsoons.

- Later monsoons.
- Heavier monsoons.
- Drier monsoons.
- Changes in the timing of seasons (e.g., earlier spring).
- Winters are less cold.
- Winters are more cold.
- Snow not falling in winter.
- Late frost in April/May.
- Other (specify).
- Don't know.

16. You stated that bees are declining because of insecticides or herbicides. **Do you know the names of any of these pesticides**?
    (a) If yes, please name the insecticide or herbicide you are referring to.
    (b) Which crops are these pesticides are used on?
17. You stated that bees are declining because of disease. **Please describe the symptoms of this disease in your own words.**
18. Did you experience a **change in the *honey yield per hive* over the past years**?
    - Yes, an **increase** in honey yield per hive.
    - Yes, a **decrease** in honey yield per hive.
    - No change.
    - Don't know.
19. **How many years ago did this change start?**
20. **How much honey did you produce *per individual hive* (average amount per hive) during each of the time periods below?** Give the answers in the same units as you answered previously and consider only the final product (pressed honey), rather than honey comb. Answer 999 if you don't know.
    (a) Honey yield **3 years** ago:
    (b) Honey yield **5 years** ago:
    (c) Honey yield **10 years** ago:
    (d) Honey yield **more than 10 years** ago:
21. **What units** are you recording honey yield in?
    Kilogram or liters or Manna or Dharni.
22. **Does the decline in beehives, bee populations and/or honey yield affect your livelihood?**
    Yes (go to question 23) or No (go to question 24) or Don't know.
23. **How does the decline affect you**? (Tick all that apply, do not prompt.)
    - Loss of income.
    - Loss of honey for own consumption (eating, medicine, puja).
    - Loss of beeswax production.
    - Decrease in crop quality.
    - Decrease in crop yield.
    - Other.
24. **Why does the decline not affect you?**
    - I have other income.
    - I still have sufficient beehives to fulfill my need for honey.
    - I still have sufficient beehives to fulfill my need for wax.
    - I don't grow pollinator-dependent crops.
    - I switched to other farming activities.
    - I have never got significant livelihood benefits from beekeeping.
    - Other
25. **Do you have any apple trees?**
    Yes (go to question 26) or No (go to question 29).
26. **Have you experienced a change in the yield of apples per tree over the past years?**
    - Yes, there has been an **increase**.

- Yes, there has been an **decrease**.
- No change.
- Don't know.

27. **How many years ago did the change in apple yield start?**
28. Have you experienced a **change in the quality of apples** over the past years?
    - Yes, there has been an **increase** in quality.
    - Yes, there has been an **decrease** in quality.
    - No change.
    - Don't know.
29. **How has the quality of apples changed**? (read out options)
    - Apples are smaller.
    - Apples are bigger.
    - Apples are less round.
    - Apples are more round.
    - Apples are often deformed.
    - Apples taste worse.
    - Apples taste better.
    - Apple color has changed.
    - Apples rot more quickly.
    - Other (specify other change).
    - Don't know.
30. **How many beekeepers are there currently keeping bees in your village?**
31. Has the number of beekeepers in your village changed over the past years?
    - Yes, there has been an **increase**.
    - Yes, there has been an **decrease**.
    - No change.
    - Don't know.
32. **How many beekeepers were there in your village at each of these time points?** Answer 999 if you don't know.
    (a) Beekeepers **3 years** ago:
    (b) Beekeepers **5 years** ago:
    (c) Beekeepers **10 years** ago:
    (d) Beekeepers **more than 10 years** ago:
33. What are the **main reasons you keep bees**? Read out options.
    - To produce my own honey for consumption.
    - To produce my own honey for puja (worship).
    - To produce my own honey for medicine.
    - To sell honey.
    - To sell wax.
    - To make beeswax products (balms, candles).
    - To save the bees.
    - For crop pollination.
    - I find it enjoyable.
    - Other (specify other reason).
34. **How do you inspect your colonies**? Read out options
    - By looking at the movement of bees at the hive entrance.
    - By opening the end of the log hive and looking inside at the size of the colony.
    - By looking at the combs that I can see in my log hives.
    - By taking combs out and putting them back in (using a top bar or modern hive).
    - By looking at the combs at the time of harvesting the honey.
35. **How often do you inspect the movement of bees at the hive entrance?**
    - Every day.
    - Every week.
    - Every 2 weeks.

- Every month.
- Every few months.
- Once per year.
- Once every few years.
- Never.

36. **When do you inspect the hives by opening the hive?**
    - When harvesting honey.
    - When deciding whether the honey is ready to harvest.
    - When the movement decreases at the hive entrance.
    - To check for queen cells.
    - At swarming time.
    - In the weeks after hiving a swarm.
    - Other (specify).
37. **Which months during the year are your bees active?**
    - Baisakh (April–May).
    - Jyesth (May–June).
    - Asad (June–July).
    - Shrawan (July–August).
    - Bhadau (August–Sep).
    - Asoj (September–October).
    - Kartik (October–November).
    - Mangsir (November–December).
    - Push (December–January).
    - Magh (January–February).
    - Falgun (February–March).
    - Chait (March–April).
    - Don't know.
38. **Which months during the year do you extract honey from your hives?**
    - Baisakh (April–May).
    - Jyesth (May–June).
    - Asad (June–July).
    - Shrawan (July–August).
    - Bhadau (August–September).
    - Asoj (September–October).
    - Kartik (October–November).
    - Mangsir (November–December).
    - Push (December–January).
    - Magh (January–February).
    - Falgun (Februaru–March).
    - Chait (March–April).
39. **Do you supplementally feed your hives** (e.g., sugar syrup/ honey and candy)? Yes (go to question 40) or No (go to question 42).
40. What do you feed your bees with?
    - Sugar syrup.
    - Sugar candy.
    - Honey.
    - Koiro sweet turnip boiled down.
    - Buckwheat 'desu' made of buckwheat flour and honey.
    - Other
41. **Which months during the year do you supplementally feed your bees?**
    - Baisakh (April–May).
    - Jyesth (May–June).
    - Asad (June–July).
    - Shrawan (July–August).
    - Bhadau (August–September).

- Asoj (September–October).
- Kartik (October–November).
- Mangsir (November–December).
- Push (December–January).
- Magh (January–February).
- Falgun (February–March).
- Chait (March–April).
- Don't know.

42. **Do you treat your hives for parasites/diseases?**
    (a) If yes, please provide a brief description of how you treat your bees for disease and what products you use.
43. **How much do you help/collaborate with other beekeepers to maintain your hives?** A lot (very regularly) or occasionally (not essential) or not at all.
44. **What sources of information are most important** in informing how you manage your bees? Read out options and select all that apply.
    - Learning from my household members (people in my household with more experience than me).
    - Attending knowledge-sharing events organized by beekeeping organizations.
    - Government guidelines.
    - Books on beekeeping.
    - Personal communication with other beekeepers from my village.
    - Personal communication with other beekeepers from other villages.
    - Own experience.
    - Internet—looking things up on a smart phone or computer.
    - Competition.
    - Other.
    - Don't know.
45. **Do you know about any wild honeybee colonies in and around your village?**
46. **Have you noticed a change in *wild honeybee* populations over the past years?**
    - Yes—an **increase**.
    - Yes—a **decrease**.
    - **Remained the same**.
    - Don't know.
47. **Do you think honeybees use the same flowers as wild insects?**
    Yes or No or Don't know.
48. **Which months during the year do you think wild insects and honeybees compete for food?**
    - Baisakh (April–May).
    - Jyesth (May–June).
    - Asad (June–July).
    - Shrawan (July–August).
    - Bhadau (August–September).
    - Asoj (September–October).
    - Kartik (October–November).
    - Mangsir (November–December).
    - Push (December–January).
    - Magh (January–February).
    - Falgun (February–March).
    - Chait (March–April).
    - Don't know.

Appendix C. In-Depth Interview with Lead Beekeeper

Transcription and Translation of the Interview of Lead Beekeeper
Name of facilitator: Dr. **Naomi Saville**
Principal Research Associate, Institute for Global Health, University College London
Respondent: Lead Beekeeper, Patmara Village, Patarasi RM (anonymous)
Place of Interview: HERD Office, Chandannath-4, Jumla, Nepal
Date: 15 September 2021
Attendees: Dr. Susanne Kortsch, Mr. Manish Rokaya

Begin transcript 00:00:00, recording not yet started
Naomi: What are the reasons behind in declining bees and honey production
Recording starts 00:00:05
Lead beekeeper: As we know that Bee can fly three km away from their home hive to feed flower. During feeding flower and water, all bees are getting contaminated because the bee of bazar area are usually contaminated with Butachlor as it is used to in the water of rice field so the effect of herbicide Butachlor is not only limited in bazar area and surprisingly also seen in upper Himalayas like Chimara of Jumla. As a result bees are declining and honey production is also declined. **Naomi**: Can we record the conversation that we are doing, if not we forget?
Lead beekeeper: Yes why not? *(Laughing)*

00:02:01
Naomi: What are the other causes after Butachlor?
00:02:02
Lead beekeeper: Use of insecticide such as Nuvan, Malathion and Sythion in improper time. And the concerned authorities should aware farmers about the proper use of insecticide in proper time but they are not doing it. Thus it can also be the reason behind decline in bee.
00:02:06
Naomi: What might be other reasons in decline in number of bees?
00:02:26
Lead beekeeper: Farmers are not prioritizing bee keeping practice any more as compared to past we used to prioritize. Farmers don't know about the importance of bees in pollination. They don't understand about the importance of bee in crops, food production and vegetable production. As a result they are not prioritizing beekeeping.
00:08:25
Naomi: What are other causes?
00:08:30
Lead beekeeper: There is no good coordination between three tiers of government and the three tiers of government are not aware about their responsibility. Similarly local governments don't understand the importance of beekeeping. The concerned authorities such as District Forest Office, Community Forest Development Committee, District Agriculture Development Office, local government and farmers are unaware about the importance of bee keeping. For example excessive collection of medicinal herbs from the forest is the sole reason behind the habitat destruction and decline in bees. Concerned authority like District forest office and community forest development committee are not taking action about people for harvesting herbs excessively. When it comes to harvest there should be strict laws like some years they can harvest some years they should not harvest. But people just carry on harvesting every year as a result there are fewer flowers in forest. The importance of pollination is not communicated in concerned authorities

especially DADO and local government in the importance of pollination in quantity and quality of crop production and fruit production. Hence, the communication between forest office, community forest committee, DADO, farmers, local government and bee keepers themselves is not sufficient. Also the concerned authority, farmer and bee keepers are not coordinating to make sure that over cropping and harvesting of these herbs is prevented.

00:14:39

Naomi: How prevalent of bee diseases affect population of bees in Jumla?

00:14:46

Lead beekeeper: *(excitedly)* I have no word in front of you, as you are bee specialist, but if I have to say I would say there is no prevalent of such diseases in our community. In the context of Jumla, bee get increased in the month of(April) Chaitra, Baisakh, Jestha and Asar at a same time people use insecticide and pesticide for crops and fruit. While in this period queen in hive is producing many eggs inside the hive. So whole colonies of bees get affected from these insecticide and pesticide sprayed in plants and these bee get back to the hive and the bees inside the colony get killed. Mite is also another problem. Increased mites result absconding of bees.

00:18:16

Naomi: What about the effects of climatic change?

00:18:27

Lead beekeeper: Yes, there is massive effect of climatic change, when bee start to increase during April, May and June at the same time rain occurs when it should not come, when there should be more flowers, there are few flowers, there is no nectar and pollen when there should be in flower and there is heavy rain fall which usually washes away pollen and nectar from flower. (Sadly) There is so worst condition for bee by the nature and human too. We human don't feel the effect of climatic change but bee is the one that feel and suffer from the climatic change.

00:20:42

Naomi: Is there a problem of overgrazing forest by cow and sheep which affect population of bee?

00:20:58

Lead beekeeper: There is no such problem of overgrazing due to cow and sheep but there is something that effect bees. In comparison to past we used to rear less cows and sheep now, but the yield is less nowadays it might due to unsuitable time and climatic change.

00:22:04

Naomi: What sort of effect is caused by change in flowering time of flower as you have already said that it cause problem in bee?

00:22:10

Lead beekeeper: I think that flower has own planning and process to grow, for example. In the time of today, cucumber should be flowering till the time of Bhadra and Ashoj whereas in older time it used to grow and have flowers during this time. It is all due to climate change, i.e., excessive dry hot weather and the use of Butachlor herbicide which decreases the longevity of plant and flowering pattern change nowadays. So plants are growing fast but they are also dying earlier so flowers are not available at the same time.

00:23:50

Naomi: Is there a problem of pine martens here comparison to past and its population is increasing or decreasing?

00:23:58

Lead beekeeper: Yes, the population of pine marten is increasing as well as number of bear is also increasing. It is because in past time there used to be

tigers [leopards] which eat these animals and make balance but nowadays no single tiger is found here. Pine martens are not hunted by man. The meat, skin or anything else of this animal is considered not useful. In the ecosystem, there are no such predators which eat pine martens, so it becomes chief on its own. Nowadays, it is seen even in bazar area eating and destroying entire bee hives.

00:25:28

Naomi: How the problem of poor management of bee hive is in your area?

00:25:32

Lead beekeeper: Yes I have already told you that there is no coordination and communication on importance of bees between local government, DADO and concerned authorities. There is lack of awareness in general public to government official in pros of bee keeping. So the beekeeping is decreasing as due to lack of support and awareness from concerned authorities.

00:26:12

Naomi: Do you agree with this statement that poor management of hive by beekeeper is another problem in decreasing bee and honey production or not?

00:26:21

Lead beekeeper: If we plant apple, we need water, manure (cowdung), labor, pests and time to look after after caring and to protect from animals, but if we just put bee in hive, we think all work is done. There is no management of colonies. People don't know how to manage colonies. They don't know about the disease, they don't inspect and they don't feed. And at the end of season they collect honey.

Naomi notes: I'm little confused about the bee keeping management he is saying earlier Earlier he is saying about the government side management and now he told about the beekeeper side.

00:27:16

Naomi: *(Excitedly)* How about the problem of hornet?

00:27:21

Lead beekeeper: Nowadays hornets are increasing. They used to put colony nearby beehive by which they kill the bees for their food. In comparison to past population of hornet increased dominating bee population.

00:28:31

Naomi: How about the wild honey, i.e., sallah maha [honeydew honey from pine sap] responsible in increasing or decreasing population of honey bee?

00:28:40

Lead beekeeper: I think there is no any research conducted in this topic. Wild honey is usually produced during winter season. If bees eat wild honey they get poisoned so it is believed that it is so harmful for domestic bees. Also, it is believed that where the wild honey put colony in the tree, the tree get decayed fast. And so I'm not sure that wild bee cannot cause problem in domestic bees.

00:30:46

Naomi: Is it expensive or cheaper to maintain hive? Can it cause a problem or not?

00:30:54

Lead beekeeper: There is Nepalese proverb that "aau mauri jaau mauri" which mean bee put colony and stay in their own and can also go away from hive in their own. It is so beneficial to keep bee. It is so cheap to do. It takes so less time and less labor. We usually don't do anything for bee. I usually look after it for two times one time when there is colonization and another time for collecting honey and feeding them only. There is no need

of such capital for beekeeping. Making of beehive is problem but for them who want to keep bee they can make in their own. We should look after some while to protect from honey badger and hornet only. The big problem is in the lack of communication in local government, concerned authorities and farmer abut beekeeping and management.

00:33:25

Lead beekeeper: We used to have a saying that "ek kisan ek bagaicha, euta jarsi gaai euta mauri ko ghar" which means in each farming household there should be apple farm, there should be one 'jersey' cow and there should be one bee hive in farm which promote agriculture production with bee keeping. But it is not implemented through all sector even by ourselves.

00:35:51

Naomi: Which problem do you think is most important among climate change, use of insecticide, pine marten?

00:36:15

Lead beekeeper: The important reason is extensive use of insecticide and pesticide. Herbicide like Butachlor should be banned which is the major cause, climatic change is second cause and lack of awareness about bee keeping among farmers is third important cause of decline in population of bee. I think climate change issue cannot be solved by ourselves. The measure should be taken by government. And also increased number of honey badger [pine marten?] affect the bee population.

00:37:23

Naomi: How less number of flower affect the bee? And what are the reasons for flowers declining in our locality?

00:37:29

Lead beekeeper: It is due to lack of control in overgrazing of herbs and excessive collection of flora and fauna of medical importance. Also climatic change affect the longevity of plant and flower.

00:38:18

Naomi: What sorts of climatic change affect decline in flower?

00:38:52

phone rang of Lead beekeeper

Lead beekeeper: We are facing increasing temperature. Temperature is increasing year by year. Expert should be curious on this issue but no one is here to talk about climatic change. For example in 2045 BS this area used to be snowier but now there is no such big snow fall. In near future it will be hard to see snow. *(Excitingly)*

00:40:23

Naomi: What sort of change in pattern of weather did you feel in these years?

00:40:43

Lead beekeeper: There is no raining when there should be and there is no snow when there should be. Sometime there is heavy rainfall when there should not be. And we know the pattern of weather in past but now we have so unpredictable weather. Flowers are flowering earlier but do not have longevity. That's why bees don't have flower to feed them and die.

00:42:22

Naomi: What are the insecticide and pesticide and for what crops and vegetable they used for?

00:43:10

Lead beekeeper: Butachlor is significantly used herbicide and it remains for long time. It is use in rice field. Malthion and Sythion are used for vegetables and fruit for example cucumber, cauliflower, cabbage, pumpkin, carrot and apple. The concerned authorities like DADO are not making

farmers aware on the use of these insecticides and pesticides. People are using haphazardly. If people use these insecticides and pesticides in night time, it will be beneficial for bees.

00:44:58

Naomi: Is there production increase or decrease in recent year?

00:45:07

Lead beekeeper: Yes, there is decrease in honey yield in these years. Yielded honey is not even sufficient for bee.

00:45:29

Naomi: What about three years ago?

00:45:35

Lead beekeeper: Three, four kilogram per hive three years ago from approximately 9 hives. This year I get 2–3 kg from the hive in the month of Asaar. We should look after the hive during 1 July to 15 July when there is no egg. Previous year, I have collected only 1–1.5 kg per hive only. In total, how much is the yield before three years? When I had 30 hives also, the yield was only about 3 kg.

Naomi: What about 5 years ago, 10 years ago and more than 10 years ago?

Lead beekeeper: I have collected 50 kg in total about five years ago from 26 hives. I have collected 100 kg in total about 10 years ago from 25 hives. I have collected 300 kg in total about more than 10 years ago from 35 hives.

00:49:10

Naomi: What about the production of apple? From how many years that apple production change?

00:49:13

Lead beekeeper: Recent news showed that this year apple produced in good quantity but in my field apple produced in less quantity. Overall, the production of apple is decreasing about four or five years ago.

00:49:43

Naomi: What about the quality of apple?

00:49:50

Lead beekeeper: The quality of apple is not as good as like that of past. Apple are not so dark and big round as that of past. I think it is all due to climate change. Apple also taste not so good. Flower of apple start to fall earlier.

00:51:52

Naomi: How many beekeepers are there in your locality?

00:51:57

Lead beekeeper: *(happily)* Now I'm the only one in my village. One year earlier there were two more beekeepers but now they don't have.

00:52:23

Naomi: What about 3 years ago, about 5 years ago, 10 years ago and more than 10 years ago?

00:52:28

Lead beekeeper: There were four people about three years ago. There were nine about five years ago. There were two or three about 10 years ago. There were three or four about more than 10 years ago.

00:54:05

Naomi: What is the reason behind beekeeping?

00:54:10

Lead beekeeper: My fathers used to keep from my childhood and I have kept bee for many years myself and I have got the training on management of bee by organization. I have also registered Karnali Bee Rearing Institution

and it also encourage me for keeping bee. It is so cost effective and it is so easy. We use this honey to eat and to sell.

00:55:35

Naomi: How do you inspect your colonies?

00:55:42

Lead beekeeper: We used to look after the movement of bee. And also we used to look after the opening of hive also.

00:56:16

Naomi: When you open and look inside the log hive? How do you inspect your colonies?

00:56:28

Lead beekeeper: We inspect when there is no good movement, we look inside the hive. As Apis cerana don't like to be touched. We should watch once a week inside the hive but we inspect in urgency only.

00:57:03

Naomi: How often do you look after top bar hive?

00:57:13

Lead beekeeper: We inspect when there is needed only as *Apis cerana* don't like to be touched. We generally inspect inside the hive when you are going to take honey from hive. And we inspect queen cells inside the hive sometime and inspect whether there is diseases or destruction made by other animal like rat. We look the honey, the size of colony and combs from the mouth of hive and confirm whether bee is doing good or bad. And also we look combs at the time of harvesting the honey.

00:58:42

Naomi: How often do you look/inspect after the movement of bee at the hive entrance?

00:58:51

Lead beekeeper: We look frequently after hive hive nearby home and we look once a week for hive which we have put far away from home.

00:59:25

Naomi: When do you generally look inside the hive?

00:59:40

Lead beekeeper: We generally look inside the hive When we are going to harvest honey and also to decide whether the honey is ready to harvest or not. When the movement decreases at the hive entrance we also inspect and we also check how many queen cells are there also we look At swarming time.

1:00:27

Naomi: Do you inspect new colony or not?

1:00:38

Lead beekeeper: Yes, I do inspect to know whether it accept or not in the hive and also confirms its stability inside the hive. We look new colonies whether to confirm that it is producing honey and forming many combs during night.

1:01:13

Naomi: Which months during the year are your bees active?

1:01:19

Lead beekeeper: Bees are generally active from Chaitra to Ashoj. From Ashoj 15 they start to become less active. In the month of Kartik they become so less active. In the winter it is hard for their movement.

1:01:57

Naomi: Which months during the year do you extract honey from your hives?

1:02:08

Lead beekeeper: We extract honey in the month of Kartik (from Kartik 25 because honey is shield and good. Some people extract also in the month of Ashoj and Kartik but it is not good as there may be eggs. In Asar we also extract honey only after confirming that there are no eggs in the combs. I extracted honey this year during Asar it was good.

1:03:26

Naomi: What do you feed your bees with? And Which months during the year do you feed your bees?

1:03:32

Lead beekeeper: We generally feed them in winter season and rainy season especially shrawan. I fed them with honey syrup with water in the ratio of 1:2. I did not feed candy and sugar till date. We feed bees maximum in the month of Poush to Chaitra [December to April]. If there is heavy rainfall, we also feed them during Shrawan [July/August]. According to the healthiness and movement of bee among hive, we usually prefer feeding weak hive.

1:04:54

Naomi: Do you treat your bees with disease?

1:04:58

Lead beekeeper: I have not seen such dreadful disease for bee. In Jumla, there is only problem of mite for bee.

1:05:18

Naomi: How much do you help/collaborate with other beekeepers to maintain your hives?

1:05:26

Lead beekeeper: I usually suggest my all friends to keep bees. And I also give advice and to neighbor bee keepers frequently and who are willing to take advice, as I'm the vice chairperson of XXXX Co-operative Organization.

1:06:08

Naomi: Can you please provide the names of all the beekeepers or advisors who you collaborate with?

1:06:21

Lead beekeeper: *Interview section removed for privacy reasons*

1:13:35

Naomi: Are you a member of a beekeeping organization/group/cooperative?

1:13:42

Lead beekeeper: Yes I'm the member of XXXX Co-operative Organization.

1:14:15

Naomi: What are your main reasons for being part of this group?

1:14:18

Lead beekeeper: As I'm the vice-chair person of this co-operative organization, we have meeting in which we discuss about the effective management of beekeeping. We sell all our honey through this co-operative as possible. We have also collected wax sometimes but now we do not collect wax. Although wax is important due to lack co-ordination with wax market we are unable to sell those wax. Please make help us with the necessary co-ordination. People can borrow necessary equipment from this co-operative. People can also take loan for beekeeping purpose.

1:19:05

Naomi: How often do you get involved with this beekeeping organization/cooperative?

1:19:10

Lead beekeeper: We have monthly meeting.

1:20:04

Naomi: What sources of information are most important in informing how you manage your bees?

1:20:11

Lead beekeeper: As I was born in bee keeper family, it also gives experience to do beekeeping. When I was working in DADO, Jumla, I get opportunity to take training on beekeeping that encourage me in modern beekeeping. And also I have book of beekeeping.

1:21:14

Naomi: Do you have books related to honey bee?

1:21:15

Lead beekeeper: Yes, I have beekeeping book.

1:21:21

Naomi: Do you have government direction information on beekeeping?

1:21:23

Lead beekeeper: Government directions' are very less studied.

1:21:48

Naomi: Do you look something on internet?

1:21:54

Lead beekeeper: Not much seen.

1:22:18

Naomi: As global temperature is rising, do you know about global climate change?

1:22:25

Lead beekeeper: Due to excessive use of plastic and degradation of forest, illegal killing of wild animals and birds, it promote climatic change. In the past, wild deer used come nearby our home; now, it is hard to find these animal in forest. As well as there were few houses having steel sheet roof but now there are many houses of this that also increase the temperature. In about 2030 BS, we drink water of this river jugada but now we cannot even take bath there. Something is bad happened in the environment nowadays. There is so much unpredictable weather nowadays. When there must be rain, there is no rain, when there should not be rain, there is heavy rainfall. I think we human are the main responsible for this. There is more warmer in these years, as I wore few clothes earlier but now with these clothes I feel so hot. And there is extreme cold in the morning. Relatively, there is less snow falling relative to past years.

1:29:32

Naomi: What are the main problem do you face in beekeeping?

1:29:42

Lead beekeeper: The first point is due to lack of unified socialistic development in beekeeping. Due to lack of awareness about importance of beekeeping among farmers. Lack of communication by local organization on beekeeping.

1:31:45

Naomi: As you have said use of Butachlor, competition among bees, climatic change and less flowers, which is the most important challenges?

1:32:36

Lead beekeeper: The Butachlor is the main reason. Climatic change is the second most reason. Destruction of forest by overgrazing of herbs and medical importance plant from plant flowering times of crop plants changed.

1:34:51

Naomi: Do you know about any wild honeybee colonies in and around your village?

1:34:56

Lead beekeeper: Yes, very few hive are seen nowadays. The population of these bee is decreasing because if man know and find it's colony, people destroy the whole colony for honey.

1:32:02

Naomi: Where do you get your bees from?

1:32:07

Lead beekeeper: Originally it is wild bee but now on breed of domestic bee we get it at swarming season (bherr phaatnay bela). We get from each one another.

1:37:34

Naomi: Do you think honeybees compete with wild insects?

1:37:47

Lead beekeeper: In my experience there is no competition among bees and wild insect. Apis cerana do not sit on flower where Bhamara (bumblebees) had taken place earlier [visited]. *(phone rang of **Lead beekeeper**)*

1:39:37

Naomi: In which ways does the decline in bee and honey production affect you?

1:39:42

Lead beekeeper: It has directly affected my livelihood by decreasing loss of income. It is hard to get enough honey for consumption and sell. There is no exact research on importance of pollination on apple and we farmers don't know exactly but it affect crop and apple production as I kept my hive in my apple farm.

1:42:26

Naomi: Do you want to say something about these questions and for our correction?

1:42:43

Lead beekeeper: I feel very glad to participate in this study. Jumla is the perfect one for agriculture but people see us as hungry. We are lacking necessary equipment and technical advice on agriculture. We are lacking local government on these sectors. With the less effort and capital, we can do beekeeping with more pros. It is so beneficial in direct or indirect way. I argue you all respected persons, NGOs and INGOs to make an enabling environment for beekeeping through awareness and technical guidance.

End of Transcript

Appendix D. Pollination Field Data

Appendix D.1. Pollinator Surveys

Pollinator surveys were conducted every two weeks from 18 April to 4 November 2021 to cover the main period of agricultural and ecological activity. The flowering, cropping and active pollinator season in Jumla usually begins at the start of April. In each of the 10 study villages, a 600 × 600 m sampling area was drawn around the center point of the village, and the landscape inside this study area was divided into three different landcover categories using QGIS Version 3.16.8 [52]. The three landcover types were as follows: village (village houses and associated vegetable gardens); crop (areas under arable cultivation); and semi-natural (non-cultivated areas including grassland, forest, scrub etc.). For each of the three habitat types, three fixed survey plots of 60 × 60 m were randomly located in each village using QGIS; these were subsequently ground-truthed to check that they were safe and accessible for data collectors to visit. This gave nine plots in total for each village and 90 plots across all 10 villages. Every two weeks from April to November, a 40 min survey was conducted to record the visitation of insect pollinators to crop and non-crop plants inside each plot. To our knowledge, there are no vertebrate crop pollinators in Nepal,

so we limited our surveys to insects only. Surveys were conducted between the hours of 09.00 and 17.00 when temperatures exceeded 15 °C and when rain was absent or light. During each survey, data collectors spent 40 min walking haphazardly at a constant pace between flowering patches within the plot, and captured any insect they observed visiting a flower. The details of each capture event (including host plant species, specimen code, time, and location) were recorded on Android tablets using a custom-built data collection app in CommCare Version 2.48.3 (http://www.commcarehq.org/home/, 10 April 2024), an open-source, cloud-based data collection platform. Insect specimens were transferred to a killing tube containing ethyl acetate and subsequently pinned and labeled to await identification. Plants were identified by data collectors using a custom-made Plant Atlas for Jumla District, and species identifications were checked for accuracy by a botanist from the national herbarium of Nepal. All insect specimens were identified by insect taxonomists (see Acknowledgments) and are stored in the Central Department of Zoology, Tribhuvan University, Nepal.

Appendix D.2. Pollen Analysis Methods

The number of pollen grains on each individual insect specimen was quantified by swabbing the insect with glycerin jelly and counting the total number of pollen grains on each insect using light microscopy. Insects were only sampled if they were in suitably good condition (i.e., no major damage like a lost head, abdomen or thorax); in the case of major damage, a reserve specimen was selected instead. A single cube of jelly was held with a pair of forceps and used to swab each insect across the entire right-hand side of its body. We consistently limited pollen sampling to the right-hand side of the insect's body to reduce the number of pollen grains that need to be counted, thereby ensuring a more accurate final count. Final counts were multiplied by two in all cases to scale up to the level of the whole insect. Areas sampled include the right-hand side of the insect's face, head, back, side, front legs and underside. The only areas avoided were those where pollen had been gathered into a tight basket and was therefore unavailable for pollination (e.g., the pollen baskets on the back legs of a honey bee or the pollen bundles underneath a solitary bees' legs). Once all pollen was collected from the body, we placed the cube of jelly on a clean glass slide and put a cover slip on top. The jelly was gently heated over a low flame until it started to melt and spread evenly across the slide. Pollen grains were then counted systematically under a light microscope (Zeiss Primo star) using a haemocytometer. In cases where it was impossible to count all grains, we sub-sampled the slide (using the haemocytometer grid), and counted only the grains in the right-hand half or bottom-right quarter; values were then multiplied accordingly. Finally, we calculated the mean pollen carrying capacity of each insect taxon by taking a mean of the total number of pollen grains recorded across all replicates of the taxon.

Appendix E. Supplemental Results

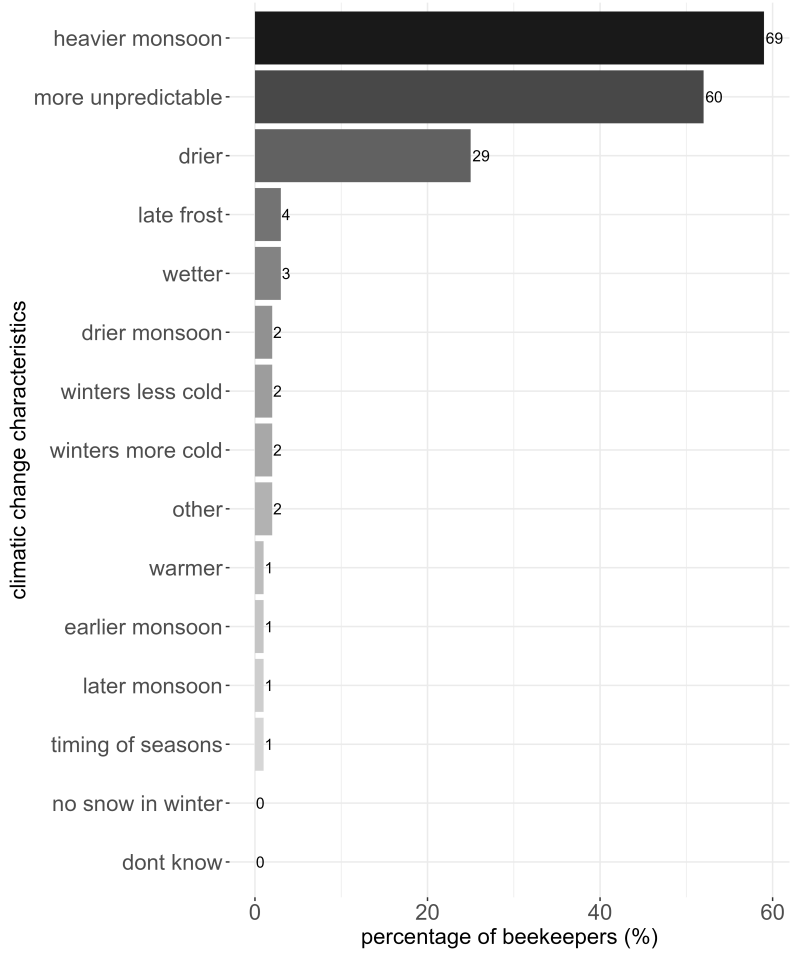

Figure A3. Bar plot showing the main features (ranked) of the changes in the climate according to the beekeepers. The percentages on the x-axis reflect the proportion of beekeeper respondents out of the 116 in total, who listed a given feature as the most important characteristic of the climatic changes experienced. The numbers at the end of the bars are the actual number of respondents which the percentage on the x axis corresponds to.

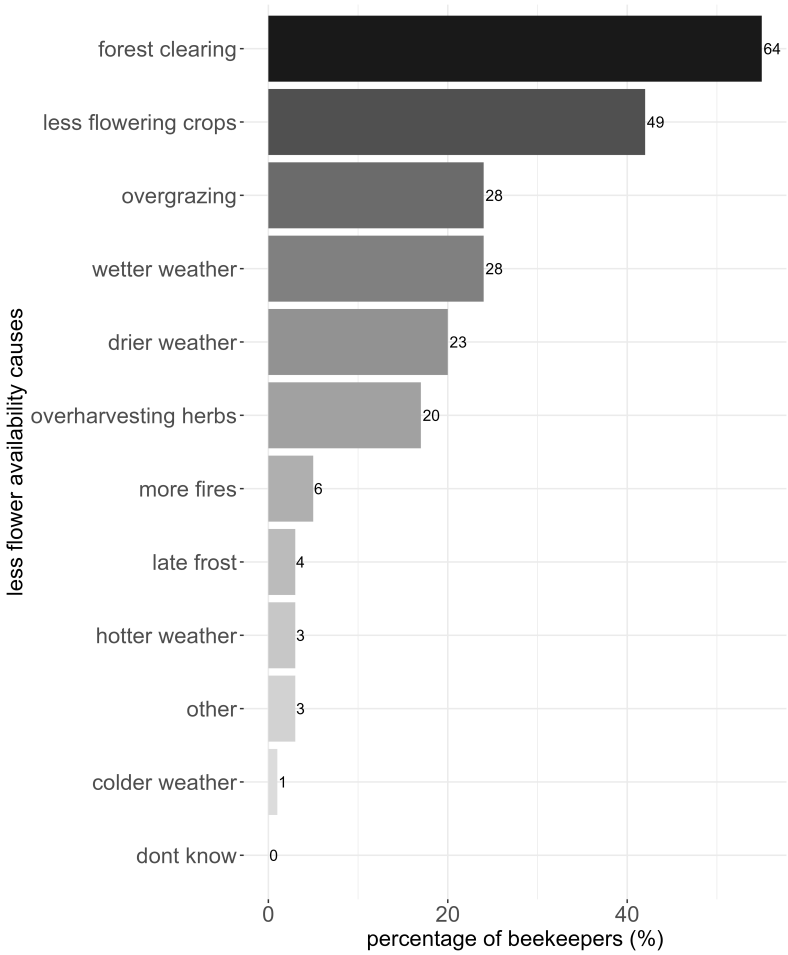

Figure A4. Bar plot showing the main characteristics (ranked) of less flower availability according to the beekeepers. The percentages on the x-axis reflect the proportion of respondents out of the 116 in total, who listed a reason for fewer flowers as important. The numbers at the end of the bars are the actual number of respondents which this percentage corresponds to.

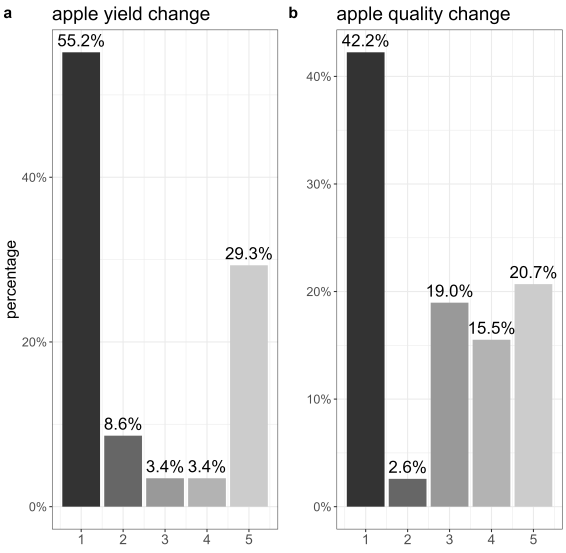

Figure A5. Bar plot showing the percentage of beekeepers who experience changes in apple (**a**) yield and (**b**) quality: 1 = decrease, 2 = increase, 3 = no change, 4 = do not know, 5 = NAs.

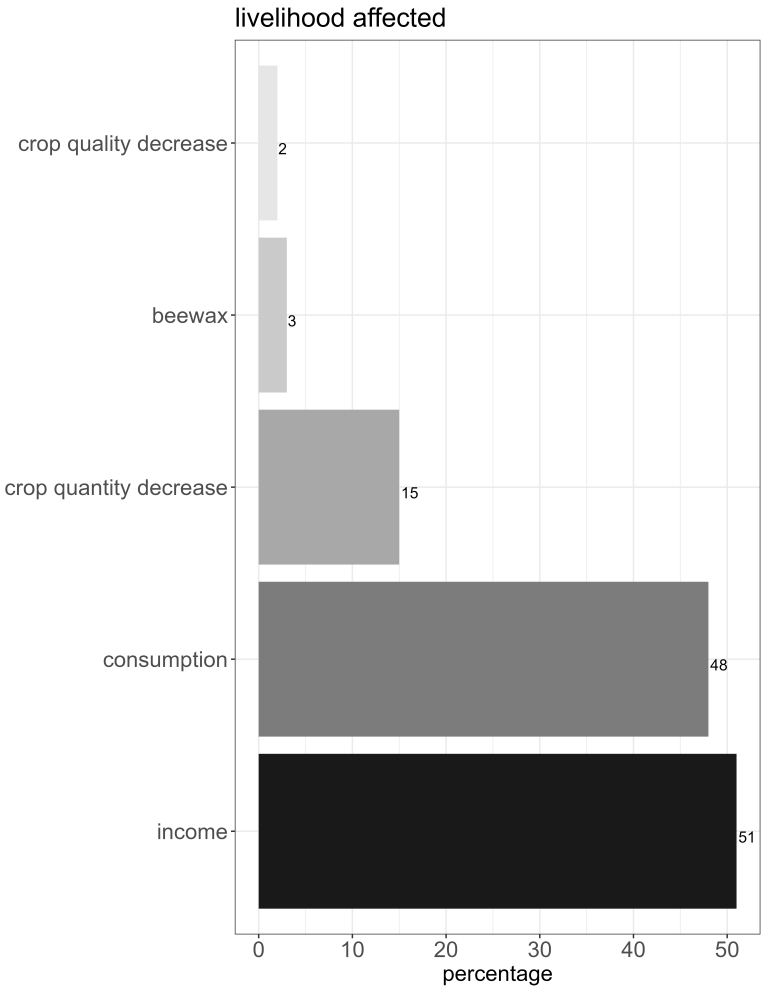

Figure A6. Bar plot of livelihood impacts. The percentages reflect the proportion of beekeeper respondents who listed a given impact as important.

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