

# Approaches and tools for assessing mountain forest ecosystem services

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# Abbreviations

ARIES	Artificial Intelligence for Ecosystem Services
CFs	Community forests
GIS	Geographic information system
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs Tool
MEA	Millennium Ecosystem Assessment
MIMES	Multiscale Integrated Models of Ecosystem Services
TEEB	The Economics of Ecosystems and Biodiversity
TESSA	Toolkit for Ecosystem Service Site-based Assessment

# Executive summary

Mountain forest ecosystems provide a wide range of direct and indirect contributions to the people who live in the mountains and surrounding areas. Occupying steep slopes at high elevation, these ecosystems provide services such as stabilizing slopes, regulating hydrological cycles, maintaining rich biodiversity and supporting the livelihoods of those who are diverse in culture but vulnerable to poverty and food security. To manage these services sustainably, their diverse values must be recognized, assessed and valued. To support this assessment, this paper 1) reviews several tools for assessing the sociocultural, economic and ecological values of mountain forest ecosystem services, 2) demonstrates case studies of tool applications from several countries namely, Bhutan, India, Indonesia, Iran and Nepal, and 3) discusses assessment challenges that should be considered in the application of these tools.

Several tools are applicable in the assessment of sociocultural, economic and ecological values of mountain forest ecosystem services. *Sociocultural values* can be assessed with focus group discussions, participatory mapping tools, household or expert surveys and Q methodology. *Economic values* can be assessed with stated-preference techniques, revealed-preference techniques and benefit transfer. *Ecological values* can be assessed with the Toolkit for Ecosystem Service Site-based Assessment, the Integrated Valuation of Ecosystem Services and Trade-offs Tool, Artificial Intelligence for Ecosystem Services, and the Multiscale Integrated Models of Ecosystem Services.

Case studies in Bhutan, India, Indonesia, Iran and Nepal demonstrate applications of these assessment tools. *In Bhutan*, an application of benefit transfer showed that the average total value of forest ecosystem services was over USD 14.5 billion per year. *In India*, an application of stakeholder and household analyses indicated that a total of 29 different ecosystem services are available and sustain livelihoods of local communities near the Maguri Mottapung wetland. *In Indonesia*, an application of Q methodology identified anticipated benefits and concerns of forest watershed stakeholders related to certification applications for a payment for ecosystem services. *In Iran*, an application of the Integrated Valuation of Ecosystem Services and Trade-offs Tool showed that the regulation of ecosystem services has been declining in Hyrcanian forests despite the forests' critical roles in the region. *In Nepal*, an application of a spatial analytical approach and participatory assessment techniques identified key mountain ecosystem services for community forests at the Charnawolti sub-watershed of Dolakha, and demonstrated forest restoration on degraded lands over the last two decades.

Several challenges exist for the assessment of mountain forest ecosystem services and these must be reflected in assessment design. These challenges include the complexity of defining and classifying ecosystem services; limited availability of data on ecosystem services; uncertainties associated with climate change; complex relationships among services including trade-offs and synergies; and limitation of assessments to build successful payments for ecosystem services.



# 1 Introduction

Managing landscapes so they fulfil multiple demands of society is becoming a major challenge for policy makers. Land use and land cover are changing rapidly in line with the increasing population and changing demands of society (Ramankutty et al. 2002; Acevedo et al. 2010). In many parts of the world, natural vegetation is being cleared to make way for agriculture (Zak et al. 2008); and elsewhere, agricultural land is being revegetated for wood production, carbon farming or watershed protection. In many cases, changes in land use and land cover affect the ability of landscapes to support human health and well-being (Foley et al. 2005; MEA 2005; Hector and Bagchi 2007). Consequently, predicting the impacts of such changes on human welfare has become an active field of research (e.g. Foley et al. 2005; Zak et al. 2008; Polasky et al. 2011; Baral et al. 2014, 2016).

Ecosystem services reflect the ability of landscapes to support human lives, as these services represent the direct and indirect contributions of ecosystems to human well-being (TEEB 2010a). Ecosystem services represent diverse benefits from ecosystems to people, including the provision of food and water, regulation of climate and water, support for habitats for wildlife and maintenance of cultural values (MEA 2005; TEEB 2010a). These services play a vital role in maintaining human welfare, including the livelihoods of those living in forests around the world. Costanza et al. (2014), for example, asserted that the total value of ecosystem services in 2011 was approximately USD 125–145 trillion per year.

Mountain forests provide ecosystem services that support rich biodiversity, many livelihoods vulnerable to poverty and diverse indigenous cultures; this has led to an increased interest in mountain forest ecosystem services (e.g. Nasi et al. 2002; Maynard et al. 2010; Wilson et al. 2010; Price et al. 2011; Grêt-Regamey et al. 2012; Jacobs et al. 2016; Sears et al. 2017a, 2017b). Mountain ecosystems cover about 22% of the Earth's surface, contain large primary forests and have high biodiversity. These ecosystems are vital in stabilizing slopes and regulating the hydrological cycle. In turn, these services from mountain forests support mitigating flood and landslide effects downstream and provisioning clean water to downstream cities around the world (MEA 2005; Price et al. 2011; Grêt-Regamey et al. 2012; Gleeson et al. 2016). In addition, mountains are home to approximately 915 million people (Gleeson et al. 2016). Many of them are vulnerable to poverty and food security, heavily dependent on mountain forests for food and income and they are diverse in culture (MEA 2005; Price et al. 2011). Mountain forest ecosystem services play vital roles in providing basic needs for these marginalized people, supporting their economic activities and maintaining their cultural values.

Assessment is a key component of the management of mountain forest ecosystem services. It allows objective understandings of impacts of mountain forest ecosystems on human welfare; it raises awareness about the importance of these ecosystems to policy makers, local communities and environmental groups; it supports decision-makers to understand the value of mountain forest ecosystem services and identifies stakeholder preferences for the management of these services; and it helps inform land use planning to stakeholders and the public. However, ecosystem services assessment is complex and involves the assessment of sociocultural, economic and ecological values. This paper reviews mountain forest ecosystem services (Section 2), several potential tools for assessing sociocultural, economic and ecological values of these services (Section 3), demonstrates case studies of the assessment of these services from Bhutan, India, Indonesia, Iran and Nepal (Section 4), and addresses those assessment challenges that should be considered in assessment design (Section 5).

# 2 Mountain forest ecosystem services

## 2.1 Definition

Several definitions exist for ecosystem services (Table 1). One of the influential definitions is from the Millennium Ecosystem Assessment (MEA), and it defines ecosystem services as “benefits that people obtain from the nature” (MEA 2005). Many studies have refined this definition to improve the applicability of ecosystem services for decision-making, as outputs of ecological functions or processes that directly or indirectly relate to human well-being (Boyd and Banzhaf 2007; Wallace 2007; Fisher et al. 2009; TEEB 2009). Embedded in the MEA definition, for instance, The Economics of Ecosystems and Biodiversity (TEEB) defines ecosystem services as “the direct and indirect contributions of ecosystems to human well-being” (TEEB 2010a). Our paper uses this TEEB (2010a) definition to define mountain forest ecosystem services, since this definition explicitly recognizes different values of mountain forest ecosystem services, including sociocultural, economic and ecological values.

**Table 1. Definitions of ecosystem services in the literature.**

Reference	Definition
Costanza et al. (1997)	Benefits human populations derive, directly or indirectly, from ecosystem functions
Daily (1997)	Conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life
MEA (2005)	Benefits people obtain from ecosystems
TEEB (2010a)	Direct and indirect contributions of ecosystems to human well-being

## 2.2 Classification

A proper classification of mountain forest ecosystem services can support stakeholders and policy makers to make land use decisions and to investigate synergies, redundancies and trade-offs among ecosystem services provisioned by mountain forests. Differentiated categories exist for ecosystem services from different disciplines, different management purposes and different understandings of their complexity (e.g. de Groot et al. 2002; MEA 2005; Wallace 2007; Costanza 2008; Fischer et al. 2009). Of these categories, this paper follows four categories from the TEEB – provision services, regulating services, habitat services, and cultural and amenity services – since this framework supports the assessment of diverse values of ecosystem services by explicitly recognizing both direct and indirect contributions of mountain forest ecosystems to human well-being (TEEB 2010b) (Table 2).

## 2.3 Characteristics

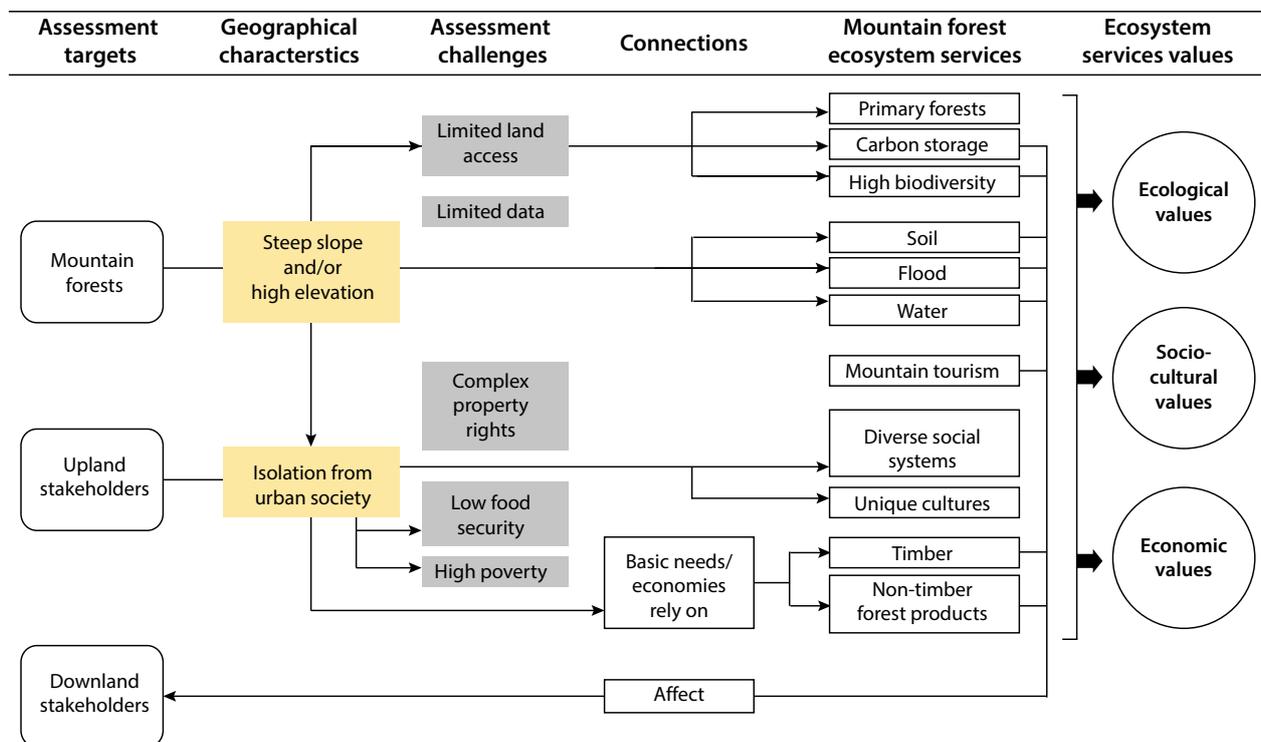
The main characteristics of mountain forest ecosystems include the existence of high slope and/or high elevation (MEA 2005; Grêt-Regamey et al. 2010; Price et al. 2011). These geographical characteristics are closely linked with mountain forest ecosystem services (Figure 1). Steep slopes and high elevation, for example, create forest watersheds that regulate floods and provide clean water to large populations in downstream areas. Steep slopes and high elevation create geographical barriers to accessing mountain forest landscapes so that such landscapes are less developed than undulating lowland. These

**Table 2. Categories of ecosystem services from mountain forests.**

Categories	Examples of mountain forest ecosystem services
Provisioning services	<ul style="list-style-type: none"> <li>• Timber for buildings and constructions for mountain communities</li> <li>• Firewood as an energy source for mountain communities</li> <li>• Non-timber forest products used by mountain communities</li> </ul>
Regulating services	<ul style="list-style-type: none"> <li>• Maintaining hydrological cycles for clean water</li> <li>• Water retention for mountain forests such as cloud forests</li> <li>• Mitigating avalanches and downstream flooding</li> <li>• Carbon sequestration in mountain ecosystems</li> </ul>
Habitat services	<ul style="list-style-type: none"> <li>• Maintaining life cycles of migratory species in mountain ecosystems</li> <li>• Maintaining genetic biodiversity in mountain ecosystems</li> <li>• Global hotspots for biodiversity in mountain ecosystems</li> </ul>
Cultural and amenity services	<ul style="list-style-type: none"> <li>• Intrinsic spiritual and aesthetic values from mountain forests</li> <li>• Recreational opportunities from mountain forests</li> <li>• Customs and belief systems of many mountain communities</li> </ul>

Sources: TEEB (2010b) and Price et al. (2011)

barriers often result in more primary forests, higher carbon stocks, richer biodiversity in mountain forest landscape compared with lowland areas. In addition, many communities in mountain forests have their own cultures and social systems, partially because they have little opportunity to interact with urban cultures and systems. On the one hand, this socio-ecological environment supports ecotourism for cultural and biodiversity experiences. On the other hand, these geographical barriers make local communities socially, economically and politically isolated from urban areas, limiting their access to social, economic and health infrastructure. Consequently, these communities are vulnerable to poverty and they lack food security. Their basic needs, such as food and medicine, rely heavily on mountain forest ecosystem services.

**Figure 1. Impacts of mountain slope and elevation on ecosystem services.**

### 3 Tools for assessment of mountain forest ecosystem services

Mountain forest ecosystem services provide sociocultural, economic and ecological values to service stakeholders (MEA 2005; Grêt-Regamey et al. 2010; Price et al. 2011) (Figure 2). Mountain forests are socioculturally connected with forest people (e.g. a tree species that has spiritual significance for local communities), produce inputs for economic activities of local communities (e.g. timber and fuelwood) and provide ecological benefits to communities both in and beyond mountain areas (e.g. carbon stored in trees). Assessment of these values is important for a comprehensive understanding of mountain forest ecosystem services, as all of these values illustrate direct and indirect benefits of mountain forest ecosystems to human well-being.

Several tools are applicable for assessing sociocultural, economic and ecological values of mountain forest ecosystem services (Table 3). These tools can be grouped into stakeholder analysis, market analysis and modeling analysis. The tools have their own strengths of being able to assess a particular value of ecosystem services (e.g. modeling analysis for ecological values of ecosystem services), although some tools can be used for assessing several values (e.g. InVEST for ecological and cultural values). For instance, while some modeling tools can assess sociocultural values of ecosystem services, they mainly focus on recreation and tourism (e.g. InVEST). Due to these different strengths, these tools can complement each other and can be jointly implemented to assess multiple values of mountain forest ecosystem services. In addition, these tools are differentiated in terms of required data, technical capacity, time and cost (e.g. Bagstad et al. 2015). These requirements must be considered in selecting a tool. This section introduces and reviews these tools based on their main strengths in assessing the sociocultural values (Section 3.1), economic values (Section 3.2) and ecological values (Section 3.3) of mountain forest ecosystem services.

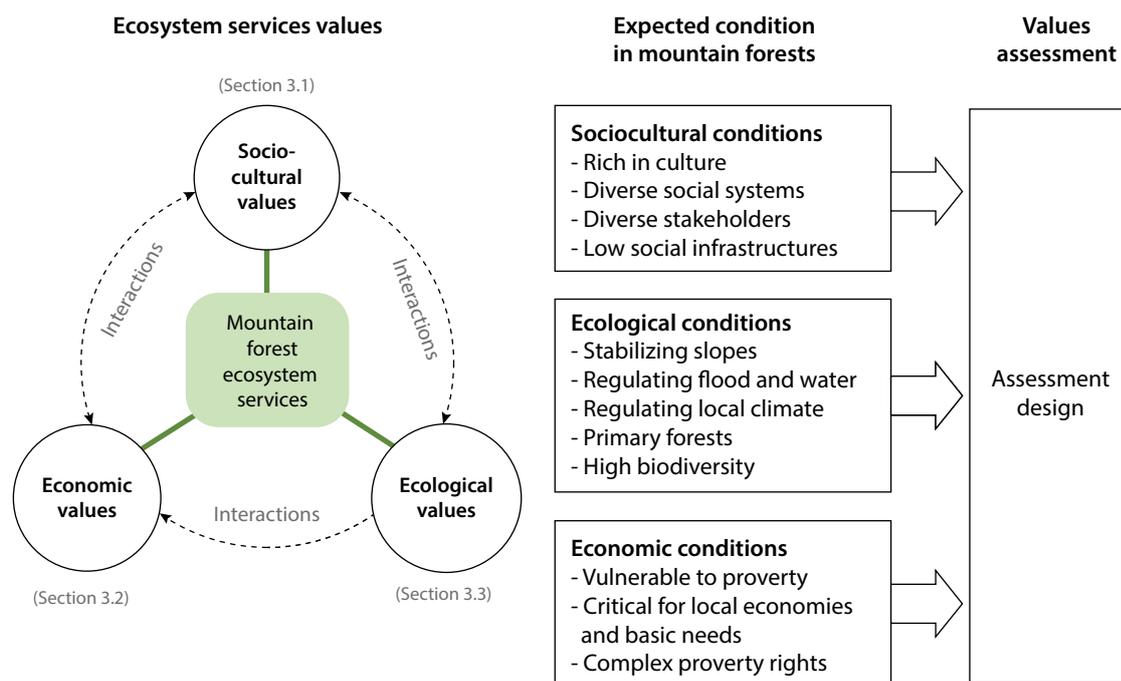


Figure 2. Multiple values of mountain forest ecosystem services and their interactions.

**Table 3. Descriptions of assessment tools for mountain forest ecosystem services.**

Assessment tools	Measurable values			Assessment types			
	Socio-cultural	Economic	Ecological	Qualitative	Quantitative	Survey-based	Spatial
<b>Stakeholder analysis</b>							
Focus group discussion	●	○	○	●	-	●	-
Participatory mapping	●	○	○	●	-	●	●
Stakeholder or expert surveys	●	○	○	●	●	●	-
Q methodology	●	○	○	●	●	●	-
<b>Market analysis</b>							
Stated-preference technique	-	●	-	-	●	●	-
Revealed-preference technique	-	●	-	-	●	○	-
Benefit transfer	-	●	-	-	●	-	-
<b>Modeling analysis</b>							
Toolkit for Ecosystem Service Site-based Assessment (TESSA)	○	●	●	-	●	-	●
Integrated Valuation of Ecosystem Services and Trade-offs Tool (InVEST)	○	●	●	-	●	-	●
Artificial Intelligence for Ecosystem Services (ARIES)	○	○	●	-	●	-	●
Multiscale Integrated Models of Ecosystem Services (MIMES)	○	●	●	-	●	-	●

(● Highly related | ○ partially related | - unlikely to be related)

### 3.1 Assessment of sociocultural values

Sociocultural values of mountain forest ecosystem services can be defined as nonmaterial benefits from mountain forest ecosystems following the definition of the Millennium Ecosystem Assessment (MEA 2005). These benefits include recreational facilities and tourism, aesthetic appreciation, inspiration, a sense of place and educational value. Sociocultural values play critical roles in sustainable management of mountain forest ecosystems since many communities live in mountain forests and their cultures heavily depend on mountain forest ecosystems (Price et al. 2011, Paudyal et al. 2018b). In other words, any changes in mountain forest ecosystems could readily affect their social capital and well-being (e.g. MEA 2005). Management of these ecosystems should reflect wider considerations of the social choices and preferences of these stakeholders (Farber et al. 2006; Sherrouse et al. 2014). Assessment of sociocultural values is critical since these values cannot be fully

captured by an economic valuation of ecosystem services (Kumar and Kumar 2008; TEEB 2010b; Chan et al. 2012). Assessment of sociocultural values would also allow understanding local values and indigenous knowledge related to mountain forest ecosystem services; identifying local priorities; anticipating potential conflicts over competing service uses; and building data for assessment of economic and ecological values of these services (Kyle et al. 2004; Paudyal et al., 2018b; Plieninger et al. 2013; van Ripper et al. 2012, 2017). Several tools can be utilized for assessment of these values, including: focus group discussions, participatory mapping tools, stakeholder or expert surveys, and Q methodology analysis (MEA 2005; Burkhard et al. 2012b; Busch et al. 2012; Scolozzi and Geneletti 2012; Infield et al. 2015).

**Focus group discussions** are applicable to identifying sociocultural values of mountain forest ecosystem services based on stakeholder perspectives and their dynamic interactions (e.g. Paudyal et al. 2015; Bhatta et al. 2016). These discussions should be designed to mitigate potential barriers for forest communities to be fully engaged in discussions because they might be new to a concept of ecosystem services; they might be embedded in different social norms, systems and languages; and/or they might be socially marginalized (Bloor 2001; MEA 2005; Price et al. 2011). Design of these group discussions requires effective strategies to explain a concept of ecosystem services to local communities (e.g. preparing images or maps) at the beginning of discussions, to invite participants while also considering any potential power imbalance among stakeholders, and to hire a facilitator who is knowledgeable and familiar with local society, culture and languages. Although a focus group discussion can be an independent assessment tool, it is often used to prepare an application of other assessment tools, such as in the design of participatory mapping, household surveys or Q methodology analysis (Paudyal et al. 2015; Bhatta et al. 2016; Jaung et al. 2016).

**Participatory mapping** can be used to visualize connections between local communities and forest mountain ecosystems (e.g. Corbett 2009; Paudyal et al. 2015). It can identify social, cultural and historical knowledge of marginal groups in mountain forests, such as indigenous people (Corbett 2009). Such knowledge could illustrate socio-ecological values of mountain forest ecosystem services, and their aspects might differ from aspects from mainstream stakeholders, such as government and private sectors. Several methodological tools are available for participatory mapping, and each tool is associated with a different cost and technical complexity (Corbett 2009). *Hands-on mapping*, for instance, requires communities to draw a basic map and has low cost and technological demand (Corbett 2009). However, hands-on mapping cannot produce geo-referenced mapping results so that it is hard to transpose them as scaled maps. *Mapping with scaled maps and images* requires ready-to-use scaled maps of mountain forests and/or their photos (Corbett 2009). Mapping results could be more precise than hands-on mapping results and they might be transferable to a geographic information system (GIS) (e.g. Burkhard et al. 2012b; Haines-Young et al. 2012; Vihervaara et al. 2010, 2012). However, such scaled maps might be unavailable for some mountain forests, and it would be costly to produce these maps (e.g. drone-based mapping). Moreover, its mapping results might be still subjective and error prone, as the accuracy depends on the knowledge and experience of the expert or professional for a particular ecosystem type. *Mapping based on GIS* should result in accurate mapping results (Corbett 2009). Because of GIS' high accuracy, these results could be more useful when communicating with other stakeholders including local governments. However, maintenance of a GIS would be costly and technically challenging, particularly for those local communities in mountain forests.

**Household or expert surveys** can be used to identify the sociocultural values of mountain forest ecosystem services (e.g. Bhatta et al. 2016). Conducting surveys might be administratively less challenging than other tools that require meetings among diverse stakeholders, such as participatory mapping and focus group discussions. For the same reason, surveys would not require consideration be given to imbalanced political powers among stakeholders. In contrast, surveys are limited to capturing dynamic interactions among stakeholders, which would be valuable inputs for a holistic assessment of the sociocultural values of ecosystem services. Several methodological tools are available for

household or expert surveys (Willcock et al. 2016). *Language-based surveys* can be effective in conveying meaning and ideas of ecosystem services to participants, but they are time consuming. *Image-based surveys* can be powerful for rapid communication and engaging the sense and emotions of participants, but these surveys can be ambiguous in conveying meaning and ideas about ecosystem services. Moreover, many studies have applied qualitative indicators, such as different degrees of ecosystem services provision (e.g. high, moderate or low) or different trends of provision (e.g. increasing, decreasing or stable trends).

**Q methodology** is applicable to the analysis of mountain ecosystem stakeholders in terms of their agreements and disagreements with issues related to ecosystem services management (e.g. Jaung et al. 2016). The main advantages of Q methodology are that it allows analysis of holistic views of diverse stakeholders, and that it can be conducted with a few key informants (Watts and Stenner 2012). The method requires the development of dozens of statements (40–50 statements) addressing management issues (e.g. “My community is culturally connected with forest watersheds.”) (Brown 1980; Watts and Stenner 2012). These statements are often developed using a focus group discussion as it allows the identification of issues related to diverse stakeholders. These statements are called ‘Q statements.’ In addition, the method requires survey participants who are often key informants of ecosystem services stakeholders to be identified. Q methodology surveys ask participants to indicate their agreements or disagreements with the developed statements. This survey procedure is called ‘Q sorts.’ Respondents’ opinions are ranked and recorded using a Q sort board whose shape follows a quasi-normal distribution. Q sort results are statistically examined to identify which statements are dominantly agreed or disagreed with among different stakeholders. These results indicate holistically the dominant stakeholder views on management issues and which stakeholders support these views.

### 3.2 Assessment of economic values

Assessment of economic values of mountain forest ecosystem services is critical for analyzing the feasibility of market-based management schemes for these services, such as payments for ecosystem services, voluntary carbon markets and biodiversity banks (Burgin 2008; Wunder 2015; Hamrick and Gallant 2017). Although market-based schemes are not a silver bullet, these schemes could be cost efficient and effective in provisioning mountain forest ecosystem services where property rights of ecosystem services are well established and transaction costs are low (e.g. Engel et al. 2008; Jayachandran et al. 2017). Vigorous economic valuation of mountain forest ecosystem services is also critical for lowering the transaction costs of developing market-based schemes. In a scheme of payments for environmental services, for instance, costs that service users must pay to join the scheme (e.g. USD 10 per month) could be much higher than the users’ true preferred costs (e.g. USD 3 per month) if this USD 10 per month payment is a result of an overestimation of users’ willingness to pay for services. This bias would increase transaction costs, make the scheme cost inefficient, and even discourage service user participation in the scheme. Three main approaches would be available for economic valuation of mountain forest ecosystem services: 1) stated-preference techniques, 2) revealed-preference techniques, and 3) benefit transfer.

**Stated-preference techniques** have been a major tool for economic valuation of ecosystem services, including contingent valuation and choice experiments; they are applicable to economic valuation of various mountain forest ecosystem services. They are non-market valuation methods designed to estimate monetary value on ecosystem services by directly asking preferences of survey participants (Bateman et al. 2002; Haab and McConnell 2002). These techniques can be used to elicit downstream water users’ willingness to pay for protection of upstream forest watersheds, or forest owners’ willingness to accept (with compensation) protection of mountain forests. Obtaining robust valuation results is a complex task requiring considerable efforts to reduce measurement errors and biases in survey design and administration, such as understanding the sociocultural backgrounds of participants before designing surveys, developing scientific scenarios of ecosystem services management for

surveys, building credible scenarios so that participants would believe their welfare would be affected by their responses (e.g. their agreement with a new government tax), conducting pilot tests of surveys and obtaining informed consent from participants (Arrow and Solow 1993; Carson 2000; Bateman et al. 2002; Whittington and Pagiola 2012). Further caution is required when designing stated-preference surveys for communities in mountain forests whose economic values might differ culturally (e.g. no private property rights) or whose conceptual understandings differ (i.e. it may be a challenge for them to understand a concept of maximum willingness to pay) (e.g. Mangham et al. 2009; Kenter et al. 2011).

**Revealed-preference techniques** have been applied to economic valuation of ecosystem services by employing market data (Champ et al. 2003). These data include price premiums for rooms with a mountain view in a hotel, indicating economic values of scenic beauty of mountain landscapes (e.g. hedonic price method); transportation costs of tourists for cultural experiences of a tribe in a mountain area indicating the economic worth of cultural values of mountain landscapes (e.g. travel cost method); and carbon prices in the voluntary carbon market (e.g. Hamrick and Gallant 2017). Revealed-preference techniques are considered robust approaches to economic valuation since they are embedded in real market data. However, these techniques would not be applicable if no market data related to mountain forest ecosystem services were available. For this reason, stated-preference techniques are alternatives to these techniques for ecosystem services whose markets do not exist yet.

**Benefit transfer** has been applied for economic valuation of ecosystem services by applying their available economic values at one site (or ‘study site’ that is already being examined for economic valuation) to another similar site (or ‘policy site’ that will undergo policy analysis) (Rosenberger and Loomis 2003; Plummer 2009); the method is applicable to mountain forest ecosystem services if valuation data are available (e.g. Kubiszewski et al. 2013). In a simplistic way, the main steps involve 1) analyzing mountain forest ecosystem services at a policy site, such as species diversity and bird numbers in mountain landscapes for ecotourism; 2) reviewing the literature on economic values of these services at other sites; 3) selecting a study site based on the literature review and comparing ecosystem conditions between policy and potential study sites, such as bird type and habitat size; and 4) transferring economic values of selected services from a study site to a policy site (Rosenberger and Loomis 2003). The main advantages of this technique are time and cost savings, which are a key requirement of many policy analyses. However, the technique is subject to various errors, so it must be applied with caution and the application should follow guidelines, such as a thorough literature review of potential study sites, and validation of benefit transfer results (Rosenberger and Loomis 2003; Plummer 2009).

### 3.3 Assessment of ecological values

Assessment of ecological values is vital for the management of mountain forest ecosystem services since it supports quantifying ecosystem services; identifying service providers and users; analyzing temporal changes in services; measuring delivered services in payments for ecosystem services; allocating resources among competing uses of services; decision-making for sustainable land use; and selection of conservation priority sites (Chen et al. 2006; Naidoo et al. 2008; Nelson et al. 2009; Egoh et al. 2011; Burkhard et al. 2012a). Several modeling tools are available for assessing the ecological values of mountain forest ecosystem services (Burkhard et al. 2010; Hayha et al. 2015; Paudyal et al. 2015). These tools must be selected in regard to targeted ecosystem services for assessment, assessment scope and scale, available data, cost, time, technical capacity of stakeholders and available technical support. This section introduces four modeling tools potentially applicable to this assessment task: 1) the Toolkit for Ecosystem Service Site-based Assessment, 2) the Integrated Valuation of Ecosystem Services and Trade-offs Tool, 3) the Artificial Intelligence for Ecosystem Services, and 4) the Multiscale Integrated Models of Ecosystem Services.

**Toolkit for Ecosystem Service Site-based Assessment (TESSA)** has adopted a simple approach to assessing and monitoring ecosystem services at the site scale (Peh et al. 2013). The tool allows assessment of watershed services, wild goods, cultivated goods and recreation in mountain landscapes. One of the advantages of this tool is that it does not require any advance technical knowledge or financial resources (Peh et al. 2013). The tool provides a guideline that illustrates eight steps for the successful assessment of ecosystem services at a site scale. It mainly focuses on stakeholder identification and engagement to explore various ecosystem services and to understand ecosystem services rights and value systems that different stakeholders obtain. Another important feature of the tool is that it requires assessing and identifying policy or strategy gaps in ecosystem services management, so their assessment could improve these policies at the site or across a broader region. Although TESSA uses a simple approach and focuses on stakeholders, stakeholder identification and their effective engagement might still be challenging owing to the complexity of ecosystem services management.

**The Integrated Valuation of Ecosystem Services and Trade-offs Tool (InVEST)** is open-source software developed by the Natural Capital Project for assessment and valuation of ecosystem services (Sharp et al. 2016). The tool provides several established models for assessing ecosystem services related to mountain forests, including: water yield for reservoir hydropower production, nutrient delivery, sediment delivery, habitat quality, forest carbon, visitation of recreation and tourism and crop pollination from bees (Sharp et al. 2016). The tool is applicable for the spatially explicit valuation of mountain forest ecosystem services, and it assists in developing sustainable planning and making decisions related to the management of mountain forest landscapes (Sharp et al. 2016; Baral et al. 2009, 2013, 2014; Outeiro et al. 2015; Arunyawat and Shrestha 2016). InVEST has been widely used across various countries in many types of ecosystems to assist in decision-making (Polasky et al. 2011; Baral et al. 2014; Arunyawat and Shrestha 2016) and is currently being validated worldwide (Kareiva et al. 2011).

**Artificial Intelligence for Ecosystem Services (ARIES)** is a new methodology and web-based application designed to assess ecosystem services, including mountain forest ecosystem services (Villa et al. 2011, 2014). The tool can illuminate values of these services to humans and helps decision-making related to ecosystem services. Mountain forest ecosystem services assessible by this tool include carbon sequestration and storage, aesthetic views, flood regulation, sediment regulation, water supply and recreation (Bagstad et al. 2011). ARIES and the corresponding rapid assessment software toolkit can currently handle a sizable cross section of issues of ecosystem services management. The methods and models are being fine-tuned in case studies in Madagascar, USA, Mexico and Spain. Compared with TESSA and InVEST, however, ARIES would require higher technical capacity and more time to develop a model (e.g. Bagstad et al. 2011).

**The Multiscale Integrated Models of Ecosystem Services (MIMES)** is a suite of models for land-use change and decision-making for spatial planning, including forest landscapes (Boumans et al. 2015). These models quantify the effects of land use change on ecosystem services and are applicable at global, regional and local levels (Boumans et al. 2007, 2015; Grigg et al. 2009). The MIMES use input data from GIS sources and time series data to simulate ecosystem components under different scenarios defined by stakeholder inputs. These simulations can help stakeholders evaluate how development, management and land use decisions would affect natural and human-built capital (Grigg et al. 2009). However, development and application of the MIMES would require considerable time and technical expertise (Bagstad et al. 2013).

## 4 Case studies

This section demonstrates five case studies of tool applications to assessment of mountain forest ecosystem services in Bhutan (using benefit transfer), India (using household and informant surveys), Indonesia (using Q methodology), Iran (using the InVEST) and Nepal (using participatory mapping and spatial analysis). These studies indicate negative or positive impacts of anthropogenically driven land use changes on the capacity of mountain forest ecosystems to provide services important for maintaining human well-being. Moreover, these studies show that restoration efforts to enhance one service of mountain forest ecosystems could compromise – or improve – another service, as various ecosystem services are in trade-off or complementary relationships.

### 4.1 Bhutan: Preliminary valuation of forest ecosystem services

Kubiszewski et al. (2013) estimate the value of ecosystem services in Bhutan and identify service users at the local, national and global level to demonstrate the roles of ecosystem services in Bhutan's national well-being. The study applies the benefit transfer method based on the studies on valuation of ecosystem services in similar ecological conditions in Bhutan. The total value of ecosystem services was estimated as USD 15.5 billion per year, which was four times higher than the national gross domestic product. Eighteen different forest ecosystem services were identified, including five provisioning services, nine regulating services and four cultural services. The average total value of forest ecosystem services was over USD 14.5 billion per year and accounted for over 93 percent of the total ecosystem services in Bhutan. With 71 percent forest cover, Bhutan's forest contributes to global climate mitigation with a value equivalent to USD 3.5 billion per year. However, this study acknowledges that the ecosystem services as public goods and services cannot be exchanged or marketed in the monetary value. This economic valuation of ecosystem services helps our understanding of their contributions to societies in Bhutan and highlights the significance for policy decision-making and national accounting.

### 4.2 India: Wetland ecosystem services and livelihood interface in Assam

Bhatta et al. (2016) assess drivers of ecosystem change, and the flow of ecosystem services impacting on local livelihood dependency at the local scale in the Maguri Mottapung wetland. This wetland is connected to mountain forest watersheds and is an important bird area in Assam state of India. The study employed both quantitative and qualitative analyses, including a semistructured questionnaire at the household level (10%), a focus group discussion, a key informant survey, and a stakeholder workshop identifying key drivers of change, community preference, ranking and value of various ecosystem services. The study showed that a total of 29 different ecosystem services are available, sustaining the livelihoods of local communities; however, many of them are declining. In particular, the fish stock is in critical decline, impacting directly on poor households. Unsustainable harvesting, siltation and use of chemicals in surrounding tea gardens are considered major drivers of wetland ecosystem change, and thus of the flow of ecosystem services. The study suggests the urgent need of a participatory management plan engaging local communities while developing government plans and programs at the local level.

### 4.3 Indonesia: Q methodology analysis of forest watershed stakeholders in Lombok

Jaung et al. (2016) apply Q methodology for an analysis of holistic perspectives of forest watershed stakeholders on certification of forest watershed services in Lombok, Indonesia. Upstream forest watersheds in Narmada district in Lombok are a source of piped water used in the Province of West Lombok. To protect these mountain forest watersheds, a scheme involving payments for environmental services has been implemented since 2010, where service providers are upstream forest communities; service users are piped-water consumers in West Lombok; and intermediaries are a multistakeholder institution (or *Institusi Multi Pihak*), local governments, NGOs and academics. Certification is a potential tool to improve monitoring of the scheme, but its application would be possible only when stakeholders support certification, as it is a market-based tool. The study used Q methodology to examine stakeholder perspectives on certification by interviewing nine key informants from the service providers, service users and intermediaries. Results indicated that these stakeholders had three major perspectives on certification: 1) cautious anticipation of improving the scheme through adoption of certification, 2) anticipation of benefits to upstream communities accrued through adoption of certification, and 3) skepticism about certification in general. These identified stakeholder perspectives support not only designing a certification system from the stakeholder perspectives, but also analyzing the feasibility of certification application for a payment for environmental services. Furthermore, these results revealed stakeholder perceptions about links among mountain forest ecosystem services (i.e. improvement of upstream biodiversity can support upstream watershed management).

### 4.4 Iran: Rapid assessment and scenario modeling of mountain ecosystem services

Zarandian et al. (2016) assess multiple ecosystem services in Hyrcanian forests of northern Iran based on rapid, qualitative and quantitative modeling approaches (Figure 3). The unique Hyrcanian forests provide vital ecosystem services for diverse groups of beneficiaries. Although the region contains globally significant natural habitats for the conservation of biological diversity, it is experiencing a rapid rate of forest conversion mainly derived from housing and farming development. To analyze the roles of these forests, the study assesses multiple ecosystem services in the region. First, to identify key services and their statuses, the study combined land use and land cover remote sensing data with locally gathered qualitative data through expert value judgment and direct interviews with sample households. Using the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) tool, the study later quantified and mapped three prioritized services: habitat provision as a proxy for biodiversity, carbon storage and water balance. Assessment results indicated the current distributions of available services, and patterns of their temporal changes through a comparison between three plausible scenarios: 1) business as usual; 2) protection-based zoning, which reflects an expansion of the protected area boundary to prevent land use changes; and 3) collaborative zoning through redefining the protection boundary simultaneously with an adjustment to meet local stakeholders' objective of expansion of anthropogenic cover. According to the study, the regulated supply of ecosystem services is gradually declining as well as having impacts on the integrity of the region. However, application of multiple ecosystem services maps as outputs of the modeling process, which shows the accurate quantities and the ecosystem services hotspots across the landscape, can significantly inform the spatial planning of the region and reduce the conflicts among various stakeholders, potentially creating win-win solutions for all.

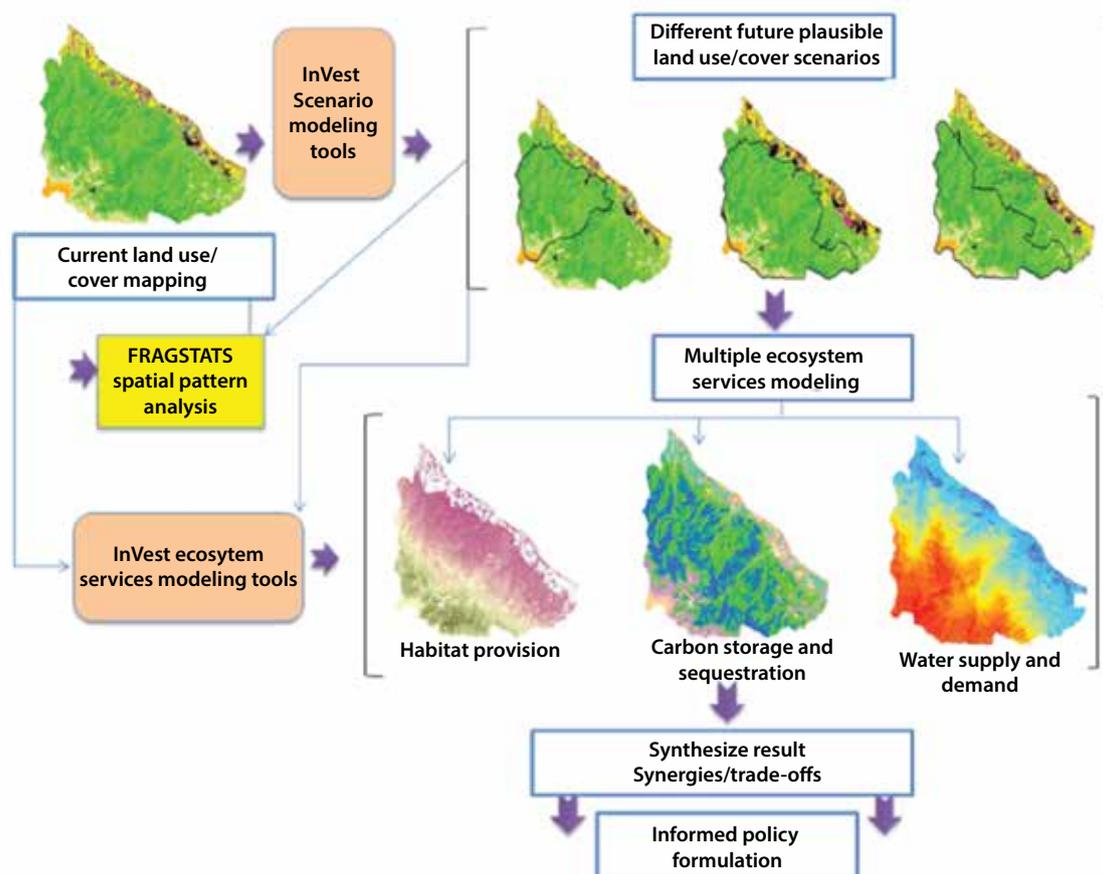


Figure 3. Research steps used by Zarandian et al. (2016).

#### 4.5 Nepal: Rapid assessment and mapping of ecosystem services in community-managed forests

Community forests (CFs) provide ecosystem services vital for local to global communities. Assessing and mapping ecosystem services are key requirements to creating an awareness of the values obtained from CFs amongst decision-makers for a base of policy and management decisions (Paudyal et al. 2017). However, the status and trend of change of these services in CFs have been little known because of a lack of clear policy, appropriate data, methods and tools in Nepal and similar data-poor countries (Paudyal et al. 2015). Using a case study of CFs at Charnawolti sub-watershed of Dolakha, Paudyal et al. (2015) assess a local community's prioritized ecosystem services and their perceptions of changes as a result of the implementation of community forestry in the middle hills of Nepal between 1990 and 2013 by combining a spatial analytical approach and participatory assessment techniques. The results showed that the substantial restoration of forests on degraded lands over the period of two decades as a result of community forestry has significantly increased the flow of ecosystem services and biodiversity that are beneficial for local, regional, national and international users. The study assessed a total of 19 ecosystem services important to the local communities in the sub-watershed, and local community members and experts prioritized timber, firewood, fresh water, carbon sequestration, water regulation, soil protection, landscape beauty as well as habitat for biodiversity for further planning and management of CFs. However, there were strong variations in the valuation of different ecosystem services between local people and experts, between genders, and between the various statuses and income classes in the local communities. The study demonstrates that a rapid approach using participatory tools, integrated with free-access satellite images and repeat photography, are suitable in this data-poor region. By interactively engaging with local people and experts, these tools can be used to quickly map and prioritize ecosystem services values as a valuable first step for integrating ecosystem services-based management into community forestry.

# 5 Assessment challenges

This section discusses five challenges for assessing mountain forest ecosystem services: complexity of defining and classifying ecosystem services (Section 5.1); limited data on ecosystem services (Section 5.2); uncertainties associated with climate change (Section 5.3); diverse relationships among ecosystem services, including trade-offs and synergies (Section 5.4); and limitations of assessments when developing successful payments for ecosystem services in mountain landscapes (Section 5.5). These challenges must be considered in designing an assessment of mountain forest ecosystem services.

## 5.1 Complexity with definitions and classifications

Multiple and complex definitions and classifications for ecosystem services often confuse ecosystem stakeholders and policy makers (Wallace 2008), including those for mountain forest ecosystem services. Ecosystem services have been classified in several ways depending on disciplines, purposes of ecosystem management and an understanding of their complexity (e.g. de Groot et al. 2002; MEA 2005; Wallace 2007; Costanza 2008; Fischer et al. 2009). One of the most widely applied classifications, for example, comes from the Millennium Ecosystem Assessment (MEA), which uses four broad categories: provisioning, regulating, cultural and supporting services (MEA 2005). However, Fisher et al. (2008) note the potential for double counting errors with the MEA classification if we attempt to value ecological processes (e.g. weathering, soil formation, nutrient cycling, etc.), which support multiple ecosystem services. Concerning any oversimplification of the complex and dynamic reality, moreover, Costanza (2008) proposes an alternative system that classifies each type of ecosystem services based on their spatial characteristics (e.g. origin, location and flows) and market characteristics (e.g. from excludable to non-excludable, and from rival to non-rival). On the other hand, many authors consider that a common definition and classification framework for ecosystem services remains a major challenge (Haines-Young and Potschin 2009), as studies on ecosystem services are often too singular, question dependent or context related (Burkhard et al. 2012a). Others argue that the definition of a common classification framework is neither feasible nor necessary (Costanza 2008). It is thus a complex matter to define and classify mountain forest ecosystem services, and such complexity challenges any assessment of these services.

## 5.2 Limited data

Assessment of ecological values of mountain forest ecosystem services can be constrained by limited data and high data collection costs (e.g. Sharma et al. 2015). Although proxies are often used to quantify and map ecosystem services, these proxies might not fit into primary data for key ecosystem services, such as biodiversity, carbon storage and recreation; it is suggested that these proxies only be applied for a general assessment of ecosystem services and for identification of hotspots or priority sites for multiple ecosystem services (Eigenbrod et al. 2010). The very high-resolution remotely sensed images have the potential to fill this data gap on the forest cover change for quantifying associated mountain forest ecosystem services. However, these datasets are still not accessible in many developing countries due to the high cost of acquiring the dataset.

### 5.3 Uncertainties with climate change

Global environmental changes, coupled with other stressors, are affecting the ability of mountain forest ecosystems to continuously provide the quality and quantity of ecosystem services. Assessments of climate change and its consequences for the provision of ecosystem services have been the focus of many studies (Pearing 2010; Dossena et al. 2012; Garcia-Lopez and Allue 2012; Jochum et al. 2012). However, there are still considerable debates and uncertainties on the nature and extent of impact due to variable projections and different climate change scenarios. Such ambiguity has hindered prompt adaptive responses, and societies may run the risk of going beyond critical tipping points (Bellamy and Hulme 2011; Lenton 2011).

### 5.4 Trade-offs and synergies among ecosystem services

Assessment of mountain forest ecosystem services would be complex due to diverse relationships among these services, including trade-offs and synergies. Trade-offs among these services occur when an increase in one service leads to a decrease in another service, and these trade-offs represent important externalities in current approaches to ecosystem services management (Rodriguez et al. 2006; Bennett et al. 2009). Trade-offs can be classified based on spatial scale (e.g. location of trade-offs), temporal scale (e.g. timing of trade-offs) and reversibility (e.g. the possibility of perturbed ecosystem services returning to an improved state) (MEA 2005; Rodriguez et al. 2006). Typically, trade-offs arise from management choices and specific management practices made by human society that can change the nature, magnitude and direction of services provided by ecosystems (MEA 2005; Rodriguez et al. 2006). For example, the development of large-scale hydropower in Bhutan could negatively affect biodiversity, soil conservation and downstream water quality. For this reason, TEEB Bhutan (n.d.) is assessing the potential impact of large-scale hydropower development on the provision of ecosystem services from the upstream mountains due to impacts of land use change in the upstream areas on the environment and the downstream areas.

Synergies occur when two or more services either increase or decrease together as a response to the same driver (Bennett et al. 2009). For example, a synergistic relationship exists among wildlife habitat and recreation opportunities in protected areas such as national parks and wildlife reserves. Protected areas not only provide better habitat for wildlife but also enhance opportunities for recreation and ecotourism (Lindsey et al. 2007). To assess synergies between services, it is necessary to monitor diverse bundles of ecosystem services from different conversion and management states (Braat and de Groot 2012).

### 5.5 Payments for ecosystem services

Although ecosystem services assessment is required for development of payments for ecosystem services in mountain forest landscapes, assessment alone is not sufficient for successful development. Rather, development of this scheme requires that additional conditions are met, such as well-defined property rights of mountain forest ecosystem services, sufficient demand for services from users, strong institutional capacity for administrating and monitoring payments for ecosystem services, and low transaction costs (e.g. Paudyal et al. 2018a; Wunder 2005, 2015; Engel et al. 2008). Payments for ecosystem services are a scheme designed to trade services between users (e.g. downstream water users) and providers (e.g. upstream forest owners) (Wunder 2015). It might support conservation-effective and cost-efficient management of mountain forest ecosystem services, but only if all the abovementioned conditions are met, since these conditions are prerequisites for 'conditionality.' Conditionality is a key criterion used to define payments for ecosystem services (Wunder 2015). For instance, it encourages service providers to deliver ecosystem services since they would not receive compensations without service delivery. However, conditionality cannot be established if property

rights of mountain forest ecosystem services do not exist; service users have low demand for services; stakeholders have limited capacity for administrative and technical management of ecosystem services; and/or transaction of ecosystem services is too costly. Therefore, ecosystem services assessment alone does not suffice for successful development of payments for ecosystem services in mountain forest landscapes. Rather, other conditions for conditionality should be met as well.

## 6 Conclusions

Mountain forest landscapes benefit not only the livelihoods of those living in mountain landscapes, but also those living downstream. Assessing these benefits from sociocultural, economic and ecological perspectives is a vital component of the sustainable management of mountain forest ecosystem services. To support the assessment, this paper reviewed 1) potential tools for the assessment of sociocultural, economic and ecological values of these services, 2) case studies of tool applications in Bhutan, India, Indonesia, Iran and Nepal, and 3) existing challenges for assessment. Sociocultural values could be assessed by focus group discussions, participatory mapping tools, household or expert surveys, and Q methodology. Economic values could be assessed by stated-preference techniques, revealed-preference techniques and benefit transfer. Ecological values could be assessed by several modeling tools, such as the Toolkit for Ecosystem Service Site-based Assessment, the Integrated Valuation of Ecosystem Services and Trade-offs Tool, the Artificial Intelligence for Ecosystem Services tool, and the Multiscale Integrated Models of Ecosystem Services. Furthermore, case studies demonstrated an application of benefit transfer in Bhutan; stakeholder and household survey analyses in India; an application of Q methodology to stakeholder perceptions of certification application to a payment for ecosystem services in Indonesia; an application of the InVEST in Iran; and participatory mapping and spatial analysis in Nepal. The paper also addressed the fact that the design of ecosystem services assessment needs to consider assessment challenges, including the complexity of defining and classifying ecosystem services, limited data of ecosystem services, uncertainties associated with climate change, complex relationships among ecosystem services, and limitations of the assessment tool involved in building successful payments for ecosystem services.

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Mountain forest ecosystems provide a wide range of direct and indirect contributions to the people who live in the mountains and surrounding areas. Occupying steep slopes at high elevation, these ecosystems provide services such as stabilizing slopes, regulating hydrological cycles, maintaining rich biodiversity and supporting the livelihoods of those who are diverse in culture but vulnerable to poverty and food security. This paper (i) reviews several tools for assessing the sociocultural, economic and ecological values of mountain forest ecosystem services, (ii) demonstrates case studies of tool applications from several countries namely, Bhutan, India, Indonesia, Iran and Nepal, and (iii) discusses assessment challenges that should be considered in the application of these tools.

In Bhutan, an application of benefit transfer showed that the average total value of forest ecosystem services was over USD 14.5 billion per year. In India, an application of stakeholder and household analyses indicated that a total of 29 different ecosystem services are available and sustain livelihoods of local communities near the Maguri Mottapung wetland. In Indonesia, an application of Q methodology identified anticipated benefits and concerns of forest watershed stakeholders related to certification applications for a payment for ecosystem services. In Iran, an application of the Integrated Valuation of Ecosystem Services and Trade-offs Tool showed that the regulation of ecosystem services has been declining in Hyrcanian forests despite the forests' critical roles in the region. In Nepal, an application of a spatial analytical approach and participatory assessment techniques identified key mountain ecosystem services for community forests at the Charnawolti sub-watershed of Dolakha, and demonstrated forest restoration on degraded lands over the last two decades. Several challenges exist for the assessment of mountain forest ecosystem services and these must be reflected in assessment design. These challenges include the complexity of defining and classifying ecosystem services; limited availability of data on ecosystem services; uncertainties associated with climate change; complex relationships among services including trade-offs and synergies; and limitation of assessments to build successful payments for ecosystem services.



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