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Quantification of ecosystem services providing socio-economic benefits to customary owners of natural resources in Pauri, western Himalaya

Shashidhar Kumar Jha [a], A.K. Negi [a], Juha M. Alatalo [b,*]

[a] *Department of Forestry and Natural Resources, Hemvati Nandan Bahuguna Garhwal (A Central) University, Uttarakhand, India*
[b] *Environmental Science Center, Qatar University, Doha, Qatar*

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ABSTRACT

Climate change has negative consequences for the biophysical environment and an observable impact on flows of ecosystem services. Considering the high relevance of ecosystem services, it is imperative to analyze the present status of ecosystem services flows, for effective planning to cope with natural and anthropogenic catastrophes. It is equally important to identify drivers of natural resource deterioration. In a study conducted among 545 randomly selected households in 91 villages along an altitudinal gradient (<1200 m asl (zone A), 1200–1800 m asl (zone B), >1801 m asl (zone C)) in Pauri District, Uttarakhand, India, a multi-disciplinary bottom-up, indicator-based approach was applied for identification and normalization of indicators pertaining to ecosystem services. The greatest reduction in ecosystem services was recorded in zone A (0.56), followed by zone B (0.46) and C (0.35). The greatest estimated deterioration was seen in supportive (0.48) and regulatory (0.47) services. The perspective provided can facilitate adaptive management of ecosystems along an altitudinal gradient in the Himalayas, e.g., the district-level quantification of ecosystem services can guide policy-makers and planners towards more efficient adaptation planning and help minimize the gap between local requirements and policy/program formulation.

1. Introduction

Climate change has not been uniform globally on either a spatial or temporal scale (IPCC, 2014b), but has negative consequences for biophysical environments worldwide and an observable impact on flow of ecosystem services (Alcamo et al., 2003). There is evidence of declines (Geest et al., 2019), contractions (Warren et al., 2001; Forister et al., 2010), shifts in species distribution (Chapin et al., 2000; Parmesan, 2006; Rockstrom et al., 2009; Harsch et al., 2009; Warren et al., 2013), altered community composition (Demske et al., 2016), reduced productivity (Zhang et al., 2013; Alekhya et al., 2015), and other physiological changes indicating a reduction in ecosystem service flow (Shrestha et al., 2012; Singh et al., 2015; Brook et al., 2008). The complex interactions of biophysical, economic, political, and social elements at various scales are the co-factor of climate change impacts (Ewert et al., 2015). These impacts are context or place specific, so it is difficult to generalize climate change impacts.

Ecosystem services can be categorized into four types; provisioning, cultural, regulatory, and supporting services (De Groot et al., 2002), which constitute the basis of human survival and are closely related to the well-being of communities. The most common provisioning services are food, water, fuelwood, fodder, and non-timber forest products (NTFP) (Roy et al., 2018; Maiti et al., 2016), while examples of cultural services are eco-tourism, recognition as heritage sites, and sacred groves (Kostic et al., 2018; Gajic et al., 2019). Regulatory services include nutrient cycling, erosion control, and carbon sequestration (Verma et al., 2014; Pandey et al., 2016; Gajic et al., 2019), while supporting services include biodiversity and providing habitats for flora and fauna (Millennium Ecosystem Assessment (MEA), 2005; Pietrzykowski et al., 2018). Among the ecosystem services available, commercially important provisioning (fodder & fuelwood) and cultural services (tourism) are of great concern to many communities in the Indian Himalayan region.

The Himalayas is one of 34 global hotspots of biodiversity and supports over 20% of the human population, either directly or indirectly, in Hindu Kush Himalaya (Pradhan et al., 2012; Rasul, 2014). The Indian Himalayan Region as a whole supports nearly 50% of all flowering plant species in India, of which 30% are endemic. These include 8000 species of angiosperms (40% endemic), 44 species of gymnosperms (15.91% endemic), 600 species of pteridophytes (25% endemic), 1737 species of

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* Corresponding author.
E-mail address: jalatalo@qu.edu.qa (J.M. Alatalo).

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bryophytes (32.53% endemic), 1159 species of lichens (11.22% endemic), and 6900 species of fungi (27.39% endemic) (Singh and Hajra, 1996). The region is also home to 816 tree species, 675 edible plant species, and 1743 species of medicinal value (Samant et al., 1998). Many of these species have been identified as being particularly vulnerable to climate change, due to their narrow geographical and climate ranges and limited dispersal opportunities (Thuiller et al., 2005; Gibson et al., 2010). The Himalayan ecosystem is extremely fragile and sensitive to change, and the lives in the region are highly susceptible to mountainous specificities (fragility, topography, inaccessibility, etc.)

Aside from geographical constraints, the Himalayan ecosystem is also threatened by natural and anthropogenic factors. Out of all of the natural factors, climate change (rise in temperature and variation in rainfall) is the most significant, intensifying the potential for catastrophe (INCCA, 2010; Jha et al., 2020). Climate change affects the flow of ecosystem services through changes to hydrological processes, moisture-energy distribution, and carbon dioxide concentrations (Shaw et al., 2012; Nelson et al., 2013; Lamarque et al., 2014), and several studies have shown that climate change exerts additional pressure on ecosystem services (Bangash et al., 2013; Seidl et al., 2016; Lang et al., 2017; Schirpke et al., 2017). IPCC (2014b) also asserted that the impact of climate change is more significant in climate sensitive sectors i.e. natural support systems (forest, agriculture, horticulture, etc.). Anthropogenic factors, meanwhile, include such factors as urbanization and population pressure for resource extraction. They alter the patterns and dynamics of ecosystems, which greatly impacts ecosystem services and human well-being (Kueppers and Snyder, 2012; Zhong and Wang, 2017). Moreover, the forest ecosystem in the Himalaya is greatly affected by forest fires, the majority of which are anthropogenic, in this region, and which significantly impact undisturbed vegetation, soil biota, and wildlife, and restrict the flow of services.

Anthropogenic pressures and climate change impact ecosystem services in several ways, resulting in a series of economic and non-economic losses and damages. Economic losses are understood to be the loss of resources, goods and assets that are commonly traded in markets, while non-economic losses and damages involve services or items which are not commonly traded in markets (UNFCCC, 2013), such as water and air purification, habitat, biodiversity, and other related flows of services. Using specific indicators, the present study endeavored to assess non-economic losses and damages and advocate for the prioritization of adaptation actions along the altitudinal gradient. The livelihoods of 1.6 billion people worldwide depend on forests for a variety of goods (food, fodder, agriculture, housing, and an array of marketable minor forest products) and services (amelioration of microclimate, water and air purification) (Chao, 2012), a figure which includes around 60 million people who are members of indigenous or tribal groups, who rely almost entirely on the services provided by forests (Jha et al., 2018). These populations are marginalized section of the society, and are highly vulnerable to interruptions in the flow of services. Indeed, their dependence on vulnerable ecosystems for services constrains the livelihoods of marginalized mountainous communities (Adams et al., 2018). There is therefore an urgent need to strengthen the capacity of the Himalayan ecosystem to provide a continuous flow of services, and identify site-specific factors which may hinder the flow.

Previous studies have argued that an integrated bottom-up strategy is needed to resolve environmental stewardship and provide ecological services in the Himalayan region (Pandey and Jha, 2011; Sinha and Mishra, 2012; Jha, 2020). The present study endeavored to assess the flow of ecosystem services along the altitudinal gradient in the Himalayan region, with the objective of bringing the flow of ecosystem services to the attention of planners and policy makers. The importance of including ecosystem services in environmental policies was also highlighted by Egoh et al. (2012) in their Millennium Ecosystem Assessment. The present study adopted a approach to the assessment of flows of services, and could act as a guide for conservation strategies and management of environmental services, going forward. Target 14 of the Convention on Biological Diversity refers to the conservation of ecosystem resources for the purpose of improving livelihoods and well-being, as well as fulfilling the needs of women, indigenous and local communities, and the poor and vulnerable (Egoh et al., 2012; Chong, 2014). On the same basis, the present study attempted to identify any prominent indicators responsible for reduced flows of services. The study also highlighted specific actions that may strengthen the adaptive capacity of forest ecosystems and reduce their vulnerability, by reinforcing the flow of services, combatting poverty and safeguarding the rights of indigenous people in the long run. In this study, we advocate for a coordinated, integrated, cross-sectoral policy framework with a long-term focus, which needs to be implemented if we are to sustain ecosystem functioning. The approach needs to provide a context for the advancement of sustainable science, one which is primarily based on the impact of climate change on the supply of ecosystem services, and which may include varied viewpoints from local stakeholders, such as the traditional users of the natural resources.

Given the relevance of ecosystem services, it is imperative that we address the flow of ecosystem services and identify the factors that strengthen ecosystem health and subsequently augment the flow of services. The present study aimed to perform an assessment, or quantification, of ecosystem services along an altitudinal gradient in the Indian Himalaya region, using a bottom-up, indicator-based approach. Specific objectives were to i) identify indicators that make important contributions to the flow of ecosystem services; and ii) quantify or assess the flow of ecosystem services along the altitudinal gradient for sustainable management of resources. Improving the flow of services is of paramount importance in the Himalayan region, for the specific purpose of resource management under climate change. Quantification of ecosystem services would also be helpful for identification and prioritization of sectors for policy formulation, and may facilitate the implementation of a suitable regional adaptation program. An additional aim of this study was to provide recommendations about what should be prioritized within altitude and sectors for adaptation action, going forward, all while helping to develop a robust, integrated approach that will increase our capacity to combat climate-related risks at the national and local level.

2. Study area

The study was conducted in Pauri District, Uttarakhand, Western Himalaya, India (29°20′-30°15′N, 78°10′-79°20′E), along an elevation range of 295 m to 3116 m and encompassing a land area of 5230 km^2 (ISFR, 2019). The district consists of a total of 3447 villages and 15 blocks (developmental units) with a population of 686,527 individuals. The population growth rate indicated a negative trend (−1.51%) (Census of India, 2011). The population density is 129 persons per km^2 and the sex ratio is 1103 females per 1000 males. The literacy rate in the district is 82.59% (males 93.18%, females 73.26%), compared with 74.04% nationally in India (males 82.14%, females 65.46%) (Census of India, 2011). The region has a sub-temperate to temperate climate, with mean annual temperature of 25–30 °C (45 °C in June and 1.3 °C in January) and mean annual rainfall of 2180 mm, with over 90% of precipitation falling in the monsoon period (July–September) (Jha et al., 2020).

The topography of the district is mountainous (Fig. 1). The cross-section of fluvial valleys displays a convex form, with steep valley sides, interlocking spurs descending towards the main channel, and terraced agricultural fields on the gentle slopes of the valley sides. The local people, known as Garhwali, are mostly engaged in agriculture and also have a high dependency on forest resources. Mountainous terrain, water scarcity, and highly labor-intensive work are the major constraints to agriculture. The occurrence of diverse topographical and orographic features has resulted in remarkable biodiversity in the region, with 61.72% of the area under forest cover (ISFR, 2019).

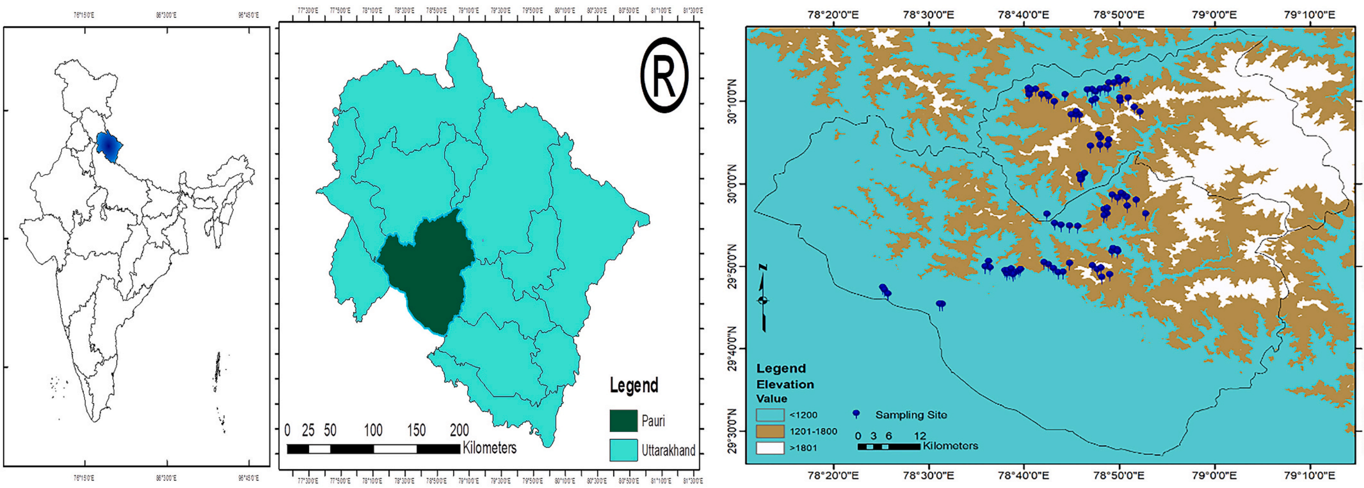

Fig. 1. Digital elevation model of Pauri District, Western Himalaya, India, showing the location of the study site.

3. Sampling strategies

The study compared inter and intra-structural indicators of ecosystem services and climate change along the altitudinal gradient, with a particular focus on dynamics of land utilization patterns for natural resources. The study area was divided into three zones: zone A (<1200 m asl), zone B (1200–1800 m asl), and zone C (>1801 m asl). Stratified random sampling was applied to gather information on the households in the selected villages in each zone with the help of questionnaire and face-to-face interviews, preferably conducted with the head of the household. The heterogeneity of villages was maintained by selecting additional villages in each zone.

Households in mountainous settings are sparsely distributed and generally engaged in their livelihood activity during daytime, making it difficult to obtain large samples. Out of all the villages (3447 villages), 91 (30 in zone A, 32 in zone B, 29 in zone C) were surveyed in the study area. The villages were selected on the basis of the villagers' dependency on forests. To avoid homogeneity in responses, a minimum of five and maximum of 10 respondents from each participating village were selected for interview. A total of 545 respondents from the three predetermined altitudinal zones (182 in zone A, 187 in zone B, 176 in zone C) were interviewed for data collection.

The interviews were conducted in Hindi and the local language, with the support of one local resident. The questionnaire covered issues and questions pertaining to all aspects of natural capital integrated into the indices (types of services), used here to determine the flow of ecosystem services. Moreover, phytosociological assessment was carried out to compare the status of ecosystem services along the altitudinal gradient. A total of 71 quadrants (19 in zone A (OF 5, MDF 9, DF 5), 22 in zone B (OF 8, MDF 10, DF 4), and 30 in zone C (OF 19, MDF 5, DF 6)) of 500 m^2 each (20 m × 25 m), were laid down at intervals of 500 m elevation, for comparisons of biomass, diversity, regeneration, and lopped branches/ trees.

4. Critetia for selection of indicators

An indicator has been defined as a variable measure of system behavior in terms of essential and perceptible attributes (Holling, 1978). The indicator is a readily available piece of information which can be easily obtained in a pragmatic manner. Over the years, it has been defined by various authors in a series of contexts, giving rise to such definitions as: proxy – phenomenon specific information (McQueen and Noak, 1988); parameter – provides information on the state of the phenomenon and also defines it as a value that is measured or observed (OECD, 1993); index – set of information (Hammond et al., 1995), and variable – function from an observable variable (Gallopin, 1997). Furthermore, an indicator could also be a piece of information (Bakkes et al., 1994); a statistical measure (Tunstall, 1992); or a sub-index or component of an index comprised of a small collection of information (Ott, 1978; Hahn et al., 2009; Pandey and Jha, 2011). For the present research context, an indicator is understood to be a noticeable local variable or piece of information, selected on the basis of its significance for livelihoods, the local economy, or conservation and resource management (availability, accessibility & usability). Initially, 39 indicators were selected with the help of literature reviews, published literature, stakeholder consultations and site visits. The number of indicators was later reduced to 24, after questionnaire testing and the first level of assessment i.e. normalization. Indicators which held similar value for the selected altitudes were eliminated.

In the present study, a set of indicators for respective ecosystem services was established and considered sufficient for comparing the flow of services along an altitudinal gradient. The study was somewhat limited by its inability to access some indicators, such as altitude-specific climate change with finer resolution, which in identifying altitude-specific changes would have produced results with a finer level of detail. Unfortunately, access to and analysis of this indicator constitute a cumbersome process. Moreover, several other altitude-specific indicators could have been used for the assessment, but would have led to difficulties in comparison. Consequently, only the proxy or indicators that provided sufficient information, were easily comparable, and could be understood at a local, regional and global scale, were selected for this assessment.

5. Analytical framework

There have been various studies seeking to assess and evaluate the flow of ecosystem services. These include: integration of ecosystem services into conservation (Egoh et al., 2012); analysis of ecosystem services (Seppelt et al., 2011); mapping ecosystem services value (Burkhard et al., 2012;Martinez-Harms and Balvanera, 2012); cultural ecosystem services (Milcu et al., 2013); economic valuation (Laurans et al., 2013); the role of agriculture in ecosystem services (Tancoigne et al., 2014); meta-analysis of key terrestrial regulatory ecosystem services (Viglizzo et al., 2016); trends of ecosystem service research (McDonough et al., 2017); regulation of ecosystem services (Sutherland et al., 2018); ecosystem services in landscapes (Englund et al. 2017); and trends of forest ecosystem services (Mengist and Soromessa, 2019). However, none of the above studies have addressed the matter with the help of qualitative and quantitative explanations, which is why we chose to conduct our study, hoping to outline the flow of ecosystem services and identify important climate change indicators along the altitudinal gradient.

For our assessment, we applied a bottom-up, indicator-based approach (Hahn et al., 2009). This approach is useful for comparative assessment, prioritizing actions and influencing subsequent decision-making, as it allows for the comparison of specific characteristics (Schirpke et al., 2017). In the present study, the approach involved participatory assessment (household surveys, participatory rural appraisals, focus group discussions) and field measurements (phytosociological analysis) (Table 1). A total of 24 indicators were selected for the study, with special emphasis on improvement or deterioration in flow of services over the past 10–15 years, and their comparison along the altitudinal gradient.

The information was converted into indicators, which were then normalized and sorted into such ecosystem services as provisioning, regulatory, supportive and cultural services. Each of the services consisted of site-specific indicators. The indicators were identified by literature specific to the area or similar regions (e.g., Sharma et al., 2009; Urothody and Larsen, 2010; Pandey, 2010; Pandey and Jha, 2011; Tse-ring et al., 2012; Sandhu and Sandhu, 2014; Pandey et al., 2016; Gerlitz et al., 2016; Pandey et al., 2016; Jha et al., 2018), preliminary field surveys, and expert consultation. Primary qualitative and quantitative data were converted into indicators. The indicators initially used different units or scales, and were normalized on the basis of their functional relationship with ecosystem services, e.g., whether ecosystem services increased with an increase in the value of the indicator (positive relationship, Eq. (1)), or decreased with an increase in the value of the indicator (negative relationship, Eq. (2)).

$$\mathrm{Index}_{sv} = \frac{S_v - S_{\min}}{S_{\max} - S_{\min}} \tag{1}$$

$$\mathrm{Index}_{sv} = \frac{S_{\max} - S_v}{S_{\max} - S_{\min}} \tag{2}$$

where S_V is the average value of the indicator at village level, and S_{min} and S_{max} are the minimum and maximum values of the indicator.

The indicators were averaged after standardization, using Eq. (3) to calculate the value for the indexes:

$$M_v = \frac{\sum_{i=1}^{n} Index}{n} \tag{3}$$

Where M_V is one of the indexes or ecosystem services, *Index* is the sum of the value of the i^{th} indicator, and *n* is the number of indicators. It is assumed that an increase in the value of the indicators equates to a decrease in the flow of services, and vice-versa.

Table 1
Parameters used for phytosociological analysis along an altitudinal gradient (Zone A to C) in Pauri District, Western Himalaya, India.

No.	Parameter	Formula
1	Biodiversity (Shannon and Weaver, 1963) (H)	H = − ∑ pi In pi where H = Shannon index of diversity, pi = proportion of importance value of the i^{th} species (pi = ni/N), ni is the importance value index of the i^{th} species, and N is the importance value index of all species
2	Species richness (Margalef, 1958)	=S-1/ln(N) where S is total number of species and N is number of individuals
3	Biomass	Growing Stock Density (GSD) (FSI, 1996), Above Ground Biomass Density (AGBD) (Brown et al., 1999), Below Ground Biomass Density (BGBD) (Cairns et al., 1997) and Total Carbon Density (TCD)

6. Results & discussion

6.1. Respondents' perception of climate change

Initially, impacts of climate change in Pauri district were analyzed using five indicators (Table 2). The impact of climate change was seen to increase with altitude, with the highest score for an indicator recorded in zone C (0.72). The households of zone C resided in closer proximity to a climate-sensitive natural support system, so they could identify even the smallest changes in the climate and its subsequent impacts. Indeed, climate sensitivity of the natural support system has been up for debate by IPCC since 2007. The dependency was comparatively lower in zone B (0.54) and zone A (0.32) (Table 2), while the indicator scores for increased intensity and frequency of rainfall, and decreased number of rainy days, were highest for zone C (0.71) and lowest for zone A (0.23). The score for reported variation in temperature trends was also highest for zone C (0.86) (Table 2). However, variations in both summer temperature and winter (February–March) temperature were observed to be higher for zone C. Alterations to climate parameters resulted in increased incidence of extreme events, with the highest incidence recorded in zone C (0.85), followed by zones B (0.34) and A (0.01). The variation in climate in the district is corroborated by previous studies reporting climate data (Jha et al., 2020) and the perceptions of inhabitants (Rao et al., 2018; Jha et al., 2020). According to official data for India (MoEF., 2012), there have been clear changes in climate patterns in the Himalayan region in recent years. The temperature in the Himalayan region is estimated to be increasing at a rate of 0.06 °C per

Table 2
Indicators selected for assessing climate change along the altitudinal gradient (A-C) in Pauri District, Western Himalaya, India.

Components	Indicators	Explanation	Zone A	Zone B	Zone C
Climate Change	Increased intensity and frequency of rainfall, and decreased number of rainy days	More run-off and alterations to perennial water availability	0.23	0.54	0.71
	Increased temperatures and related extreme events, e.g., drought, forest fire, etc.	Result in loss of species, biomass production and forest cover	0.50	0.73	0.86
	Increased temperatures February–March	Loss of water (evaporation), alterations to flowering, pollination, fruiting, and impacts eco-tourism	0.75	0.80	0.83
	Increased summer temperatures	Affects long-term water availability; facilitates shifting of species; alters forest composition, reduces biomass production, biodiversity and species richness	0.11	0.29	0.34
	Increased numbers of rainfall-related extreme climatic events	Rainfall-related extreme events result in landslides and also affect eco-tourism	0.01	0.34	0.85

Source: Primary household survey in the Pauri District.

year (Shrestha et al., 2012) and the mean value is predicted to increase from 0.9 °C in 1970 to 2.6 °C by 2030 (INCCA, 2010).

6.2. *Climate change impacts on the flow of ecosystem services*

Climate is an important environmental influencing factor for ecosystems, one with various implications. Rise in temperature, for example, force species to migrate towards higher elevation, or to expand their ranges poleward (Demske et al., 2016); other facets of climate change, such as shifts in the tree lines of mountain systems (Harsch et al., 2009), declines in populations, and altered phenology (timing of events) (Miller-Rushing and Primack, 2008; Yu et al., 2010), also have a significant impact. IPCC AR4 suggests that approximately 10% of species assessed thus far will be at an increasingly high risk of extinction for every 1 °C rise in the global mean temperature. The rate of species extinction is likely to soon exceed the upper limit of observed natural rates given in the fossil record (IPCC, 2007). Changes to natural ecosystems alter their productivity and are likely to bring about changes in services such as carbon storage and sequestration, nutrient cycling, and provision of food, fiber, timber, water, etc. (George and Alftine, 2016). These changes may also lead to shifts in ecological conditions and could perpetuate the spread of pathogens, parasites, and diseases (Erica et al., 2017). There is also a chance that they could modify tree physiology and defense mechanisms, with potentially severe effects on ecosystem functions and the flow of ecosystem services that they provide (Botkin et al., 2007; Chevin et al., 2010). Climate change and human intervention have restricted the ability of ecosystems to temper the impacts of extreme conditions, thereby heightening their susceptibility to damage. A detailed discussion on the flow of ecosystem services is carried out in the next section.

Overall, climate variability has severely exacerbated the potential for sudden and irreversible changes in ecosystems.

6.3. *Quantification of ecosystem services*

6.3.1. *Provisioning services*

Provisioning services include provision of food, fiber, fuel, and water from forests. The coping and adaptation strategies of vulnerable households often rely heavily on provisioning services (Locatelli, 2016). In the study, these services were recorded along the altitudinal gradient with the help of seven indicators. The highest provision of services was recorded in zone C (0.39), where we had actually expected provision to be lowered due to higher susceptibility to climate change. These results were likely due to the larger area under forest cover, lower population density, and fewer fire-susceptible forest species that were found in zone C compared with the other zones. The dominant forest tree species in zones A (0.62) and B (0.56) are highly susceptible to fire, as shown by Jha et al. (2018, 2020). The relevance of forest composition to forest fire liability was first underlined by Shank and Noorie (1950). Indeed, the Himalayan region has seen a significant increase in forest fires (by 90%), as well as more intentional fires (Levine et al., 1999). Moreover, several studies have reported that climate change and the subsequent rise in the temperature of the surroundings tends to optimize the conditions for a potential forest fire (Negi, 2007; INCCA, 2010; Jha et al., 2018).

Increased fire incidence limits access to natural resources, particularly fodder, fuelwood and NTFP. This access was most constrained in zone A (0.43), followed by zones B (0.30) and C (0.28) (Table 3). Furthermore, higher population pressures and unsustainable extraction of forest resources were found to work alongside the impacts of climate change in increasing levels of species shift and extinction (Harsch et al., 2009). The extinctions of further species were reported by respondents, but are lacking scientific evidence. Rises in temperature also endangered medicinal plants which thrive only at very high elevations (Grabherr, 2009). Limited access to, and availability of, forest resources only serves to make local communities more vulnerable, which has been identified previously by Owuor et al. (2005) in Walton et al. (2006) in the

Table 3
Indicators selected for assessing ecosystem services along the altitudinal gradient (A-C) in Pauri District, Western Himalaya, India.

Ecosystem services	Indicators	Explanation	Zone A	Zone B	Zone C
Provisioning Services	Dominant forest species susceptible to fire*	Species which are susceptible to fire are more prone to forest fires which disrupt the flow of provisioning services (fodder, fuelwood, timber, food, etc.)	0.62	0.56	0.17
	Sufficient fodder and fuelwood	Sufficient fodder and fuelwood from nearby forests represent a balance between resource availability and extraction, and facilitate provisioning services	0.43	0.30	0.28
	Access to non-timber forest products	NTFP (apart from fodder and fuelwood) are an additional income source and are also considered food supplements	0.35	0.29	0.27
	Dependency on natural water sources	Natural water sources are susceptible to climate change	0.14	0.29	0.37
	Potable water sources	Perennial sources and adequate water availability are a quantum of provisioning services	0.73	0.66	0.61
	Potable water sources during summer	Perennial water sources, especially during the summer and monsoon seasons, when water is scarce, reflect adequate flows of ecosystem services	0.78	0.60	0.62
	Potable water availability (months)	Year-round water availability strengthens capacity	0.25	0.26	0.38
Regulatory Services	Dried-up water sources (past 10 years)	Indicates climate change impact on water ecosystem and reflects reduction in regulatory services	0.80	0.92	0.73
	Variation in water quality (past 10 years)	Indicates that climate has induced extreme events, which deteriorate water quality	0.70	0.15	0.18
	Deterioration in water quality and increases in waterborne diseases	Deterioration of water quality due to extreme events, which leads to waterborne diseases	0.25	0.26	0.28
Supporting Services	Individuals (no./ha)*	The more individuals per hectare, the greater the	0.49	0.45	0.40

(*continued on next page*)

Table 3 (*continued*)

Ecosystem services	Indicators	Explanation	Zone A	Zone B	Zone C
		supportive capacity of an ecosystem			
	Lopped trees (no./ha)*	Lopped trees hinder the flow of supporting services	0.65	0.61	0.48
	Regeneration (%)*	Regeneration has the potential to restore soil nutrient availability and cycling	0.55	0.42	0.40
	Biodiversity*	Increased biodiversity has a stabilizing effect on ecosystem functions	0.59	0.39	0.35
	Species richness*	Rich biota have a greater capacity to increase and maintain ecosystem stocks (plant biomass) and ecological rates (nutrient cycling) than impoverished communities	0.56	0.48	0.39
	Biomass production*	Biomass production is 'ecosystem structural components' and is considered intermediate goods and services. The higher the quantity (tons / ha), the better the services	0.50	0.45	0.41
Cultural Services	Ecotourism	Mountains make for alluring ecotourism destinations and attract numerous tourists	0.23	0.12	0.19
	Religious (temple)	Religious temples are popular eco-tourism destinations for those with spiritual or cultural beliefs	0.69	0.55	0.32
	Sacred groves	Traditional rules can serve a conservation role. Limited or no activities within the forest result in a higher flow of service activities in the forest and a correspondingly higher flow of services	1.00	0.80	0.10

Source: Primary household survey and field measurement in the Pauri District.

[*] Indicates assessment based on field measurements.

Philippines.

The use of provisioning services is often the result of a lack of alternative options, and can be a symptom of poverty rather than a solution for adaptation (Pattanayak and Sills, 2001). It can be assumed that households which depend on a natural water source (e.g., river, spring, etc.) are more vulnerable to climate change and its impacts. In the study area, dependency on natural water sources was reported to be highest in zone C (0.37) and lowest in zone A (0.14). Diverse water sources were reported in zone A (0.61), but the majority were seasonal (Table 3). However, water availability was found to be superior in zone A even in the summer, due to better overall supply and management. Given their dependency on perennial sources, water availability was restricted in zones B (0.26) and C (0.38), especially during the summer and the monsoon periods. Water provision is one of the major ecosystem services affected by climate change in the Himalayan region, and has severe consequences for downstream populations. Local communities in the study area were severely affected by reduced streamflow and its consequences for water provision, as in many parts of the district, exceptionally hot and dry summers diminish the flow even further. Water availability, together with accessibility (Rajesh et al., 2014), storage and sanitation (Connor, 2015), and infrastructure (Cross et al., 2006), are significant determinants for the implementation of adaptation programs, which should be implemented as soon as possible. On the understanding that policy amendments take time, it is suggested that these aims could be met more efficiently through the mainstreaming of related actions in developmental programs.

6.3.2. *Regulatory services*

Ecosystems influence hydrological functioning through their contribution to rainfall interception, evapotranspiration, infiltration, purification, and groundwater recharge (Locatelli, 2016). This influence can reduce the impacts of climate variation and provide several benefits for dependent communities. Mountain ecosystems contribute to regulating the global climate by mediating carbon, energy, and water balance. In addition, a healthy ecosystem can strengthen the flow of services and temper the impacts of extreme conditions, thereby reducing their susceptibility to damage. A healthy ecosystem also reduces soil erosion and landslide hazards, which are partially climate-related. Regulatory services in the study area were directly proportional to altitude, with a reported score of 0.40, 0.42, and 0.58 for zones C, B, and A, respectively. A number of water sources have dried up in the past 10 years, with the incidence of this reported to be highest in zone B (0.92), followed by zones A (0.80) and C (0.73). Sharma et al. (2009) and Chaudhary and Bawa (2011) have also reported the drying up of water sources in the Himalayan region. In addition, deforestation, rising global temperature, increased precipitation, and winter droughts have reduced natural groundwater recharge (Tambe et al., 2011), which has led to drying up of natural springs and declining base flow in streams (Rawat et al., 2011). High variation in water quality was reported in zone A (0.70), with comparatively little variation in zones B (0.15) and C (0.18) (Table 3). Deterioration in water quality and increase in waterborne diseases was similar for the three zones (Table 3). A reduction in water quality in Pauri District has been reported previously by Pandey and Jha (2011) and Jha et al. (2018).

6.3.3. *Supporting services*

Supporting services, such as nutrient cycling, oxygen production, and soil formation, underpin the provision of the other 'service' categories. Supporting services for socio-ecological services were analyzed using eight indicators for open, moderately dense, and dense forest, including individuals (number/ha (ha)), lopped trees (number/ha), regeneration, biodiversity, species richness, and biomass production. The highest score for services was recorded for zone C (0.41), followed by zones B (0.47) and A (0.56). The highest density of individual trees (834 individuals/ha) and the lowest incidence of lopped trees (56 individuals/ha) were recorded in zone C (0.40 and 0.48, respectively).

Stem density in the dense forest of zone A was 716 trees/ha, which was within the range reported by Sharma et al. (2010) for Indian forests (295–850 trees/ha) and by Saxena and Singh (1982) for forests in Kumaun Himalaya (420–1300 trees/ha). However, the range was lower than that reported by Gairola et al. (2011a, 2011b) (990–1470 trees/ha) for forests in western Himalaya. The overall tree density in zone B ranged from 286 to 907 trees/ha. The tree density of *Quercus leucotrichophora* (273 trees/ha) in zone B (1200–1800 m asl) was lower than that reported by both Gairola et al. (2011a, 2011b) (1470 trees/ha at altitude 1400–1600 m asl) and Pandey (2001) (792–1111 trees/ha). *Quercus leucotrichophora* was found to be the dominant species in zone C. Dominance of *Quercus leucotrichophora* at high altitude has also been reported by Sharma et al. (2009) (Garhwal Himalaya), Singh et al. (2000) (Kumaun and Garhwal Himalaya), Singh and Singh (1992) (Indian Himalaya), and Koirala (2004) (East Nepal). The forest in the study area is deteriorating at a higher rate, suggesting that priority should be afforded to developing community-based multi-species afforestation, fire monitoring programs, agro-forestry, and fodder banks, as important components of the climate change strategy. Actions for strengthening ecological services supply will need to be accounted for at different levels of decision-making, in order to maintain forest health and improve household income in the long run. Moreover, greater regeneration (88 individuals/ha), biodiversity (2.40), and species richness (8) were recorded in zone C (0.40, 0.35, and 0.39, respectively) (Table 3). Fewer individuals (484 individuals/ha), more lopped trees (65 individuals/ha), less regeneration (31 individuals/ha), lower biodiversity (2.16), and lower species richness (5) were recorded in zone A (than zones B & C). Climate change is both a cause and an effect of biodiversity loss, and directly or indirectly changes the pattern and dynamics of energy flow and material circulation (Zhong and Wang, 2017), which in turn greatly impacts the Himalayan ecosystem and the flow of services.

One of the key supporting services provided by forests is carbon removal from the atmosphere (carbon sequestration) and the long-term storage of this carbon in biomass, dead organic matter, and soil carbon pools (Sintayehu, 2018). Biomass production in the study district was increased with altitude, from 43 metric tons (t)/ha in zone A to 47.50 t/ha in zone B, and 88 t/ha in zone C. Biomass production by *Pinus roxburghii* in zone A (112 t/ha) was higher than reported by Rana (1985) and almost similar to that reported by Chaturvedi and Singh (1986) and Chaturvedi (1983) for the Kumaun region of India. More than 57% of the biomass contribution came from *Pinus roxburghii* (88 t/ha) in zone B. Higher AGBD for *Pinus roxburghii* was reported by Sharma et al. (2011) (134.1 t/ha at altitude 1000–1500 m asl), Sheikh et al. (2009) (173.39 t/ha), Gairola et al. (2011a, 2011b) (183.05 t/ha) and Kumar et al. (2019) (213 t/ha) for Pauri Garhwal. However, Haripriya (2000) reported lower AGBD (69.50 t/ha) for *Pinus roxburghii.* The highest AGBD, BGBD, and TCD were recorded for *Cedrus deodara* (179 t/ha, 46 t/ha, and 103 t/ha, respectively) in zone C. Sundriyal et al. (1994) reported a AGBD range of 368–682 t/ha in higher altitude forests of Eastern Himalaya. Further, the AGBD estimated for *C. deodara* forest was lower than that reported by Sharma et al. (2011) (518.20 t/ha) and Sharma et al. (2010) (434 t/ha) for forest in Garhwal Himalaya.

6.3.4. *Cultural services*

Cultural services include recreation, and esthetic value. In our study, cultural services provision was analyzed based on ecotourism, religious temples, and sacred groves. It was found that cultural services were comparatively more prevalent in zone C and very similar in zones A and B. Ecotourism was highest in zone B (0.12), followed by zones C (0.19) and A (0.23), with zones B and C claiming several tourist spots and thereby attracting tourists from adjoining states. With locals involved as support staff, there is a risk that tourism revenue will only benefit state organizations and big tour operators (Steinicke and Neuburger, 2012). On the other hand, while a few households in zones B and C do operate homestays, they do not provide adequate facilities to attract mass tourism. This region would benefit from a successful model of equitable access to tourism revenues, particularly one that integrates community development needs into conservation goals.

Religious services, especially temples and sacred groves, were found with greater frequency in zone C (0.32 and 0.10, respectively) (Table 3), where locals and visitors from adjoining states would often visit the temples and groves. The flow of mass tourism to these places is diminished, although they have the potential to be tourist spots. Reasons may include lack of management, inadequate tourist facilities, and a less pleasant climate. Climate change and tourism act synergistically, which facilitates the spread of alien species (Tolvanen and Kangas, 2016), and the potential results (road blockage due to landslide) may alter tourism flows even during the peak season in the mountains. On the other hand, the district provides a subsidiary route to India's distinguished religious tourism (char-dham), so it would be possible to enhance the tourism inlets and homestays in the district by means of suitable advertisement of hotspots, as well as implementation of tourist management programs.

7. Conclusions

The Himalayan Mountains are one of the most diverse ecosystems, providing a wide range of ecosystem services to humanity. Climate change, together with anthropogenic pressures on distribution range, have the power to alter ecosystems and are therefore a serious threat to biodiversity and resilience. Reduced flows of services affects communities who depend on them for their livelihoods, as well as those who are not directly dependent but benefit from other components such as clean air, carbon sequestration, soil erosion, etc. To ensure the adequate flow of ecosystem services, then, we must implement altitude-specific forest management plans. The most diminished flow of ecosystem services was recorded in zone A (<1200 m asl), followed by zones B (1200–1800 m asl) and C (>1800 m asl). The flow of services in these zones have been altered, modified, and influenced by climate change, human history, culture, and traditional practices for thousands of years. There is therefore an urgent need to ensure the sustainability of ecosystems and the uninterrupted flow of services. Within this, it is also crucial that the flow of services be understood and managed as a mosaic of integrated socio-ecological systems, encompassing systems across political and sectoral boundaries and linking upstream and downstream conservation action with local climate adaptation.

The most diminished flow was found within supportive and regulatory services. In order to improve and upgrade these flows, we would be well-advised to abide by local understanding of good practice, in terms of conservation and restoration of degraded land. The flows could also be improved through adoption and upscaling of existing community-centric approaches which have previously had significantly positive ecological, economic, and social impacts. Effort is required to build on regional cooperation and increase national and global investments.

There is a need for sustainable water management, including rainwater harvesting, rejuvenation of traditional water sources, qualitative monitoring of public water supply system, development of low-cost water purification systems, a cadre of trained personnel in water management (qualitative and quantitative), and a mechanism for inspection. The initiative will also require the direct involvement of regional and local governments, academia, NGOs, and local communities at each level.

Regional efforts will enhance the flow of ecosystem services while conserving biodiversity and species richness and promoting sustainable development. Moreover, investments in mountain ecosystems should be directed to where they are most needed, where they will maintain the flow of services, alleviate poverty, and enhance sustainable livelihoods. With a wide range of priorities for investment, assessments should be carried out which highlight the importance of the flow of ecosystem services, giving rise to trade-offs in the Himalayan region which are beneficial for all.

The district-level quantification of ecosystem services described in this paper could guide policymakers towards more efficient adaptation planning in ecosystem service-based climate change adaptation. To support adaptation efforts, the government should introduce consistent incentives across a wide range of policy areas to strengthen ecological services. Moreover, context-specific adaptation measures are required for sectors with greater declines in the supply of services.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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