Participatory assessment and mapping of ecosystem services in a data-poor region: case study of community-managed forests in central Nepal

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Highlights

- Community-managed forests provide a wide variety of ES to people with benefits that range from local to global scales.
- The participatory GIS approach is useful for spatial ES mapping in data-poor regions.
- Local people’s perception and expert opinion are appropriate tools for identifying key ES in community-managed forest landscapes.
- Land use changes resulted in positive impacts on timber production, biodiversity and carbon sequestration as a result of the re-vegetation of degraded hills in Nepal.

Abstract

Community-managed forests (CMF) provide vital ecosystem services (ES) for local communities. However, the status and trend of ES in CMF have not been assessed in many developing countries because of a lack of appropriate data, tools, appropriate policy or management framework. Using a case study of community-managed forested landscape in central Nepal, this paper aims to identify and map priority ES and assess the temporal change in the provision of ES between 1990 and 2013. Semi-structured interviews, focus group discussions, transect walks and participatory mapping were used to identify and assess priority ES. The results indicated that community forestry has resulted in the substantial restoration of forests on degraded lands over the period of 1990 to 2013. Local community members and experts consider that this restoration has resulted in a positive impact on various ES beneficial for local, regional, national and international users. Priority ES identified in the study included timber, firewood, freshwater, carbon sequestration, water regulation, soil protection, landscape beauty as well as biodiversity. There were strong variations in the valuation of different ES between local people and experts, between genders and between different status and income classes in the local communities. In general, whereas CMF provide considerable benefits at larger scales, local people have yet to perceive the real value of these different ES provided by their forest management efforts. The study demonstrated that participatory tools, combined with free-access satellite images and repeat photography are suitable approaches to engage local communities in discussions regarding ES and to map and prioritise ES values.

Keywords: community forestry, participatory tools, local knowledge, developing countries, ecosystem services assessment, repeat photography, expert opinion

1. Introduction

In recent years, community forestry (CF) has become a globally popular approach to forest management (Agrawal and Chhatre, 2006; Purnomo, 2012). CF has been considered a successful national strategy to improve rural livelihood and environmental protection in Nepal, where local communities are protecting and managing forest resources to increase forest cover and conditions (Acharya, 2003, Khadka et al., 2012; Maren et al., 2013; MFSC, 2013; Niraula et al., 2013; WB, 2001) to provide forest products such as firewood, timber, fodder, leaf litter (Birch et al., 2014, Gautam et al., 2004; Pokharel et al., 2012) and other ecosystem services (ES). Although community-managed forests (CMF) are protected and managed by local communities, the benefits are consumed by local, regional, national and international users (FAO, 2013; Muhamad et al., 2014; TEEB, 2010). For example, many provisioning ES such as food, timber for local construction, firewood and fodder are used by local people, whereas other services, such as watershed protection, wildlife habitat and recreation, benefit users at the national or international level (Birch et al., 2014). ES, such as increased carbon sequestration, have a global significance (Bowler et al., 2012; Costanza, 2008). However, there have been few studies to assess and map ES supplied from CMF to date, in part because of a lack of clear policy directive or management framework but also because of a lack of data, methods and tools in developing and data-poor countries, such as Nepal. These two challenges interact, and identifying, assessing and mapping ES from CMF are key requirements to creating an awareness of the values obtained from CMF amongst planners and decision makers and to providing a basis for policy and management (Burkhard et al., 2012; Crossman et al., 2013; MEA, 2005; Muhamad et al., 2014). For example, ES quantification can improve efficiency investment to support improved forest management (Crossman et al., 2011; Crossman and Bryan, 2009; Farley and Costanza, 2010) and determine the extent to which compensation should be paid for the loss of ES in liability regimes (Payne and Sand, 2011).

Spatial information on the local uses and perceptions of ES can improve landscape planning and management within rapidly changing landscapes (Abram et al., 2014; Baral et al., 2014c), and a wide range of methods and tools have been utilised to assess ES. These include: biophysical and environmental models (Bryan et al., 2010; Crossman et al., 2012); expert opinion or professional judgment (Burkhard et al., 2010; 2012; Vihervaara et al., 2010; Yapp et al., 2010, Palomo et al., 2013); users perception (e.g., Smith and Sulivan, 2014) or social and community values (Raymond et al., 2009; Sherrouse et al., 2011; van Oort et al., *in this volume*); participatory approaches (Fagerholm et al., 2012; Palomo et al., 2013); visual knowledge by repeat photography (Garrard et al., 2012; Niraula et al., 2013; Webb et al., 2010); participatory geographical information system (PGIS) tools (Baral, 2008; Brown, 2013; Brown and Denovan, 2014; Brown et al., 2012; Sieber, 2006); and remote sensing and GIS tools (Baral et al., 2014b; Frank et al., 2012; Vihervaara et al., 2012).

Each approach has its strengths and limitations. For example, participatory approaches and expert opinion can provide rapid ES assessment but the accuracy and reproducibility of results may be lower (Krueger et al., 2012; Jacobs et al., 2014). In contrast, on-site measurement and mapping may be more accurate but it takes more time and resources (Baral et al., 2014c). In data-poor regions such as Nepal, participatory approaches are preferred as they do not require a substantial amount of expensive biophysical data (Baral et al., 2014c; van Oort et al., *in this volume*), and they can be applied rapidly. Local situations are often better understood by local people than by outside experts (Nightingale, 2005; Ojha et al., 2009) and their perceptions of the value of different ES are critical for future management (Peruelo, 2012; van Oort et al., *in this volume*).

This study aims to assess a local community's priority ES and their perceptions of changes as a result of the implementation of CF in a landscape in the middle hills of Nepal between 1990 and 2013. A spatial analytical approach and rapid assessment techniques were used to identify, map and assess trends in the supply of ES across the landscape and to rank the importance of different ES for local livelihoods and community welfare.

2. Methods

2.1 Study area

Dolakha district is located in the central mid hills of Nepal, 133 km northeast of Kathmandu, the capital city (Figure 1, see KML file[1]). The district covers 219,100 ha, of which 35% are Himalaya/high mountains, 40% high hills and 25% mid-hills (DDC, 2011) that range in elevation from 732 m to 7,148 m above sea level (DDC, 2011). Although small in area, the

[1] KMZ file representing study area is available in online version of the article.

Dolakha district has a high diversity in climate, vegetation and land uses because of the variation in altitude (DDC, 1999). This district is typical for the variety of landscapes and ecosystems in the mid-hills of Nepal (Niraula et al., 2013).

In the district, the watersheds of two small rivers, the *Charnawoti* and *Dolati* – tributaries of the *Tamakoshi* River – were selected for the study. CF has been implemented in these watersheds since the early 1980s with the support of a Nepal-Swiss CF Project, financed by the Swiss Development Cooperation. Management of most of the forests in these watersheds has been transferred to local communities. The total area of the two watersheds is 15,930 ha, distributed over a wide altitude range from 850 m to 3,500 m above mean sea level (Shrestha et al., 2012). Forests occupied 63% of the total land area, followed by agricultural (36%) and pasture land (1%).

The study area consisted of 82 Community Forests User Groups (CFUGs) and 12,739 households who have been managing 7,183 ha as CMF (DoF, 2014). These CMF comprise approximately 70% of the forested area in the study landscape (Shrestha et al., 2011). The study landscapes were selected based on the following criteria: more than 20 years of CF, accessibility for study, good forest conditions, and the inclusion of a variety of forest types.

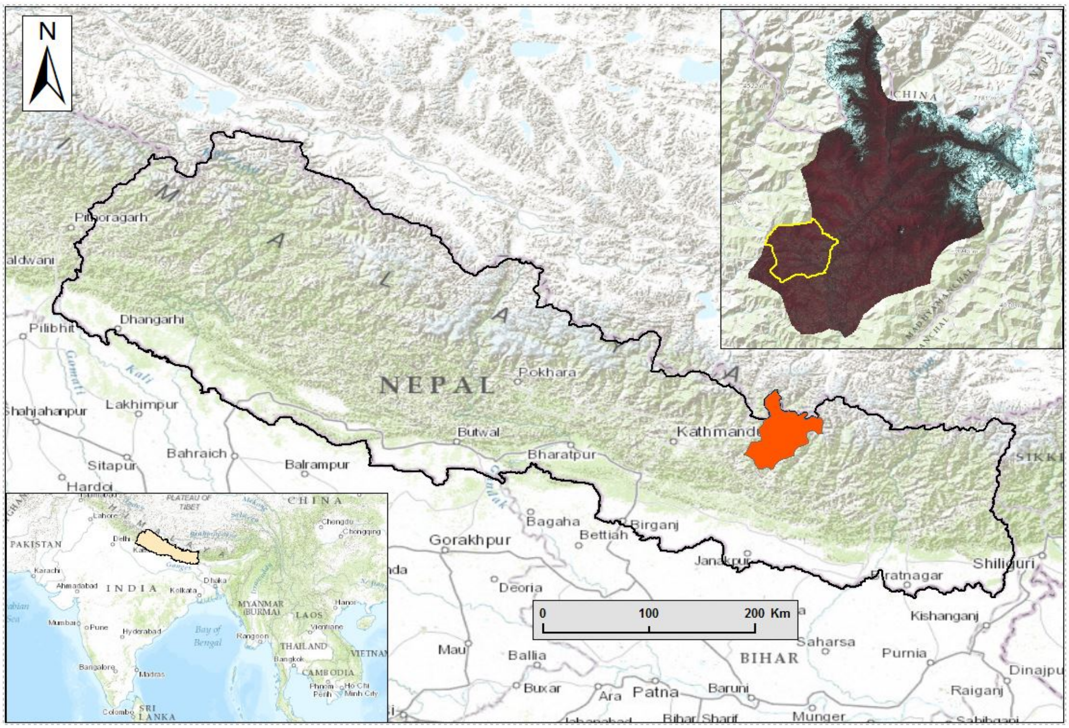

Fig 1: Location of study area: catchment of *Charnawoti* and *Dolati* rivers, tributaries of *Tamakoshi* River surrounding of Charikot, district headquarter of Dolakha district

2.2 Study design

A combination of approaches was used in the study (Table 1, Figure 2, details also in Appendix I: online supporting material), including direct field observation, semi-structured interviews (SSI, e.g., Bryman, 2001; Patton, 2002), focus group discussions (FGD, e.g., Gray, 2004; Waldegrave, 2003), repeat photography (e.g., Garrard et al., 2012; Niraula et al., 2013; Webb et al., 2010) and expert opinions (e.g., Burkhard et al., 2009, 2012; Vihervaara et al., 2010; Yapp et al., 2010, Palomo et al., 2013). This information was integrated with land use and land cover information procured from government agencies and in a geographical information system (e.g., Brown, 2004; Fagerholm and Kayhko, 2009; Plieninger, 2013; Tyrvainen et al., 2007). The results of these approaches are, to some extent, subjective and the accuracy and reliability of outputs depend on the degree to which local communities understand the functioning of the study landscape (Baral et al., 2013).

Table 1: Summary of methodologies used to assess community perceptions and expert opinion of ecosystem services in community managed forests in the middle hills of Nepal (SSI: Semi Structured Interview; FGD: Focus Group Discussion; CFUG: Community Forestry Users Groups; TEEB: The Economics of Ecosystem and Biodiversity;GIS: Geographical Information System, PGIS: Participatory GIS).

Task	Evaluation classes	Data sources or tools used	Who was involved?	Outputs
Identification and assessment of the status of ES supply	3. Very high, 2. High, 1. Low 0. Very low	Field observation; SSI, FGD, satellite image, photographs	CFUG members, experts, researchers	Table of ES (based on TEEB, 2010), their status and location of users
Identification and assessment of the scale of ES users	*Scale of users:* a. Onsite, b. Local, c. Regional, d. National e. Global	Field observation; SSI, FGD, satellite image, photographs	CFUG members, experts, researchers	Table of ES (based on TEEB, 2010), their status and location of users
Ranking of ES based on contribution to livelihoods	a. High value b. Medium value c. Low value d. No value	FGD, satellite image, photographs	CFUG members, experts, researcher	Prioritised ES presented in word cloud
Assessment of trend in ES	a. Heavily increasing, b. increasing, c. no change, d. decreasing and e. heavily decreasing	FGD, satellite image, photographs	CFUG members, experts, researcher	Flower diagram
Spatial mapping of prioritised ES	Relative ES abundance[a] (high relative capacity, medium relative capacity, low relative capacity, no capacity	Satellite image, GIS, PGIS	Researcher and GIS expert	Spatial maps of priority ES

[a] Relative ES abundance follows Burkhard et al., (2010a, 2010b, 2014).

2.3 Sample selection

A total of 10 CFUGs were selected from 82 CFUGs proportionately from three climatic zones using stratified random sampling; i.e., two out of 17 CFUGs from upper tropical (below 1,000 m), five out of 39 CFUGs from sub-tropical (1,000–2,000 m), and three out of 24 CFUGs from alpine (2,000–3,000 m) climatic zones (DDC, 2011). One FGD was conducted in each selected CFUG. One hundred interviewees for SSIs were identified through consensus in the FGD, 10 from each selected CFUG, to include members of disadvantaged groups such as women, indigenous nationalities and marginalised caste groups to ensure the views of these groups were reflected in the ES assessment. In addition, ten experts working in the government office and non-governmental organisations within the study landscape, e.g., the District Forest Office, and the District Federation of CFUGs, were also individually consulted.

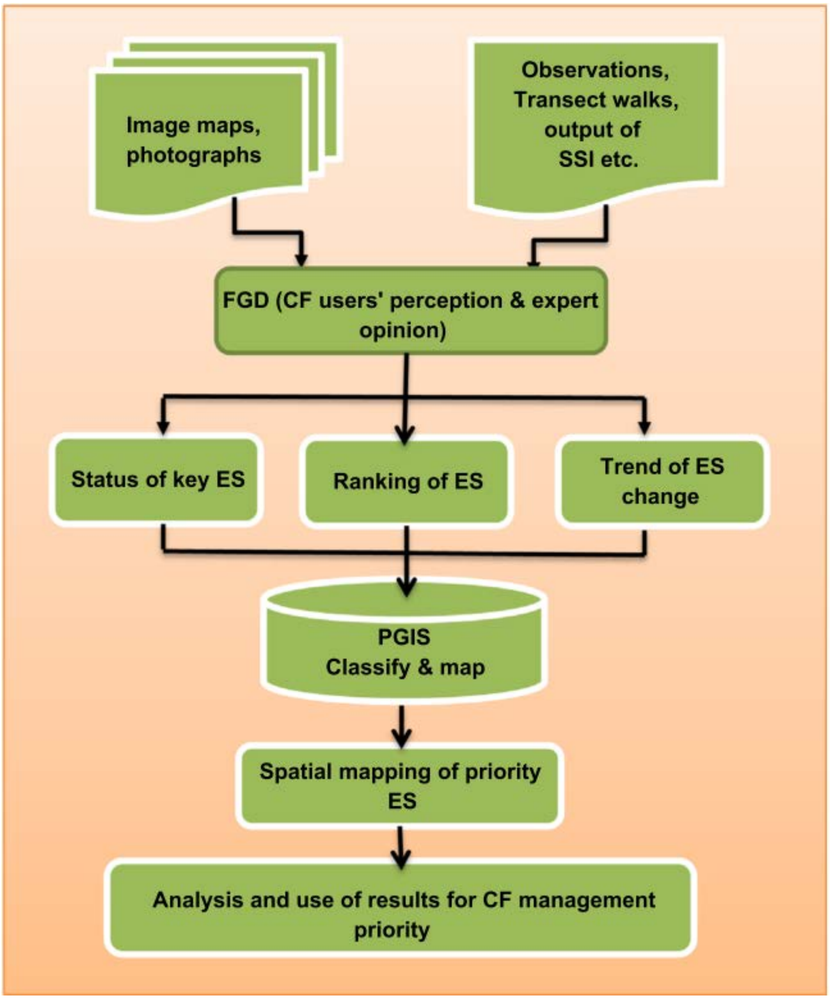

Fig 2: The methodological approach and flow for assessing and priority mapping of key ES in community-managed forests landscape

2.3.1 Identification and assessment of ecosystem services

SSIs were conducted in the months of March and April 2013, and the results were triangulated using other methods such as direct observations, transect walking and repeat photography. CFUG members (n=10) representing various groups related in age, gender, caste, education, occupation and economic status were identified. A list of experts was identified from the district and divided into two groups, e.g., senior and junior, based on experience in the study area. Interviewees were introduced to the concepts and types of ES (Appendix II: online supporting material) and the purpose of the study.

People's perceptions of ES derived from the local landscape were obtained using questions relating to the types of ES according to the method of Abram et al. (2014). The interview proceeded based on questions and possible options within each question (Appendix III: online supporting material) such as the variety and type of ES, the scale of use and the users of the ES. Responses were tabulated in a spreadsheet. This process was repeated for each of the 100 respondents across the 10 CFUGs. The ES, beneficiaries and scale of users were summarised according to a range of categories and combined in a single table using 'The Economics of Ecosystem and Biodiversity (TEEB)' framework (TEEB, 2010).

2.3.2 Prioritisation and mapping of ecosystem services

Many ES identified in the study area are not of equal priority for the community. It is also not feasible to manage all ES with the same importance and limited resources. During the SSI process, the respondent was requested to rank the top five ES from the list, presented in a numeric scale from 5 to 1, from highest to lowest priority based on their contribution to the livelihoods and wellbeing of the community. The result was a priority-ranking table in each CFUG formed by aggregating the responses from the interviewees. This was repeated in 10 CFUGs. A combined priority-ranking table was also created between the ES and frequency (sum of the numeric ranking value of an ES from 10 tables). An alternative priority-ranking table was prepared according to the perception of experts.

A word cloud was used to express the priority ranking of ES. The word cloud is a graphical representation where the size of each word in the cloud indicates the relative frequency of the occurrence of the word (see Clement et al., 2008; Hayes, 2008; McNaught and Lam, 2010;

Miley and Read, 2011; Wu, 2012). The word cloud creates a quick visual image, which allows for simple interpretation, comparison and contrast (Clement et al., 2008; Miley and Read, 2011). Each ES was incorporated with a frequency according to its priority in the program *Wordle* (*http://www.wordle.net*). Separate word clouds were generated from the two ranking tables for comparing and contrasting the priorities of the community and of the experts.

2.3.3 Perceptions of changes in ecosystem service supply between 1990 and 2013

During the SSIs, respondents were asked to discuss the status of land use and its effects on the supply of ES between 1990 (past condition) and 2013 (current status). The results were verified through a number of FGDs, repeat photography and field observations. The opinions of CFUG members and experts regarding changes in ES were scaled in five categories: highly increased (++), increased (+), stable (0), decreased (-) and highly decreased (--). The final results are presented in flower diagrams (see Figure 5; comparable figures were used in Baral et al., 2014b; Foley et al., 2005), where larger petals indicate a higher supply of respective ES in the study area.

2.3.4 Spatial distribution of ecosystem services

Distribution maps of major ES were prepared using participatory GIS techniques (Baral, 2008; Brown, 2013; Brown and Denovan, 2014; Brown et al., 2012; Sieber, 2006). Base maps were produced from Landsat 4 TM (Thematic Mapper) satellite imagery from 1990 (Figure 3a) and Landsat 8 OLI (Operational Land Imager) imagery from 2013 (Figure 3b) from the United States Geological Survey portal[2]. The images were cropped to cover the study area and checked for geo-location accuracy. No correction was required as the geo-location accuracy of the images was found to be within a pixel. The band combination for the map presentation was chosen in such a way that land cover would appear in natural colours. The image maps were printed in colour at 1:30,000 scales and were overlain on major settlements and roads for reference.

[2] http://earthexplorer.usgs.gov

The interpretation of the maps was part of the FGD with the participants involved identifying physical features, forests and other resources in the base maps. Then, the participants marked the locations of places that provided different ES on these maps using a set of symbols and colours to indicate types and abundance (e.g., the darker the colour, the higher the abundance of the ES). All marks and symbols from 10 different FDGs were subsequently transferred into a single image for each ES. In the case of overlapping symbols that were not matching from different FGDs, the marking of the FGD that was closer to the area was considered more reliable or of higher priority. The maps were then converted into digital format and were geo-referenced to use as a basis for generating maps of ES supply in 1990 and 2013 using the following approach.

To prepare the ES maps, the images were first clustered into ten different groups using the K-means clustering algorithm. More clusters were initially created, as it is always easier to merge them later if required. The clustered images were converted to vector maps and imported to GIS. The tools from the Open Foris Geospatial Toolkit[3] of the Food and Agriculture Organisation of the United Nations were used. The vector maps produced from the imagery were overlaid on corresponding base maps with the records of the participatory ES mapping. Based on those participatory maps, a particular ES class was assigned to each polygon of the imported vector layer in GIS. In the case of the polygons that covered two or more ES marks/symbols in the participatory map, the ES was assigned based on that which covered a majority of the area. The areas that were not covered by any symbol during participatory mapping were assigned ES classes based on expert knowledge by comparing the image signature of the marked area. Feedback from community members was sought on accuracy and improvements of the ES supply map.

[3] http://www.openforis.org/tools/geospatial-toolkit.html

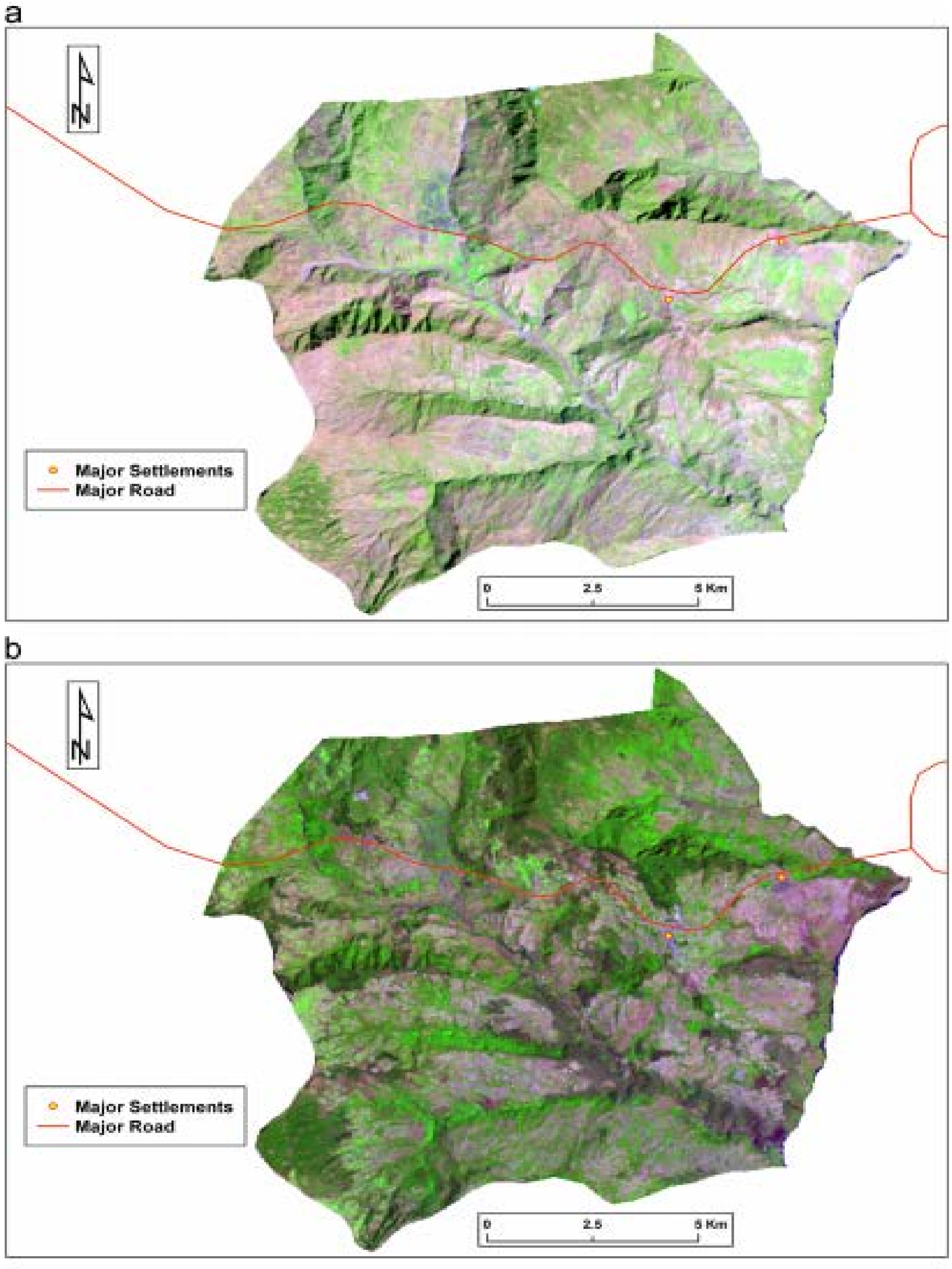

Fig. 3.Base maps for participatory mapping purpose, prepared using Landsat imagery of two time periods for identification, change analysis and spatial mapping of key ecosystem services in the study landscape. Note: dark green colour indicates forests, light green grasslands and brown colour shows agriculture lands (including residential areas). a: Base map prepared using Landsat 4 data from 1990. b: Base map prepared using Landsat 8 data from 2013.

3. Results

3.1 Key ecosystem services in community-managed forests

The empirical study showed that the studied landscape provided wide ranges of ES to communities on local, regional and global scales (Table 2). CFUG members and experts were critically engaged and defined 19 ES that were important in the local context through a consensus in the decision-making process. These ES were grouped according to TEEB (2010) into four categories: seven ES in provisioning services (ecosystem goods), seven in regulating services, two in habitat or supporting services and three in cultural services based on the knowledge and perception of local people and experts (Table 2). Ecosystem goods identified by participants were extractive or consumptive use ES, e.g., timber, firewood and water. Non-consumptive use ES were identified as air regulation, carbon sequestration, water purification, recreation and storm protection. Some ES with non-use value have also been identified in the study areas. Such ES are often strongly linked with social and cultural values of the local communities, e.g., religious sites, landscape beauty and the presence of non-game animals. Many ecosystem goods provided by CMF are site-specific, e.g., timber, firewood, fodder and leaf litter are available to the people of the study area and those in the vicinity, whereas most of the regulating and cultural services are available to a wide range of people from within the CFUGs and beyond.

Table 2: Summary of the key ES identified in the study area, description of the ES indicators, location of potential beneficiaries and the ES status/trend in the past two decades as perceived by a consensus of CF users and experts of the studied landscape (afterBaral et al., 2013 and Burkhard et al., 2012).

Type of ES	Description of ES	Indicator of ES	Measurement units	Beneficiary type	Location of beneficiaries	Local trend	Reasons for change
Provisioning services (Ecosystem goods)							
Food production (from agricultural land and forests)	Provision of food grains from agricultural lands; provision of berries, wild fruits, mushrooms, and support of honey production by forests	Cultivable land; amount of food materials	ha; tonnes ha^{-1}	Private	O	-	Shrubs decreased and large trees increase in forest area. Foods in understory are slowly disappearing
Forage production	Forage production potentiality from forests and grasslands for local livestock	Number of fodder producing species per ha and hectares of grassland	HL ha^{-1} or tonnes ha^{-1}	Private	O–R	++	Planted fodder trees and converted agriculture land to forest and grassland
Timber production	Timer stock at harvestable age in CMF	Number of large and mature trees per ha of dense forest	tonnes ha^{-1}	Private	O–R	++	Substantial pine plantation in early 1990 in denudated hills.
Firewood	Presence and abundance of preferred firewood species	Wood fuel biomass per ha; no. of fuelwood species per ha	tonnes ha^{-1}; kJ ha^{-1}; no. ha^{-1}	Private	O–R	++	Substantial pine plantation in early 1990 in denudated hills.
Generic resources	Variety of tree, shrub and herb species	No. of new species observed in CMF per ha	no. ha^{-1}	Private/ public	N–G	+	No. of species increase due to forest cover and plant diversity
Local medicines	Variety of tree, shrub and herb species with biomedical value	No. of species of medical value per ha / harvestable amount (kg or tonne) per ha	no. ha^{-1}; tonnes ha^{-1}	Private/ public	L–R	+	Pine forests reduced number species of medical value at understory
Freshwater	Increased groundwater stock by percolation and retention, which is available for drinking, irrigation and hydropower	Presence of water bodies such as no. of springs, ponds and streams; no. of projects using water (watermills, hydropower plants, etc.)	ML ha^{-1} yr^{-1}	Private/ public	O–R	++	Forest helps to reduce surface runoff and facilitate percolation, which recharges aquifers
Regulating services							
Fresh air regulation	Trees provide fresh oxygen and also absorb dust particles/toxins from atmosphere	Total leaf area (TLA); amount of pollutant in air	TLA ha^{-1}; no. of pollutants	Public/ private	O–G	+	Forest cover has increased, providing fresh oxygen and absorbing air pollutants
Carbon sequestration	Atmospheric carbon capture by trees, shrubs and herbs	Increasing hectares of forest cover; % of large trees per ha	tonnes ha^{-1} yr^{-1} or Mg ha^{-1} yr^{-1}	Public/ private	O–G	++	Carbon sequestration increases as hectares of forests increase (dense forests)
Groundwater recharge	Vital role of vegetative forest cover in regulating water flow and retention of water	Ground water recharge rate (net amount of water availability throughout the year downstream)	m^3 ha^{-1}	Public/ private	O–R	+	Suitable water source downstream
Natural hazard regulation	Forests act as a natural buffer, helping to protect from strong winds, landslides and other disasters	No. of landslides and other natural hazard cases per year	no. yr^{-1}	Public/ private	O–R	+	Created buffer of trees along roadsides and controls landslides
Water purification	Pure water running in streams	Quality and quantity of purified water	m^3 ha^{-1} or ML ha^{-1}	Public/ private	O–R	+	Forests help to percolate water runoff and purify water downstream
Disease regulation	Reduced diseases by regulating fresh air and water purification	Number of people affected by water and air borne diseases	No. of incidents yr^{-1}	Public/ private	O–R	?	
Crop pollination	Increased production of crops from larger population of bees and other insects that help pollinate forests and agricultural crops	Amount of food; no. of pollinators	tonnes ha^{-1}; no. ha^{-1}	Public/ private	O–R	+	Birds, bees and other pollinators increase as biodiversity increases
Habitat or supporting services							
Soil protection	Landslide prone areas covered by vegetation	Net savings in soil loss per ha	tonnes ha^{-1} yr^{-1}	Public/ private	O–R	++	Trees disrupt runoff rate and also hold soil
Biodiversity/ habitat for wild animals	Provides refuge to a large number of plants and wild animals. Observed/reported recurrence of wild animal and plant species in the forests	No. of new plants and wild animals	no. ha^{-1}	Public/ private	L–G	+	Increase of natural and plantation forests in the study area over the past 20 years
Cultural services							
Spiritual and religious values	Presence of temples and religious sites	Locations of temples and spiritual sites; no. of people visiting these locations	no.; no of visitors yr^{-1}	Public	O–L	0	Spiritual and religious values are the same as before

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Type of ES	Description of ES	Indicator of ES	Measurement units	Beneficiary type	Location of beneficiaries	Local trend	Reasons for change
Aesthetic values	Enjoyment of a landscape's scenic beauty	No. of visitors appreciating the visual quality of the landscape	no. yr^{-1}	Public	O–R	+	Denudated hills became forested, which beautifies the surroundings
Recreation and ecotourism	Opportunity for recreation and ecotourism	No of recreation sites; no. of visitors	no.; no of visitors yr^{-1}	Public	O–R	+	Road access improved and the area is being developed for hiking and picnicking

Note: Keys to the status: '++' highly increasing; '+' increasing; '-' decreasing; '--' highly decreasing; '0' no change; ‘?’ not known. Key to scale of users: 'O' onsite users (who are living inside and adjoining forests and have been protected and managed ES), ‘L’ - local users (off-site but living within the forest surroundings up to 10 km distance from the forests and have also protected and managed ES;‘R’ - regional users (who are living between 10 km and 1000 km downstream of the forests and in nearby cities, but have not contributed to resource management; ‘N’ - national users within a country (people living in the country of the study’s landscape (Nepal) who also have not contributed to resource management);‘G’ - global users (people worldwide who have not contributed to resource management, and do not know where the landscape is located). Key to measurement units: ‘no.’ - number;‘ ML’ - megalitres;‘HL’ - head load (——————————30 kg);‘tonnes’ - metric tonnes (1000 kg);‘ha’–hectare; ‘ha^{-1}’- per hectare;‘yr^{-1}’- per year;‘m3’- cubic metre.

3.2 Priority ecosystem services

Priority ES varied according to the respondents’ background and interests (Figure 4). Priority given by CFUG members was different than the experts and represented their daily needs (Figure 4a). The study showed that the long-term experience of the local community in the participatory management of CMF was important in forming their views. For example, CFUG members have preferences for food production, firewood, timber production, biodiversity and spiritual values, whereas the experts had a wider view (Figure 4b), assigning higher priority to timber production, biodiversity, carbon sequestration and freshwater.

Among the CFUG members, different interest groups had different views on the priority ES. For example, female CFUG members assigned priority to firewood for domestic consumption, whereas men assigned higher priority to timber production for household construction or income. Blacksmiths assigned high priority to charcoal production and the poorest members prioritised food production, such as mushrooms and various types of fruits. Experts from government offices assigned priority to timber production for increasing revenue, whereas experts working in civil society organisations prioritised provisioning and regulating services, e.g., food production, freshwater, climate regulation, water cycle regulation and natural hazard reduction for the betterment of livelihoods.

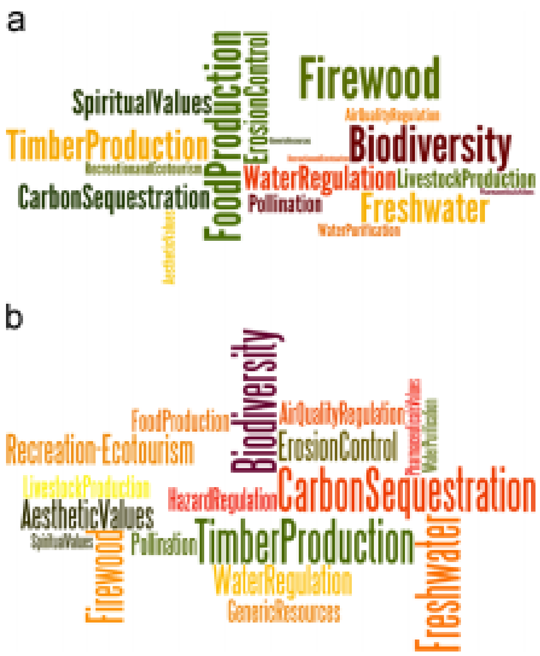

Fig. 4: Word clouds showing priority ecosystem services (ES) in study area. The actual words were originally represented in Nepali language and translated to English for the publication. The word size indicates the priority of respective ES (the larger in the size was the higher priority given by the respondents). a: Prioritisation of ES by community members. b: Priority ES based on experts' opinion

3.3 Ecosystem services changes in the past two decades

The analysis of repeat photography, field observations and respondent opinions indicated that the forest area in the study region increased by 1,149 ha (7.2%) between 1990 and 2013. Most of the agricultural lands and grasslands have changed to low-density forests, and 2,517 ha of low-density forests have become high-density forests (Niraula et al., 2013). Based on the perceptions of local people and field observations, this land cover change resulted in a significant change in the supply of various ES (Figure 5). ES such as timber, firewood, carbon sequestration and freshwater or biodiversity were perceived to have increased the most, whereas food production from the landscape as a whole had gradually decreased over a 20-year period.

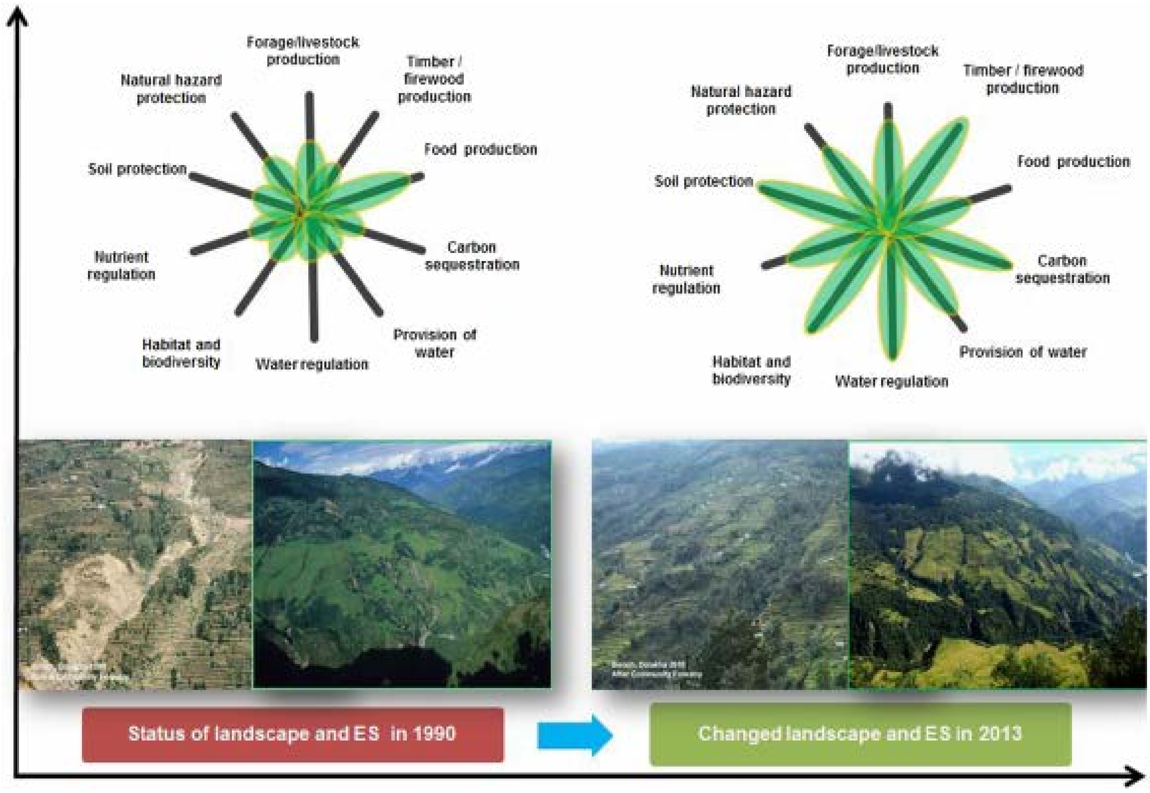

Fig. 5.Typical land use transition (below photographic documentation) in the study landscape and effects on key ecosystem services (flower diagrams above). (Figure inspired by Foley et al., 2005; Photo credit:Pokharel and Mahat, 2009).

3.4 Spatial distribution of priority ecosystem services

The study identified three ES of high priority in this region: timber production, food production, carbon sequestration as well as biodiversity. Local people perceive the potential source of income and a means for reducing climate change impacts as reasons for the high priorities of carbon sequestration and biodiversity. The spatial distribution of these ES varied considerably (Figures 6a to 6h). Timber production is concentrated to the northeast of Charikot city and near the banks of the *Tamkoshi* and *Charnawoti* rivers, whereas food production is distributed throughout the study area. Likewise, rich biodiversity areas are concentrated in the sub-tropical region in the lower part of the *Charnawati* river. Carbon sequestration is distributed throughout the landscape but is highly concentrated where timber production and biodiversity are high. The landscape’s capacity for timber production, biodiversity and carbon sequestration were substantially enhanced in 2013 compared to 1990 levels, whereas the land areas being managed for agriculture declined and the quantity of food grain production decreased in that time period.

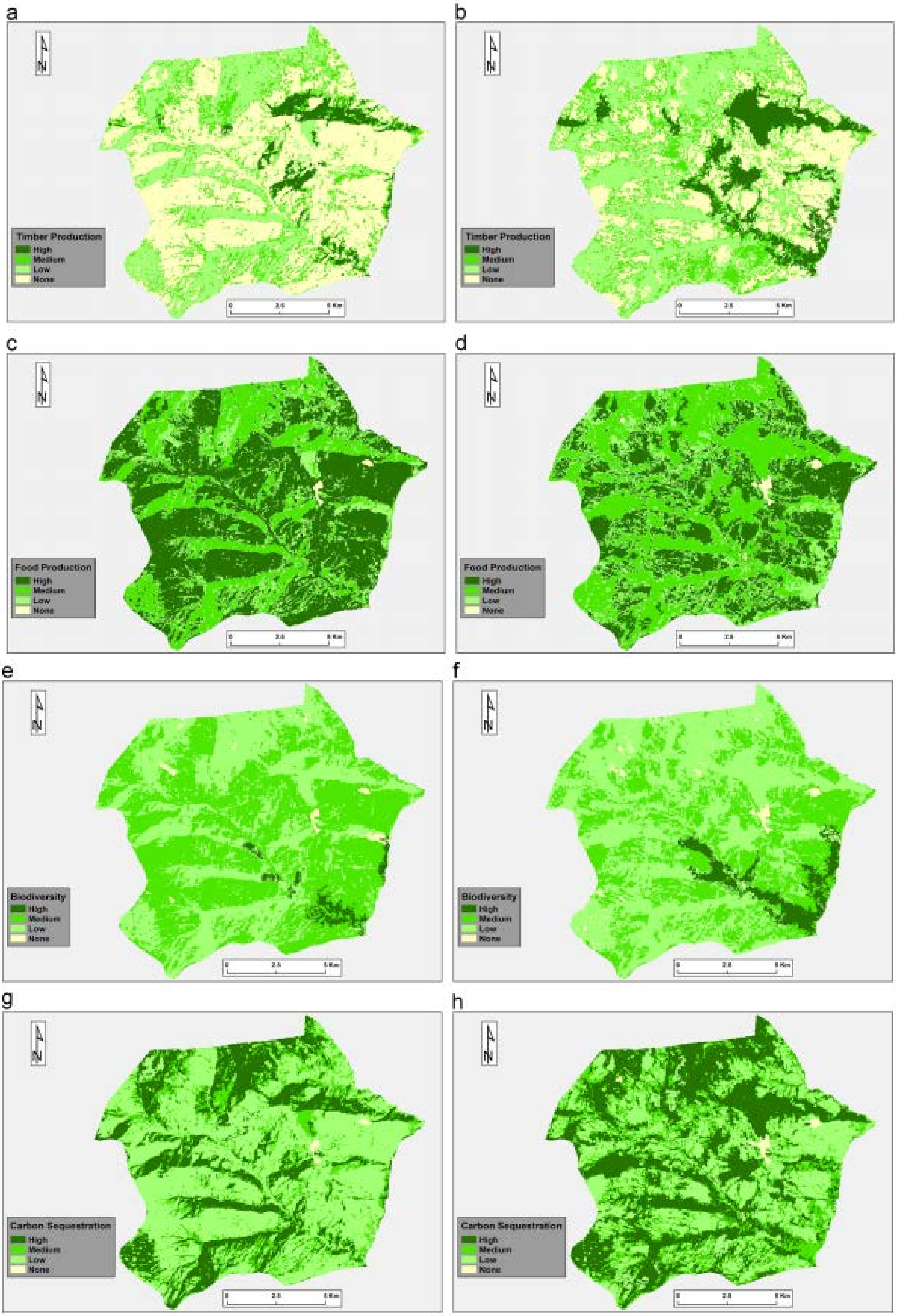

Fig. 6.Spatial distribution of four major ecosystem services (ES) and their changes in supply between 1990 and 2013 in typical complex community-managed forests of Dolakha, Nepal. a: Timber

production ES supply in 1990. b: Timber production ES supply in 2013. c: Food production ES supply in 1990. d: Food production ES supply in 2013. e: Biodiversity in 1990. f: Biodiversity in 2013. g: Carbon sequestration ES supply in 1990. h: Carbon sequestration ES supply in 2013.

4. Discussion

This research provides an overview of how local people and experts perceive the ES supplied from a landscape containing CMF and how they have changed between 1990 and 2013. The study demonstrates how stakeholders' knowledge, experiences, values and perceptions can potentially be used and spatially expressed in quick ES mapping in a data-poor area. However, the perception of priority ES depends on who is involved, where they live and their interactive relationship with the landscape (Garrard et al., 2012).

The novelty of the study lies in the use of relatively simple, participatory tools for assessing and mapping various ES at the landscape level. The results of the assessment show a trend of increasing supply of several ES in the study area in the past two decades, contrasting with previous studies at larger scales, which indicate a global trend of declining ES supply (e.g., Costanza et al., 1997, de Groot et al., 2002, MEA, 2005). For example, timber production, firewood and freshwater are declining in many parts of the world but are increasing substantially in our study area. In contrast, food production is increasing globally but is decreasing in our study area. Increases in ES supply are primarily related to increasing forest cover as a result of new plantations and local stakeholders' efforts in conservation and improving the condition of degraded forests. As a result of the CF program, substantial areas of agricultural lands and grasslands have become forests and large areas of sparse forests have become dense forests (Niraula et al., 2013, Niraula and Maharjan, 2011). The increased use of natural gas for cooking purposes in recent years has reduced the use of firewood in many villages, reducing the pressure on forests (IEA, 2006). Many respondents suggested that the increase in forest cover has significantly enhanced the infiltration capacity of the land and, consequently, freshwater flow has increased, sedimentation has decreased and the quality and quantity of water for irrigation and hydropower consumers downstream has increased.

According to the respondents, the influx of visitors to the landscape for ecotourism has increased in the past few years. It was assumed that this increase was a result of the increased aesthetic and recreational values of the landscape as provided by the increased forest cover and improved forest conditions. To benefit from this development, many CFUGs are promoting ecotourism and the Dolakha is becoming a popular tourist destination for the people of Kathmandu. Consequently, clusters of CFUGs have the potential to increase their income by charging visitors entrance fees and providing accommodations and associated services for tourists.

There is an inflow of people migrating into the study area from adjoining districts and even from cities, which is in contrast to the trend of outmigration from rural areas elsewhere (CBS, 2012). Respondents claimed that this was because of development and business opportunities that had emerged as a result of increased forest cover and ES in the study area. In contrast, a decreasing population trend was reported in certain remote villages as a result of land abandonment. Land abandonment may have positive as well as negative effects on ES (Luck et al., 2009; Baral et al., 2014a). In many cases, land abandonment may increase forest cover and have positive effects on the biodiversity and ES. However, land abandonment causes a decrease in food production and, if the abandoned land is not properly managed, may lead to a reduction in the ES supply as a result of the infestation of weeds and other pests in the landscape (Baral et al., 2014a).

The supply of many ES, such as carbon sequestration, natural hazard reduction, water regulation and soil protection (which enhances food production), was perceived to be higher than prior to the implementation of CF. There is the potential to generate income from those services and improve the rural economy through measures such as payments for ecosystem services (Bhatta et al., 2014). The livelihoods of local communities depend primarily on the supply of ES (Birch et al., 2014, FAO, 2013). This was demonstrated in the prioritisation of ES, where local communities prioritised those ES that are important to their livelihoods (Figure 4a). The differences in priority for certain ES indicated different levels of understanding about ES and their priority for local use (Figure 4). Our observation in the FGDs was that people involved in businesses such as tour operations and hotel management prioritised cultural and regulating services. Women CFUGs members placed priority on firewood as they are responsible for collecting firewood and cooking (Sigdel-Baral, 2014). Men were more interested in timber production for household and revenue generation. Poorer members of the communities assigned higher priority to the supply of forage and food for their subsistence livelihoods, which corroborates with the recent study by Sigdel-Baral (2014).

In this research, the participatory GIS helped to map indigenous knowledge at the local scale. This was also found to be valuable in other studies (Baral, 2008; Brown and Denovan, 2014; Brown et al., 2012; Sieber, 2006). The PGIS process engages local people in the assessment by integrating and contextualising complex spatial information into a comparably simple visualisation process. Mapping the ES supply can help to empower marginalised people in natural resource management who have little access to technology. This can improve participation in decision-making processes. Such maps can be produced with relative ease and at a low cost, as satellite images can be downloaded free of charge and do not require a high level of expertise to classify and process. Public participation in ES mapping and resource planning processes works not only to identify areas of common values or differences, but can be an illustrative and instructional tool for decision making. One example of effective dialogue and building trust between the community and decision makers comes from pre-planning for the development of community-based forest management in Nepal and elsewhere (Adhikari et al., 2014).

Using participatory techniques involving people's perception in assessing and prioritising ES in community-managed forest landscapes is rather new. This study provides only an initial indication of the possibilities. The relationship between perceptions and the actual use of goods or services such as timber production, water yield and quality, forage, carbon sequestration or biodiversity was not assessed in this study. Furthermore, the studied landscape is relatively small; therefore, results cannot simply be extrapolated to larger regions. The semi-structured qualitative process and the interpretation of repeat photography, topographic maps and satellite imagery as a source of information may also include unintentionally influenced community members' perceptions or expert judgments in the assessment process.

The results of this study can be further refined and developed and validated for new sites to provide a more robust analytical process for ES assessment.

5. Conclusions

The results of this study indicated that as a result of a CF program operating over the last 25 years, there has been a significant increase in forest cover in the studied landscape. This increase has resulted in a perceived increase in the provision of a wide range of ES that benefit local community members and wider populations across Nepal and beyond. Many ES, such as timber, firewood, freshwater, carbon sequestration, water regulation, soil protection, landscape beauty as well as biodiversity, were perceived to have increased in the study area. There were strong differences in the perceived value of different services among local people and experts and between genders and those of different class status and income class in the local communities. In general, whereas the ES provide considerable benefits at wider scales, local people have yet to perceive the real values of the different ES provided by their forest management efforts.

The study also demonstrated that participatory tools, integrated with free access satellite images and repeat photography, are suitable approaches to engage local communities in discussions about ES. Such tools can be used to quickly map and prioritise ES values. This can be a valuable first step for integrating ES-based management into CF. By considering both biophysical and socioeconomic values associated with ES, participatory approaches can improve efforts to integrate publicly perceived values into the decision-making processes of land and resource management, especially in data-poor regions.

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Supplementary materials

S 1: Description of data collection tools applied in the research

1. **Repeat photography and satellite images**

Photographs and satellite images of various time periods were collected and visually interpreted at time of discussion with community people, focus groups and experts, and explained how land use and land cover and associated ES have changed over time. These tools provide information regarding status and change of various ES. Further, these tools offer explicit detection of changes (e.g., land use and land cover as well ES changes) in the study area, which can be interpreted easily and rapidly without any advance tools and techniques. These techniques have been utilised by various authors (e.g., Niraula and Maharjan, 2011; Garrard et al., 2012, Niraula et al., 2013) and reported as simple approach, that can easily be understood by local forest users. Webb et al. (2010) argued that repeated photography techniques can potentially be used in assessments of ES, which is a valuable and efficient means of monitoring change everywhere.

Figure 7a: Photograph taken in 1989

Figure 7b: Photographs taken in 2010

Figure 7: Repeated photography of study area showing forest cover change in last two decades (Photos reproduced with permission from Elsevier Limited)

2. **Semi-structured interviews**

SSI is recommended as a good source of information in the case study (Patton, 2002), and is suitable to address more specific issues which also ensure cross-case analysis (Bryman, 2001). The interview aims to tap knowledge and experience of local users and experts for identify and ranking ES and to understand how and why the interviewees came to have their particular perceptions. The expressions and views of the CF users and experts were recorded in the field notes. Both the researcher and assistant took field notes and summary of the key points was verified with the interviewee at the end of each interview in order to reduce the researcher bias (Patton, 2002). During the situation setting in the interview process, interviewees were introduced to the basic concept of ES and management for local livelihoods.

3. **Focus group discussion**

FGD is a powerful means to gain opinion and experience of particular group (Krueger, 1988). FGD is suitable to record the experiences of different people, even those who are normally left out in general discussion (Waldegrave, 2003). Such FGD encourages people having same backgrounds to generate a variety of views and stimulates the discussion of new perspectives (Gray, 2004). One FGD in each selected CFUG was carried out for a specific group of local key informants including women, poor and disadvantaged groups, and ethnic minorities. A team of two people facilitated the FGDs and exchanged the roles of facilitating and note-taking in the series of discussions across focus groups. As in SSI, similar process was utilised to identify and to select priority ES in FGD.

S 2: List of potential ecosystem goods and services (TEEB, 2010) for orientation to stakeholders before conducting SSI and FGD

(1) Provisioning Services are ecosystem services that describe the material outputs from ecosystems. They include food, water and other resources.

- **Food:** Ecosystems provide the conditions for growing food – in wild habitats and in managed agro-ecosystems.
- **Raw materials**: Ecosystems provide a great diversity of materials for construction and fuel.
- **Fresh water**: Ecosystems provide surface and groundwater.
- **Medicinal resources**: Many plants are used as traditional medicines and as input for the pharmaceutical industry.

(2) Regulating Services are the services that ecosystems provide by acting as regulators e.g., regulating the quality of air and soil or by providing flood and disease control.

- **Local climate and air quality regulation:** Trees provide shade and remove pollutants from the atmosphere. Forests influence rainfall.
- **Carbon sequestration and storage:** As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.
- **Moderation of extreme events:** Ecosystems and living organisms create buffers against natural hazards such as floods, storms, and landslides.
- **Waste-water treatment:** Micro-organisms in soil and in wetlands decompose human and animal waste, as well as many pollutants.
- **Erosion prevention and maintenance of soil fertility:** Soil erosion is a key factor in the process of land degradation and desertification.
- **Pollination:** Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee.
- **Biological control**: Ecosystems are important for regulating pests and vector borne diseases.

(3) **Habitat or Supporting Services** underpin almost all other services. Ecosystems provide living spaces for plants or animals; they also maintain a diversity of different breeds of plants and animals.

- **Habitats for species:** Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migrating routes.
- **Maintenance of genetic diversity:** Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial crops and livestock.

(4) **Cultural Services** include the non-material benefits people obtain from contact with ecosystems. They include aesthetic, spiritual and psychological benefits.

- **Recreation and mental and physical health:** The role of natural landscapes and urban green space for maintaining mental and physical health is increasingly being recognised.
- **Tourism:** Nature tourism provides considerable economic benefits and is a vital source of income for many countries.
- **Aesthetic appreciation and inspiration for culture, art and design:** Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.
- **Spiritual experience and sense of place:** Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

S 3: Some sample questionnaires used during SSIs and FGDs

Section 1

1. What direct economic benefits / products do you obtain from the landscape?" Such as: various foods from forests, timbers, firewood, fodders, leaf litter, food grains from agriculture land etc.
2. What are indirect benefits provided by landscape for you, your family and wider society? Yes or no from the list provided and seeking their additional inputs.
3. Do your landscape provide home for numbers of flora and fauna?
4. Does the forest play a significant cultural and spiritual role for you, your family and society as whole?"
5. What are using these ES such as private/personal uses or public use?

6. At which scale (on-site, local, regional, national and global) are these ES used and enjoyed?

Section2

7. What are the five most important ES provided by the landscape in contribution of local livelihoods and community well-being? Answer in order of importance (with checklist).

8. Which trends (e.g., highly increasing, increasing constant, decreasing, and highly decreasing) do these ES follow in last two decades? Why?

Section 3

9. Could you please locate / mark top ranking ES on the base maps? In each FGD, the group members mark distribution of ES in base map using different color or symbol for intensity of various ES.