Contributions of non-timber forest products to people in mountain ecosystems and impacts of recent climate change

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ABSTRACT
Non-timber forest products (NTFPs) are some of nature’s most important contributions to people in mountain regions and their provision is increasingly affected by climate change. Here, we identify the types of NTFPs and their contributions to people in the mountain communities of the Upper Madi Watershed of Nepal and describe how these are being impacted by climate change. We used a field-based household survey supplemented with key informant interviews to collect quantitative and qualitative data on their use of NTFPs and perceptions of recent climate change impacts. Our results show that mountain communities accrue multiple benefits from NTFPs including provisioning services (fuelwood, food, fodder, bamboo products, fiber, agricultural tools, and medicines) and cultural services (ornaments, and ritual products). Most NTFPs are used for subsistence but some also have market value. Locals perceived climate change to be impacting NTFPs and their benefits to people, in particular via increases in extreme events such as hailstorms and pest plant invasion. Understanding the contributions of NTFPs to people and the impacts of climate change is crucial for supporting policymakers, stakeholders, and practitioners in designing and implementing adaptation strategies for the continued supply, protection, and management of NTFPs in mountain communities.

1. Introduction
Non-timber forest products (NTFPs) include all biological material (except timber) extracted from forests for human use and wellbeing (Hamilton 1998). Medicinal and aromatic plants (MAPs), wild vegetables, edible fruit, wooden utensils, bamboo, fibre, fodder, and fuelwood are among the most common NTFPs (Shackleton and Shackleton 2004; Rasul et al. 2008; Negi et al. 2011; Birch et al. 2014). These ecosystem services are some of nature’s most important contributions to people (Diaz et al. 2018). NTFPs are especially important in mountain communities which are home to 12% of the world’s population and around 10% of the world population directly depends on mountain resources including NTFPs for their livelihoods (Schild 2008). Several studies have recognised the contribution to mountain communities of NTFPs such as food, medicine, forage, and fibre. For example, Kang et al. (2012) documented 159 wild food plant and 13 wild edible fungus species which were used by more than 50% of people in the Qinling Mountains of China. Srissawat et al. (2016) reported 179 species of medicinal plants from Khao Luang Mountain hills of Thailand used to treat 15 different types of skin disease. Similarly, Fortini et al. (2016) identified 106 species of medicinal plants from the Mainarde Mountains of Italy used as internal remedies for ailments such as digestive system disorders and external application to treat skin diseases.

Most NTFPs are consumed directly, but some also form an important component of household livelihoods (Pant et al. 2012; Zhyla et al. 2018; Yadav et al. 2019), providing opportunities for off-farm employment and income for mountain people (Yadav et al. 2019). For example, in Nanda Devi Biosphere Reserve of western Himalaya around 74% of household income is generated from NTFP (Yarshgumba) harvesting (Yadav et al. 2019), and an average of 58% of the total annual household income and 78% of cash income in Jumla district of Nepal is contributed by wild collected medicinal plant products (Timmermann and Smith-Hall 2019). NTFP-based economic activities contribute up to 90% of the rural household income in Nepal (Bista and Webb 2006). Pant et al. (2012) estimated the total annual benefits from forest ecosystem services in three districts of Nepal was equivalent to US$125 million and 80% of this was from NTFPs. Every year, between 10,000–15,000 tonnes of NTFPs are harvested in Nepal and traded to India and other international markets, with an estimated value of US$8.6 M (Edwards 1996). They also provide other services to mountain communities including cultural benefits (Sardeshpande and...
Shackleton 2019), ecotourism and education (Har et al. 2018), and stabilisation of degraded and exposed mountain slopes (Negi et al. 2011).

Climate change is expected to significantly impact the provision of NTFPs in mountain regions (IPCC 2007). Climate change predictions for mountain regions include increases in temperature exceeding global averages as well as local changes in precipitation patterns. In recent decades, temperatures have increased 0.5–0.7°C per decade across the European Alps (Gobiet et al. 2014), the Colombian Andean Central mountain range (Ruiz et al. 2008), and in the eastern and central Tibetan Plateau (Liu et al. 2006). Rises of 0.06°C-0.12°C per year have been reported in the Nepal Himalayas (Shrestha et al. 2017), along with changes in precipitation patterns, decreases in duration of snow cover, and the melting of glaciers (Gobiet et al. 2014). The increase in global average temperatures and change in precipitation patterns will impact the provision of NTFPs and affect livelihoods in mountains (Liu et al. 2006; Maroschek et al. 2009; Penuelas et al. 2017; Chakraborty et al. 2018). Warmer temperatures can drive plant species in mountain regions to shift their distribution to cooler, higher elevations (Kelly and Goulden 2008; Boisvert-Marsh et al. 2014) facilitating an increase in species richness on mountain summits (Steinbauer et al. 2018), and leading to an increase in local extinction risks due to competitive replacement of slow growing plant species (Beniston 2003; Lamsal et al. 2017; Steinbauer et al. 2018). Warmer temperatures put additional stress on high mountain plant populations which typically have poor dispersal mechanisms (Morgan and Venn 2017) or highly specific habitat requirements (IPCC 2014). Climate change is also expected to increase exposure to other risks such as more frequent and severe forest fires, storms, landslides, and floods. These impacts threaten the provision of NTFPs and the livelihoods of mountain people (Kohler et al. 2010). While some positive impacts of climate change on ecosystem services have been identified, for example Bellard et al. (2012) suggested that many plants are likely to benefit from more clement temperature and increased CO₂, resulting in an increase of biomass production, most impacts are detrimental.

Among the different categories of NTFPs, MAPs have received more focus as they are the most traded NTFPs in Nepal, while the contribution of other categories of NTFPs has been largely overlooked (Upreti et al. 2016). Research to date has focused primarily on quantifying the goods and services provided by mountain forests (Lamsal et al. 2018b) and only a few studies have assessed the impacts of climate change on NTFPs, likely due to inadequate climatic and historical bioclimatic data (Chitale et al. 2018). For example, the provision of NTFPs was found to decrease with an increase in temperature and heavy rainfall in Abia state, Nigeria (Ibe 2018). The availability of NTFPs was reduced by climate-induced landslides in Balakot, Pakistan (Shahzad et al. 2019). Climate change has adversely influenced the life-cycles and the distribution of valuable medicinal plants in Central Himalaya, India (Maikhuri et al. 2018), and is predicted to shift the range of some major NTFP species in the Chitwan Annapurna Landscape of Nepal (Chitale et al. 2018). However, local traditional knowledge of climate change and its impacts have not been widely addressed (Dangi et al. 2018) and the impacts of climate change on NTFPs in mountain communities are not comprehensively understood.

In this study, we aim to explore the provisioning and cultural ecosystem services of NTFPs, their contributions to people in mountain communities, and their role in supporting livelihoods under recent climate change. Using the Upper Madi watershed in Nepal as a case study area, we aimed to: 1) identify the full range of plant-based NTFPs from forests; 2) understand the role of NTFPs in subsistence and cash incomes of mountain communities; and 3) quantify local peoples’ perception of climate change and its impacts on NTFPs and their contributions to people. To achieve these aims, we conducted a field survey by interviewing selected individuals from 278 households on their use of NTFPs, their perception of climate change, and its impacts on NTFPs. We also undertook key informant interviews to support both quantitative and qualitative data collection. Here, we present the results of these engagement activities and interpret the implications for other mountain communities adapting to climate change worldwide.

2. Methods

2.1. Study area

The 361 km² Upper Madi watershed study area is located on the southern slope of the Annapurna and Lamjung Himalayan range, in the Madi Rural Municipality in Kaski District, Gandaki Province, Nepal (Figure 1). The study area falls within the Annapurna Conservation Area (ACA), which is the largest protected area of Nepal and contains rich biological diversity supporting a total of 1233 plant species including 48 species endemic to the area, and provides valuable ecosystem services (NTNC 2009). The watershed has a topographic elevation from 1082 m to 7937 m above sea level (WWF 2016). There are approximately 909 households in the watershed and about 75% of these are Gurung ethnic communities, with the remainder being other castes such as Kami, Damai, Sarki, Chhetri, and Brahmin.
(MRM 2018). Most people in the study area highly depend on NTFPs for medication and livelihoods (Gurung et al. 2008). There are four main forest-use types: community owned forest, national forest, religious forest, and private forest (Gurung et al. 2008). Following climatic and altitudinal zones, the study area supports mixed forests and evergreen coniferous forests with a shrubby understory (Figure 1). The main vegetation type includes subtropical with schima-castanopsis forest, lower temperate mixed broadleaved with alder and oak forest, upper temperate mixed broadleaved with rhododendron and birch forest, and arid shrubs. The vegetation of the high Himalaya in the study area is predominately grasses including valuable medicinal plants such as Picrorhiza scrophulariflora Pennell, Aconitum gam-miei Stapf, Dactylorhiza hatagirea (D. Don) Soo, and Ophiocordyceps sinensis (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora.

The study area is highly impacted by climate change and extreme weather events such as hailstorms, strong wind, drought, and hazards such as landslides (C AMC 2017) and glacial lake outburst floods (WWF 2016). The climate of the study area spans subtropical, temperate, and alpine from south to north following the increasing elevation gradient. Precipitation from 1990 to 2018 (DHM 2019) was 744.6 mm in summer and 66 mm in winter on average (Figure 2). Over this period, summer rainfall increased by 1.7 mm yr⁻¹ and winter rainfall decreased by −0.88 mm yr⁻¹. Mean annual maximum and minimum temperatures from 1990 to 2018 recorded at the nearby city of Pokhara (DHM 2019) (located approximately 32 km southwest of the study area) were 26.38°C and 15.11°C respectively. The mean annual temperature increased by 0.044°C yr⁻¹, with an increase in mean maximum and minimum temperature of 0.045°C yr⁻¹ and 0.040°C yr⁻¹, respectively (DHM 2019).

2.2. Sampling procedure and data collection

This study is based on primary data collection through a household survey (Pandey et al. 2018) and key informant interviews (Muhamad et al. 2014) conducted at the watershed level between

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Figure 1. Land-use and broad vegetation types in the Upper Madi watershed, Nepal.

Figure 2. a) Annual mean summer and winter rainfall, and b) annual mean maximum and minimum temperatures in the study area between 1990 and 2018, data from Department of Hydrology and Meteorology, Pokhara, Nepal.
September to December 2019. Surveys and interviews were used to understand people’s perceptions of environmental change (Dangi et al. 2018) and multiple methods were implemented to enrich and cross-validate the results (Denzin 1978).

For the survey, 278 (31%) households were randomly selected from the 909 households of the Upper Madi watershed. Sample size was determined by using the formula proposed by Yamane (1967) to provide a statistically significant sample from the target population of the study area (Suleiman et al. 2017).

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n = \frac{N \times e^2}{1 + N \times e^2}
\]

where \( n \) is the sample size, \( N \) is the total number of households (here \( N = 909 \)), and \( e \) is the acceptable sample error (here \( e = 0.05 \)). As household heads are typically male in the study area, males represented 62.6% of surveyed respondents. Respondents aged >60 years formed 50.4% of the sample, while respondents aged 36–60 and 18–35 years formed 43.9% and 5.8% of the sample respectively. Most of the respondents were of Gurung ethnicity (78.8%), followed by Dalit (19.4%), and 1.8% other ethnicities. Most respondents (61.5%) had no formal education, 34.9% had primary education, 3.6% had secondary education, and no-one was tertiary educated. Almost all informants were farmers (97.5%), with 2.5% of respondents employed in the business sector. Among the total number of respondents, 34.2% of respondents had an average annual household income greater than Nepalese Rupees (NPR) 100,000 (USD 967.5), 29.9% had an income from NPR 51,000–100,000 (USD 493–967.5), and 27% had an income from NPR 25,000–50,000 (USD 242–484), respondents with income less than NPR 25,000 income accounted for 8.9%.

The selected households were contacted and all of them accepted the invitation to participate in the study. Most of the respondents were household heads (or their representatives when the heads were absent). Households heads (or their representatives) were interviewed face-to-face at their home using a structured questionnaire containing both closed and open-ended questions. The survey questions were developed after carefully reviewing the relevant literature (Kar and Jacobson 2012; Bhatta et al. 2015; Macchi et al. 2015; Balama et al. 2016; Upadhyay et al. 2017; Hussain et al. 2018). The survey questions were pre-tested with 10 households prior to survey implementation to check that the questions were clear and easily understood (Lhooest et al. 2019). Each survey interview lasted from 45 minutes to 1 hour, and responses were recorded in the questionnaire sheet by the interviewer. The survey comprised six main sections (see Supplementary Information), and here we explore sections 1–4. The sections of interest are:

- Key socio-demographic information such as gender, age, ethnicity/caste, household size, education, occupation, household income, and agricultural production
- Information on NTFPs currently collected and utilized in the study area
- Local perceptions of climate change, and
- Perceived impacts of climate change on NTFPs ecosystem services.

We used 5-point Likert scales to quantify the local perceptions of climate change and perceived impacts on NTFPs ecosystem services (Robson and McCarrant 2015). The data collected from the household surveys was enriched and triangulated by the information collected from 15 key informant interviews (Bryman 2008). Key informants were village leaders, NTFP collectors and vendors, village elders, and herbalists (e.g. traditional healers) (Huntington, 2000). They were selected using extreme case sampling based on their recognition by others in their communities as being particularly knowledgeable about the subject matter (Robson and McCarrant 2015). In-depth, face-to-face interviews were conducted individually with key informants to achieve greater insights (Dash et al. 2016) about NTFP use, seasonal collection of NTFPs, NTFPs sales and income received, and perceived climate change impacts. The answers were recorded in hardcopy and digital audio recording. Both the household survey and key informant interviews were conducted in Nepali language or in Gurung dialect. We obtained ethics approval for this study from Deakin University’s Faculty of Science, Engineering, and Built Environment Human Ethics Advisory Group (reference number STEC-31-2019-GURUNG). Before each interview, all participants were provided a plain language summary of the project and signed a consent form in their preferred language. The purpose of the study and the significance of their participation were explained to participants. Participation was voluntary and participants were free to withdraw from the survey/interview at any time. We attempted to avoid potential bias, which could be raised from an inclination of respondents towards what the researchers are looking for (Sodhi et al. 2010) by including multiple choice questions including ‘not sure’, and ‘other’ boxes where appropriate, and including questions of both positive and negative impacts of climate change. The respondents were told that there are no right or wrong answers. We maintained confidentiality and anonymity of the respondents and their responses.
2.3. Data analysis

Data were analysed both qualitatively and quantitatively to provide a deeper understanding of the ecosystem services provided by NTFPs under recent climate change, their contribution to people’s livelihoods, and local people’s perception of climate change impacts on NTFPs and livelihoods in the study area. The quantitative data obtained from the household survey were coded to facilitate data entry and numerical codes were assigned to responses for systematic organization of data into categories (Robson and McCartan 2015). The quantitative data were analysed using the Statistical Package for Social Science (SPSS 21) software and Microsoft Excel to obtain descriptive statistics such as percentages of responses, frequencies, means and standard deviations to interpret the results.

Qualitative information collected from the key informant interviews were analysed using thematic coding analysis (Robson and McCartan 2015). This information supplemented and supported the quantitative results and helped to triangulate the information collected from household surveys. In particular, key informant interviews yielded details of NTFP species and their use (medicinal plants and ritual products) and growth form, harvesting season, amount of NTFPs sold and income received, and information related to climate-driven shifts of NTFP species distributions. Most plant species’ local common names collected from household survey and key informant interviews were in the Gurung language. We later identified the botanical names and common names in English using existing literatures (Stapleton 1994; Gurung et al. 2008; Khakurel et al. 2020), the Dictionary of Nepalese Plant Names (Shrestha 1998), Annotated Checklist of the Flowering Plants of Nepal (Press, Shrestha, & Sutton, 2000), and the Catalogue of Life (Roskov et al. 2020). Linear regression was carried out to analyse meteorological data using Microsoft Excel to understand trends in climate variation and their statistical significance.

3. Results

3.1. NTFPs and their contributions to people

Mountain communities in our study area had a rich traditional knowledge of NTFP utilization which enabled us to identify 10 different categories of NTFPs collected (Figure 3). NTFPs are final services provided by forest ecosystems and are mostly provisioning services (fuelwood, food-vegetables and fruit, fodder, bamboo products, fiber, agricultural tools, and medicines) and cultural services (ornaments, and ritual products) which contribute to mountain people’s well-being and livelihoods in multiple ways. NTFPs were derived from 104 plant species (Table 1). All survey respondents reported that they made use of NTFPs for subsistence, cash income, or both. Respondents were able to collect all NTFPs except medicinal plants which required a permit from the Conservation Area Management Committee – an intermediary body between the Annapurna Conservation Area Project and residents.

3.1.1. Provisioning Services

3.1.1.1. Fuelwood. Our study revealed that 100% of the respondents (n = 278) in the Upper Madi watershed collect fuelwood as their primary source of energy. They consume fuelwood for cooking, boiling water, heating, and preparing animal feed. Ninety-nine percent of the respondents consume more than 10 Bhari (or headload, each equivalent to approximately 35–40 kg) per year (Gurung et al. 2013). They usually collect live (whole plant) fuelwood from December to February and store it for the whole year, and collect dry fuelwood from September to October (Table 2). Twenty main plant species were used as fuelwood (Table 1) of which 60%
| Local/ Common Name | English Name | Scientific Name | Growth form | Part used | Provisioning | Cultural |
|--------------------|--------------|-----------------|-------------|-----------|--------------|----------|
| Badahar            | Monkey Jack  | Artocarpus lacucha Buch. | Tree | L | + | |
| Ban Temi/Ban Tarul | Potato Yam   | Dioscorea bulbifera L. | Climber | T | + | + |
| Banmara            | Crofton Weed | Ageratina adenophora (Spreng.) | Herb | L | + | + |
| Changi/Loth Salla  | Himalayan Yew| Taxus wallichiana Zucc. | Tree | WP, S, B | + | + |
| Cheuri/ Titepati   | Mug War     | Artemisia dubia Wall. ex Besser | Herb | L | + | + |
| Chhodi/ Bilaune    | N/A         | Maesa chisla Buch. | Shrub | S | + | + |
| Chhomu/ Ghude      | Himalayan Small Bamboo | Thammocalamus spathiflorus (Trin.) Munro | Herb | S, L | + | + | |
| Chhyaudi           | N/A         | Stautonia angustifolia (Wall.) Christenhi. | Climber | F | + | + |
| Chhyodomai/ Bojho  | Sweet Flag Calamus Root | Acorus calamus L. | Herb | RZ | | + |
| Chhyou Mhais/ Nagbeli | Clubmoss | Lycopodium clavatum L. | Herb | WP | + | + |
| Chhyu Tah          | Giant Lily  | Cardiocrunum giganteum (Wall.) Makino | Herb | L | + | + |
| Chigar             | Himalayan Small Bamboo | Thammocalamus chigars (Stapleton) | Herb | S | + | + |
| Chohsi/Jhyanu     | N/A         | Eurya acuminata DC. | Shrub | WP | + | + |
| Chutro             | Common Barberry | Berberis asaica Rosb. ex DC. | Herb | WP | + | + |
| Chyarbu/Palju      | Himalayan Cherry | Prunus cerasoides D. Don | Tree | WP, F, S | + | + | |
| Chyanis/Angeri     | Lyonia | Lyonia ovalifolia (Wall.) | Tree | WP | + | + |
| Ghodtapre/Ghude    | Water Pennywort | Centella asiatica (L.) Urb. | Herb | L | + | + |
| Ghurbasan/Pakhanbed | Himalayan Small Bamboo | Bergenia ciliata (Haw.) Sternb. | Herb | WP | + | + |
| Ghyossi/Uttsi      | Alder       | Alnus nepalensis D. Don | Tree | WP | + | + |
| Gurja              | Heart-leaved Mooneseed | Tinospora cordifolia (Wildd.) Miers | Climber | L | + | + |
| Harjome            | Orchid      | Dendrobra baumoum Wall. ex Lindli. | Herb | FL | + | + |
| Herah/Malagh       | N/A         | Viburnum muliuba Buch. | Shrub | WP, F, S | + | + | + |
| Hey Nhu/ Ban Lasun | Wild Garlic | Allium wallichii Kunth | Herb | BL | + | + |
| Heytanda/Lekbadmali | Mushroom | Polygonum L. | Herb | S | + | + |
| Jali Chhyau        | Mushroom | Morchella esculenta (L.) Pers. | Fungus | F | + | + |
| Jibre Saag         | Adder’s Tongue | Ophioglossum reticulatum L. | Herb | L | + | + |
| Kau                | N/A         | Tetrastigma serrulatum (Roxb.) Planch. | Climber | L | + | + |
| Kafal              | Box Myrtle  | Morela esculenta (Buch - Ham. ex D. Don) | Tree | F | + | + |
| Kalakhulu/ Tusso   | N/A         | Hydrangea heteromalla D. Don | Tree | L | + | + |
| Kalunge Chhyau     | Mushroom | Termitomyces eurhazus (Berk.) R. Heim | Fungus | F | + | + |
| Kamu/Tite          | Himalayan Small Bamboo | Drepanostachyum falcatum (Nees) Keng f. | Herb | L, S | + | + | |
| Kanya Chhyau       | Mushroom | Pleurotus nepalensis Corner | Fungus | F | + | + |
| Kasi/Katus         | Nepal Chestnut | Castanopsis indica (Roxb. ex Lindli.) A.D.C. | Tree | F | + | + |
| Khel/ Bhojpatan    | Himalayan Silver Birch | Betula utilis D. Don | Tree | B | + | + |
| Khorpan Chhi       | N/A         | Erythrina arborens Roxb | Tree | L | + | + |
| Kudi/Siltimur      | Pepper      | Linderia neesiana (Wall. ex Nees) Kurz | Tree | F | + | + |
| Kyosi/Chilane      | Needle Wood | Schima wallichii (DC.) Korth. | Tree | S | + | + |
| Laule Tah/ Dhaga Saag | N/A | Rheum L. | Herb | L | + | + |
| Lera                | N/A         | Clematis buchananiana DC. | Climber | S | + | + |
| Lotah/Niero        | Edible Fern | Doyoperis cochleata (D. Don) C. Chr. | Herb | S | + | + |
| Mahu Tah           | Himalayan Primrose | Primula denticulata Sm. | Herb | FL | + | + |
| Malajji/ Gophula   | N/A         | Stauntonia latifolia (Wall.) | Climber | F | + | + |
| Maye Tah/ Makai Saag | N/A | Paenoa emodi Wall. | Herb | L | + | + |
| Megas/Bikha        | N/A         | Aconitum ferox Wall. ex Ser. | Herb | RZ | + | + |
| Meh Palah/ Kimbu   | Black Mulberry | Morus nigra L. | Shrub | F | + | + |
| Miphu Chhi/ Liso   | N/A         | Scurcula parasitica L. | Shrub | L, F | + | + |
| Local/ Common Name | English Name | Scientific Name | Growth Form | Part used | NTFP Ecosystem Services |
|-------------------|--------------|----------------|-------------|-----------|-------------------------|
| Mirge Chyau | Mushroom | Lentinula edodes (Berk.) Pegler | Fungus | F | + |
| Misur | Himalayan Small Bamboo | Yushania microphylla (Munro) R.B.Majumdar | Herb | S | + |
| Mowa/Khanayo | Nepal Fodder Fig | Ficus benghalensis L. | Tree | L | + |
| Nagroom | Mushroom | Griffitha frondosa (Dick.) Gray | Fungus | F | + |
| Naljyo | N/A | Schisandra grandiflora (Wall.) Hook. fil. & Thomson | Climber | F | + |
| Neri/Kukurdaino | Green Briers | Smilax aspera L. | Climber | S | + |
| Newa Si/Ashare | N/A | Viburnum nervosum D. Don | Shrub | WP | + |
| Ng-ra/Dudhilo | N/A | Ficus nervifolia Sm. | Tree | L, S | + |
| Ngis/Phalat | Blue Japanese Oak | Quercus glauca Thunb. | Tree | WP, L, S | + |
| Nishi Polhu/Allo | Himalayan Nettle | Girardinia diversifolia (Link) Friis | Herb | B | + |
| Nirmashi | N/A | Aconitum gammiei Stapf | Herb | RZ | + |
| Nishi/Kharsu | Brown Oak of Himalaya | Quercus semiserrata Roxb. | Tree | L | + |
| Noulukajuy/Khiramlo | N/A | Polygonatum verticillatum (L.) All. | Herb | RZ | + |
| Nuri chhi | N/A | Hedera nepalensis K. Koch | Climber | L | + |
| Odu Chhi/Gogon | N/A | Sauraria napaulensis DC. | Tree | L | + |
| Okhar | Walnut | Juglas regia L. | Tree | F | + |
| Olmi/Halhale | Yellow Doek | Rumex nepalensis Spreng. | Herb | L | + |
| Pahi | N/A | Commelina benghalensis L., nom. cons. | Herb | L | + |
| Palah/Aikelu | Golden Evergreen Raspberry | Rubus ellipticus Sm. | Shrub | WP, F | + |
| Panch Amle | Orchid | Dactylorhiza hatagirea (D. Don) Soo | Herb | RZ | + |
| Phurse | N/A | Hydrangea ffeatrina (Lour.) Y. De Smet & C. Granados | Shrub | WP | + |
| Pipla | Wild Pepper | Piper muelles Buch. -Ham. ex D. Don | Climber | F | + |
| Purma | Himalayan Small Bamboo | Himalayacalamus hookerians (Munro) Stapleton | Herb | S | + |
| Plema/chipe Chyau | Mushroom | Suillus granulatus (L.) Roussel | Fungus | F | + |
| Pleta Chhi/chipe Chyau | N/A | Pouzolzia sanguinea (Blume) Merr. | Herb | L | + |
| Plovu/Malinge | Himalayan Small Bamboo | Himalayacalamus cupreus Stapleton | Herb | L, S | + |
| Poral/Palagiurs | Rhododendron | Rhododendron arboreum Sm. | Tree | WP | + |
| Prapi/Firef Fire Ghans | N/A | Hydrangea aspera Buch. -Ham. ex D. Don | Tree | L | + |
| Pruma/Timur | Nepal Pepper | Zanthoxylum armatum DC. | Shrub | F | + |
| Puchutru/Kurilo | Wild Asparagus | Asparagus racemosus Willd. | Climber | BD, S | + |
| Pudki/Pachpate | N/A | Acer cappadocicum Gled. | Tree | L | + |
| Pudunchele/Padamchel | Himalayan Small Bamboo | Rheum australe D. Don | Herb | RZ | + |
| Puri | Himalayan Rhubarb | Prunus napaulensis (Ser. ex DC.) Steud. | Tree | F | + |
| Purichhi/Chuletro | N/A | Brassaopsis hainla (Buch. -Ham.) Seem. | Tree | L | + |
| Rakchan/Rato Chyau | Mushroom | Daphniphyllum himalayense (Benth.) Mull. Arg. | Tree | WP | + |
| RuRu | N/A | Laetiporus sulphureus (Bull.) Murrill | Fungus | F | + |
| Sal Tah/Sungava | Orchid | Symphyos ramosissima Wall. | Tree | L | + |
| Sati/Sattwa | N/A | Coelognye cristata Lindl. | Herb | FL | + |
| Sissi/Dhipu | Himalayan Pencil Cedar | Juniperus communis L. | Shrub | L | + |
| Syona/champ | Magnolia | Magnolia champaca (L.) Baill. ex Pierre | Tree | WP | + |
| Syu | Himalayan Small Bamboo | Yushania emeryi (Stapleton) Demoly | Herb | S | + |
| Teedo/chirta Chyau | Chirola | Svertia chirayita (Roxb.) H. Karst. | Herb | WP | + |
| Tehwu | N/A | Pyrularia edulis (Wall.) A. DC. | Tree | L | + |
were trees and 40% were shrubs. Fuelwood was collected both from the community forest and from the private forest. *Alnus nepalensis* (D. Don) is the most preferred tree species for fuelwood obtained from the private forest.

### 3.1.1.2. Food (Vegetables)
Most respondents (85%, n = 237) reported collecting vegetables. A total of 19 species of vegetables were collected of which 79% were herbs, 11% were shrubs, and 10% were climbers (Table 1). Respondents collected vegetables mostly between February and October. Eighty-four per cent of respondents collected <5 kg of vegetables whereas 1% of respondents collected between 5 and 10 kg per year. Harvested vegetables were typically consumed fresh or dried for future use.

### 3.1.1.3. Food (Fruit)
Most respondents (82%, n = 228) reported collecting fruit from the forest. Among the 20 species of fruit collected, 47% were trees, 26% were shrubs, and 27% were climbers (Table 1). Fruit are an important food supplement for the communities of the study area. It was found that people mostly consumed fruit when walking through the forest especially when collecting fuelwood and fodder which happens 2–3 times a year. The fruit are available during the months of March to June and October to December.

### 3.1.1.4. Fodder
Most respondents (76%, n = 211) reported collecting fodder for domestic animals such as buffalos, cows, oxen, and goats. Among the 20 fodder species collected, 56% were trees, 22% shrubs, 11% herbs, and 11% climbers (Table 1). Respondents reported collecting fodder mostly from October to May. Most respondents (77%) indicated that they collect fodder weekly whereas 23% reported daily collection.

### 3.1.1.5. Bamboo products
Small bamboo called *Nigalo* in Nepal is one of the most versatile NTFPs used by the mountain communities who collected 7 species of *Nigalo* (Table 1). Most respondents (75%) reported collecting *Nigalo* for multiple uses such as crafting baskets (*Doko, Dalo, Thunse*), mats (*Bhakari and Mandro*), umbrella (*Shyakhu*), bamboo shoot as...
Table 3. Income from NTFPs at the watershed level in the year 2017/2018.

| NTFPs       | Species             | Part Used | Quantity | Total value (NPR) | Proportion (%) | Benefitting households |
|-------------|---------------------|-----------|----------|------------------|----------------|------------------------|
| Medicinal plants | Yarchagumba          | Whole plant | 3.5 kg  | 2,625,000         | 21.7           | 60                     |
|             | Satruba              | Rhizome   | 640 kg  | 7,040,000         | 58.2           | 298                    |
|             | Ban Lasun            | Bulb      | 20 kg   | 87,000            | 0.7            | 15                     |
|             | Bikh                 | Rhizome   | 800 kg  | 280,000           | 2.3            | 15                     |
| Bamboo products | Mandra              | Stem Stem | 1355 pieces | 1,016,250         | 8.4            | 160                    |
|             | Bhakari              | Stem      | 680 pieces | 510,000          | 4.2            | 35                     |
|             | Perungo              | Stem Stem | 225 pieces | 45,000           | 0.4            | 3                      |
|             | Doko                 | Stem      | 555 pieces | 277,500         | 2.3            | 100                    |
| Fiber products | Bhangra             | Bark      | 50 pieces | 225,000          | 1.9            | 15                     |

food and leaves as fodder and stem for fireworks. Bamboo was mostly collected from September to January and men were mostly involved in Nigalo crafts. Bamboo craft making and trade was also one of the main sources of cash income for many poor households in the Upper Madi Watershed.

3.1.1.6. Fiber. The Himalayan nettle (Girardinia diversifolia) provided fiber commonly known as Allo in Nepal, which has both socio-economic and traditional values. 60% of the respondents indicated that they collect Allo for extraction of fiber and use it for weaving bags, grain sacks, Bhangra (a piece of traditional clothing), rope, and porters’ straps. The plant is collected twice a year in the months of September to October and December to January, and women are mostly involved in fiber processing activities. Allo products are mostly used within households with some sold for income.

3.1.1.7. Agricultural tools. About 41% of the respondents collected forest plants to make agricultural tools such as ploughs, spade handles, and sickles. Among the 6 species of plants collected, 86% were trees and 14% were shrubs (Table 1). Most respondents were dependent on agriculture but most of them acquired tools from the occupational caste Kami (Blacksmiths). Tool-making largely occurred from April to June before starting the cultivation of major crop plants such as rice, maize, and millet.

3.1.1.8. Medicines. Around 36% of the respondents reported collecting medicinal plants to treat various diseases. Some medicinal plant species are major sources of income for some households. Thirty-one species of plants were used for medicinal purposes in the study area (Table 1), 57% of which were herbs, 17% were trees, 13% shrubs, 10% climbers, and 3% fungus. Medicinal plants were collected mostly from March to September. The major human diseases and disorders treated by medicinal plants, as reported by respondents, included cuts and wounds, cholera, cough and cold, fever, abdominal pain, diarrhoea and dysentery, diabetes, gastritis, toothache, asthma, joint pain, constipation, smallpox, pinworms, high blood pressure, muscle sprain, bone fracture, jaundice and loss of appetite.

3.1.2. Cultural services

3.1.2.1. Ornaments. Seventy-four percent of respondents collected ornamental plants (5 species) from forests to decorate their houses from January to May (Table 1) believing that by doing so, their god will be happy and maintain peace and prosperity in the house.

3.1.2.2. Ritual products. About 12% of the respondents collected various plants that are used in different cultural and religious ceremonies such as marriage, death, and other worship and ceremonial uses. Respondents collected 21 species of ritual plants and among them 23% were trees, 29% shrubs, 33% herbs, and 14% climbers (Table 1). Ritual plants were mostly collected during March to April and June to July. Plant species such as Smilax aspera, Viburnum mullala, Juniperus communis, and Drepanostachyum falcatum were used during the Arghum ritual, which is performed for deceased spirits after death, Asparagus racemosus and Artemisia dubia are used in marriage ceremonies, Zanthoxylum armatum, Rhus chinensis, Lycopodium clavatum, and Prunus cerasoides are used for keeping bad spirits away, and Cynodon dactylon, Artemisia dubia and Dioscorea bulbifera are used in religious worship.

3.2. Income from NTFPs

NTFPs are used for both subsistence and cash income to households. 42% of the respondents reported collecting NTFPs to meet household needs whereas 58% of the respondents said they collected NTFPs for both household use and for earning additional income. According to key informants such as NTFP traders and Conservation Area Management Committee members, the three most important NTFPs sold by Upper Madi watershed communities were medicinal plants, bamboo products, and fiber products (Table 3). People from the watershed earned a total
income of NPR 12,105,750 (USD 117,122) from NTFPs in the year 2017/2018. Among these three NTFPs, medicinal plants (83%) were the most significant NTFP-based source of cash income to households, with bamboo products contributing 15% and fiber products 2%.

3.3. Perception of climate change and extreme events

The respondents perceived notable changes in the climate and in extreme events over last the 20–30 years (Table 4). We asked whether ‘Climate change is happening in your area’ and 86% responded in the affirmative.

Respondents reported an increase in maximum and minimum temperature, an increase in summer rainfall amount, an increase in winter drought, an increase in hailstorms, an increase in pest and insects, and an increase in invasive plant species over the last 20–30 years. Most people believe that summer temperatures have increased as had summer rainfall. Most people had also perceived an increase in winter drought, an increase in hailstorm and almost all had noticed an increase in forest pests and insects and invasive plants. Most respondents had observed a decrease in winter rainfall and almost all had perceived a decrease of snowfall (Table 4).

3.4. Perceived impacts of climate change on NTFPs and livelihoods

Respondents identified an increase in hailstorms, an increase in pest and insect attack, expansion of invasive plant species, strong wind events, changes in rainfall and temperature patterns, increased landslides and floods, and more frequent and severe winter drought as the major drivers reducing the availability of NTFPs.

Most participants perceived that hailstorm has impacted the provision of most NTFPs (Figure 4 and Figure 5). A high proportion of respondents agreed that its impacts on fruit, vegetables, fodder, ornaments, fiber products and medicines had increased. Most participants also reported that an increase in pests and insects had also impacted the provision of most NTFP including fuelwood, fodder, bamboo products, ornaments, and fruit. The moth caterpillar locally called Ghyosipti (Gazalina chrysophlopa Kollar) is the major pest that consumes leaves of trees especially Ainus nepalensis, Rhododendron arboreum and other fodder plants. The caterpillars defoliate the trees and can kill the plants. The respondents reported that caterpillar outbreaks usually occur when there is low rainfall during the post-winter months (March and April). Respondents reported that the impact of an invasive alien plant species Ageratina adenophora locally called Banmara on NTFPs had increased on fuelwoods, fodder plants, vegetables, and fiber plant. Respondents also perceived that wind, change in temperature and precipitation patterns, an increase in floods and landslides impacted the provision of NTFPs and they believed that forest fire had least influence on NTFPs. Key informants mentioned changes in flowering phenology and shifts in altitude of some NTFP species: ‘I have observed earlier flowering of some NTFP species like Laligurans (Rhododendron arboreum), Champ (Magnolia champaca) and Satuwa (Paris polyphylla)’ (Key informant). ‘Likewise, I have noticed upward shift of some NTFP species like Chilaune (Schima wallichii) and Banmara (Ageratina adenophora) which were found in the lower altitude but now they are found in the higher altitude’ (Key informant).

4. Discussion

The provisioning (fuelwood, food -vegetables and fruit, fodder, bamboo products, fiber, agricultural tools, and medicines) and cultural services (ornaments, and ritual products) of NTFPs are strongly related to the well-being and livelihoods of the communities in the Upper Madi watershed study area.

| Climate indicators        | Significantly Decreased (%) | Decreased (%) | No Change (%) | Increased (%) | Significantly Increased (%) |
|---------------------------|-----------------------------|---------------|---------------|---------------|-----------------------------|
| Maximum summer temperature| 0                           | 0             | 14            | 86            | 0                           |
| Maximum winter temperature| 0                           | 16            | 33            | 51            | 0                           |
| Minimum summer temperature| 0                           | 0             | 23            | 77            | 0                           |
| Minimum winter temperature| 0                           | 35            | 27            | 38            | 0                           |
| Summer rainfall amount    | 0                           | 7.9           | 24.1          | 67.6          | 0.4                         |
| Winter rainfall amount    | 0                           | 75.9          | 19.8          | 4.3           | 0                           |
| Summer drought            | 0                           | 7.2           | 69.1          | 23.7          | 0                           |
| Winter drought            | 0                           | 3.2           | 22.7          | 74.1          | 0                           |
| Snow fall                 | 0.3                         | 95            | 4             | 0.7           | 0                           |
| Hailstorms                | 0                           | 19.8          | 21.6          | 58.3          | 0.3                         |
| Strong wind               | 0.4                         | 18            | 40.6          | 41            | 0                           |
| Landslides                | 0                           | 17.6          | 35.6          | 46.5          | 0.3                         |
| Floods                    | 0                           | 17.3          | 36            | 46.4          | 0.3                         |
| Forest fire               | 0                           | 21            | 77            | 2             | 0                           |
| Pest and insects          | 0                           | 0.4           | 2.5           | 96.4          | 0.7                         |
| Invasive plant species    | 0                           | 0             | 0.4           | 91            | 8.6                         |
For example, all survey respondents reported that they made use of NTFPs for subsistence, cash income, or both. Medicinal plants, bamboo and fiber products were the most significant NTFPs based source of income for the local communities. The respondents noticed the change in the temperature and precipitation patterns and in extreme events over the last 20–30 years. They reported that the
increased temperatures and change in precipitation patterns have been associated with an increase in invasive plant species, insect pest species outbreaks, and an increase in extreme weather events such as hailstorms and strong winds, and natural hazards including landslides and floods. These changes in climatic variability and the increase in extreme events have impacted the availability of NTFPs and their benefits for mountain communities.

4.1. Mountain community use of NTFPs
Our findings on the use of various NTFPs by the mountain communities are similar to those reported in previous studies conducted elsewhere in mountainous environments. Almost all respondents used fuelwood as their primary source of energy which is similar to other studies conducted in the mountains of Nepal (Webb and Dhakal 2011) and in Cambodia (San et al. 2012). Vegetables, fruit, and medicinal plants are sources of food, nutrition, medicine and income for these mountain communities (Webb and Dhakal 2011; San et al. 2012). Local people from the Upper Madi watershed also used these NTFPs. Trade of medicinal plants Yashagumba (Ophiocordyceps sinensis), Satuwa (Paris polyphylla), Bikh (Aconitum ferox), Ban Lasun (Allium wallichii) are also reported in other mountain districts of Nepal (Kunwar et al. 2013). Local priests and traditional healers use medicinal plants for the treatment of different diseases and disorders. Ornaments, and ritual products are frequently used cultural services in the study area. However, the ritual plants used in the study area are quite different to those used in other communities (Bhatt 2002; Aryal et al. 2018; Kunwar et al. 2018) reflecting the context-dependent evolution of cultural and ritual practices within the local environment (Jones et al. 2020). For example, Smilax aspera, Viburnum mullaha, Juniperus communis, and Drepanostachyum falcatum were used to perform Arghum ritual (perform for deceased spirits after death), Zanthoxylum armatum, Rhus chinensis, and Lycopodium clavatum were used for keeping bad spirits away.

4.2. Perceptions of climate change and its impacts
Most respondents (86%) in the study area expressed the view that climate change is affecting their region. This finding reflects similar levels of perceived climate change to studies conducted in an alpine area in Southwest China where more than 97% of respondents reported climate change effects (Wang and Cao 2015), and in the Himalayan region of northern Pakistan where 83% of respondents reported an effect (Ali et al. 2017). While there is some evidence that local people’s perceptions of climate change may not reflect climate records (Byg and Salick 2009), perceptions of an increase in mean maximum and minimum temperatures, increases in amount of summer rainfall and decreases in winter rainfall closely aligned with the observed hydrological and meteorological data (Figure 2) (DHM 2019).

Respondents reported that hailstorms have impacted the availability of almost all the NTFPs in the study area, in particular, medicinal plants, vegetables, fruit, and ornaments (Figure 5). Botzen et al. (2010) predicted that hailstorm damage may increase in the future following temperature increases. An increase in pests and insect attack have impacted mostly fuelwood, fodder, bamboo, fruit, and ornaments. Other studies have also described the impacts of climate change on an increase or outbreak of insects and pests. For example, Pureswaran et al. (2018) reported climate change influences on the outbreak of bark beetles and defoliating insects that impact forest ecosystems. Change in weather patterns supports the growth of invasive plants and as new areas of suitable habitat become available. The plants prevent tree regeneration and degrade the habitat of NTFPs (Shrestha et al. 2019). Fodder, fuelwood, fiber products, and vegetable species were highly impacted by invasive alien plant species in the study area. It is reported that the range of the invasive Ageratina adenophora is rapidly shifting to higher elevations with the recent accelerated warming in the mountains of central Nepal (Lamsal et al. 2017) predicted that it will invade mountain ecosystems as climatic conditions become more suitable (Lamsal et al. 2018a). Early visual responses to global climate change include plant phenological changes (Corlett and Lafrankie, Jr. 1998; Xu et al. 2009). Participants in our study had observed earlier flowering of some NTFP species such as Rhododendron arboreum, Magnolia champaca (Kunwar et al. 2018) and Paris polyphylla. Chaudhary and Bawa (2011) also reported advancement of the flowering season of Rhododendron arboreum and Magnolia champaca in middle mountain ecosystems across Nepal.

4.3. Policy implications
Our results show that the use of NTFPs contributes to many dimensions of the wellbeing and livelihoods of mountain communities. The contribution of NTFPs should be recognized and secured via policies spanning multiple sectors including energy, food security, economic development, health, environmental protection, and culture. Ayurvedic medicines for example, many of which come from NTFPs, are an important component of traditional health care systems, and the health policy of India encourages the maintenance of health and wellbeing of people via
conserving the medicinal plants (Shackleton and Pandey 2014). Nepal has also adopted the Herb and NTFP Development policy (2004) to capture their substantial economic contribution by conserving and preserving high value herbs and NTFPs, and to establish Nepal as a key source of herbs and NTFPs internationally (Heinen and Shrestha-Acharya 2011). However, the NTFP policy 2004 lacks provisions for identifying and mitigating risks to this fledgling industry. This research can help identify the potential risks for effective implementation of this policy. Policy and development initiatives should include a focus on the conservation of those NTFPs having high market values, and managing the intensity of household use through various supports such as improved cultivation and domestication techniques to ensure the well-being and livelihoods of the mountain communities (Bista and Webb 2006; Kar and Jacobson 2012; Dash et al. 2016).

Increases in temperature and change in precipitation patterns have resulted in the outbreak of the pest moth caterpillar Gazalina chrysolopa and the spread of invasive plant species Ageratum adenophora in the study area, negatively impacting the provision of NTFP ecosystem services. The future vulnerability of these ecosystem services to climate change needs to be better understood and different management and adaptation initiatives implemented. For example, promoting the use of NTFP species which are more resilient to pests in regions with high incidence of pest attack, promoting mixed-species NTFPs (Field et al. 2020), or managing healthy NTFPs by selective cutting of susceptible NTFPs which promote pest attack but have few defences against infestation. For the management of invasive plant species, control measures (e.g. integrated management, biocontrol) should be implemented to eradicate weed infestations and to limit the spread to new areas. Harvest of invasive plant species may be promoted by identifying utilization values (Everard et al. 2018). An invasive plant management plan should be prepared and implemented involving local people and related stakeholders. Local people should be made aware of the invasive plant species issues and trained to implement management and eradication. Mowing pest plant infestations for the preparation of organic manure and bio-briquettes as suggested by Adhikari et al. (2018) may also aid in managing pest plant invasions. These findings support policy directions of managing and conserving valuable NTFPs, incorporating the contributions of NTFPs to the wellbeing of mountain people and addressing the impacts of climate change on NTFPs.

4.4. Innovation and contribution

Our findings provide a detailed understanding of the contribution of NTFP ecosystem services to different dimensions of the wellbeing and livelihoods of forest-dependent communities under a changing climate in the mountain environment of Nepal. Few studies have assessed the impacts of climate change on NTFPs. Rather, NTFP studies have primarily focused on wild edible foods and medicinal plants (Shackleton 2014; Maikhuri et al. 2018) and highlighting the range of ecosystem services provided by NTFPs. Our study documents the full range of NTFP ecosystem services including fuelwood, fodder, bamboo products, fibres, ornamental plants, agricultural tools, and ritual products and adds to current understanding of the impacts of climate change on NTFP ecosystem services. Impacts of invasive plant species and pests on forest ecosystem have been recorded in mountains but these studies have lacked a detailed analysis of the impacts on NTFPs ecosystem services (Pureswaran et al. 2018; Lamsal et al. 2018a). In addition, the suggested policy initiatives can contribute to the sustainable management of NTFPs and to the design of climate change adaptation strategies for NTFP ecosystem services in the mountains.

5. Conclusion

This study has highlighted the ecosystem services provided by NTFPs, their contributions to the wellbeing and livelihoods of mountain communities, and local perceptions of climate change and its impacts on NTFPs in the Upper Madi watershed of Nepal. We found that the mountain ecosystems of the study area are rich in NTFPs and that local communities are highly dependent on these services. Ten different categories of NTFPs were identified in the study area including a range of provisioning services (fuelwood, vegetables, fruit, fodder, bamboo products, fiber, agricultural tools, and medicinal plants) and cultural services (ornaments, and ritual products). Some of these services such as medicines, bamboo products and fiber products have high economic values and are important for sustaining livelihoods. Perception and experiences of the communities, supported by meteorological data, revealed that NTFPs services and their contributions to people in the Upper Madi Watershed have been negatively impacted by climate change, particularly an increase in temperature and change in precipitation patterns and an increase in the frequency and severity of extreme events. Local communities were acutely aware of the impacts of climate change on NTFPs. To ensure the well-being and livelihoods of the mountain communities while protecting NTFP ecosystem services, an appropriate balance of developmental interventions, policy initiatives, and incentives are
needed. Local adaptation practices and barriers to adaptation urgently need to be explored to inform long-term adaptation strategies and the sustainability of mountain communities and ecosystems.

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