Forest Ecosystem Services in Nepal: A Retrospective Synthesis, Research Gaps and Implications in the Context of Climate Change

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Forest ecosystem services in Nepal: a retrospective synthesis, research gaps and implications in the context of climate change

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SUMMARY

Forest ecosystem services (forest ES) in Nepal help sustain livelihoods and strengthen the national economy. However, its flow is affected by human and environmental pressures. In the present study, a systematic review of literature published between 2000 and 2017 in the ISI Web of Science, Scopus, Nepjol, and Himaldocs was undertaken to (i) explore the current research status on forest ES and (ii) identify the likely effects of future climate change on forest ES and forest-based livelihoods and economy. A total of 140 papers were obtained from these publications, of which 46 papers (33%) directly focused on forest ES in Nepal. However, the publication trends have increased only in recent years, and the distribution is non-homogenous and clustered around the central and western regions. Many studies (62%) dealt with regulating services, especially estimating carbon stock. We have listed eight major implications of this synthesis while discussing the likely effects of climate change on forest ES in Nepal. Payment for ecosystem services (PES), a global policy design, appears to be a better option to tackle climatic impacts on forest ES through adaptation measures in Nepal, in addition to more collaborative research involving universities and research organizations and expanding in spatial scale and coverage of all ecosystem service categories.

Keywords: climate change, ecosystem services, forest, Nepal, REDD+

Services d'écosystème forestier au Népal: une analyse rétrospective en ces temps de changement climatique

P. LAMSAL, L. KUMAR, K. ATREYA et K.P. PANT

Les services d'écosystème forestier (ES forestier) au Népal aident à soutenir les revenus individuels et renforcent l'économie nationale. Toutefois, leur libre déroulement est affecté par les pressions environnementales et humaines. Une étude systématique de la littérature publiée entre 2000 et 2017 dans le ISI Web of Science, Scopus, Nepjol et Himaldocs a été conduite ici pour (i) explorer le statut actuel de la recherche sur les ES forestier, et,(ii), pour identifier les effets probables du changement climatique futur sur ces ES forestier, ainsi que sur les revenus et l'économie basés sur la forêt. Un total de 140 papiers a été obtenus, provenant des publications citées, dont 43 papiers (33%) se concentraient directement sur les ES forestier au Népal. Les courants de publication n'ont cependant augmenté que dans les années récentes, et leur distribution n'en est guère homogène, et centrée sur les régions du centre et de l'ouest. Plusieurs études (62%) se penchaient sur les services de règlementation, ceux estimant le stock de carbone en particulier. Nous avons dressé une liste de huit implications majeures résultant de cette synthèse, tout en analysant les effets probables du changement climatique sur les ES forestier au Népal. Le paiement pour les services d'écosystème (PES) et un design de politique globale paraissent être de meilleures options pour faire face aux impacts climatiques sur les ES forestier, à l'aide de mesures d'adaptation au Népal, ceci en addition à la recherche plus collaborative impliquant universités et organisations de recherche, allant vers un élargissement à l'échelle spatiale et vers une incorporation des catégories de services à tous écosystèmes.

Servicios ecosistémicos forestales en Nepal: una revisión del estado de la investigación y predicciones bajo el contexto del cambio climático

P. LAMSAL, L. KUMAR, K. ATREYA y K.P. PANT

Los servicios ecosistémicos forestales (SEF) en Nepal ayudan a mantener los medios de vida y fortalecer la economía nacional. Sin embargo, su provisión se ve afectada por las presiones humanas y ambientales. En el presente estudio se realizó una revisión sistemática de la literatura publicada entre 2000 y 2017 en ISI Web of Science, Scopus, Nepjol e Himaldocs para (i) explorar el estado actual de la investigación en SEF y (ii) identificar los efectos probables del futuro cambio climático en los SEF y en los medios de vida y la economía basados en los bosques. Se obtuvieron un total de 140 artículos de estas publicaciones, de los cuales 46 (33%) se centran directamente en los SEF en Nepal. Sin embargo, las tendencias en las publicaciones han aumentado solo en los últimos años, y la distribución no es homogénea y se ha agrupado en torno a las regiones central y occidental. Muchos estudios (62%) tratan sobre la regulación de los servicios, especialmente la estimación de las reservas de carbono. El artículo enumera ocho implicaciones principales de esta síntesis a la vez que discute los posibles efectos del cambio climático en los SEF en Nepal. El pago por servicios ecosistémicos (PSE), un tipo de política global, parece ser una de las mejores opciones para abordar los impactos climáticos en los SEF a través de medidas de adaptación en Nepal, además de una investigación más colaborativa que involucre a universidades y organizaciones de investigación y un aumento tanto en la escala espacial como en la cobertura de todas las categorías de servicios de ecosistema.

INTRODUCTION

Valuation of flow of ecosystem services (ES) and natural capital stocks helps to highlight, measure, and value the degree of interdependence between humans and nature (Costanza *et al.* 2014), and disregard of such dependencies creates detrimental consequences for human wellbeing and the economy (Jax *et al.* 2013). The concept of ES links society with nature. ES refers to conditions and processes through which natural ecosystems and the species that compose them sustain and fulfill human needs (Daily 1997); the benefits that people obtain from ecosystems (MEA 2005); and direct and indirect contributions of ecosystems to human well-being (TEEB Foundation 2010). The value of average annual flow of global ecological services (17 ES and 16 biomes) to global society was estimated US$33 trillions (in the range of US$16–54 trillions) (Costanza *et al.* 1997). The forest is among the ten major ecosystem categories that the Millennium Ecosystem Assessment (MEA) identified because of its rich ES needed for human wellbeing. Global forests, in general, play an important role in balancing our climate system; however, forests are currently under extreme pressures from ongoing global climate change (Bonan 2008). Rising populations and their changing lifestyles are further escalating pressures on forests.

Forest ecosystem services, also referred to as use and non-use values obtained from forests, are important for human welfare and the national economy. A meta-analysis (de Groot *et al.* 2012) estimated a global annual value of existing tropical and temperate forest ES at US$ 5,264 and US$ 3,013 per hectare, respectively. In China, the annual forest ES is estimated to be around US$ 1.48 trillion, equivalent to almost 40.5% of GDP (Niu *et al.* 2012). Likewise, Xie *et al.* (2017) reported 46% of the forest ES to the total ES in all of China. In developing countries, environmental income accounts for approximately 28% of the total household income, and the forest share of environmental income is almost 77% (Angelsen *et al.* 2014). Despite such national/global importance of forest ES, global biodiversity loss, including forest resources, continues (Butchart *et al.* 2010). Climate change will be the second most detrimental factor to impact terrestrial biodiversity loss in the future after land-use change activities (Sala *et al.* 2000). Climate change redistributes biodiversity at temporal and spatial scales, and such redistribution affects ecosystems and the services needed for human wellbeing (Pecl *et al.* 2017). Approximately 129 million ha of forest has been lost globally between 1990 and 2015 (FAO 2016). Global land use change has caused a loss of ES (Costanza *et al.* 2014). Furthermore, intensification of the trade-off between ES — for example, agricultural land expansion, could decrease current forest land (Alcamo *et al.* 2005).

Climate change affects overall forest ES, species pattern and their distribution. Biotic interactions and provision of ecosystem services are being and will be constantly affected by climate change though the pace and magnitude of such effects are largely unknown (Montoya and Raffaelli 2010). Seidl *et al*. (2014) reported damage from wind, bark beetle and forest fires could be further intensified in the future in European forests. Climate-induced physiological stresses, insect outbreaks and wildfires in forest ecosystems have exacerbated the loss of numerous forest ES (Allen *et al.* 2010). The likely warmer and drier condition in the European Alps could encourage abiotic damage, such as forest fire, during the drought period in winter and spring while increased respiration rate later in this century added with fire and other such disturbances might lower carbon sink strength that turn back these forests as a atmospheric carbon source (Maroschek *et al*. 2009). Bugmann *et al*. (2015) also reported a likely reduction of provisioning and regulating forest ES at low elevated dry inner alpine region of Swiss Plateau with projected warming. In India, Chitale *et al*. (2014) predicted that 41.3% of the 637 endemic plant species currently found in three hotspots, viz. Himalaya, Western Ghats and Indo-Burma favoring a cooler climate, will undergo range reduction and 24.1% will undergo range expansion by 2080. Similar high latitude shift of tree species distribution has been observed in North America resulting from recent warming phenomena (Boisvert-Marsh *et al*. 2014, McKenney *et al*. 2007).

Forest ES is important to Nepal's economy because 80% of the population derives resources for livelihood from nature, such as food, fiber, freshwater, and medicine from natural habitats, and forest-based biomass provides nearly 90% of total energy consumption (BCN and DNPWC 2012). Approximately 45% of the country's land area is under forest cover, and the majority of people live in an interface between agriculture-forest environments. Almost 40% of Nepalese people are directly involved in the protection and management of forested land (Paudyal *et al.* 2017a). A study (Pant *et al.* 2012) in Nepal estimated the annual household benefits from a number of forest ES as equivalent to US$ 1,072 from provisioning services (forest goods), US$ 199 from regulating services (carbon sequestration) and US$ 228 from supporting services. Climate has vital role in the maintenance of forest ES. Department of Hydrology and Meteorology (DHM 2017) reported an increasing maximum (0.056°C/year) and minimum temperature (0.002°C/year) between 1971 and 2014 across Nepal. Also reported are the increased number of rainy days in northwest region and decreased extreme wet days in northern region. Similar finding has been observed in eastern Nepal (A.B. Shrestha *et al*. 2017) and north western Himalaya (Shafiq *et al*. 2018). The current and continuity of such climatic trends over an area could have some influences on forest ecosystem as a whole and thereby to its ecosystem services.

Nepal is highly dependent on forest ES to sustain its people's livelihood and maintain the national economy; however, there is limited and scattered research on the available forest ES in the country and the possible future impact of anticipated global and regional climate change. Therefore, this study has two objectives: (i) to explore the research status of forest ES in the country and identify existing research gaps; and (ii) to reveal the likely effect of future climate change on the national forest ES, forest-based livelihoods and the economy. The main idea of this paper is to map the forest ES that has been studied so far in Nepal and then discuss the vulnerability of forest ES from future climate change. This is important in the current context because it will visualize the existing knowledge base on forest ES and further express the readiness of the state to cope with the likely detrimental effects of climate change on the national economy and livelihood of the local forest-dependent people.

METHODOLOGY

The term "ecosystem services" was coined in 1981 (Braat 2016), but a significant amount of earlier research has been conducted on the benefits from ecosystems, and the term increased in popularity in the political arena after the publication of the Millennium Ecosystem Assessment (MEA 2005). We thus considered diverse keywords in our web search to identify the maximum available literature that discusses forest ES in Nepal. We believe that forest-human interdependence is an ancient phenomenon in Nepal, and research scholars have documented the interdependence in terms of other synonymous terms — for example, use value, non-use value, biodiversity, watershed conservation and so on. We thus conducted a systematic search of literature using the following keyword combination:

- "Ecosystem services AND Forest AND Nepal"
- "Ecosystem services AND National park AND Nepal"
- "Ecosystem services AND Conservation area AND Nepal"
- "Ecosystem services AND Community forest AND Nepal"
- "Ecosystem services AND Forest AND Livelihood OR Adaptation AND Nepal"
- "Carbon sequestration AND Forest AND Nepal"
- "Biodiversity AND Forest AND Nepal"
- "Watershed AND Forest AND Nepal"; and
- "Use value AND Forest AND Nepal".

A total of four repositories — two global viz. ISI Web of Science and Scopus and two local viz. Nepjol (https://www.nepjol.info/) and Himaldocs (http://www.icimod.org/himaldoc) — were considered for literature search published from January 2000 to November 2017. ISI Web of Science and Scopus contain the majority of published research articles in the global scale while Himaldocs is for regional scale for Hindukush Himalayas and Nepjol is a highly popular national search engine in Nepal. Initially, we retrieved a total of 500 papers from the ISI Web of Science, 571 papers from Scopus, 184 papers from Nepjol, and 116 papers from Himaldocs. The removal of duplicated material resulted in a combined total of 658 papers. We used the following three specific inclusion criteria.

- Paper titles include the term "Nepal" and at least one searched word;
- Peer reviewed and technical papers; and
- Papers with a concrete method — either statistical analysis or modeling.

With these criteria, a total of 140 research papers have been included for review and final analysis (Appendix 1).

Initially, the papers were grouped into six different research themes based on similarity in terms of research area/focus for simplicity:

- Ecosystem services;
- Forest structure, management, composition and biodiversity;
- Forest and watershed hydrology, soil erosion and land degradation;
- Community-based forest policy, management and resource distribution;
- Land use/land cover change; and
- Climatic variability and changes and human perception.

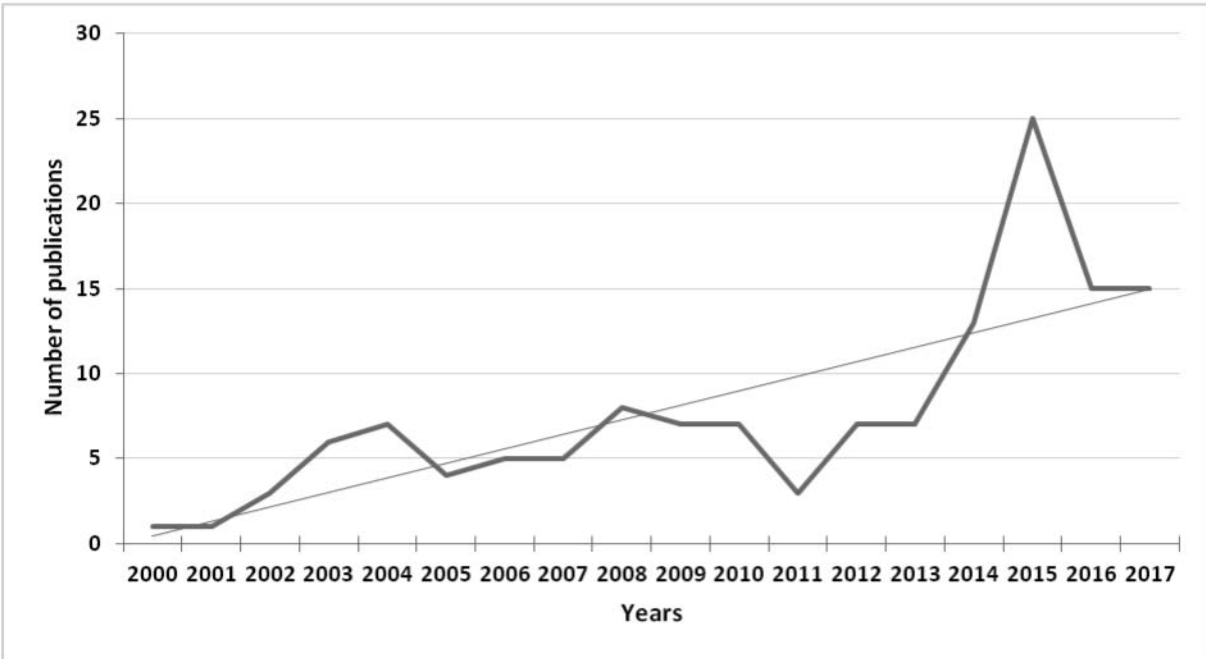
The study categorized these 140 studies according to the Millennium Ecosystem Assessment (MEA 2005) ES classification system because of its global acceptance. For the forest-based ES, however, we adopted the Forest Stewardship Council (FSC) classification system (FSC 2017) because it was locally applied in developing the FSC National Forest Stewardship Standard for Nepal. Following these two classification systems, we observed 46 publications focusing on forest ES (Supplementary 1), which were selected for further detailed review and analysis.

RESULTS

Distribution pattern of total publications

Following the inclusion/exclusion criteria resulted in a total of 140 research papers (135 peer reviewed articles and 5 technical reports) for final review and analysis (Appendix 1). Approximately 33% of the total studies were carried out in the community forest management system, 29% in protected areas, and 18% in watersheds, followed by 8% in the national forest and 2% in the farm forest. Similarly, mid-hill represents

FIGURE 1 *Temporal distribution of the total identified studies*



58% studies followed by Terai (30%) in the South, and Mountain (12%) in the north of the country. Overall, the publication trend on the subject area has been increasing in the last 17 years. The year 2000 had minimum publications and increased up to 2004, after which the number remained static up to 2012. The period between 2012 and 2017 observed an increased number of publications (Figure 1).

By research focus, nearly 33% of the studies fall under the broad category of Ecosystem Services. The focus of the papers includes resource extraction (Pandit and Thapa 2003, Adhikari *et al*. 2004, Straede and Treue 2006, Shrestha and McManus 2008, Gurung *et al.* 2010, Webb and Dhakal 2011) and carbon management (Aryal *et al.* 2013, Pandey *et al.* (2016), the role of private farm forests in carbon management (Timalsina *et al.* 2017), perception-based calculated ES trends (van Oort *et al*. 2015, Paudyal *et al.* 2015, I. Thapa *et al.* 2016), forest and soil carbon stock mapping (Yang *et al*. 2004, Shrestha *et al.* 2008, Dangal *et al.* 2017); ES based on land-use type (Bhandari *et al*. 2016, ICIMOD and BCN 2017) and changes in land cover (S. Chaudhary *et al.* 2016) as well as economic valuation of ES (Pant *et al.* 2012, Baral *et al.* 2016).

Almost 19% of the studies fall under the categories of forest structure, management, composition and biodiversity. The articles include existing forest structure and conditions (Timilsina and Heinen 2008), human disturbance of the diversity of flora and fauna (Dahal *et al.* 2015), and forest and agro-forestry management systems and their impact on growth and diversity (Acharya 2006, Regmi and Garforth 2010, Awasthi *et al.* 2015).

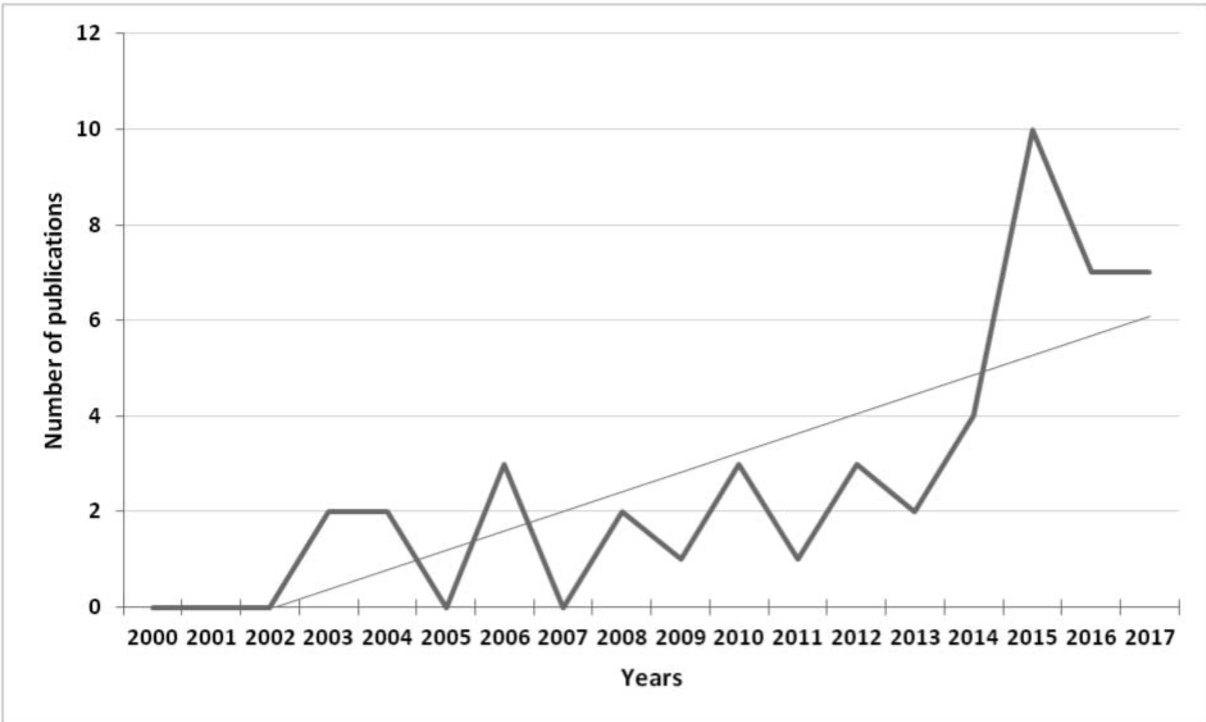
Likewise, 18% of the studies dealt with forest and watershed hydrology, soil erosion and land degradation. The articles in this category include the outmigration of people in hilly regions and the consequent process of land degradation (Jaquet *et al*. 2016), bio-economic modeling to forecast the future condition of watersheds (Sitaula *et al.* 2005), soil quality index and erosion rate in forest and agricultural land (Kunwar *et al*. 2003, Awasthi *et al.* 2005, K.C. 2012); rainfall interception loss, transpiration and canopy conductance, and forest hydrological function (Ghimire *et al.* 2014) as well as loss of soil nutrients in the context of land use/land cover change in watersheds (Shrestha *et al.* 2010).

Approximately 17% of the studies examined community-based forest policies, management and forest resource distribution. The major focus includes conservation perception (Bajracharya *et al*. 2006, Carter and Allendorf 2016, Gilani *et al.* 2017), equity distribution of forest resources (Adhikari 2004, Dhakal and Masuda 2009, Luintel *et al.* 2017), benefit cost analysis (K.C. *et al.* 2015, Parajuli *et al.* 2015), participation in forest activities (Oli and Treue 2015), and local level governance of community forest and policy implementation (Sharma *et al.* 2017).

Similarly, 13% of the studies dealt with land use/land cover change of forests and watersheds using mapping tools such as geographic information systems (GIS) and remote sensing (RS). The articles in this group include RS model calibration using carbon stock data (Karna *et al.* 2015), land cover change in protected areas (Bajracharya *et al.* 2010) and watersheds (Gautam *et al.* 2004), and forest cover and volume measurement using RS technology (Muinonen *et al.* 2012).

The lowest number of studies (0.06%) dealt with climatic variability and changes and human perception. The focus of the papers includes climate change impact on vegetation and biome using modeling (G.J. Thapa *et al.* 2016, Zomer *et al.* 2014) and human wildlife conflict due to ongoing changing climate in the trans-Himalayan region (Aryal *et al.* 2014).

FIGURE 2 *Temporal distribution of forest ES studies in Nepal*



Studies on Forest Ecosystem Services

Temporal distribution of studies on forest ES

Following MEA (2005) and FSC (2017) (Table 1), 46 (33%) papers out of the total of 140 were explicitly focused on forest ES. The trend of publication in the forest ES (Figure 2) followed the same tendency as overall publications with about one-thirds in the number (Figure 1). The first paper on forest ES was published in 2002; afterward, the publication rate increased slightly inconsistently up to 2014 but significantly increased around 2015. There were no publications in 2005 and 2007. The last five years have been a productive period for forest ES-based studies in Nepal, which are probably the result of the implementation of government and donor-initiated REDD+ piloting since 2009 (for details on REDD+, see MoFSC 2011).

Spatial distribution of studies on forest ES

Studies on the forest ES are location specific. Only 24 of the total 75 districts (32%) of Nepal were covered by studies on forest ES. Dhading is in the highest number of publications (n=6) followed by Gorkha and Lalitpur (n=4 each); Kathmandu, Dolakha and Kavrepalanchowk (n=3 each); and Ilam, Nuwakot, Chitwan, Kaski, Tanahu (n = 2 each). Likewise, only one study on forest ES was observed in each of the twelve districts (Figure 3). The majority of studies were carried out in the central and western regions of Nepal. Mid-western and far-western regions have the lowest number of studies. The spatial distribution of the papers shows that individual researchers mostly confine their research around the capital city of Kathmandu, where road access is easy. Furthermore, in Nepal, majority of externally funded projects are donor driven and in most cases, they have their dominant voice in picking up the project areas as per their convenience.

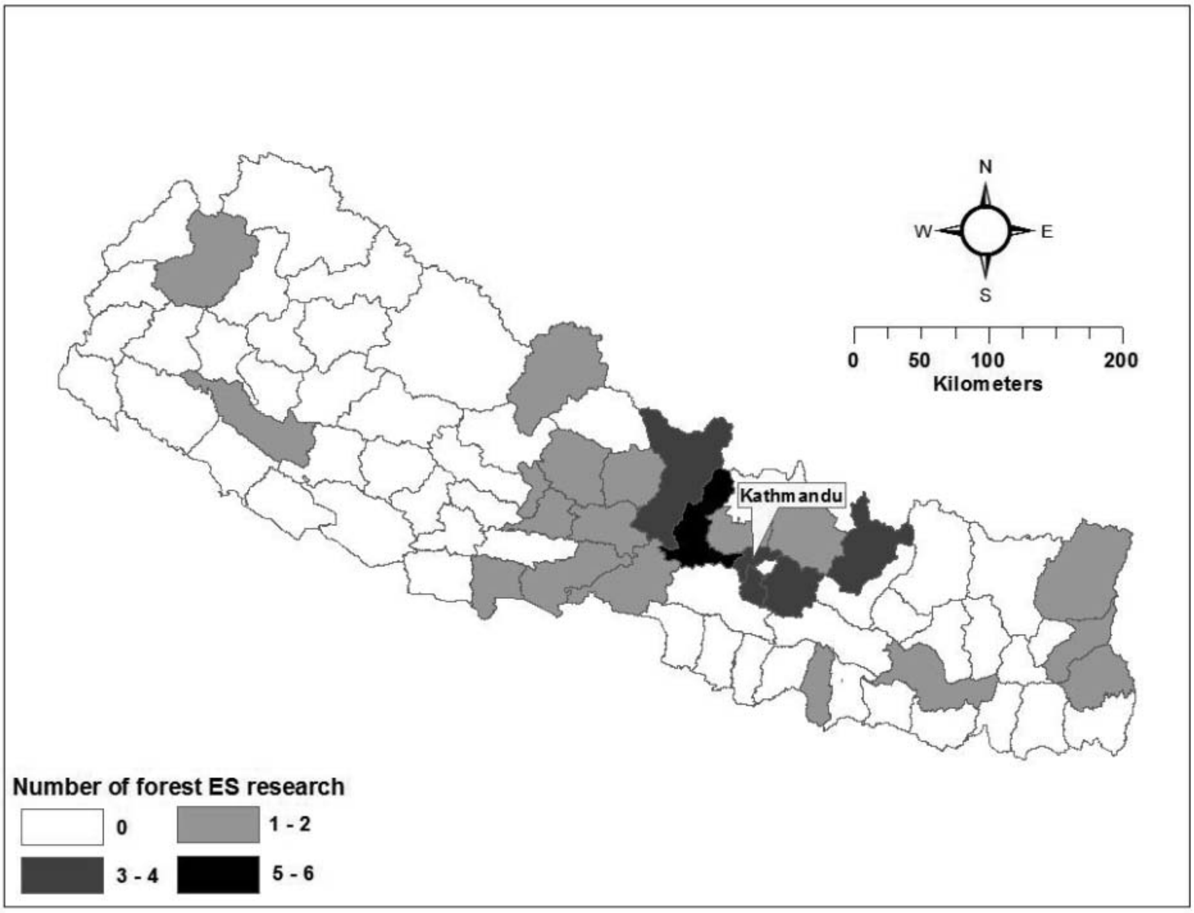
Documentation of types of forest ES

Sixty-two percent of articles out of 46 focused on regulating services of forests, followed by provisioning (47%), supporting (19%), and cultural (19%) services. Similarly, 59% of the articles focused on only one type of forest ES, 9% discussed three types of forest ES, and 17% of the articles analyzed more than ten types of forest ES. The term "ecosystem services," which first appeared in Timilsina *et al.* (2007), was mentioned by only 40% of 140 articles, which indicates that research scholars had been documenting forest ES without mentioning the term "ecosystem services" but used other similar terms such as use value and non-use value.

We identified 17 types of forest ES discussed in these publications following FSC (2017) in Nepal and eight other types of forest ES based on our own assessment. We categorized all 25 types of forest ES into four major groups: cultural, provisioning, regulating, and supporting services (Table 1) following the MEA (2005).

We looked into the frequency of studies for each type of forest ES (Figure 4). For cultural services, the recreation/tourism potential is the most commonly mentioned forest ES, followed by spiritual activities. Fodder and fuelwood were the most stated forest-based provisioning services, followed by timber, other NTFP and freshwater. Likewise, carbon sequestration dominated the regulating services, followed by erosion control, climate stability, air quality regulation and flood control. Similarly, refugium or habitat of the biota dominated

FIGURE 3 *Spatial distribution of forest ES studies across Nepal*



the research on supporting services, followed by biodiversity, pollination and soil formation.

We observed the maximum number of studies on forest carbon stock (Table 2). The average value of forest carbon stock is approximately 160.42 ton/ha. It varies with the geographical region, forest types, and measurement methodology. However, we observed maximum sequestration for mixed forests (229 ton/ha) in terai, and the least in the high mountain (40 ton/ha).

DISCUSSION

The Himalayan landscape provides ES to nearly 1 billion people (Singh and Thadani 2015). Likewise, forest ES has significant social and economic value to the people in this region, including Nepal. For the last three decades, the Nepalese people have been managing forest resources in the form of community-based forest, which has been providing many ES, which has significance as local (timber, firewood, food and water) and global (climate regulation, flood and erosion control and habitat improvement) benefits (Paudyal *et al.* 2017b). The country has traditional farming systems where the forest provides diverse goods and services to subsistence farming communities (Maren *et al.* 2013). Because climate change is real, happening, and already appears in the form of ecosystem degradation (Seidl *et al.* 2016), acquiring knowledge of its possible impact on forest ES in Nepal is crucial in the context of projected warming across the Himalayas.

This systematic search provided 140 peer-reviewed scientific papers, and only 33% accounted for forest ES in their studies. Such studies are mostly clustered around central and western regions of the country. There are uncertainties on how and where climate change could impact forest ES in Nepal because our existing knowledge base is limited compared to other developed countries. None of the studies mentioned how forest ES are currently being or will be affected in the future with a changing climate. Furthermore, the majority of the studies are qualitative rather than quantitative and are hardly focused on climatic impact. However, the publication trends have been encouraging in recent times. Forest ecosystems in Nepal are vulnerable to future climate change because locals have witnessed significant climatic threats in recent times, such as prolonged droughts and erratic rains; however, the extent of impacts is largely unknown due to a lack of extensive empirical research in climate science (Lamsal *et al.* 2017). Here, we have noted eight major implications of the current synthesis study for the likely effects of climate change on the forest ES in Nepal.

First, field-based perception studies on forest ecosystems in Nepal (CBS 2017, Thapa *et al.* 2015, Timilsina-Parajuli *et al.* 2014) clearly depict several impacts of climate change

TABLE 1 *The identified forest ES in Nepal*

Category (MEA 2005)	Forest based ecosystem services (FSC 2017)	Studies in Nepal (√=Yes, x=No)	Studies in Nepal but not mentioned in the FSC (2017) classification system
(1) Cultural services	(a) Aesthetic and landscape beauty	X	
	(b) Cultural values and symbolism	✓	
	(c) Educational opportunities	X	
	(d) Recreational activities	✓	
	(e) Spiritual enrichment	✓	
	(f) Tourism	✓	
(2) Provisioning services	(a) Fish (e.g., from coastal forests and mangroves)	X	(e) Tree and grass fodder; (f) Leaf litter; (g) Livestock grazing; (h) Game
	(b) Medicines/NTFP	✓	
	(c) Production of food, fuelwood and timber	✓	
	(d) Water supply	✓	
(3) Regulating services	(a) Carbon sequestration	✓	(m) Ground water recharge; (n) Nutrient regulation; (o) Natural hazard mitigation
	(b) Climate regulation and stabilization (e.g., moderation of temperature extremes)	✓	
	(c) Control of pests that affect plants and animals	✓	
	(d) Decomposition of wastes	X	
	(e) Disease control	X	
	(f) Erosion control	✓	
	(g) Improvements in air quality	✓	
	(h) Maintenance of regional precipitation patterns	X	
	(i) Mitigation of floods and droughts	✓	
	(j) Moderation of the force of winds and waves	X	
	(k) Protection from the sun's harmful UV rays	X	
	(l) Water purification	✓	
(4) Supporting services	(a) Biodiversity conservation	✓	(f) Refugium (biota habitat)
	(b) Dispersal of seeds	X	
	(c) Maintenance and renewal of soils and soil fertility	✓	
	(d) Pollination of crops and natural vegetation	✓	
	(e) Translocation of nutrients	X	

in the forests. When forests degrade, the flow of forest ES is depleted, and it will first affect low-income and disadvantaged people. Several studies (Adhikari 2005, Gurung *et al.* 2011, Iversen *et al.* 2006, Timsina 2003) show that elites (high-income people) capture most of the forest products and resources, leaving less to low-income inhabitants. Low-income locals have a low adaptive capacity (Gentle and Maraseni 2012) and are deprived of capital assets (human, social natural, physical and financial) (Dulal *et al.* 2010), making climate change an additional burden. Similarly, the decreased flow of forest ES might make forests less attractive to locals in the future, which could have consequences for the existing forest governance policy and the livelihood of the dependent community.

Second, outmigration due to climatic extremes such as less rainfall and consequent drought has been a common phenomenon around the globe, including Nepal. A recent study (Missirian and Schlenker 2017) noted that climate refugees in developing countries would not only migrate internally to escape future warming consequences but also be forced to cross the international border of developed nations. Low rainfall and drought has caused the mobility of the population from the Ethiopian highland regions because of the reduced adaptive capacity (Gray and Mueller 2012). The trend of out-migration in Nepal is widespread for diverse socio-economic reasons, including recent climatic extremes (Gautam 2017, K.C. *et al.* 2017). For example, the long drought, crop failure and water supply depletion caused two

FIGURE 4 *Frequency of studies on the types of forest ES (A: cultural services, B: provisioning services, C: regulating services, D: supporting services)*

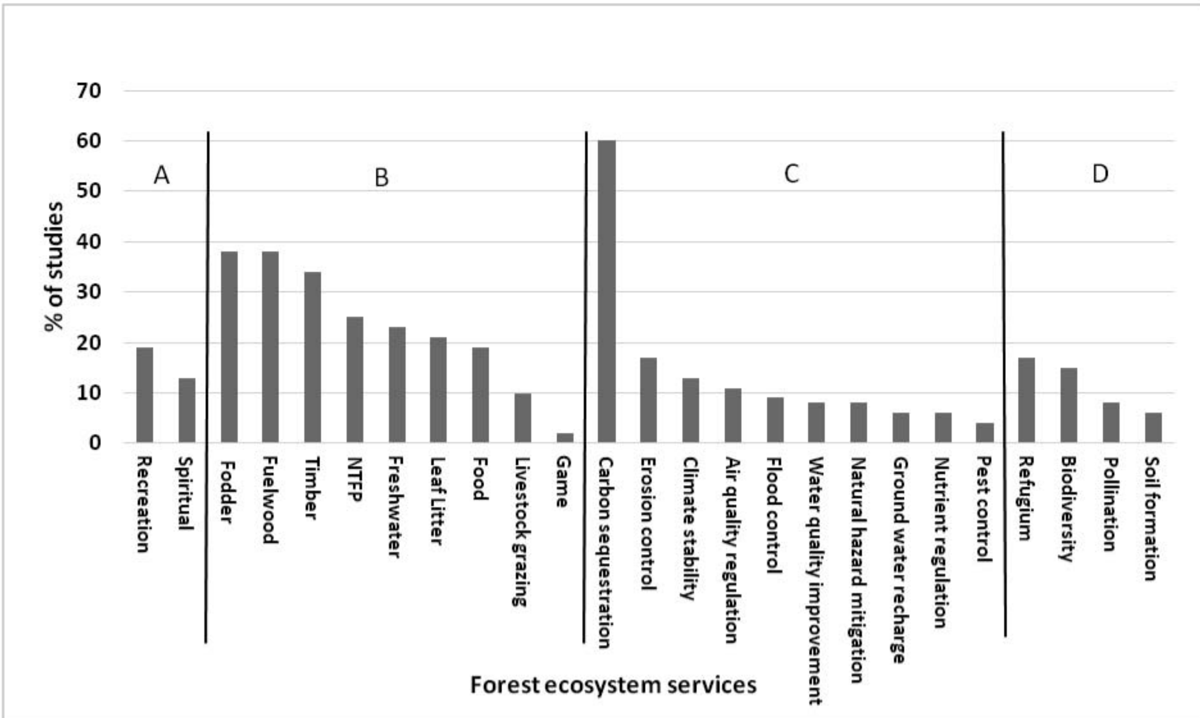


TABLE 2 *Average carbon stock of forests in Nepal*

Region	Forest types	Measurement	Carbon stock (ton/ha)	References
Terai	Mixed forest	AGB, BGB, SOC	228.76	Gurung *et al.* (2015)
Terai	Mixed forest	AGB	140.02	Mandal *et al.* (2015)
Mid hill	Pine forest	AGB, BGB, SOC	217.00	Aryal *et al.* (2013), Dangal *et al.* (2017)
Mid hill	Mixed forest	AGB, BGB, SOC	206.48	Aryal *et al.* (2013), Birch *et al.* (2014), Karki *et al.* (2016), Peh *et al.* (2016), Pradhan *et al.* (2012), Shrestha and Singh (2008), Thapa-Magar and Shrestha (2015)
Mid hill	Mixed forest	AGB, BGB	223.51	Maraseni *et al.* (2014)
Mid hill	Mixed forest	AGB	173.61	Gilani *et al.* (2015), Mbaabu *et al.* (2014), Shrestha *et al.* (2013)
Mid hill	Mixed forest	SOC	53.61	H.L. Shrestha *et al.* (2017)
Mountain	Mixed forest	SOC	40.41	H.L. Shrestha *et al.* (2017)
Total average			160.43	

Note: AGB = aboveground biomass; BGB = belowground biomass, SOC = soil organic carbon

villages viz. Samjong and Dhey of the upper Mustang, to migrate to Namashung village in 2016 (https://reliefweb.int/). The changes in temperature and precipitation greatly affect the drought stress levels of an area (Albert *et al.* 2015) and, ultimately, the forest structure and its function (Pfeifer *et al.* 2018). Dahal *et al.* (2016) also confirmed the presence of increased drought in central Nepal over the last decade, which could result not only in agricultural land desertification due to land abandonment but also create a shortage of human resources in the long term to manage existing forest management programs. Such a situation could directly hamper the sustainable management of the community forest and the continuous flow of forest ES.

Third, forest fires and insect/disease outbreaks of forest trees are potential hazards as a result of the changing climate. For instance, Bentz *et al.* (2010) projected an increase in the outbreak of mountain pine beetles both in US and Canada in the future, along with its niches (Dhar *et al.* 2016). Forest pest and disease outbreaks could become more frequent and intense in the future (Sturrock *et al.* 2011). Similarly, van Bellen *et al.* (2010) and Tian *et al.* (2011) projected possible increased forest fire incidence in the future in Canada and China, respectively, which could weaken the existing carbon sequestration potential along with other key forest ES. Forest fires are one of the major drivers of forest resource degradation in Nepal (R.P. Chaudhary *et al.* 2016), and future climate change could further intensify the situation. The provisioning services of forests that shape peoples' livelihoods, such as timber, fuelwood, fodder and NTFP, could be seriously depleted by forest fires and insect/disease outbreaks.

Fourth, the sustainability of watersheds largely depends on the forest condition because it protects against soil erosion, reduces floods and supplies nutrients to downstream agricultural land and maintains water balance in the watersheds. Climate-induced changes in the vegetation structure and composition in a watershed could disrupt the water balance through the increased evapotranspiration rate (Sun *et al.* 2008), which could affect downstream water flow and transport of nutrients to agricultural land. Ekness and Randhir (2015) reported that climate change might alter the eco-hydrologic attributes of a watershed by changing available soil moisture, evaporation, precipitation patterns and runoff, which impact soil degradation and erosion. Native vegetation cover can counteract many detrimental impacts, such as erosion and floods (Zuazo and Pleguezuelo 2008); however, this is uncertain in the event of reorganized plant communities as a result of a future warming climate. Nepal has numerous hilly and mountain watersheds that have been sustained by a mosaic of vegetative covers. The future shift and re-assemblage of existing vegetation could increase many watershed ecosystem disservices, affecting the water supply, agricultural production and, ultimately, livelihoods.

Fifth, the release of soil organic carbon (SOC) due to the degradation of forest and agricultural land is equally likely in the future. Soil carbon can easily be released into the atmosphere as a result of small increase in temperature because the carbon cycling process is sensitive to temperature (Classen *et al.* 2015). Warming may decrease the SOC by increasing the rate of mineralization of organic matters in soil. Vegetation cover maintains optimal soil temperature (Song *et al.* 2013, Aalto *et al.* 2013), which sustains soil ecosystem functions for diverse belowground biotic and abiotic interaction. Carbon conservation programs such as REDD+ is active globally, with more than 550 active programs and estimated annual transactions at US$ 36–42 billion (Salzman *et al.* 2018). The piloting of REDD+ is ongoing in Nepal with diverse outcomes. Some studies found REDD+ to be an appropriate scheme with the carbon trading option (Gurung *et al.* 2015, Pandit *et al*. 2017) given its ability to trap and conserve optimum carbon, while others criticize it in the context of forgone benefits from forests that used to provide for locals (Maraseni *et al.* 2014, Pandey *et al.* 2014). Our analysis on carbon stock data (Table 2) shows that Nepal's forests have good sink capacity; however, its effectiveness depends on the forest types and physiographic location. Moreover, the carbon stock data we derived are conservative estimates as it is an average of different forest types located in different geographical and climatic conditions obtained by individual studies. With uneven distribution of the individual studies and lack of a comprehensive study, the carbon stock data should not be taken as representative to the country.

Sixth, the shift of the forest vegetation biome, especially in temperate zones, has already been reported (Yadava *et al.* 2017) and predicted (Kerns *et al.* 2017) elsewhere, including Nepal Himalaya (Schickhoff *et al*. 2015, G.J. Thapa *et al.* 2016, Chaitra *et al*. 2018). The loss of resilience through human-induced actions is one of the keys to such a regime shift (Folke *et al.* 2004). Such shift could result in vacant landscapes becoming occupied by novel species with physiological and phenological traits tolerable to that area, leading to altered plant structure and composition that could change the overall biodiversity. However, it is uncertain whether such new assemblages will hold more carbon in its biomass and help to continue the flow of forest ES to the dependent communities by retaining socio-economically important tree species. For instance, with future warming, Thapa *et al.* (2016) projected the shift and fragmentation of lower and mid-montane forests of Nepal that could have detrimental impacts on forest ES, especially food and fiber provisioning for human well-being, and supportive functions, such as habitats for many endangered flora and fauna. Shift in invasive plant niche is expected in the region (Thapa *et al.* 2018). Zomer *et al.* (2014) anticipated the shift in bioclimatic conditions throughout the Kailash Sacred Landscape, which may affect all forest ES. Chaitra *et al.* (2018) projected increased net primary productivity of forests in the major Himalayan watersheds from warming climate, which could in turn affect the availability of water and other nutrients in soil. Likewise, Schickhoff *et al*. (2015) projected a northward niche shift of Himalayan tree line vegetation species with future climate change and anticipated biodiversity loss, reduced water supply and agricultural productivity.

Seventh, climate-induced land use/land cover change could intensify future forest ES. Significant changes in forest ES due to changes in land use/land cover have been reported (Arowolo *et al*. 2018, Balthazar *et al.* 2015, Hu *et al.* 2008, Tolessa *et al.* 2017). Schirpke *et al.* (2017) reported a likely decrease in forage production in the mountain ecosystems of the central Alps from combined land cover and climate change. Similar outcomes in the reduction of forest ES has been observed in the eastern Tibetan Plateau (Tang *et al.* 2018). Nepal has witnessed a dynamic forest cover change over the past 50 years. For instance, the national forest cover was 38% of the total area in the 1970s but rapidly reduced to 29% in the 1990s (Paudel *et al.* 2016) and recovered to 44.47% (DFRS 2015) at present. Agricultural expansion to secure food security and increased urbanization has exerted pressure on the forest areas in Nepal. Climatic extremes, such as floods and landslides, are regular catastrophic events both in PA and non-PA networks across the country. Such events have reduced the spatial extent of forest cover that could hamper supporting services, mainly wildlife habitats and the continuation of resource flows to buffer zone communities. In Nepal, S. Chaudhary *et al.* (2016) reported a depletion of forest ES by almost 94% over the last three decades as a result of land cover change in the Koshi Tappu region, with climatic impacts still unidentified. However, the land use/land cover impact is comparatively higher for ES than that of climate change (Polce *et al.* 2016).

Eight, water resources for drinking and agricultural purpose is an important forest ES of Nepal. Several case studies across the regions (Bangash *et al.* 2013; Chang and Bonnette 2016) already reported stress on water provisioning services from climate change-driven events. The degradation of mid hill mixed sub-tropical and temperate forests could lose humus-laden top soil, thereby slowing down the infiltration process and accelerating water erosion along with the depletion of soil nutrients. The extent of land degradation in Nepal is high. Nearly 10% of cropland, 36% of forest and 37% of range land is in a degraded condition (MoEST 2008). It is estimated that approximately 46% of the total land area is prone to water erosion, 4% is prone to wind erosion, and 2% is prone to chemical and physical degradation (Acharya and Kafle 2009). This is likely to affect the water supply provision of most watersheds in Nepal. Furthermore, such reduced soil nutrients and water scarcity may affect traditional agroforestry practices in rural Nepal. A recent countrywide study reported a drying of water sources in the hills of Nepal (CBS 2017).

In recent times, the focus on non-market valuation and market-based policy design, such as payment for ecosystem services (PES), has helped bring ES into the mainstream and attract political support for ecosystem conservation (Gomez-Baggethun *et al.* 2010). PES refers to the creation of a market for ES and adding value to environmental services while the concept has also widely been used in the exchange of watershed services between upstream and downstream communities as buyers and sellers through monetary trade. Commonly initiated four land use proxy for watershed services are improved land practice, improved agricultural and ranching practices, agroforestry and sustainable forest management and ecosystem conservation (Porras *et al.* 2008).

The PES scheme has enhanced adaptation to climate change around the globe, for example, in Kenya (van de Sand *et al.* 2014), Uganda (Jayachandran *et al.* 2017), China (Liu *et al.* 2008), Mexico (Corbera *et al.* 2009) as well as improved environmental services and livelihood of the locals (Bremer *et al.* 2014, Corbera *et al.* 2009, Gross-Camp *et al.* 2012, Liu *et al.* 2008, Pagiola 2008, Zheng *et al.* 2013). Nepal has also adopted PES through the REDD+ program and has piloted it in some selected watersheds and community forests. Because the initial outcomes of REDD+ are mixed, its countrywide implementation requires further analysis to understand whether it helps forest-dependent households adapt to climate change through carbon conservation. It would improve livelihoods through careful use and conservation of environmental services only if the social benefits of forests are fully considered (Karky and Skutsch 2010, Maraseni *et al.* 2014, Pandey *et al.* 2014). However, we suggest developing a national PES policy and providing technical as well as institutional strengthening capacity-building support to local communities for its successful implementation of REDD+ in Nepal. However, caution should be made on the setbacks in implementing PES scheme as was evident in some other countries (Porras *et al*. 2008), such as slow and low fund commitment by the buyers and perceived it as public relation rather than environmental benefits, higher dependence of local scheme on government and donors for start-up cost, and difficulties in tracing delivery evidence of environmental services.

The community forestry management system in Nepal has recently shifted its focus from subsistence to innovation in the marketing of ecosystem services for local welfare (Paudel and Ojha 2013). However, locals managing these forests in Nepal have yet to fully understand the diverse ES values generated through the conservation effort (Paudyal *et al*. 2015). Most community forests in Nepal are a mixed natural forest, demonstrating rich species diversity, which can withstand the impacts of climate change and supply forest ES. People, however, only recognized provisioning services over the other three categories because of their tangible nature (Murali *et al.* 2017), which warrants the need for PES programs with more local participation, making them aware of the diverse forest ES. Almost 3.8 million households are currently engaged in community-based forest management in Nepal (Pathak *et al.* 2017). The participation of locals in PES in Mexico, for example, made locals aware of the diverse types of ES and motivated forest conservation (Arriagada *et al.* 2018).

Formulating and implementing appropriate policies and plans at the national level will play a key role in maintaining and safeguarding forest ecosystems and the continuous flow of diverse services for the people's wellbeing. Incorporation of the climate change adaptation framework in a local level planning process is essential to increasing the adaptive capacity of low-income households (Bhatta *et al*. 2015). The National Adaptation Program of Action (NAPA), as recent government-initiated climate change adaptation program for urgent and immediate needs, is already being implemented at the local level across the country. Local Adaptation Plan of Action (LAPA) is developed for some local level government units particularly in western parts of the country. The government is in the process of developing National Adaptation Plan (NAP) for mid-term and long term adaptation measures. Forest ES can be incorporated and emphasized through NAPA, LAPA and NAP so that it becomes recognized and valued by all the stakeholders, including locals, resource planners and policy makers. Resource planners and policy makers need to be well informed about the nation's forest ecosystem and its services to formulate relevant plans, policies, and action.

Access to reliable forecasts, both current and the future, of the ecosystem state and their potential services is imperative for resource planners and policy makers (Clark *et al.* 2001, Maes *et al.* 2012). This could be a challenge for Nepal because our study revealed a scant knowledge base on forest ES, and an uncertain outcome can be expected through its possible interaction with a current and future warming climate. However, a recently implemented 10-year Forestry Sector Strategy 2016–2026 (GoN 2016) has emphasized the importance of the flow of forest ES and the need to tackle climate change impacts for the future development of the country's forestry sector.

This study is systematic reviews of literature published between 2000 and 2017 in the ISI Web of Science, Scopus, Nepjol and Himaldocs about forest ES in Nepal. Therefore, a limitation of this study should be noted that any publication published beyond this time frame and sources are not included in the paper.

FINAL REMARKS

Our study revealed the association of a majority of locals to forests through a community-based forest management system due to their high dependence on forest resources given that the country is based on an agro-ecological farming system to sustain livelihoods and secure food security of majority of people. Therefore, any changes to the flow of goods and services from the forests that we highlight and discuss here would directly affect agricultural and basic household activities in Nepal. The forestry sector contributes almost 15% to the national gross domestic product (GDP) (MFSC 2009); however, the full account of forest ES to the national economy is still unknown, although the country has been benefitting from it for a long time. These factors necessitate more research on the likely impacts of climate change on forest ES and the effect it could have on people's livelihoods. It would be helpful for the government to prepare site specific suitable adaptation and mitigation plans along with formulation of necessary policy updates focusing on forest ES. Similarly, to fully recognize and accept forest ES, information on its contribution to the national economy is a must. This requires an in-depth economic valuation of cultural, provisioning, regulating and supporting forest ES and making it available to the general public and government officials.

We conclude that in the context of eight major effects of climate change on the forest ES of Nepal as anticipated above, the understanding of the adaptive capacity of people and the vulnerability of forest ecosystems to climate change is not well developed in Nepal. Engagement of locals in conservation is not sufficient; instead, finding the 'connection' between users and nature is important for long-term sustainability. We thus recommend building socio-ecologically resilient community through enhancing forest ES and developing sound PES mechanisms for better connecting people with the nature. The existing knowledge base on Nepal's potential forest ES as well as likely outcomes due to the interaction with current and projected changing climate is very weak. Whatever knowledge is available only pertains to a few districts, with many districts having no recent recorded research activity on this topic. This demands immediate research covering all geographical regions of the country to fill those gaps, which in turn will pave the way to managing and conserving our forest resources. Developing a strong knowledge base of national level forest ES is the key need at present, including focusing on biophysical aspects (temperature and precipitation change, hazard, glacial retreat, biological diversity) as well as social aspects (livelihood). We, therefore, recommend for a strong research network within existing universities and research organizations, and the government needs to enact a policy to link and fund all government prioritized research works through such universities and research organizations in the country.

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Supplementary 1 *In-depth analysis of 46 forest ES articles identified through a systematic review*

SN	Reference	Forest ES category and sub-category (See Table 1)	Study Area and Methods	Key Findings	Implication to Climate Change
1	Kunwar *et al.* (2003)	3f	Soil erosion analyzed in Likhu Khola watershed using 12 locations.	Soil erosion rate is lower in the Sal forest than in agricultural land use.	Future climatic extremes may increase soil erosion from agricultural land, and forest covers helps conserve the loss of soil. The inclusion of tree species in agricultural land (agroforestry) could be an option for future sustainable agriculture.
2	Pandit and Thapa (2003)	2b	324 HHs interviewed in Malekhu Khola watersheds in the Dadhing district.	Locals use 16 types of NTFP from the forest. NTFP depletion was slow in CF. Lack of proper institutional arrangement was a major cause of such depletion.	Overharvesting of NTFP, timber mismanagement of the forest and climate change (CC) will reduce forest ES in the future.
3	Adhikari *et al.* (2004)	2c, 2e, 2f	330 HH interviewed from 8 CFs in the Kavre and Sindhupalchowk districts.	Socio-economic status of HH determines resource extraction from community forest (CF). Low-income HHs have limited access to certain products and lack equity rights of forests resource distribution.	Low-income people are more vulnerable to CC due to limited coping mechanisms. Empowering them socially and economically is paramount.
4	Yang *et al.* (2004)	3a	Different land use system selected in Mardi watershed in Kaski district.	Forest surface soil contains higher SOC compared to grassland and agricultural land.	Deforestation and agricultural land degradation will emit existing SOC reservoir. Recycling organic matter, avoiding fires in the forests and agriculture land, and erosion control will increase SOC.
5	Acharya (2006)	2c, 2e, 4a, 4f	35 HH interviewed from two villages in the Parbat district.	Traditional agroforestry practices were extremely significant for subsistence farming by reducing pressure to CF. There is a lack of incentives to adopt these practices.	Fire and disease outbreak resulting from the CC impact on agroforestry. A timely mitigation and adaptation program is sought at the local level. Traditional practices can be revived governing socio-ecological resilience to the changing climate.
6	Bajracharya *et al.* (2006)	1f, 2c, 2b, 2d, 2e, 2f, 4a, 4f	Social survey in 10 villages in the Annapurna Conservation Area in the Mustang district.	Community-based conservation activities are beneficial, and the benefits of such conservation outweigh the cost. The conservation activities resulted in numerous forest ES.	Male outmigration due to frequent drought may create a shortage of manpower. Resource conservation and climate adaptation interventions should be focused on the remaining women and children.
7	Straede and Treue (2006)	2b, 2c, 2e, 2h	18 HHs interviewed from the Chitwan National Park over a 12-month period.	People from the buffer zone rely on the park forest for forest ES not available in the buffer zone forest.	Increasing the population in or near the buffer zone can increase pressure on the forest ES from national parks. Creating alternative employment and finding substitutes for some forest ES can reduce this pressure.

SN	Reference	Forest ES category and sub-category (See Table 1)	Study Area and Methods	Key Findings	Implication to Climate Change
8	Shrestha *et al.* (2008)	3a	521 HHs interviewed from three CFs in the Pokhare Khola watershed in the Dhading district.	Soil carbon in the forest varied with forest types; SOC are found to be higher in agricultural land than forest land. Forest lands are degraded.	Degraded and overused forests cannot retain soil carbon. Supporting natural regeneration helps conserve soil and water more than tree plantation of exotic species.
9	Shrestha and McManus (2008)	2c, 2e	A total of 521 HHs interviewed from three CFs in the Kathmandu, Tanahu and Kaski districts.	The management approach is protectionism, resulting in less flow of forest ES to the users. Individual participation in the decision making is minimal.	The current protection-oriented forest management approach will be ineffective in the coming decades. Use of local knowledge and community level participation in the decision making is important for forest conservation. Local knowledge can be utilized for CC adaption and forest conservation.
10	Dhakal and Masuda (2009)	2c	KIIs and FGDs done in six CFUGs in the Rupandehi, Nawalparasi and Chitwan districts.	Low-income people benefit less from the pricing system. The elite group captures most of the benefits of CF.	The poor are not only economically and socially vulnerable to forest ES but also to CC due to low adaptive capacity. Empowering them can help forest resources conservation.
11	Gurung *et al.* (2010)	2e	400 HHs interviewed from the four buffer zones of the Chitwan National Park.	30% of the HHs still depend on CF and the park to graze their livestock. The trend of stall feeding is increasing.	Practice of agroforestry system, which is resilient to CC, could meet the demand of fodder. Livelihood diversification, aside from rearing livestock in the area, could be an adaptation policy.
12	Karky and Skutsch (2010)	3a	Three CFUG each from the Ilam, Lalitpur and Manang districts were analyzed using the cost benefit technique	CF may be the cheapest way to abate carbon through trading; however, there is an opportunity cost because it offers various non-monetary services, which is an incentive for conservation.	There is a feasible REDD policy scenario where carbon abatement and CFUG user rights are guaranteed. It shows a linkage of carbon abatement with CC mitigation. Costs per ton of carbon sequestration can help estimate economic viability of REDD policy in Nepal.
13	Regmi and Garforth (2010)	2c, 2e	32 HHs interviewed along with a few KIIs.	Many constraints on the development of farm forestry exist. Policy is needed to enhance farm forestry.	Market-based policy measures can be developed to remove and weaken the constraints of agro-forestry development to enhance production of food, fuel wood and timber, which help abate the impact of CC in forestry.
14	Webb and Dhakal (2011)	2c	276 HHs in 39 villages of the Galauda Pokhare Khola watershed of the Dhading district.	Use of public forest for fuel wood collection is higher than for private forests, providing 17% of demand, possibly causing degradation of the natural forest.	Fuelwood is the sole source of energy for the majority of HH in Nepal. Large land owners should use their own fuelwood resources and allow small land owners access to the public forest. Factors affecting firewood collection behavior from public forests and private farms should be identified and managed to continue firewood supply under changed climatic conditions.

SN	Reference	Forest ES category and sub-category (See Table 1)	Study Area and Methods	Key Findings	Implication to Climate Change
15	K.C. (2012)	3f	Land cover and soil loss assessment done in the Galauda Pokhare watershed in the Dhading district.	Erosion from forest land use is lower compared to agricultural land use. Water erosion alone is the most important variable for soil loss in the mid hill of Nepal.	Extreme climatic events such as high rainfall and subsequent flooding due to CC in the hilly terrain of Nepal could increase soil erosion from both forest and agricultural land use in the future. Promotion of agro-forestry with multipurpose trees can reduce soil erosion from farmlands under extreme weather events.
16	Pant *et al.* (2012)	2b, 2c, 2e, 2d, 2f, 2g, 3a, 4c	450 HHs from nine VDC in the Ilam, Pachthar and Taplejung districts were interviewed, and market-based economic valuation was applied.	Forest ES was found to be important for the livelihood of locals as it makes a significant economic contribution to HH economy.	Understanding the contribution of the forest in the livelihood of villagers residing near the forest can encourage them to conserve the forest as the natural capital of their livelihoods. Forest conservation by locals is cheaper than that of the government, which helps to maintain forest ecosystems and increase the flow of forest ES even under the threat of CC.
17	Pradhan *et al.* (2012)	3a	Aboveground, belowground and soil carbon analyzed in the Pokhare khola sub-watershed in the Dhading district.	Highest SOC found in the schima-castonopsis forest followed by the Sal forest, while total C sequestration was the highest in the Sal forest.	Possible changes in forest composition and structure with CC could alter the existing carbon sink capacity of forests. The uncertainty in the extent of degradation and deforestation along with climatic impact determine the exact sink capacity of future forests.
18	Aryal *et al.* (2013)	3a	Aboveground, belowground and soil carbon analyzed in a CF in the Lalitpur district.	Total C stock higher in pine dominated forests but litter and soil C higher in mixed forests.	Promotion of mixed forest can help increase SOC, which is good for forest productivity, flow of humus to farmlands downstream and slowing the runoff of rain water, which increases the infiltration rate, leading to a supply of water during the dry season downstream.
19	Shrestha *et al.* (2013)	3a	Aboveground carbon analyzed in six CF in the Dolakha district.	CF of Nepal can reduce emission by avoiding deforestation and forest degradation and enhancing carbon sink.	Forest degradation such as change in structure and composition and shift of temperate plant species to higher areas have been already established, which could have an impact on the many temperate tree species of Mid Hill in Nepal that are currently a carbon reservoir.
20	Birch *et al.* (2014)	1d, 1f, 2c, 2d, 2e, 3a, 3b,	TESSA (Toolkit for Ecosystem Services Site-based Assessment) used along with KII in CF and non CF of Phulchoki IBA	CF have higher potential of ES than forests not under the CF management system.	CF provides more forest ES than government-controlled forests. The flow of forest ES can be increased by conserving forests through the CF model, which can reduce the impact of CC change on forests.

SN	Reference	Forest ES category and sub-category (See Table 1)	Study Area and Methods	Key Findings	Implication to Climate Change
21	Maraseni *et al.* (2014)	3a	Carbon measurement and cost benefit analysis carried out in four CFUG each in the Gorkha and Chitwan districts.	REDD+ is not very attractive if the foregone benefits of forest resource use are considered.	Though REDD+ has a greater focus on CC adaptation, the social aspect of forests, such as the flow of resources to needy people, should be considered to make the endeavor successful.
22	Mbaabu *et al.* (2014)	3a	Aboveground carbon analyzed in a government and CF in the Chitwan district using remote sensing.	CF have more of a carbon sink than government-managed forests. The combined use of satellite and LIDAR data was found to be useful for a quick and more accurate assessment of carbon in forests.	Change in the forest management regime can help to increase the carbon stock in the forest, which in turn increases the carbon sink service from the forests.
23	Pandey *et al.* (2014)	3a	105 CFs were studied across three watersheds: Ludikhola in Gorkha, Khayarkhola in Chitwan and Charnawati in Dolakha under the REDD+ program.	Carbon stock density differs with forest types in CF and more under REDD+ activities, and pilot programs should also look at people's livelihood needs.	Different forest ES may have some trade-offs. Increasing one forest ES-like carbon sequestration that benefits global communities can decrease other forest ES, such as timber and fodder from the forest, affecting local communities negatively. This situation is not sustainable. To make the forest system sustainable, the needs of the local communities for forest ES should be met first so that they can effectively be engaged in conservation to increase the flow of forest ES under CC.
24	Gilani *et al.* (2015)	3a	Aboveground carbon analyzed from 112 CF, 89 leasehold forests and 4 private forests across three watersheds — Ludikhola in Gorkha, Khayarkhola in Chitwan and Charnawati in Dolakha — using remote sensing techniques.	CF under REDD+ are improving in terms of carbon stock. Use of a remote sensing tool is cost and time effective to monitor changes in biomass and calculate carbon stock for REDD+ monitoring.	Under CC and increasing uncertainty regular monitoring of forest status and carbon stock is important to design policy and timely interventions. Using RS in an annual interval can help identify the carbon stock and flow of sequestration services. Due to weak government structures, forest management practices can be more effectively implemented in CF than in government forests.
25	Gurung *et al.* (2015)	3a	Carbon stock measurement from 113 plots in the WWF TAL region.	Strong association of carbon stock with management regime, with high in PAs with strict restriction compared to CF and government forest.	Though PAs have the best stock of carbon, the flow of forest ES is low because people are not allowed to use many forest ES from PAs. Carbon sequestration is one major forest ES, but other locally used forest ES useful for livelihood supports cannot be ignored. Under CC, locals are likely to face livelihood challenges, and forest ES can support people in this case.

SN	Reference	Forest ES category and sub-category (See Table 1)	Study Area and Methods	Key Findings	Implication to Climate Change
26	K.C. *et al.* (2015)	2c, 2e, 2f	80 HHs of a CF in the Nuwakot district were interviewed, and a cost benefit analysis was applied.	Looked at a forest product extracted by a CF in a year. Benefit of conservation and management for the forest exceeds costs.	Decrease in flow of forest ES due to impacts of CC on forests can affect the livelihood of people residing near the forest. CC may increase the cost of resource conservation and decrease its benefits, affecting feasibility of forest management to sustain the flow of forest ES.
27	Mandal *et al.* (2015)	3a	Aboveground carbon calculated from three collaborative forests in the Mahottari district.	Different species show different carbon stock: *Shorea robusta* and *Terminalia tomentosa* have higher carbon stock compared to other species found in the forest.	A warming climate could enhance the carbon sinking capacity of native big tree species in lowland Nepal; however, it could have numerous detrimental impacts on the associated flora and fauna of forest ecosystems through changes in structure and composition as well as fire and disease outbreaks.
28	Oli and Treue (2015)	2c, 2e	304 HHs interviewed from ten CF in Tanahu district.	Female headed and low caste HHs participate less in CF activities. Gender, caste, HH size, livestock holding, network and amount of fuelwood extraction are significant variables in participation.	Socially and economically disadvantaged people in Nepal are more vulnerable to projected CC due to their inherent low adaptive capacity that could influence their participation in our CF program and affect the long-term success of the program itself. Such people have less access to forest ES compared to others.
29	van Oort *et al.* (2015)	2b, 2c, 2e, 2d, 2f, 2g	KIIs carried out using multi-level methods in the Jhiggu khola watershed of the Koshi River Basin	People perceived that majority of ES are in declining trend in watershed for different reasons.	Locals already perceived decreasing trend of ES in the study area of which CC also have contribution. The extreme events resulting from CC will certainly impact the status of many ES in hilly watershed as we have so far applied less adaptive measures.
30	Pandey *et al.* (2016)	3a	Aboveground and belowground carbon analyzed from 105 CFs of three watersheds: Ludikhola in Gorkha, Khayarkhola in Chitwan and Charnawati in Dolakha.	Both species' richness and carbon stocks need to be considered while designing REDD+ projects and payment mechanisms. CF user groups (CFUGs) have increased forest carbon stocks, and ongoing pilot REDD+ programs also deliver livelihood benefits, which ultimately will help adaptation to CC.	The REDD payment program can assist carbon sequestration to assist in mitigation, but it can decrease biodiversity. Biodiversity is important for CC adaptation in forest. Forestry management has trade-offs in terms of whether to maximize carbon sequestration using fast-growing trees or increase the flow of forest ES through multipurpose plan assemblage in the locality.
31	Parajuli *et al.* (2015)	2b, 2c, 2e, 2d, 2f, 4c,	Cost benefits analysis done in four CFUG from the Kaski and Syanja districts.	Net benefit from CF is high in rich HHs compared to poor HH, although poor HHs pay higher indirect costs. This requires immediate policy revision.	Forest ES originating from forests are not equally distributed among the local community. More advantaged residents receive higher benefits than less advantaged residents. The impact of CC affecting the flow of forest ES may affect the poor more because they have less say in access to a share of forest ES and other resources to utilize the available forest ES.

SN	Reference	Forest ES category and sub-category (See Table 1)	Study Area and Methods	Key Findings	Implication to Climate Change
32	Paudyal *et al.* (2015)	2c, 2b, 2d, 2e, 2f, 2g, 3a, 3g, 3f, 3m, 3l, 3o, 4d, 4f, 4a, 1d, 1f, 1e	Participatory tool, both social and remote sensing used in 10 CFUG of the Dolakha district.	Participatory tool, such as FGD, KII and transect walk when integrated with satellite image and repeat photography, facilitates ES discussion with laymen in the rural setting of Nepal. Locals perceived an increase in ES due to the implementation of CF in the area.	CF management increases the flow of forest ES to the community motivating them to strive for better management of the forests. CC impact may decrease the flow of forest ES to local communities, making the CF management less attractive to them.
33	Thapa-Magar and Shrestha (2015)	3a	Aboveground, belowground and soil carbon analyzed in 30 Sal dominated CF of the Dhading district.	Carbon stock and biomass was found to be higher in long-term managed Sal-based CF.	CF increases rate of carbon sequestration due to local-level control and management, which is more efficient than distant control by the government. Climate impacts may decrease forest ES, and locals may not benefit much. At the same time, converting the CF into a carbon-trade entity can shift forest management to remote managers, endangering the management and sustainability of the forest.
34	Baral *et al.* (2016)	3a	Market and non-market-based economic valuation done in the Jagadishpur reservoir of the Kapilbastu district.	Total economic valuation of the reservoir include forest land use and forest carbon stock.	CC threatens water resources affecting the species composition and biodiversity of terrestrial and aquatics lives. This may decrease the TEV of the forests.
35	Bhandari *et al.* (2016)	1d, 1e, 1f, 2b, 2c, 2d, 2e, 2f, 2g, 3a, 3g, 3i, 3f, 3n, 4a, 4d, 4f,	ES framework along with social survey and remote sensing used in the local watershed of the Chure region in the Surkhet district.	Locals were familiar with 10 different ES obtained from the watershed and ranked the drinking water supply as the most important. Many of the ES, especially regulating and supporting ES, are not well-known to the people.	The local can take advantage of several forest ES, with water being the most important. However, CC may affect water resources the most. The importance of forest conservation increases with increase in impact of CC.
36	S. Chaudhary *et al.* (2016)	1d, 1e, 1f, 2b, 2c, 2e, 2f, 2g, 3a, 3b, 3g, 3i, 3f, 3m, 3l, 4a, 4c, 4d, 4f,	369 HHs across the buffer zone were interviewed, along with the use of remote sensing and ES matrix in the Koshi Tappu wildlife reserve in the Saptari district.	Land cover change has degraded the ES and affects the livelihood of the locals.	Land cover change is increasing around PA due to encroachment of nearby communities, entry of domesticated animals into the habitats of wild animals, and CC and related floods, landslides and siltation. People in buffer zones have difficulty earning a livelihood without using forest ES from PAs.
37	Karki *et al.* (2016)	3a	Aboveground, belowground and soil carbon calculated in a permanent research plot of ICIMOD at Lalitpur.	Carbon stock has been increased over the year, and monitoring of the carbon stock is essential to track changes in environmental conditions.	Many of the impacts of CC reported are either extrapolated from small scale studies or are anecdotal. Studies on the measurement and tracking of impacts of CC are limited. The uncertainty of CC impacts the value of such measurements in policy making.

SN	Reference	Forest ES category and sub-category (See Table 1)	Study Area and Methods	Key Findings	Implication to Climate Change
38	Peh *et al.* (2016)	1d, 1f, 2c, 2d, 3a, 3l	TESSA framework and FGD used in the Shivapuri Nagarjun national park in the Kathamndu district to assess ES for two alternative states.	Declaration of PAs have net economic and social advantage to the people, and such valuation of ES in a conservation context can shed light on the additional value to the people and society.	The value of forest ES generated from the forest depends on their scarcity in the economy. Because the major forest ES of a national park is water and sprawling cities are facing an increasing scarcity of water, water is the main forest ES from Shivapuri Nagarjun NP. The CC impact, however, may increase the scarcity of other forest ES in addition to supplying water resources.
39	G.J. Thapa *et al.* (2016)	4f	Maxent modeling for future forest biome distribution in the CHAL and TAL of the WWF Nepal program area	Lower and mid montane forests are vulnerable to CC, while temperate upper montane and sub alpine forests are more resilient. Similarly, lower and mid mountain areas could preserve micro refugia. Both macro and micro refugia should be conserved to tackle the impact of future CC on biota	Future CC could change the existing structure of forest resources, which could have an impact on the current biota habitat for which implementation of adaptation and mitigation strategies suitable to a local context was urgently sought. CC is affecting different types of resources differently, putting uncertainty on scientists and local communities.
40	I. Thapa *et al.* (2016)	1d, 1e, 1f, 2b, 2c, 2d, 3b, 3c, 3g, 3i, 3f, 3l, 3o, 4a, 4f,	TESSA framework used in 27 IBAs across Nepal for ES assessment and monitoring.	The studied IBAs currently provide varieties of ES beneficial at the local, regional and global scale. However, with ongoing land use and CC, the balance might deviate in the future, which calls for strong national-level policies.	Increased the pressure from grazing in high-land forests due to CC impact, such as decreases in snow, ice and grassland, could influence water provisioning from the forest watershed downstream both in the short and long term. Locally derived services, such as climate and air quality regulation, wild foods and water provisioning, are vulnerable.
41	Dangal *et al.* (2017)	3a	Aboveground, belowground and soil carbon analysis in four pine-dominated CF in the Kavrepalanchowk district.	Carbon stock was found to be higher in young and intensively managed forests compared to old and traditionally managed forests.	Because pine trees do not generally allow other trees to grow, forest ES is lower in pine forests than in mixed forests. Continuation of flow of ES is important under changing climatic conditions. An intensively managed mixed forest can offer a higher flow of forest ES than solely pine trees.
42	Gilani *et al.* (2017)	1d, 1e, 1f, 2b, 2c, 2d, 2e, 2f, 3b, 3f, 3o,	100 HHs interviewed at the Sabaiya collaborative management forest in the Parsa district.	Low awareness of REDD+ program activities (94% do not know about REDD+ activities). People are sensitive to changes in the climate and the forest around them but are unaware of CC mechanisms and the links between CC and deforestation.	Awareness of CC and its impacts is necessary for planned adaptation to CC. Some communities are over sensitized because they attribute almost everything to CC, but few people understand what CC is. Illiterate or poorly literate villagers cannot understand or remember technical jargons like REDD+. We should give simple, locally understandable names to programs serving such populations.

SN	Reference	Forest ES category and sub-category (See Table 1)	Study Area and Methods	Key Findings	Implication to Climate Change
43	ICIMOD and BCN (2017)	1d, 1e, 1f, 2b, 2c, 2d, 2e, 2f, 3a, 3b, 3c, 3g, 3i, 3f, 3l, 3m, 3n,3o, 4a, 4c, 4d, 4f,	439 HHs interviewed aided with GIS and remote sensing at Rauta VDC of the Udayapur district.	Provisioning services ranked as the highest ES compared to the other three categories; however, they are well aware of all the ES they have from their natural environment.	People can easily understand provisioning services of the forest because this is readily visible and closely linked with their livelihood. Other types of forest ES, although important, are difficult for them to understand. CC may decrease the flow of forest ES, affecting the livelihood of the agriculture-based population because agriculture depends on forest services.
44	Pandit *et al.* (2017)	3a	600 HHs interviewed along with a cost benefit analysis in 47 CF of the Ludikhola watershed in the Gorkha and Khayarkhola watershed in Chitwan	REDD + brings both opportunities and challenges to CF HHs in terms of forest resource use for livelihood Vs carbon sequestration for monetary trading. The program is economically infeasible at the current carbon price.	Carbon sequestration is a forest ES that is far less important for locals than other forest ES. Changing climatic conditions and challenging livelihoods may increase the importance of forest ES other than carbon sequestration.
45	H.L. Shrestha *et al.* (2017)	3a	Soil carbon calculation under four land use categories in the Mustang and Bajhang districts.	Forest soil in Bajhang and agricultural soil in Mustang had the highest carbon levels. The soil data of both study sites indicate that the soils are not sequestering SOC to their full potential.	Properly conserved forest soil may have higher SOC than farmlands. SOC in farm land increases with the increase in the use of organic matter, such as animal dung, compost, green manuring and mulching. A higher soil temperature increases the mineralization process of organic matter, leaving lower SOC in the soil. Global warming may decrease the SOC by increasing the rate of mineralization of organic matter in the soil.
46	Timilsina *et al.* (2017)	3a	Aboveground, belowground and soil carbon calculated in a private coffee plantation (agro-forestry) in the Nuwakot district.	The private sector could play a significant role in carbon sequestration and thus should be made a stakeholder in carbon conservation programs.	Agro forestry not only increases carbon sequestration but also reduces dependency on forests, allowing the forest to grow. Thus, agro-forestry with multipurpose trees can help farmers cope with the impacts of CC.

Note: HH = household; CC = climate change; CF = community forest

Appendix 1 *List of 140 articles obtained after employing specific inclusion criteria*

1	Acharya *et al*. (2015). "Assessing vulnerability and adaptation strategies of forest dependent people to climate change in the Mid-hills of Nepal." Banko Janakari, 25:1
2	Acharya, K. P. (2006). "Linking trees on farms with biodiversity conservation in subsistence farming systems in Nepal." Biodiversity and Conservation 15(2): 631–646.
3	Adhikari, B., *et al*. (2004). "Household characteristics and forest dependency: evidence from common property forest management in Nepal." Ecological Economics 48(2): 245–257.
4	Aryal, A., *et al*. (2014). "Impact of climate change on human-wildlife-ecosystem interactions in the Trans-Himalaya region of Nepal." Theoretical and Applied Climatology 115(3–4): 517–529.
5	Aryal, S., *et al*. (2013). "Comparison of Carbon Stocks Between Mixed and Pine-Dominated Forest Stands Within the Gwalinidaha Community Forest in Lalitpur District, Nepal." Small-S 659-666.
6	Awasthi *et al*. (2015). "Does scientific forest management promote plant species diversity and regeneration in Sal (Shorea robusta) forest? A case study from Lumbini collaborative forest, Rupandehi, Nepal." Banko Janakari, 25:1
7	Awasthi, K. D., *et al*. (2002). "Land-use change in two Nepalese watersheds: Gis and geomorphometric analysis." Land Degradation & Development 13(6): 495–513.
8	Awasthi, K. D., *et al*. (2005). "Fluxes of methane and carbon dioxide from soil under forest, grazing land, irrigated rice and rainfed field crops in a watershed of Nepal." Biology and Fertility of Soils 41(3): 163–172.
9	Awasthi, K. D., *et al*. (2005). "Profile carbon and nutrient levels and management effect on soil quality indicators in the Mardi watershed of Nepal." Acta Agriculturae Scandinavica Section B-Soil and Plant Science 55(3): 192–204.
10	Awasthi, K. D., *et al*. (2007). "Plot level runoff, soil and nutrient loss in upland rainfed terraces (Bari) and aspect-wise soil quality of different land uses in Pokhare Khola watershed, Nepal." International Journal of Ecology and Environmental Sciences 33(2–3): 105–114.
11	Awasthi, N. *et al*. (2015). Does scientific forest management promote plant species diversity and regeneration in Sal (Shorea robusta) forest? A case study from Lumbini collaborative forest, Rupandehi, Nepal. Banko Jankari, 25(1): 20–29.
12	Bahadur, K. C. K. (2011). "Linking physical, economic and institutional constraints of land use change and forest conservation in the hills of Nepal." Forest Policy and Economics 13(8): 603–613.
13	Bahadur, K. C. K. (2012). "Spatio-temporal patterns of agricultural expansion and its effect on watershed degradation: a case from the mountains of Nepal." Environmental Earth Sciences 65(7): 2063–2077.
14	Bajracharya, B., *et al*. (2010). "Understanding Land Cover Change Using a Harmonized Classification System in the Himalaya A Case Study From Sagarmatha National Park, Nepal." Mountain Research and Development 30(2): 143–156.
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