

INBAR Working Paper



Technical Paper

Ecosystem Services From Bamboo Forests: Key Findings, Lessons Learnt And Call For Actions From Global Synthesis

**Kiran Paudyal, Li Yanxia, Trinh Thang Long, Shankar Adhikari, Soni Lama,
Kishor Prasad Bhatta**

2022



RESEARCH
PROGRAM ON
Forests, Trees and
Agroforestry

©The International Bamboo and Rattan Organisation 2022

This publication is licensed for use under Creative Commons Attribution-Non Commercial-Share Alike 3.0 Unported Licence (CC BY-NC-SA 3.0). To view this licence visit:

<http://creativecommons.org/licenses/by-nc-sa/3.0/>

About the International Bamboo and Rattan Organisation

The International Bamboo and Rattan Organisation (INBAR) is an intergovernmental organisation dedicated to the promotion of bamboo and rattan for sustainable development. For more information, please visit www.inbar.int.

About this Working Paper

This research was carried out by the International Bamboo and Rattan Organisation (INBAR) as part of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA). FTA is the world's largest research for development programme designed to enhance the role of forests, trees and agroforestry in sustainable development and food security and to address climate change. CIFOR leads FTA in partnership with Bioversity International, CATIE, CIRAD, INBAR, ICRAF and TBI. FTA's work is supported by the CGIAR Trust Fund: <http://www.cgiar.org/funders>

International Bamboo and Rattan Organisation

P.O. Box 100102-86, Beijing 100102, China Tel: +86 10 64706161; Fax: +86 10 6470 2166
Email: info@inbar.int

© 2022 International Bamboo and Rattan Organisation (INBAR)

List of Abbreviations

CIFOR	Center for International Forestry Research
ES	Ecosystem services
FAO	Food and Agriculture Organisation of the United Nations
GLF	Global Landscape Forum
ICRAF	World Agroforestry Centre
INBAR	International Bamboo and Rattan Organisation
MEA	The Millennium Ecosystem Assessment
NDCs	Nationally Determined Contributions
NPP	Net Primary Production
NTFPs	Non-Timber Forest Products
PES	Payments for ecosystem services
REDD+	Reducing emissions from deforestation and forest degradation, conservation of existing forest carbon stocks, sustainable forest management and enhancement of forest carbon stocks
SDGs	Sustainable Development Goals
TEEB	The Economics of Ecosystems and Biodiversity
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change

Table of Contents

1	Introduction	1
1.1	Background	1
1.2	Methods	4
2	Ecosystem Services from Bamboo Forests	5
2.1	Provisioning Services	7
2.2	Regulating Services	13
2.3	Habitat/Support Services	20
2.4	Cultural Services	23
3	Key Findings, Lessons Learnt and Call for Actions	25
3.1	Major Bamboo Forests' ES	25
3.2	Lessons Learnt	27
3.3	Call for Actions	28
	References	31
	Annex	
	List of ecosystem services from bamboo forests, including description and indicators, unit of measurement, beneficiary and scale	45

List of Figures

Figure 1: Change in total bamboo forests area from 1990 to 2020 (FAO, 2020).....	1
Figure 2: Total bamboo forest area by continent (FAO, 2020).....	2
Figure 3: Major ecosystem services from bamboo forests.....	5

List of Tables

Table 1: Qualitative comparison of ecosystem services from bamboo forests to those from natural forests, degraded forests, planted forests, grasslands and agricultural lands	6
--	---

1. Introduction

1.1 Background

Bamboo is one of the fastest-growing plants on earth, belonging to a subfamily of the grass family that is widely distributed across tropical and subtropical regions (Chauhan et al., 2016). Bamboo is widely cultivated within and outside forests in Africa, Asia, and Central and South America (Buckingham, Wu and Lou, 2014; Food and Agriculture Organisation of the United Nations [FAO], 2007; Troy Mera and Xu, 2014). There are more than 1,663 species belonging to 123 genera of bamboo throughout the world (Vorontsova et al., 2016; Wang et al., 2020). Up to 35 million ha of the global land area is covered by bamboo forest, approximately 1% of the total forest area (FAO, 2020). The total bamboo area increased by almost 50% between 1990 and 2020 (Figure 1). Although bamboo forest is available globally, Asia remains the richest continent with about 55% of total world bamboo resources (Figure 2).

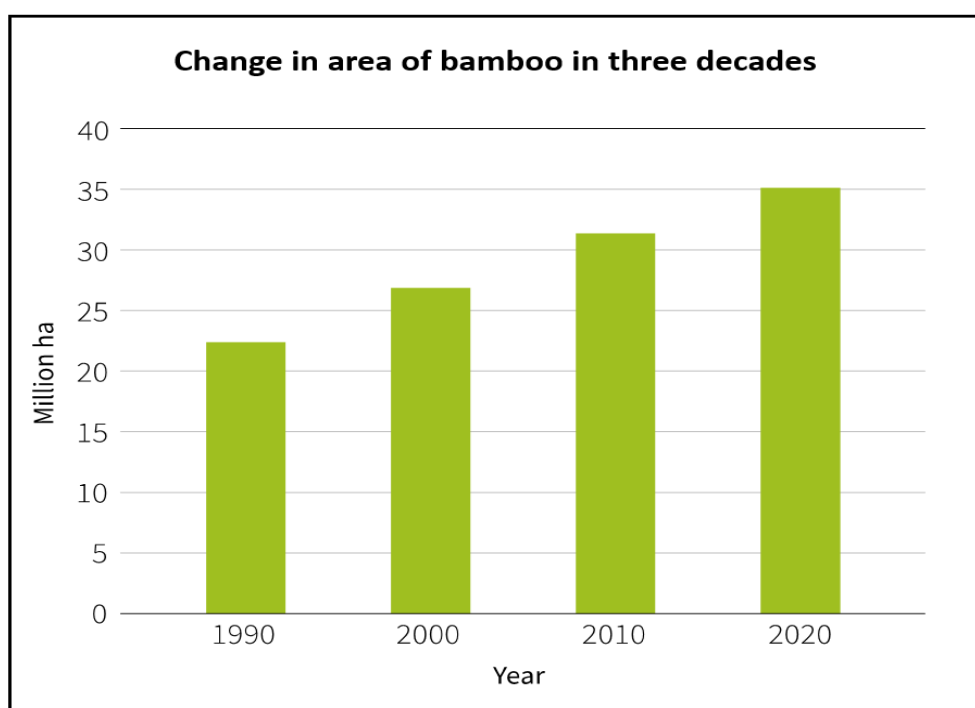


Figure 1: Change in total bamboo forests area from 1990 to 2020 (FAO, 2020)

Naturally, bamboo is an important integral part of forests and ecosystems, playing a significant role in nature conservation, environmental protection and human livelihoods across the tropics. Humans have derived benefits and services from bamboo (Bajracharya, Rajbhandary and Das, 2013). In several tropical countries, bamboo is an important component of the rural farming system and plays a critical role in rural economies, helping to sustain the livelihoods of rural people (Dev et al., 2020; ICRAF, 2020). Bamboo forests are important safety nets for

rural poor people, providing a multitude of timber and nontimber goods and services. Bamboo is a primary source of livelihoods, and bamboo stands provide materials for house construction, craft and fuelwood and protect traditional houses from strong winds (Nath et al., 2009; Nath, Lal and Das, 2015; Partey et al., 2017). People often have strong social and cultural connections with bamboo, and bamboo groves and forests have important spiritual significance for many communities.

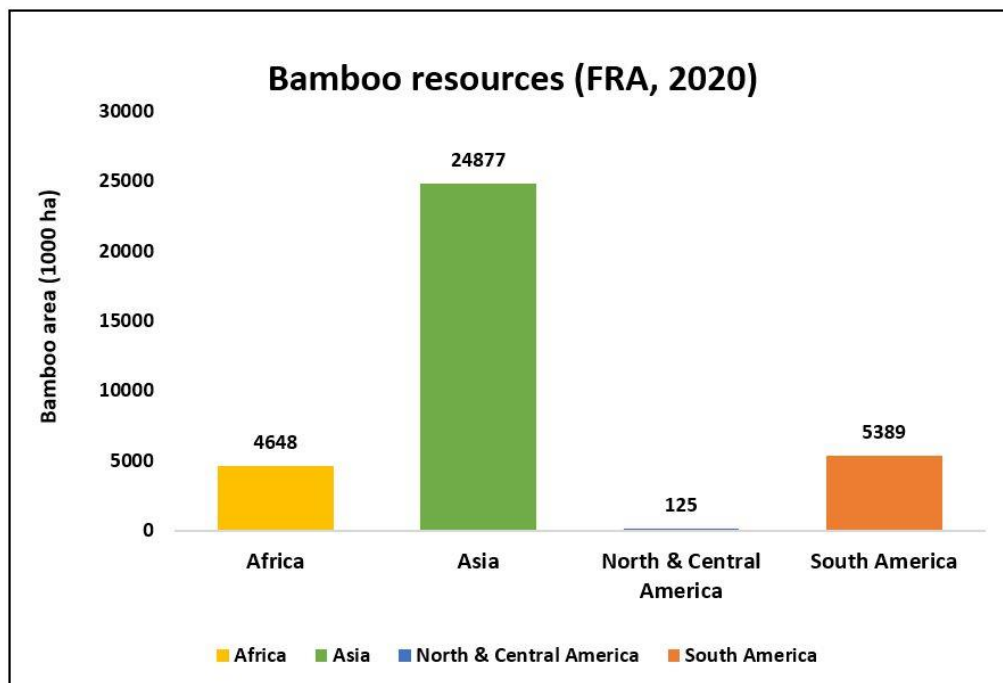


Figure 2: Total bamboo forest area by continent (FAO, 2020)

Industries based on cultivated bamboo also contribute to rural economic development (INBAR, 2019). Bamboos are the world's most traded nontimber forest products and have become important contributors in emerging economies, especially in tropical, subtropical and mountainous temperate regions (FAO, 2007, 2009; Hogarth and Belcher, 2013; INBAR, 2006; Partey et al., 2017). Bamboo industries have developed rapidly in recent years and contributed more than USD 60 billion annually in 2017 (INBAR, 2019). These industries can further contribute to green growth strategies nationally and globally (FAO, 2007; INBAR, 2019). Bamboos are a fast-growing, sustainable wood alternative with a high potential for carbon sequestration (FAO, 2007; Liese, 2009).

As more products and benefits are generated from natural and cultivated bamboo, the image of these forests is changing from the 'poor man's trees' to the input into high-tech industries that provide a new replacement for traditional timber from natural and planted forests (FAO,

2007, 2009). Raw material supply from natural forests is decreasing, and the role of bamboo in providing industrial raw materials on a global scale is likely to increase.

Bamboo forests provide important habitats and a key food for the conservation of iconic wildlife species, including the endangered giant panda (Effah et al., 2014; Phimmachanh, Ying and Beckline, 2015), Mountain gorillas (*Gorilla beringei beringei*), African golden monkeys (*Cercopithecus mitis kandti*) and many other kinds of monkeys and bamboo rats (Grueter et al., 2016; Sheil et al., 2012). Bamboo is essential for rehabilitating degraded land for erosion control and watershed protection (INBAR, 2006). Therefore, bamboo forests can contribute to landscape restoration and carbon sequestration, preventing soil and sediment loss and improving water quality (Sohel et al., 2015; Yiping et al., 2010; Zhou et al., 2005). Further, bamboo has the potential for bioenergy production, along with the delivery of other socioeconomic and environmental benefits, because it is abundantly available, is familiar to local people, is fast growing, has multiple uses, can rapidly store and sequester carbon, grows in degraded lands and has good fuel characteristics for modern bioenergy production (Sharma, Wahono and Baral, 2018).

While forest areas have decreased significantly in the tropics, bamboo forests have increased globally (Buckingham, Wu and Lou, 2014; Lei, 2001; Zhou et al., 2005). The increased amount of bamboo forests, over 35 million ha for both natural and planted (FAO, 2020), can play a key role in achieving recently adopted global forest restoration targets, such as the Bonn Challenge (to restore 150 million ha of degraded and deforested land by 2020), the New York Declaration on Forests (to restore 350 million ha by 2030; Jacobs et al., 2015; Paudyal, Putzel, et al., 2017; Reij and Winterbottom, 2017), the Great Green Wall Initiative (United Nations Convention to Combat Desertification, 2019b), Land Degradation Neutrality (United Nations Convention to Combat Desertification, 2019a) and the Sustainable Development Goals (Wood et al., 2018).

Though bamboos have been extensively used in many countries and much empirical research on bamboo has been conducted, authentic/public information regarding ecosystem services (ES) provided by bamboo forests and wider circulation assessment results are limited. In recent years, recognising the importance of bamboo forests has benefited people; some studies have been conducted on bamboo forests' ES. This is important because understanding the ES from bamboo forests can increase awareness of their importance to national and international policymakers and local communities to expand bamboo plantations for landscape restoration and investment decisions. However, a clear understanding of the

different dimensions of bamboo cultivation, its management and its potential to supply various categories of ES is essential. This report aims to address these knowledge gaps.

This report explores the potential of bamboo forests to supply various ES and highlights the global status of ES assessment through an analysis of case studies in various countries where many of the beneficiaries of these services live. This report further informs decision-makers in government and international development partners regarding the wider benefits of ES that bamboo forests can bring to their efforts in order to promote nature-based solutions to build sustainable development and green economies to improve peoples' livelihoods in bamboo-growing countries. To prepare this report, we reviewed the literature to identify the supply potential of the range of ES from bamboo forests in general and conducted a case study analysis of ES assessment in six developing countries.

1.2 Methods

This report was based on a critical review of literature related to ES from bamboo forests. We collected journal articles, conference proceedings, book chapters, government publications, technical reports, student theses and synthesis papers on the ES themes and bamboo forests to capture ES from bamboo forests. First, we collected, reviewed and analysed the existing INBAR research reports on ES from bamboo forests, including the CIFOR-INBAR's framework for assessing ES from bamboo forests, ES assessment and valuation reports of bamboo forests in Colombia, Ethiopia, Indonesia, Nepal, Peru and Viet Nam. Then we collected and critically reviewed literature of other relevant studies on bamboo ES in general and abstracted wider knowledge of bamboo uses in different functions. Furthermore, we reviewed the existing policies and market and financial instruments linking the concept of ES from bamboo forests to the practice of payment for ES. The most relevant articles and reports were analysed using applied thematic analysis (Guest, MacQueen and Namey, 2012; Paudyal, Baral, et al., 2017; Sitas et al., 2014) to analyse the information abstracted from various literature, where this analysis is designed to identify and scrutinise themes from textual data in a transparent and credible way (Guest, MacQueen and Namey, 2012; Tuckett, 2005). Finally, different themes and subthemes were identified according to the types of ES and information put together under ES types.

On 5 June 2021, the draft report was presented at a virtual workshop organised by INBAR on ES from bamboo forests. The report was also incorporated with the expert's comments and feedback.

2. Ecosystem Services from Bamboo Forests

Bamboo forests provide multiple ES and benefits to human well-being (Figure 3). While classifying major ES from bamboo forests, we follow the definition and classification proposed by the Economics of Ecosystems and Biodiversity (2010): ES is the direct and indirect contributions of ecosystems to human well-being. This definition is also based on the Millennium Ecosystem Assessment (MEA) with a slight modification. For example, supporting services in MEA are replaced by habitat services to, primarily, avoid any double counting in the ES audit (Baral, Guariguata and Keenan, 2016). A plethora of studies on types and assessment of ES from both natural forests and planted forests (Baral, Guariguata and Keenan, 2016; Gamfeldt et al., 2013; Hayha et al., 2015; Miura et al., 2015) and agricultural land (Kroeger and Casey, 2007; Power, 2010; Zhang et al., 2007) are well documented. However, such studies regarding ES from bamboo forests in a report/published article can hardly be found in the literature (Paudyal et al., 2019). Therefore, assessment of ES from bamboo forests has been extracted from specific thematic areas, such as bamboo and raw materials, bamboo and wildlife habitat, bamboo and carbon sequestration, and bamboo and soil erosion.

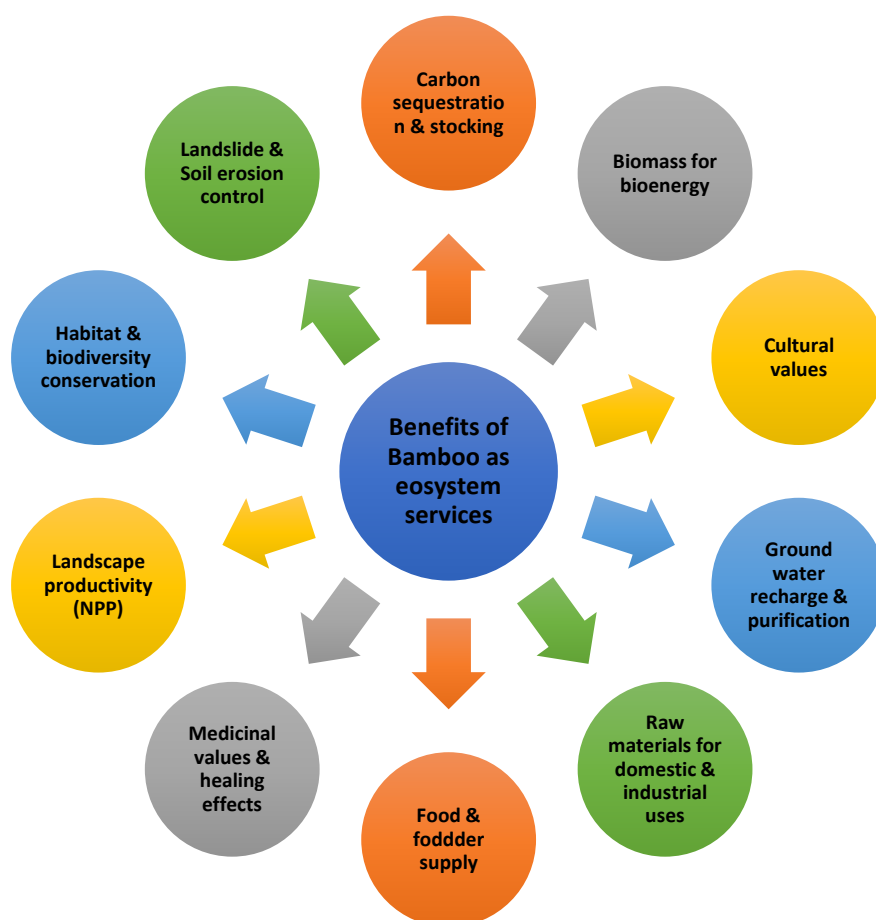


Figure 3: Major ecosystem services from bamboo forests

Hence, multiple ES provided by bamboo forests must be recognised, quantified and valued comprehensively to understand ES from bamboo forests (Annex). This aims to illustrate the direct and indirect benefits of bamboo forest ecosystems to human well-being. The literature review indicated that bamboo forests provide similar ES as those of other forests or grasslands, such as natural forests, degraded natural forests, planted forests, grasslands and agricultural lands (Table 1). However, an assessment of ES from bamboo is more complicated because bamboo can grow as monospecific stands, as part of natural and planted forests with other species or as scattered clumps and groves on agricultural land.

This chapter has attempted to identify the contributions of the bamboo forest ecosystem under the categories of provisioning services, regulating services, habitat services and cultural services. These are also compared with forests and other land use types that would be beneficial for raising general awareness about ES provided by bamboo forests and designing appropriate policies for the promotion of bamboo forests globally.

Table 1: Qualitative comparison of ecosystem services from bamboo forests to those from natural forests, degraded forests, planted forests, grasslands and agricultural lands

ES	The capacity of ES provision supplied by natural bamboo forests in comparison with				
	Natural forests	Degraded forests	Planted forests	Grasslands	Agricultural lands
Provisioning services					
Food provision	L	H	H	H	L
Forage production	L	L	H	L	H
Timber (construction materials)	L	H	L	H	H
Raw materials (except timber)	H	H	H	H	H
Bioenergy (biomass)	H	H	L	H	H
Medical resources	L	H	H	H	H
Freshwater provision	H	H	L	L	L
Regulating services					
Landscape restoration	H	H	H	H	H
Sediment retention	H	H	H	H	H
Carbon sequestration	H	H	H	H	H
Carbon stocks	L	H	H	H	H
Air quality and local climate regulation	L	H	H	H	H
Flood/landslide control	H	H	H	H	H
Groundwater recharge	H	L	H	H	H
Water purification	L	H	H	H	H
Healing	L	H	H	H	H
Moderation of extreme events	H	H	H	H	H

ES	The capacity of ES provision supplied by natural bamboo forests in comparison with				
	Natural forests	Degraded forests	Planted forests	Grasslands	Agricultural lands
Habitat services					
Habitat provision	L	H	H	H	H
Maintenance of biological diversity	L	H	H	H	H
Net primary production	L	H	H	H	H
Cultural services					
Landscape beauty and recreation	L	H	L	H	H
Recreation and ecotourism	L	H	H	H	H
Cultural/religious values	H	H	H	H	H

Note: Information given here is only indicative of identifying and comparing the ecosystem services (ES) from natural bamboo forests with other land cover categories. However, the actual provision of ES is determined by several factors, including bamboo species, bamboo forest types (natural vs planted, pure vs mixed, and monopodial vs sympodial), management objectives, geographic distribution, site conditions and management intervention. The tentative comparison is carried out to determine whether the ES from bamboo forests is higher (H), similar (S) or lower (L) than ES from other land uses.

2.1 Provisioning Services

Provisioning services are the tangible products that people obtain from ecosystems. For example, water, food, wood, medicinal products and other goods are material benefits (MEA, 2005). Bamboo forest provides many economic goods whose services rural households directly depend on for their livelihoods. Provisioning services from bamboo forests are vital in the human economy and often have well-developed markets and valuation systems. However, the values of these services may be much more important in rural livelihoods than is reflected in the prices they fetch on local markets. It is therefore critical to understand them. This section reveals many provisioning services supplied by bamboo forests, from local to global benefits.

2.1.1 Food provision

Bamboo forests are considered primary food sources for human beings and wild and domestic animals. Studies have shown that more than 200 species of bamboos provide food from wild and cultivated areas worldwide (Paudyal et al., 2019), primarily through the edible and palatable bamboo shoots and leaves. Bamboo shoots, the young culms of bamboo plants, are mostly used as food items in Asian countries. These juvenile shoots have high nutritive values and are rich in proteins, carbohydrates, vitamins and minerals such as potassium, phosphorous, magnesium, sodium, iron, calcium and selenium (Nirmala, Bisht and Laishram, 2014; Wang et al., 2020). They are also rich in dietary fibres and low in fat and sugar (Nirmala, Bisht and Haorongbam, 2011). Therefore, the fresh bamboo shoots have a crisp and crunchy texture and a sweet taste, imparting a unique flavour. The bamboo shoots can be consumed in various forms, including raw, canned, boiled, marinated, fermented, frozen, liquid and

medicinal forms (Choudhury, Sahu and Sharma, 2012). However, not all bamboo shoots are edible, and the consumption pattern of bamboo shoots in many cases is traditional, nonstandardised, seasonal and region specific, with little value addition (Choudhury, Sahu and Sharma, 2012).

Besides edible bamboo shoots, bamboo leaves have been used as a good food source for many years. These leaves also have antioxidant, antimicrobial, anti-inflammatory, antihelminthic, antidiabetic and antiulcer properties in their various extracts and components (Wang et al., 2020). For example, bamboo leaves have been used as wrapping materials for Chinese rice pudding and Japanese sushi for thousands of years. Bamboo leaves were also used to make tea for a drink (Wang et al., 2020).

Even though bamboo foods were traditionally treated as a regular cuisine in some Asian countries, nowadays, the consumption of bamboo shoots has quickly spread to other continents due to worldwide food trade. So far, the annual consumption of bamboo shoots has been estimated beyond 2 million tonnes (Wang et al., 2020). This shows the popularity of bamboo food throughout the world, making it one of the highest palatable dishes in delicacies, and it was recently honoured as 'the food of [the] rich man' (Wang et al., 2020; Page 2).

As one of the major provisioning services of bamboo forests, it has different uses and beneficiaries both at public and private levels. These benefits are distributed on-site and from the local level to the regional level (10–1,000 km; Paudyal et al., 2019). Compared to food provision from other land uses (such as natural forest and agricultural land), bamboo forest has a lower capacity. In contrast, it has a higher capacity to provide food than degraded forests, planted forests and grasslands (Paudyal et al., 2019).

2.1.2 Forage production

Bamboo forests are equally important for forage production and the provisioning of forage for livestock. Forage production is most challenging during the winter in highlands and drier months in other locations due to the scarcity of green forage. Livestock has to rely on stall-fed cereal crop residues and low-quality rangeland hay.

Against this backdrop, bamboo leaves, which are from evergreen species throughout the year, support green forage production during the dry period with high crude protein and mineral contents. Therefore, evergreen bamboo producing year-round litter production with relatively high nutritive characteristics may provide a valuable supplementary source of feed for livestock (Partey et al., 2017). For example, bamboo leaves are already used as fodder for

ruminants in India and Nepal, particularly when pasture is scarce during the winter months. Bamboo (*Dendrocalamus hamiltonii*) and dwarf bamboo leaves are extensively used as green fodder. Studies have shown that all species of bamboo used as fodder have shown positive effects on cattle, particularly young calves, and have reportedly increased milk production (Partey et al., 2017).

Similarly, bamboo species such as *Phyllostachys* spp., *Semiarundinaria fastuosa* and *Arundinaria gigantea* can withstand winter temperature and retain some green leaves even in late winter (Halvorson et al., 2011). Halvorson et al. (2011) demonstrated that the nonstructural carbohydrates in bamboo leaves decreased throughout the growing season and then remained stable or increased during winter. Conversely, crude protein was relatively low in young leaves compared to late-season or overwintered leaves. Concentrations of fibre and protein were sufficient to meet the maintenance needs of adult goats. Therefore, the ability of bamboo to remain green and maintain nutritive value throughout winter suggests that it can serve as winter forage for livestock (Halvorson et al., 2011).

Forage production is primarily used for private use to feed livestock, and the level of beneficiaries ranges from on-site and at the local level to the regional level. Bamboo forest is considered to have a higher forage production capacity than planted forests and farmland. However, natural forests, grassland and even degraded forests have higher production capacities than bamboo forests (Paudyal et al., 2019).

2.1.3 Construction timber and raw materials

Contrary to the earlier belief that bamboo is the 'poor man timber', it is gaining attention as a timber construction material and as a source of raw materials for various purposes. Many bamboo species provide construction timber and are used for building raw materials, modern engineered bamboo products, composite panels and boards.

Bamboo possesses excellent strength properties, especially tensile strength. However, the strength and mechanical properties of bamboo are influenced by several factors, including the type of species, harvesting age, climatic and soil conditions, moisture content, location of the sample concerning the length of the culm, and the presence or absence of nodes (Asif, 2009). Bamboo culms must be harvested at least after the age of three years and in the dry season and must be handled appropriately, cured and stored before use to achieve optimum performance (Asif, 2009).

Being a light yet tough substance, bamboo forms a hardwood, particularly after treatment against rot and insect infection, and can be widely used as a construction material. It possesses strength, versatility and flexibility, making it suitable for different applications within the construction sector. Further, bamboo can be used as construction wood in almost every part of a house, such as the foundation, walls, roofs and flooring. Bamboo housing, for instance, is quite common in many countries, such as Bangladesh, China, Costa Rica, Ecuador, India and Indonesia (Asif, 2009). Therefore, bamboo is a natural building/construction material and is well recognised for its durability, affordability and flexibility (Manandhar et al., 2009).

Bamboo provides raw materials for various types of enterprises, from traditional domestic uses to industrial uses such as different types of bamboo housing, flooring, crafts and fibre for pulp, paper and clothes. Nowadays, the concept of engineered bamboo has come to the fore to reduce the variability of the natural material (Sharma et al., 2015). Engineered bamboo products result from processing the raw bamboo culm into a laminated composite, similar to glue-laminated timber products. These products allow the material to be used in standardised sections and have less inherent variability than the natural material (Sharma et al., 2015). Therefore, engineered bamboo may well replace steel, wood and concrete in many uses due to its favourable characteristics, such as low cost, easy availability and reasonably high strength. As a result, bamboo can be used to reinforce cement matrices, replacing conventional, relatively scarce materials such as mild steel and galvanised steel mesh or fibres (Asif, 2009).

Bamboo can be regarded as a renewable source of construction material for several reasons. First, harvesting bamboo products has virtually no impact on the environment, and the harvested area can be sustainably replenished. Second, bamboo has lower embodied energy than other construction materials, such as concrete, steel and plastic. The production of timber and construction materials from bamboo forests is comparatively lower than from natural forests and planted forests. Still, bamboo forest provides a higher amount of these materials than grassland and farmland. Primarily, these materials offer both public and private uses, and the scale of beneficiaries can range from local to global levels (Paudyal et al., 2019).

2.1.4 Bioenergy

Bamboo has traditionally been used as a domestic energy source and a substitute for wood charcoal and mineral coal. Bioenergy can replace fossil fuels and decrease carbon footprints. The concept of bioenergy was derived from reducing the dependency on fossil fuels while addressing the growing concern of energy demand through renewable energy (Gielen et al.,

2019; Popp et al., 2014). Therefore, selecting species is crucial, providing a sustainable feedstock supply for bioenergy production without impacting the environment and food security (Sharma, Wahono and Baral, 2018). This is where the role of bamboo comes in, as bamboo can be developed as a bioenergy crop to produce sufficient bioenergy feedstock with limited impact on food security and the overall environment. The essential characteristics of bamboo as a bioenergy crop include being abundantly available, being popular among local people, growing fast, having multiple uses, rapidly storing and sequestering carbon, and growing in degraded lands. More importantly, bamboo has good fuel characteristics for modern bioenergy production, high productivity and a short rotation. It is a potential feedstock for generating electricity through power plants and biofuels to substitute fossil fuels. Therefore, integrating multipurpose perennial bamboo crops into energy systems can substantially achieve renewable energy targets while supporting degraded land restoration (Sharma, Wahono and Baral, 2018). The beneficiaries of bioenergy products range from local to regional levels, and in most cases, private entities are the primary users. Compared to natural forests, planted forests and farmland, bamboo has a higher capacity to produce bioenergy (Paudyal et al., 2019).

2.1.5 Medicinal resources

Bamboo forest contributes to traditional and indigenous medicine derived from various bamboo products. Bamboo has antifungal and antibacterial properties because a naturally occurring bioagent gives bamboo resistance to destructive microbes, such as bacteria and fungi. Bamboo can also serve as traditional medicine and provide spiritual healing. In traditional Chinese medicine, bamboo shavings are used to treat cold and flu symptoms. The shavings are ingested to fight nasal congestion, fever and convulsions. A similar drug is also made using bamboo sap in both liquid and solid forms to treat similar symptoms (Gagliano et al., 2021). In addition, bamboo leaves are used as a traditional remedy to treat fever in China and Japan. Similarly, bamboo has its importance in Ayurveda – a traditional system of Indian medicine. Ancient Ayurvedic, Indo-Persian and Tibetan systems of medicine recommend bamboo and its products for the treatment of various ailments (Nirmala and Bisht, 2015).

Bamboo medicinal applications were first mentioned in India around 10,000 years ago. 'Tabasheer' (or 'Banslochan'/'bamboo manna') has been used since ancient times as a cooling tonic and aphrodisiac and for asthma, cough and other debilitating diseases (Nirmala, 2018). For example, Chyawanprash is a health tonic prepared from several herbs, including bamboo manna. The tonic is named after a sage – Chyawan, the first to prepare it. Its vital characteristic features include rejuvenating all tissues in the body, supporting overall strength and energy,

promoting muscle mass, helping in supporting healthy immune and supporting healthy functioning of the heart and respiratory systems, among others (Sharma et al., 2019).

There are a couple of examples where bamboo is used as traditional medicine. In ancient China, Succus bambusae, a kind of light liquid extracted from fresh culms of *Phyllostachys glauca* McClure, *Phyllostachys nuda* McClure or other bamboo species in the same genus, was documented in *Bencaojingjizhu* (Variorum of the classic of materia medica, Tao Hongjing, the fifth century A.D.) as medicine to cure phlegm, fever, cough, hiccups, asthma and bronchitis (Dharmananda, 2004; Shen et al., 2019). Further, in Chinese medicine, bamboo leaves are used to reduce the energy of 'fire' (inflammation) and treat hypertension, arteriosclerosis and cardiovascular disease (Koide et al., 2011; Shen et al., 2019). Similarly, fermented bamboo shoot mixed with crushed leaves of *Allium porrum* was used to cure influenza (Sun et al., 2021). The paste made can also be applied to treat fungal infections. Decoction of tender shoots of *Bambusa nutans* can be applied on wounds and poisonous bites. Other uses include the shoots being boiled in water, and the soup is taken in cases of stomach ulcers (Dharmananda, 2004). Tender shoots of *Bambusa tulda* are boiled in water, the soup is taken in cases of poxes and other skin diseases, and the paste is applied on poisonous bites and injuries (Dharmananda, 2004). The soup is also used as an astringent and as eardrops. The sap of bamboo shoots has been found to contain hydrocyanic acid, leading to antiseptic and larvicidal properties for the cooling and healing of cuts (Sun et al., 2021). Further, bamboo shoots are used to ease labour and expel placenta by inducing uterine contractions (Nirmala et al., 2018). A poultice of the shoots is often used for cleaning wounds and healing infections (Sun et al., 2021).

Another aspect of the health benefits of bamboo includes, as an antioxidant, the prevention of cancer and degenerative diseases (Shen et al., 2019). Bamboo slows down the ageing process and promotes cardiovascular health. The main antioxidants in bamboo leaves and shoots are phenols, vitamins C and E and mineral elements such as selenium, copper, zinc, iron and manganese (Nirmala et al., 2018). Even bamboo food, especially those derived from bamboo shoots, has many health benefits. It includes low calorie and sugar content, a negligible amount of fat but high in protein, vitamins and minerals and can be used for heart protection, weight loss, immune system strengthening and wound cleaning. The medicinal value and use of bamboo products range from local to global levels, and both public and private users can reap its benefits (Paudyal et al., 2019).

2.1.6 Freshwater provision

Bamboo forests contribute significantly to water source protection, helping to protect water sources, conserve water and supply fresh water to local communities. While bamboo can absorb up to 90% of rainwater, trees absorb an average of 35%–40% rainwater (Sofiah, Setiadi and Widyatmoko, 2018). That is why people in Colombia have said they plant water when they grow bamboo (Sujarwo, 2018). Bamboo acts as a reservoir by collecting and storing large amounts of water in its rhizomes and stems during the rainy season and returning water to the soil, rivers and streams during droughts. One hectare of *Guadua* bamboo can store approximately *30,000 litres of water* (Schroder, 2021a; Schroder, 2021b). Bamboo's extraordinary ability to hold and control large amounts of water makes it a plant that can help **reduce soil desertification**. The extensive root system and forest cover of bamboo prevent streams from evaporating and can raise groundwater levels within a few years. Schroder (2021a) found that the groundwater level in bamboo forest areas has risen by 10 metres within 20 years, which made water available in the nearby region.

Usually, the scale of use of the freshwater provision is concentrated on-site and at the local, regional and national levels by both public and private users. Bamboo forest can be considered to have a higher capacity in terms of freshwater provision than natural forests, degraded forests and agricultural land (Paudyal et al., 2019).

2.2 Regulating Services

Regulating services consist of ecosystem processes that maintain ecological conditions favourable to life. For example, maintaining air and soil quality, providing flood and disease control and pollinating crops are some of ecosystems' regulating services. They are often invisible and, therefore, mostly taken for granted (MEA, 2005). Bamboo forests have been found to be effective in supplying such critical services (Paudyal et al., 2019). Bamboo forests provide some regulating services at a higher level than other forests. The regulating services associated with bamboo forests include regulating ecosystem processes such as climate regulation, natural hazard regulation and water purification. This section reveals many regulating services supplied by bamboo forests, from local to global benefits.

2.2.1 Landscape restoration

Restoration of degraded land through planting bamboo is one of the viable strategies for forest landscape restoration. As part of larger landscape restoration, the bamboo plantation in degraded land could restore its productive use (Dev et al., 2020). This would, in turn, alleviate some of the pressure on the forest from development works and provide communities with secure income (Rebelo and Buckingham, 2015). Some of the key characteristic features of

bamboo that support degraded landscape restoration include rapid growth, soil binding and erosion control properties, adaptive capability, nutrient and water conservation of land and the provision of a continuous and permanent canopy (FAO and INBAR, 2018). For instance, bamboo can grow on degraded and marginal soils – where many native species, particularly in tropical regions, have difficulty becoming established. If there are compacted soils, bamboo's extensive interconnected root system can break up soil particles – thereby increasing permeability, reducing compaction and, over time, allowing other less competitive species to become established in the degraded land (Gautam, Aryal and Lamichhane, 2018; Tardio et al., 2018).

Furthermore, bamboo can thrive in degraded land depleted of nutrients, and the introduction of bamboo enriches soil fertility (ICRAF, 2020). Likewise, bamboo forests maintain a microclimate in the understory and soil moisture due to the thick layer of litter in the ground, which is also one of the most important factors for restoring degraded land (Benzhi et al., 2005; Rebelo and Buckingham, 2015). Sharma, Wahono and Baral (2018) concluded that bamboo's ability to grow on degraded lands and its fast growth, long root system and easy maintenance prove it is a powerful resource for restoring degraded land. Therefore, bamboo forest has a higher capacity for landscape restoration than other land uses. The benefits of landscape restoration can be realised at the local to regional levels (Paudyal et al., 2019).

2.2.2 Carbon sequestration and carbon stock

Bamboo grows faster and can sequester carbon from the atmosphere at a faster rate than many tree species. Bamboo forests have high carbon storage potential due to their rapid growth rate and high annual regrowth after harvesting. For example, the annual carbon fixation of Moso bamboo (*Phyllostachys Pubescens*) forests is estimated at 1.3 times the value of that of a tropical mountain rain forest (Guomo and Peikun, 2004) and 1.4 times the value of that of Chinese fir (*Cunninghamia lanceolata*) (Zhao et al., 2009). Similarly, the carbon sequestration potential of many bamboo species is comparable to or often higher than that of many fast-growing species. For example, in Bangladesh, the total carbon sequestration of five-year-old common bamboo (*Bambusa vulgaris*) was found to be higher (15.53 t/ha/year) than that of other fast-growing hardwood species, such as Acacia (*Acacia auriculiformis*) (10.21 t/ha/year) for an 11-year-old crop (Sohel et al., 2015). Similarly, in India, the rate of aboveground carbon sequestration in a mixed patch of *Bambusa* species (*B. vulgaris*, *B. balcooa* and *B. cacharensis*) ranges between 18.93 and 23.55 t/ha/year (Nath et al., 2012).

A recent INBAR study shows that bamboo has a lower total carbon content (94–392 tC/ha) than timber forests (126-699 tC/ha) but similar carbon content as tree plantations (85–429 tC/ha). The carbon sequestration potential of *Phyllostachys Pubescens* (Moso) bamboo plantation under regular harvest is 305.77 t C/ha in 60 years – which is comparable to Chinese fir (*Cunninghamia lanceolata*), a fast-growing species, growing in similar conditions (Kuehl, Li and Henley, 2013). However, if the substitution of carbon-intensive materials with harvested bamboo products is included in the calculation, the carbon emissions reduction potential of a managed giant bamboo species forest, such as Moso, can be significantly higher than that of Chinese fir (296 tC/ha vs 237 tC/ha) growing under the same conditions (van der Lugt, Long and King, 2018).

Interestingly, even though a portion of bamboo biomass is harvested and removed each year, this is rapidly replaced within a single growing season. Increased bamboo biomass indicates a higher amount of carbon storage. Therefore, bamboo forests' long-term average carbon sequestration and carbon storage are static, regardless of the product end-use. Further, the high annual carbon accumulation rate indicates that bamboo forest is one of the most efficient types of forest vegetation for carbon fixation (Benzhi et al., 2005; Rebelo and Buckingham, 2015).

Carbon sequestration and carbon storage are vital ES from bamboo forests. The beneficiaries and the benefits of carbon sequestration can be wider from local to global levels. The carbon sequestration capacity of bamboo forest is considered higher than that of other land-use types. Still, in the case of carbon stock, the natural forest might have a higher capacity than bamboo forest (Paudyal et al., 2019).

2.2.3 Air quality, noise reduction and local climate regulation

Bamboo forests filter the air and remove odours, pollutant gases and dust particles from the air through the action of leaves and bark. This is why bamboo stands can also be called 'natural oxygen bars'. In a study conducted at the National Forest Park in Chongqing city, China, the concentration of negative oxygen ions in the air of a bamboo forest was two times that in an adjacent evergreen broad-leaved forest (Song et al., 2011). Further, as bamboo has a rough leaf surface, it can also effectively capture dust particles. For example, the surface of a bamboo leaf can capture 4–8 gm⁻² of dust, which helps to improve the air quality. Bamboo can also reduce noise levels. Study shows that a 40 m wide bamboo belt can reduce noise levels by 10 to 15 dB (Song et al., 2011).

Improved air quality makes local climate better. Forests also influence local and global temperatures and the flow of heat. Individual trees can transpire hundreds of litres of water per day and help regulate the local climate. Further, accumulations of carbon in forests, including bamboo forests, help regulate the climate. For example, a higher annual rate of carbon accumulation in bamboo species compared to other tree species means bamboo forest or bamboo-dominated forest or agroforestry system could be one of the most efficient systems for carbon fixation and climate regulation (van der Lugt, Long and King, 2018). In addition, increasing the lifespan of bamboo products and making them more durable with modern technology would prolong bamboo's carbon storage, delaying release into the atmosphere (Partey et al., 2017). All these services, including air quality, noise reductions and climate regulation from bamboo forest, can be realised for public use at all levels (Paudyal et al., 2019).

2.2.4 Erosion/flood/landslide control and sediment retention

Bamboo clumps or forests are considered effective, resilient erosion control measures and protect slopes against erosion and soil mass loss (Tardio et al., 2018). Bamboo forests control floods and landslides by holding soil particles together through a complex network of roots and rhizomes. As a result, these phenomena reduce the deposition load downstream.

Studies show that a bamboo plantation helps to reduce the average soil erosion by 80%, and an established bamboo plantation significantly reduces soil erosion by up to 27 t soil/ha/year (FAO and INBAR, 2018). Bamboo forests have an extensive rhizome system, a thick litter layer, highly elastic culms and a dense canopy. These characteristics give bamboo forests a high capacity for erosion control, soil and water conservation, landslide prevention, protection of riverbanks, and windbreak and shelterbelt potential (Kaushal, Singh, et al., 2020; Kaushal, Tewari, et al., 2020, Kaushal, Kumar, et al., 2021; Patra et al., 2021; Song et al., 2011).

Bioengineering is an effective measure, especially with using bamboo as a biological resource, for slope protection against erosion, soil conservation and slope stabilisation. For example, the design of the bamboo-gridded palisade, as in the case of the Danav Khola area of Nepal, provides a potential solution to the slope vulnerabilities detected in the intervention area. In addition, the possibility of introducing bamboo stands surrounding the bioengineering structure could be useful for multiple reasons, such as supplying source materials to replace damaged elements in the structure, helping to prevent erosion and extending the proposed intervention to other stretches of the riverbank (Tardio et al., 2018).

In combination with other species, bamboos work as effective soil conservation measures. In Peru, erosion control and sediment retention have been identified as the most critical ES from the mixed plantation with bamboo species (Chuchon et al., 2021) because bamboo mainly grows on marginal soil with low soil fertility. Compared to other species, bamboo has dense foliage protecting against beating rains. Bamboo can be harvested without disturbing the soil (Benzhi et al., 2005; Parthey et al., 2017). Therefore, bamboo is used as a soil conservation measure throughout the world. In Brazil, for example, bamboo species such as *Bambusa blumeana* and *Phyllostachys pubescens* are used to prevent nutrient loss, control soil erosion and improve soil structure (Kaushal, Tewari, et al., 2021; Parthey et al., 2017; Patra et al., 2021).

Similarly, a five-year field experiment conducted in China indicated an average surface soil run-off per month in bamboo forests of only 0.10 m³ ha⁻¹, which is equivalent to only 77% of the rate for a Chinese fir forest and 35% of the rate for a *Pinus massoniana* forest (Parthey et al., 2017; Song et al., 2011). As a result, the sediment delivery rate was 0.18 kg ha⁻¹, amounting to only 42.8% of the rate for the Chinese fir forest and 23.6% for the *P. massoniana* forest (Parthey et al., 2017; Song et al., 2011). In India, a bamboo-based agroforestry system was developed to restore degraded agricultural land – including three bamboos (*B. bambos*, *B. nutans* and *Dendrocalamus strictus*) and other intercrop species, such as soybean, moong, wheat, urad, pigeon pea and mustard (Behari et al., 2004; Parthey et al., 2017).

The antierodibility index, the ability of soil-resisting water dispersing and suspension in the top 40 cm of the soil, in a bamboo forest was found to be 1.05, which is higher than that of a *Robinia pseudoacacia* forest (0.98), *Metasequoia glyptostroboides* forests (0.52) and *Populus deltoides* forests (0.38). Similarly, Moso bamboo (1.33) had a higher antierodibility index than Chinese fir (0.35), *Quercus acutissima* (-0.75) and *P. massoniana* (-0.89) in the South Hilly Region of Jiangsu Province, China. This means the ability of the Moso bamboo forest to stabilise soil was 1.5 times that of the *P. massoniana* forest (Song et al., 2011). Another study from China shows that the bamboo plantation also reduces the average soil erosion by 80 per cent, up to 27 tons soil/ha/year (FAO and INBAR, 2018).

In a community forest at Kavrepalanchowk district, Nepal, degraded land has been converted into productive forest through restoration from Moso bamboo plantation. Here, Moso bamboo is recommended as a suitable bamboo species for the ecological restoration and reclamation of degraded land in the Mid-hills of Nepal due to its soil-binding capacity and fast growth (Gautam, Aryal and Lamichhane, 2018). These examples reinforce that bamboo forest has a

higher capacity for regulating floods and landslides and controlling erosion than other land-use categories.

2.2.5 Water source conservation and groundwater recharge

Forests, including bamboo forests, affect the hydrological cycle because they intercept rainfall, enhance water infiltration and percolation, and reduce run-off properties. These forest functions are important for soil and water conservation. Therefore, conserving and regulating the available water is one of the major ES from bamboo forest.

Studies show that more than 90% of bamboo forests are found in the source regions of major rivers and lakes and along riverbanks in China. These forests play an important role in regulating water flows and in water source protection and conservation. In addition, compared to the Chinese fir forest, the Moso bamboo forest was found to have about 30% to 45% more water conservation function. The water conservation function includes a comprehensive index, mainly canopy interception, water holding of the litter layer and woodland soil infiltration of the water storage reservoir. Similarly, the water conservation function in the Moso bamboo forest was also about 46.7% and 57.4% stronger than that in the *P. massoniana* forest and the *Castaneam ollissima* forest, respectively, but about 37.2% less than in the *Cycloba lanopsisglauca* forest in Tonneglu, Zhejiang province, China (Song et al., 2011). be regarded as one of the forest types with more substantial water conservation potential.

Large-scale natural and planted bamboo forests can directly impact eco-hydrological processes, including moisture retention, groundwater recharge and water purification. Bamboo forests induce landscapes to filter out and decompose organic waste. For example, bamboo forests have a strong capacity for rainfall interception and moisture retention (Kaushal, Kumar et al., 2021). The Moso bamboo forest has 1.3 times higher rainfall interception capacity than the Chinese fir forest (Onozawa et al., 2009). Similarly, the canopy interception ratios for rainfall and stem flow were also 6.1% and 6.3% higher respectively in the Moso bamboo forest than in the Chinese fir forest. As a result, a single Moso bamboo can hold 5 kg of water and reinforce 4 m² of soil, so 1 ha of the Moso bamboo forest can store 3,750 to 4,200 tonnes of water at the saturation point (Song et al., 2011). This also impacts relative humidity, as these forests typically have 5%–10% higher relative humidity than in adjacent open fields during the summer (Song et al., 2011).

Bamboo forests help maintain the ground cover in the case of annual selective harvesting. In this case, bamboo forests protect the soil, conserve water sources and maintain a groundwater table. Even in harvested bamboo, the roots can bind the soil, prevent water run-

off and survive due to its long underground root systems. In Allahabad, India, an INBAR-supported bamboo project has helped raise the water table by over 15 metres in 10 years and turned a blasted brick-mining area prone to frequent dust storms to productive agricultural land. Similarly, bamboo is one priority species in Ethiopia to restore the country's degraded water catchment areas (FAO and INBAR, 2018; Global Landscape Forum, 2020). One of the critical features of a study from Chishui, China, is that bamboo forest contributes to improved water regulation. A comparison of soil conditions between a bamboo plantation and a sweet potato farm found that bamboo plantations had 25% less water run-off (FAO and INBAR, 2018).

2.2.6 Water purification

In addition to water source protection, groundwater recharge and an increase in the water table, bamboo forest also serves the function of water purification. Bamboo naturally acts as an antibacterial and antifungal agent and is capable of absorbing chlorine, bad odour and toxic substances from water. Bamboo replaces healthy minerals (such as sodium, potassium and iron), transforming ordinary water into mineral water (Das and Saha, 2013).

2.2.7 Moderation of extreme events

Bamboo forests act as a natural buffer, helping to protect against wild animals (by preventing them from entering villages), strong winds, storms, landslides and other disasters and reducing damaging impacts. In Sri Lanka, as part of ecosystem-based adaptation practices, the bamboo tree is planted as one of the most common trees/plants in combination with other tree species that anyone can see along the rivers to protect from soil erosion and floods. These trees protect against soil erosion and hold floodwater from reaching nearby settlements (Khaniya, Gunathilake and Rathnayake, 2021). Similarly, a degraded riverside in Bardibas, Nepal, was developed into a plant-rich environment by planting bamboos and other forest seedlings. It has now been turned into Nepal's unique model for micro-watershed conservation while moderating the impact of extreme events, such as landslides and floods (FAO and INBAR, 2018). These services are public, and anybody can realise the benefits locally, especially at a site level (Paudyal et al., 2019).

2.2.8 Healing effects of bamboo forests

Another aspect of the medicinal value of bamboo forest is related to psychological, physiological and spiritual healing (Hassan et al., 2018; Lyu et al., 2018, 2019). Bamboo forests are increasingly being used in the healing landscape in many countries, such as China and Japan. It enhances spiritual development, clears negative energy and brightens the mood. The rustling of the leaves in the wind is magical and gives a very soothing feeling. It bolsters

self-worth and self-esteem and helps to balance grace and strength. Bamboo grooves are also considered a favourite place for meditation. For example, in Japan, a study shows that walking in a bamboo forest improves mood and reduces anxiety, including significantly increased mean meditation and attention scores in adults (Hassan et al., 2018). Similarly, another empirical field study on bamboo forest therapy in southern China evaluated the mood of participants in the bamboo forest environment compared to the urban environment. The study showed that the participants' scores for tension and anxiety, anger and hostility, depression, fatigue, and confusion after bamboo forest therapy were significantly lower than those of the participants in the urban area. This, in turn, can increase positive mood and decrease negative mood, regulating overall psychological responses (Lyu et al., 2018).

Another study in China indicates that a three-day bamboo forest therapy session improved participants' psychological and physiological well-being and enhanced the immune functions of the male college students (Lyu et al., 2019). This might be the reason bamboo has always been considered an emotional, motivational and inspirational plant. Though forest bathing (spending time in forests) has been recognised as an effective practice for relaxation and high-level cognitive functioning (Yu and Hsieh, 2020), spending time in bamboo forests has been found to be more effective for psychological and spiritual healing (Hassan et al., 2018).

2.3 Habitat/Support Services

Providing living spaces for plants or animals and maintaining a diversity of plants and animals are 'supporting services' and the basis of all ecosystems and their services. The habitat services from bamboo forests refer to the importance of bamboo ecosystems in providing habitat for species and protecting genetic diversity. This section reveals many regulating services supplied by bamboo forests, from local to global benefits.

2.3.1 Habitat provision

Bamboo forests provide suitable habitats for different species, both flora and fauna. Many wild animals prefer bamboo forests as their habitat because of abundant bamboo foliage. The animals also eat the tender leaves and the tender shoots of bamboo foliage. For instance, bamboo forests provide habitats for many mammals and birds in Peru (Chuchon et al., 2021). Red pandas (*Ailurus fulgens*, endangered species) live mainly in bamboo forests. Hence, the destruction of bamboo forests is the primary reason for their extinction (R. Li et al., 2015; Ocko, 2015). The Asian giant panda (*Ailuropoda melanoleuca*) and the Himalayan black bear (*Selenarctos thibetanus*) also depend heavily on bamboo forests for their feed (Malcolm et al., 2014). Further, the world's second-smallest bat (*Tylonycteris pachypus*, 3.5 cm) nests

between nodes of mature bamboo, entering through holes created by beetles (Bystriakova et al., 2003; Yeasmin et al., 2015).

Bamboo forest provides habitat for other species, such as elephants (*Elephas maximus*), wild cattle (*Bos gaurus* and *B. javanicus*) and various species of deer (*Cervidae*) and primates (including *Macaca macaques* and leaf monkeys, Presbytis), pigs (*Suidae*), rats and mice (*Muridae*), porcupines (*Hystricidae*) and squirrels (*Sciuridae*) in the South Asian region (Yeasmin et al., 2015). They are primarily considered subsidiary feeders on southeast Asian bamboo forests (Yeasmin et al., 2015). These sorts of habitat services are publicly available, and the scale of the services ranges from on-site and at the local level to the national level (Paudyal et al., 2019).

2.3.2 Maintenance of biological diversity

Besides habitat services, bamboo forest plays an important role in maintaining and enhancing wildlife biodiversity because it provides different varieties of bamboo species and habitats for wild animals. Bamboo provides food and habitat for numerous insects in the soil and tree layers and spiders, butterflies, birds and other higher life forms (Song et al., 2011; Yiping and Henley, 2010). For example, Amazon forests provide refugia for some 440 bird species, where 25 bird species are confined only to bamboo thickets. Likewise, more than 15 Asian bird species nest exclusively in bamboo forests as a significant proportion of their habitat; many of these are rare and threatened (Yeasmin et al., 2015). Over 6.3 million square kilometres of Asian forest potentially contain bamboos. The highest densities are indicated in Northeast India, from Burma to southern China and from Sumatra to Borneo. The highest figures for potential species richness (144 species per square km) were recorded in forests of South China, including Hainan Island (Bystriakova et al., 2003). These bamboo-dominated biodiverse forests are suitable habitats for varieties of wildlife species. Giant pandas eat almost exclusively the tender culms and shoots of bamboo. Similarly, other animals, such as elephants, wild oxen, brown bears and wild boars, depend greatly on bamboo shoots and leaves.

Bamboo forests also increase the number of bird species and the number of birds. For example, in the *Phyllostachys glauca* forest and its surrounding areas in the Tai Mountains of Shandong Province, seven orders, 16 families and 63 species of birds can be found, accounting for 43% of the total birds in these mountains. A study in Chilean temperate forests found that bird species richness was positively correlated with bamboo cover (Reid et al., 2004). Compared with the biodiversity services of bamboo forests, natural forests are

considered to have higher values, whereas bamboo forests have a higher value than planted forests and farmlands (Paudyal et al., 2019).

2.3.3 Net primary production

Net primary production (NPP) is a vital ecosystem function that affects several ES (Sousa, Longo and Santos, 2019). It indicates the overall productivity of a landscape that supports the increment of other ES (Zhang et al., 2003). NPP is also an important indicator of forest biomass accumulation and carbon sink capacity. Some studies show that NPP from bamboo forests have gained much attention because of their high carbon sequestration potential and supply capacity of other ES (Chen et al., 2018; Mao et al., 2020; Song et al., 2017). Bamboo (*Phyllostachys pubescens*) expansion into adjacent forests is a widespread phenomenon in tropical and subtropical regions accompanied by changes in productivity, nutrient accumulation and biogeochemical cycles. Comparing NPP in a bamboo-dominant forest to a neighbouring secondary evergreen broad-leaved forest in South China using the space-for-time substitution method, Song et al. (2017) concluded that the mean NPP of the former was 30.0 t ha⁻¹ yr⁻¹, which was 51.5% greater than that of the latter (19.8 t ha⁻¹ yr⁻¹) cycles. A study in Japan shows bamboo forests have a higher productivity of production than Cedar forests (Shimono et al., 2021).

Similarly, several studies in semi-arid, dryland ecosystems and agroforestry systems show bamboo forests have high NPP compared to many forests and sole crops (Dev et al., 2020; Shimono et al., 2021). In the Bundelkhand region of central India, a *Dendrocalamus strictus*-based agroforestry system has produced a higher amount of leaf biomass, bamboo stock and sustained crop production over the years (ICRAF, 2020). Research shows an ample scope of bamboo-based agroforestry in that region because of the low capital investment requirement and its ability to cope with frequent drought. This has also proved to be a potential alternative to arable cropping in semi-arid tropics land to enhance productivity and economic returns and offer the best livelihood options (Dev et al., 2020; ICRAF, 2020). This research offers the following conclusions:

- The land equivalent ratio is higher and has greater land-use efficiency in the bamboo-based agroforestry system than in sole-crop systems.
- Soil fertility and quantity of nutrients in the soil are much higher in the agroforestry system than in sole-crop systems because high bamboo leaf litter and fine-root decomposition enhance soil organic matter.
- Bamboo-based agroforestry systems are commercially more viable than sole-crop systems because overall land productivity increases due to better land use.

2.4 Cultural Services

Nonmaterial benefits obtained from ecosystems are called 'cultural services', such as cultural and religious importance, as well as aesthetic, recreational and educational values (MEA, 2005). These services contribute to the development and cultural advancement of people. These include how ecosystems play a role in local, national and global cultures; knowledge building and the spread of ideas; interactions with nature; and recreation (Malanson and Alftine, 2016). Building on the unique Bamboo Cultural Complex globally, a dynamic relationship between the physical and immaterial values of bamboo is gradually developing with increasingly sophisticated uses (Perez et al., 2014). Bamboo has been used throughout history and is associated with 'cradle to grave' (Buckingham, Wu, Lou, et al., 2014 in the page 771; Paudel and Lobovikov, 2003 in the page 382) . Cultural services are among the most important values people associate with bamboo forests in many situations, and it is critical to understand them. This section reveals many cultural services supplied by bamboo forests, from local to global benefits, as other land uses/forest types provide.

2.4.1 Landscape beauty, recreation and ecotourism

Bamboo forests create landscape beauty by preventing land degradation and enhancing landscape restoration and greenery. A recent study in China indicated that most bamboo forest landscapes are characterised by high and relatively high landscape quality areas. This implies bamboo forest or bamboo-dominated forest landscape has high aesthetic and recreational values (Wu, Zhong and Deng, 2019). Therefore, bamboo forests provide opportunities for ecotourism and recreational activities by promoting greenery and landscape beauty (FAO and INBAR, 2018; Rebelo and Buckingham, 2015). For instance, the Bamboo-Lined Path at Yunqi in Hangzhou, the Shunan Bamboo-Sea in Changning and the bamboo forest along the Lijiang River in Guilin are popular tourist destinations due to the scenic beauty created by bamboo forests (China Discovery, 2021). In addition, Xianning is known as the famous 'hometown of bamboo' and has distinctive conditions for bamboo forest ecotourism in China (Lei and Chengyu, 2019).

Nowadays, bamboo forests are also a unique and important component in southeast Asia, especially Chinese gardens and landscapes. For instance, *Bambusa multiplex*, *Phyllostachys aurea*, *Phyllostachys bambusoides* and other species are popular ornamental plants in gardens and have even been used as materials for Chinese bonsai (Song et al., 2011). Bamboo is now well known and is the most preferred plant in Chinese landscape design because of its unique, beautiful foliage and fast-growing characteristics. In addition, the bamboo forest environment is more natural, comfortable, open and bright, with pleasing

ambient noise. It is better for psychological and physical relaxation than other forests, making it a suitable recreational site (Lyu et al., 2019). These services are publicly available from the local level to the regional level.

2.4.2 Cultural and religious values

Bamboo materials have been used from the cradle to the grave in many countries because of religious and cultural values associated with bamboo (Perez et al., 2014). Bamboo forest remains an essential part of rural livelihoods and civilisation. China has various cultural and religious values related to bamboo uses (Yeromiyani, 2021). A long history of bamboo handicrafts with exquisite workmanship, such as carvings and weavings, has made Chinese artisans famous worldwide. Bamboo pens, brushes and musical instruments were invented 3,000 years ago (Yeromiyani, 2021). Due to its graceful and upright shape, bamboo has noble characteristics and is grown to encourage people to cultivate good character (Song et al., 2011).

The cultural and religious services from bamboo forests are publicly available on-site and at the local level. Similarly, the capacity of bamboo forest in terms of cultural and religious values are higher than that of any other land-use class (Paudyal et al., 2019).

3. Key Findings, Lessons Learnt and Call for Actions

This report offers many similarities and differences in supplying bamboo ES worldwide and summarises the following key findings and some calls for action to tap and develop the unrealised potential of ES from bamboo forests.

3.1 Major Bamboo Forests' ES

Bamboo forests provide a wide range of ES that generate sociocultural, economic and ecological values and services for local and global stakeholders. Bamboo forests are socioculturally connected with forest and people (e.g., having spiritual significance for local communities); produce raw materials for economic activities, with local and industrial applications (e.g. timber, medicine, water, biofuel and crafts); and provide ecological benefits to communities both in and beyond local areas (e.g. carbon stock/sequestration). Many studies have indicated that bamboo ES are comparable with those of other land-use types. Generally, ES supplied by bamboo forests are higher than those of other land-use types, such as degraded forests, planted forests, grasslands and agricultural lands, but lower in natural forests.

Here, some key findings related to ES from bamboo forests are discussed in four categories: provisioning services, regulating services, habitat services and cultural services.

3.1.1 Provisioning services

- **Bamboo is an important component of the rural farming system:** Bamboo plays a critical role in rural economies, helping to sustain the livelihoods of rural people, and offers an essential co-benefit to society and can increase the income of local communities by providing a higher amount of biomass, food supply, medical products and raw materials for industry and domestic uses. Bamboo has a shorter rotation of three to six years and a higher density (>10,000 culms per ha) than other tree species, thereby providing more biomass for raw materials. A plantation of giant bamboo (*Dendrocalamus giganteus*) with 200 bamboo clumps per hectare can produce an annual yield of about 2,000 poles, with approximately 50 tonnes of biomass.
- **Bamboo can substitute the wood demand:** The high valued utilisation of bamboo promotes economic development and saves forest resources to protect the ecological environment as a wood substitute. Contrary to the earlier belief of 'poor man timber', bamboo has been gaining attention as construction timber and is used to build raw

materials, modern engineered bamboo products, composite panels and boards because of its excellent tensile strength.

- Bamboo forests contribute significantly to water source protection and help in supplying fresh water to local communities. While trees absorb an average of 35%–40% of rainwater, bamboo can absorb up to 90% of rainwater. Bamboo acts as a reservoir by collecting and storing large amounts of water in its rhizomes and stems during the rainy season and returning water to the soil, rivers and streams during droughts. A study shows that a hectare of *Guadua* bamboo can store approximately 30,000 litres of water.

3.1.2 Regulating services

Bamboo forests can be more effective than other forests in providing many regulating services, including soil erosion control, landscape restoration, carbon sequestration, groundwater recharge, protection against extreme events (such as floods, storms and landslides) and healing effects. However, regulating services depend on the type of bamboo forests, with natural bamboo forests having a higher capacity than planted monoculture bamboo forests. Studies have shown that almost all regulating services are higher in bamboo forests, except for natural forests.

- **Bamboo has high carbon sequestration and carbon stocking potential:** Bamboo is widely regarded as an ideal plant for carbon sequestration and is believed to play a larger role in reducing carbon dioxide in the atmosphere. It absorbs carbon dioxide and releases oxygen into the atmosphere three to four times higher than many other trees. Many studies show that bamboo forests have a higher carbon sequestration rate and carbon stock than natural and planted forests (FAO and INBAR, 2018; Thokchom and Yadava, 2015; Yen and Lee, 2011; Yiping et al., 2010; Yuen et al., 2017).
- Bamboo forests have a higher capacity for groundwater recharge and a better local capacity for water purification than natural and planted forests. This is because a dense canopy with mixed and diverse vegetation types, particularly natural forests, consumes more water. Further, many studies indicate that soil conditions have reduced surface run-off by 25% due to bamboo-based agroforestry/bamboo plantation compared to sole crops in Chishui, China (FAO and INBAR, 2018).
- **Bamboo is an important species for landscape restoration:** Expanding bamboo plantations is the cheapest way of reversing land degradation and is appropriate for meeting global restoration goals. Bamboo forests are considered effective in protecting slopes against erosion and soil mass loss because of their complex network of roots

and rhizomes. Studies have indicated that a bamboo plantation can reduce the average soil erosion by 80%, a significant reduction of up to 27 tonnes of soil/ha/year.

- Bamboo forests are increasingly being used as health, psychological and spiritual healing landscapes in southeast Asia. The rustling of the leaves in the wind is magical and gives a very soothing feeling that enhances spiritual development, clears negative energy and brightens the mood. Bamboo grooves are also considered a favourite place for meditation.

3.1.3 *Habitat services*

- The NPP of the bamboo-based agroforestry system is higher than that of sole-crop systems. It has been proven that the bamboo-based agroforestry system is a potential alternative to arable cropping in semi-arid tropics land to enhance productivity and economic returns and offer the best livelihood options.
- Bamboo forests provide suitable habitats for many florae and faunae by supplying abundant food and foliage. These forests have a greater capacity for maintaining and enhancing wildlife biodiversity than planted forests and agricultural land, but some studies show a lower capacity when compared with natural forests.

3.1.4 *Cultural services*

- The landscape beauty of bamboo forests and their potential for nature-based tourism have increased in many countries, such as China, Ethiopia, India, Indonesia and Japan. Research has revealed that many people prefer the unique aesthetic view of bamboo forests to degraded natural forests, grasslands and agricultural land.

3.2 Lessons Learnt

The following key lessons are critical for bamboo plantation/management and the supply of various ES from bamboo forests:

- It is evident that bamboo is an important component of the rural farming system and plays an important role in rural economics to sustain the livelihoods of rural people.
- Bamboo cultivation could replace plantation forestry or be integrated with forestry in the tropics and subtropics to provide a wider range of benefits and services. Most importantly, bamboo is considered an alternative to forest trees globally and can provide domestic or industrial raw materials at reasonable prices.
- Bamboo can be a vital tool for landscape restoration. Expanding bamboo plantations can be one of the cheapest ways of reversing land degradation and is appropriate for meeting global restoration goals. Being particularly fast growing and adapted to

cultivation in harsh environments, bamboo may be preferred than other species for rehabilitating highly degraded areas. However, the success of landscape restoration from bamboo requires the consideration of several factors, including (i) the careful implementation of restoration projects, (ii) decision-making and planning with local participation, (iii) incorporation of local knowledge and (iv) awareness campaigns by clearly highlighting to people the benefits of bamboo plantations for reversing degraded land and other tangible benefits.

- Bamboo can grow as monospecific stands, natural and planted forests with other species or scattered clumps and groves in agricultural land. This makes the assessment of ES from bamboo more complicated.
- There is a trade-off observed between provisioning and regulating services from bamboo forests that depends on the management objectives of bamboo forests. Suppose a bamboo forest is managed for the shoots (food provision). In that case, they are harvested within two months, which can negatively impact the production of total biomass and raw material supply. This phenomenon can also have a negative impact on many other regulating services, such as carbon stocks, carbon sequestration and sediment retention.

3.3 Call for Actions

This report reveals that the following should be urgently addressed to promote ES from bamboo forests nationally and internationally.

Global plantation target can be replaced by bamboo: The planted forest increases globally each year. Since bamboo forests provide a higher level of ES than planted forests, bamboo, instead of other plantation species, should be planted massively for multiple benefits to people from the local level to the global level.

Economic analysis of bamboo plantation: Studies related to the economic benefits of bamboo should be conducted, which can include consideration of the domestic uses frequently ignored as perceived benefits. For this, additional studies should be carried out to understand ES supply from different bamboo plantations. Additional ES studies are required to increase appropriate ES payment rates for different forest types, encouraging owners to better forest conditions.

Promotion of the bamboo-based agroforestry system: The NPP of the bamboo-based agroforestry system is higher than that of sole-crop systems and has been proved to be a potential alternative to arable cropping in semi-arid tropics land to enhance productivity and

economic returns and offer the best livelihood options. Hence, government/international agencies should promote the bamboo-based agroforestry system for better economic returns to farmers in the semi-arid tropical region under drought and uncertain weather conditions.

Policy tools for bamboo ES: Although many studies have recognised bamboo's higher carbon sequestration and carbon stock potential, bamboo management has been given little priority globally for this purpose. More attention to carbon farming through bamboo plantations could help to mitigate climate change impacts. Given the potential for bamboo to act as a carbon sink, there is a need for greater integration of bamboo into national and international policies and mechanisms to manage the effects of global climate change. Further, the increased amount of bamboo forests globally can play a key role in achieving recently adopted global forest restoration targets. There is a strong need for integration of bamboo forest and its ES into existing international policy frameworks: UN Decade on Ecosystem Restoration (2021–2030); the Bonn Challenge; the New York Declaration on Forests; the Great Green Wall Initiative; Land Degradation Neutrality; reducing emissions from deforestation and forest degradation, conservation of existing forest carbon stocks, sustainable forest management and enhancement of forest carbon stocks (REDD+); the United Nations Framework Convention on Climate Change (UNFCCC); Nationally Determined Contributions (NDCs); Sustainable Development Goals (SDGs); and others. For this, bamboo financing mechanisms such as biodiversity finance, carbon credits, and payment for ES should be initiated nationally and globally to encourage growers to expand bamboo plantations.

Global database on bamboo's ES: Statistics on the ES from bamboo forests are often poor and inconsistent, and tools and common approaches are missing. Bamboo forests are rarely found as standalone forests; instead, they are widely distributed either in forests or on agricultural land in combination with other tree species or agricultural crops. These forests are either planted bamboo forests or naturally grown bamboo forests. Tools, techniques and methods for assessment and valuation of ES from bamboo forests have been poorly developed, and preparing a database is complicated, hindering proper decision-making regarding bamboo forest management. Therefore, more studies should be undertaken to produce information for a global/national database regarding assessment, valuation and other aspects of ES from bamboo forests. For this, additional resources for relevant studies and projects should be allocated nationally and internationally.

Global bamboo ES network: Several national and international policy and advocacy forums have been working globally that do not deal with promoting ES from bamboo forests. However, a global network/forum of bamboo forest ES needs to be initiated to enhance awareness

among national/international policymakers regarding the importance of promoting bamboo's ES and lobbying for appropriate policy instruments.

References

- Ahammad, R., Stacey, N. and Sunderland, T.C.H. (2019) 'Use and perceived importance of forest ecosystem services in rural livelihoods of Chittagong Hill Tracts, Bangladesh'. *Ecosystem Services*, 35, pp. 87–98 [online]. Available at: <https://doi.org/10.1016/j.ecoser.2018.11.009>
- Asif, M. (2009) 'Sustainability of timber, wood and bamboo in construction', in: *Khatib, J.M. (Ed.), Sustainability of Construction Materials (Woodhead Publishing Series in Civil and Structural Engineering)*. Woodhead Publishing Limited, pp. 31–54. Available at: <https://doi.org/10.1533/9781845695842.31> (Accessed 20 Oct 2021)
- Bajracharya, M.S., Rajbhandary, S. and Das, A.N. (2013) 'Socio-economic impacts of bamboo enterprises in the Mid-hills of Nepal: a case study on Pahari community at Badikhel Village, Lalitpur'. *Banko Janakari*, 22, pp. 19–25 [online]. Available at: <https://doi.org/10.3126/banko.v22i2.9195>
- Baral, H., Guariguata, M.R. and Keenan, R.J. (2016) 'A proposed framework for assessing ecosystem goods and services from planted forests'. *Ecosystem Services*, 22, pp. 260–268 [online]. Available at: <https://doi.org/10.1016/j.ecoser.2016.10.002>
- Basumatary, A., Middha, S.K., Usha, T., Brahma, B.K. and Goyal, A.K. (2015) 'Bamboo, as Potential sources of food security, economic prosperity and ecological security in North-East India: an overview'. *Research in Plant Biology*, 5, pp. 17–23.
- Behari, B., Agarwal, R., Singh, A.K. and Banerjee, S.K. (2004) 'Spatial variability of pH and organic carbon in soils under bamboo-based agroforestry models in a degraded area'. *Indian Forester*, 130, pp. 521–529.
- Benzhi, Z., Maoyi, F., Jinzhong, X., Xiaosheng, Y. and Zhengcai, L. (2005) 'Ecological functions of bamboo forest: research and application'. *Journal of Forestry Research*, 16, pp. 143–147.
- Bock, F. (2014) 'Green gold of Africa – can growing native bamboo in Ethiopia become a commercially viable business?' *The Forestry Chronicle*, 90, pp. 628–635 [online]. Available at: <https://doi.org/10.5558/tfc2014-127>
- Buckingham, K.C., Wu, L. and Lou, Y. (2014) 'Can't see the (bamboo) forest for the trees: examining bamboo's fit within international forestry institutions'. *AMBIO: A Journal of the Human Environment*, 43, pp. 770–778 [online]. Available at: <https://doi.org/10.1007/s13280-013-0466-7>
- Bystriakova, N., Kapos, V., Lysenko, I. and Stapleton, C.M.A. (2003) 'Distribution and conservation status of forest bamboo biodiversity in the distribution and conservation

- status of forest bamboo biodiversity in the Asia-Pacific region'. *Biodiversity and Conservation*, 12, pp. 1833–1841 [online]. Available at: <https://doi.org/10.1023/A>
- Chaowana, P. (2013) 'Bamboo: an alternative raw material for wood and wood-based composites'. *Journal of Materials Science Research*, 2, pp. 90–102 [online]. Available at: <https://doi.org/10.5539/jmsr.v2n2p90>
- Chauhan, O.P., Unni, L.E., Kallepalli, C., Pakalapati, S.R. and Batra, H.V. (2016) 'Bamboo shoots: composition, nutritional value, therapeutic role and product development for value addition'. *International Journal of Food and Fermentation Technology*, 6, pp. 1–12 [online]. Available at: <https://doi.org/10.5958/2277-9396.2016.00021.0>
- Chen, S., Jiang, H., Cai, Z., Zhou, X. and Peng, C. (2018) 'The response of the net primary production of Moso bamboo forest to the on and off-year management: a case study in Anji County, Zhejiang, China'. *Forest Ecology and Management*, 409, pp. 1–7 [online]. Available at: <https://doi.org/10.1016/j.foreco.2017.11.008>
- Chen, X., Zhang, X., Zhang, Y., Booth, T. and He, X. (2009) 'Changes of carbon stocks in bamboo stands in China during 100 years'. *Forest Ecology and Management*, 258, pp. 1489–1496 [online]. Available at: <https://doi.org/10.1016/j.foreco.2009.06.051>
- Chin, K.L., Ibrahim, S., Hakeem, K.R., San Hang, P., Lee, S.H. and Lila, M.A.M. (2017) 'Bioenergy production from bamboo: potential source from Malaysia's perspective'. *BioResources*, 12, pp. 6844–6867 [online]. Available at: <https://doi.org/10.15376/biores.12.3.6844-6867>
- China Discovery (2021) *Top 6 bamboo forests in China | best China bamboo seas in 2021* [online]. Available at: <https://www.chinadiscovery.com/articles/top-bamboo-forests.html>
- Choudhury, D., Sahu, J.K. and Sharma, G.D. (2012) 'Value addition to bamboo shoots: a review'. *Journal of Food Science and Technology*, 49, pp. 407–414 [online]. Available at: <https://doi.org/10.1007/s13197-011-0379-z>
- Chuchon, J.E.C., Cardenas, R.P., Durai, J., Long, T.T. and Li, Y. (2021) *Ecosystem services and cost-benefit analysis of natural forests and mixed bamboo systems in Peru*. INBAR Working Paper. Beijing: INBAR.
- Coggins, C.R. (2000) 'Wildlife conservation and bamboo management in China's southeast uplands'. *The Geographical Review*, 90, pp. 83–111 [online]. Available at: <https://doi.org/10.2307/216176>
- Dai, E., Wang, X.L., Zhu, J.J. and Xi, W.M. (2017) 'Quantifying ecosystem service trade-offs for plantation forest management to benefit provisioning and regulating services'. *Ecology and Evolution*, 7, pp. 7807–7821 [online]. Available at: <https://doi.org/10.1002/ece3.3286>
- Das, S. and Saha, M. (2013) 'Preparation of carbon nanosphere from bamboo and its use in water purification'. *Current Trends in Technology and Science*, 2, pp. 174–177.

- Dev, I., Ram, A., Ahlawat, S.P., Palsaniya, D.R., Singh, R., Dhyani, S.K., Kumar, N., Tewari, R.K., Singh, M., Babanna, S.K., Newaj, R., Dwivedi, R.P., Kumar, R.V., Yadav, R.S., Chand, L., Kumar, D. and Prasad, J. (2020) 'Bamboo-based agroforestry system (*Dendrocalamus strictus* + sesame – chickpea) for enhancing productivity in semi-arid tropics of central India'. *Agroforestry Systems*, 94, 1725–1739 [online]. Available at: <https://doi.org/10.1007/s10457-020-00492-8>
- Dharmananda, S. (2004) *Bamboo as medicine* [online]. Available at: <http://www.itmonline.org/arts/bamboo.htm> (Accessed: 11 November 2021).
- Effah, B., Boampong, E., Asibey, O., Pongo, N.A. and Nkrumah, A. (2014) 'Small and medium bamboo and rattan enterprises in economic empowerment in Kumasi: perspectives of producers'. *Journal of Social Economics*, 1, pp. 11–21.
- Embaye, K. (2000) 'The indigenous bamboo forests of Ethiopia: an overview'. *AMBIO: A Journal of the Human Environment*, 29, pp. 518–521 [online]. Available at: <https://doi.org/10.1579/0044-7447-29.8.518>
- Food and Agriculture Organisation of the United Nations (2007) *World bamboo resources: a thematic study prepared in the framework of the Global Forest Resources Assessment 2005*. Non-wood Forest Products 18 [online]. FAO: Rome, Italy. Available at: <http://www.fao.org/3/a-a1243e.pdf> (Accessed: 18 December 2018).
- Food and Agriculture Organisation of the United Nations (2009) *The poor man's carbon sink: bamboo in climate change and poverty alleviation*. Non-Wood Forest Products 8 [online]. FAO: Rome, Italy. Available at: <http://www.fao.org/tempref/docrep/fao/012/k6887e/k6887e00.pdf> (Accessed: 18 December 2018).
- Food and Agriculture Organisation of the United Nations (2020) *Global Forest Resources Assessment 2020: main report* [online]. Rome: FAO. Available at: <https://doi.org/10.4324/9781315184487-1>
- Food and Agriculture Organisation of the United Nations and International Bamboo and Rattan Organisation (2018) *Bamboo for land restoration*. INBAR Policy Synthesis Report 4. Beijing: INBAR.
- Gagliano, J., Anselmo-Moreira, F., Sala-Carvalho, W.R. and Furlan, C.M. (2021) 'What is known about the medicinal potential of bamboo?' *Advances in Traditional Medicine* 1-19 [online]. Available at: <https://doi.org/10.1007/s13596-020-00536-5>
- Gamfeldt, L., Snall, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., Ruiz-Jaen, M.C., Froberg, M., Stendahl, J., Philipson, C.D., Mikusinski, G., Andersson, E., Westerlund, B., Andren, H., Moberg, F., Moen, J. and Bengtsson, J. (2013) 'Higher levels of multiple ecosystem services are found in forests with more tree species'. *Nature*

- Communications*, 4, pp. 1–8 [online]. Available at: <https://doi.org/10.1038/ncomms2328>
- Gang, L.O.U. (2018) 'The application of bamboo elements in "new Chinese-style" landscape design'. *Journal of Landscape Research*, 10.
- Gautam, G., Aryal, R. and Lamichhane, P. (2018) 'Restoration of degraded land through Moso bamboo (*Phyllostachys pubescens*) plantation in the Mid-hills of Nepal'. *Banko Janakari*, 27, pp. 150–153 [online]. Available at: <https://doi.org/10.3126/banko.v27i3.20560>
- Gielen, D., Boshell, F., Saygin, D., Bazilian, M.D., Wagner, N., Gorini, R. (2019) 'The role of renewable energy in the global energy transformation'. *Energy Strategy Reviews*, 24, pp 38–50. Available at: <https://doi.org/10.1016/j.esr.2019.01.006>
- Global Landscape Forum (2020) *Bamboo, rattan, and forest biodiversity* [online]. Available at: <https://www.globallandscapesforum.org/glf-news/bamboo-rattan-and-forest-biodiversity/> (Accessed: 12 May 2021).
- Grueter, C.C., Robbins, M.M., Abavandimwe, D., Ortmann, S., Mudakikwa, A., Ndagijimana, F., Vecellio, V. and Stoinski, T.S. (2016) 'Elevated activity in adult mountain gorillas is related to consumption of bamboo shoots'. *Journal of Mammalogy*, 97, pp. 1663–1670 [online]. Available at: <https://doi.org/10.1093/jmammal/gyw132>
- Guest, G., MacQueen, K. and Namey, E. (2012) *Introduction to applied thematic analysis*. Thousand Oaks: SAGE Publications.
- Guomo, Z. and Peikun, J. (2004) 'Density, storage and spatial distribution of carbon in *Phyllostachy pubescens* forest'. *Scientia Silvae Sinicae*, 26, pp. 20–24 [online]. Available at: <https://doi.org/10.11707/j.1001-7488.20040604>
- Gupta, A. and Kumar, A. (2008) 'Potential of bamboo in sustainable development'. *Asia Pacific Business Review*, 4, pp. 100–107 [online]. Available at: <https://doi.org/10.1177/097324700800400312>
- Halvorson, J.J., Cassida, K.A., Turner, K.E. and Belesky, D.P. (2011) 'Nutritive value of bamboo as browse for livestock'. *Renewable Agriculture and Food Systems*, 26, pp. 161–170 [online]. Available at: <https://doi.org/10.1017/S1742170510000566>
- Hassan, A., Tao, J., Li, G., Jiang, M., Aii, L., Zhihui, J., Zongfang, L. and Qibing, C. (2018) 'Effects of walking in bamboo forest and city environments on brainwave activity in young adults'. *Evidence-Based Complementary and Alternative Medicine*, 2018, pp. 1–9 [online]. Available at: <https://doi.org/10.1155/2018/9653857>
- Hayha, T., Paolo, P., Paletto, A. and Fath, B.D. (2015) 'Assessing, valuing, and mapping ecosystem services in alpine forests'. *Ecosystem Services*, 14, pp. 12–23 [online]. Available at: <https://doi.org/10.1016/j.ecoser.2015.03.001>
- Hogarth, N.J. and Belcher, B. (2013) 'The contribution of bamboo to household income and rural livelihoods in a poor and mountainous county in Guangxi, China'. *International*

- Forestry Review*, 15, pp. 71–81 [online]. Available at: <https://doi.org/10.1505/146554813805927237>
- International Bamboo and Rattan Organisation (2006) *The partnership for a better world—strategy to the year 2015*. Beijing: International Bamboo and Rattan Organisation.
- International Bamboo and Rattan Organisation (2019) *Bamboo facts: what makes bamboo a strategic resource for green economy development?* [online]. Available at: <https://www.inbar.int/bamboo-facts-what-makes-bamboo-a-strategic-resource-for-green-economy-development/> (Accessed: 7 August 2019).
- Jacobs, D.F., Oliet, J.A., Aronson, J., Bolte, A., Bullock, J.M., Donoso, P.J., Landhäuser, S.M., Madsen, P., Peng, S., Rey-Benayas, J.M. and Weber, J.C. (2015) 'Restoring forests: what constitutes success in the twenty-first century?' *New Forests*, 46, pp. 601–614 [online]. Available at: <https://doi.org/10.1007/s11056-015-9513-5>
- Kaushal, R., Kumar, A., Alam, N.M., Singh, I., Mandal, D., Tomar, J.M.S., Mehta, H., Lepcha, S.T.S., Long, T.T. and Durai, J. (2021) 'Assessment of eco-hydrological parameters for important sympodial bamboo species in Himalayan foothills'. *Environmental Monitoring and Assessment*, 193, pp. 1–13 [online]. Available at: <https://doi.org/10.1007/s10661-021-09231-7>
- Kaushal, R., Singh, I., Thapliyal, S.D., Gupta, A.K., Mandal, D., Tomar, J.M.S., Kumar, A., Alam, N.M., Kadam, D., Singh, D. V., Mehta, H., Dogra, P., Ojasvi, P.R., Reza, S. and Durai, J. (2020) 'Rooting behaviour and soil properties in different bamboo species of Western Himalayan foothills, India'. *Scientific Reports*, 10, pp. 1–17 [online]. Available at: <https://doi.org/10.1038/s41598-020-61418-z>
- Kaushal, R., Tewari, S., Banik, R.L., Thapliyal, S.D., Singh, I., Reza, S. and Durai, J. (2020) 'Root distribution and soil properties under 12-year old sympodial bamboo plantation in Central Himalayan Tarai Region, India'. *Agroforestry Systems*, 94, pp. 917–932 [online]. Available at: <https://doi.org/10.1007/s10457-019-00459-4>
- Kaushal, R., Tewari, S., Thapliyal, S.D., Kumar, A., Roy, T., Islam, S., Lepcha, S.T.S. and Durai, J. (2021) 'Build-up of labile, non-labile carbon fractions under fourteen-year-old bamboo plantations in the Himalayan foothills'. *Heliyon*, 7, e07850 [online]. Available at: <https://doi.org/10.1016/j.heliyon.2021.e07850>
- Khaniya, B., Gunathilake, M.B. and Rathnayake, U. (2021) 'Ecosystem-based adaptation for the impact of climate change and variation in the water management sector of Sri Lanka'. *Mathematical Problems in Engineering*, 2021, 8821329 [online]. Available at: <https://doi.org/10.1155/2021/8821329>
- Koide, C.L.K., Collier, A.C., Berry, M.J. and Panee, J. (2011) 'The effect of bamboo extract on hepatic biotransforming enzymes – findings from an obese–diabetic mouse model'.

- Journal of Ethnopharmacology*, 133, pp. 37–45 [online]. Available at: <https://doi.org/10.1016/j.jep.2010.08.062>
- Kroeger, T. and Casey, F. (2007) 'An assessment of market-based approaches to providing ecosystem services on agricultural lands'. *Ecological Economics*, 64, pp. 321–332 [online]. Available at: <https://doi.org/10.1016/j.ecolecon.2007.07.021>
- Kuehl, Y., Li, Y. and Henley, G. (2013) 'Impacts of selective harvest on the carbon sequestration potential in Moso bamboo (*Phyllostachys pubescens*) plantations'. *Forests Trees and Livelihoods*, 22, pp. 1–18 [online]. Available at: <https://doi.org/10.1080/14728028.2013.773652>
- Ladapo, H.L., Bello, O.O. and Bello, R.O. (2017) 'Utilization of vast Nigeria's bamboo resources for economic growth: a review'. *Journal of Research in Forestry, Wildlife and Environment*, 9, pp. 29–35.
- Lei, G. and Chengyu, F. (2019) 'Research on bamboo forest ecotourism development in Xianning City based on SWOT analysis'. *Advances in Social Science, Education and Humanities Research*, 347, pp. 273–276.
- Lei, J. (2001) 'A development strategy for bamboo resource and industry in China' in Zhu, Z. (ed.) *Sustainable development of the bamboo and rattan sectors in tropical China*. Beijing: China Forestry Publishing House, pp. 1–18.
- Li, P., Zhou, G., Du, H., Lu, D., Mo, L., Xu, X., Shi, Y. and Zhou, Y. (2015) 'Current and potential carbon stocks in Moso bamboo forests in China'. *Journal of Environmental Management*, 156, pp. 89–96 [online]. Available at: <https://doi.org/10.1016/j.jenvman.2015.03.030>
- Li, R., Xu, M., Wong, M.H.G., Qiu, S., Sheng, Q., Li, X. and Song, Z. (2015) 'Climate change-induced decline in bamboo habitats and species diversity: implications for giant panda conservation'. *Diversity and Distributions*, 21, pp. 379–391 [online]. Available at: <https://doi.org/10.1111/ddi.12284>
- Liese, W. (2009) 'Bamboo as carbon sink-fact or fiction?' *Journal of Bamboo and Rattan*, 8, pp. 103–114.
- Liese, W., Welling, J. and Tang, T.K.H. (2015) 'Utilization of bamboo' in *Bamboo*. Cham: Springer, pp. 299–346. Available at: https://doi.org/10.1007/978-3-319-14133-6_10
- Lin, W., Yang, F., Zhou, L., Xu, J.-g. and Zhang, X.-q. (2017) 'Using modified Soil Conservation Service curve number method to simulate the role of forest in flood control in the upper reach of the Tingjiang River in China'. *Journal of Mountain Science*, 14, pp. 1–14 [online]. Available at: <https://doi.org/10.1007/s11629-016-3945-z>
- Linderman, M., Bearer, S., An, L., Tan, Y., Ouyang, Z. and Liu, J. (2005) 'The effects of understory bamboo on broad-scale estimates of giant panda habitat'. *Biological*

- Conservation*, 121, pp. 383–390 [online]. Available at: <https://doi.org/10.1016/j.biocon.2004.05.011>
- Liu, W., Hui, C., Wang, F., Wang, M. and Liu, G. (2018) 'Review of the resources and utilization of bamboo in China' in: *Khalil, H.P.S.A. (Ed.), Bamboo – current and future prospects* [online]. IntechOpen, pp. 133–142. Available at: <http://dx.doi.org/10.5772/intechopen.76485> (Accessed: 21 July 2019).
- Lyu, B., Zeng, C., Deng, S., Liu, S., Jiang, M., Li, N., Wei, L., Yu, Y. and Chen, Q. (2018) 'Bamboo forest therapy contributes to the regulation of psychological responses'. *Journal of Forest Research*, 24, pp. 61–70 [online]. Available at: <https://doi.org/10.1080/13416979.2018.1538492>
- Lyu, B., Zeng, C., Xie, S., Li, D., Lin, W., Li, N., Jiang, M., Liu, S. and Chen, Q. (2019) 'Benefits of a three-day bamboo forest therapy session on the physiological responses of university students'. *International Journal of Environmental Research and Public Health*, 16, 4991 [online]. Available at: <https://doi.org/10.3390/ijerph16244991>
- Malanson, G.P. and Alftine, K.J. (2016) *Ecological impacts of Climate change, biological and environmental hazards, risks, and disasters* [online]. Academic Press, pp. 397–426. Available at: <https://doi.org/10.1016/B978-0-12-394847-2.00022-X>
- Malcolm, K.D., McShea, W.J., Garshelis, D.L., Luo, S.J., Van Deelen, T.R., Liu, F., Li, S., Miao, L., Wang, D. and Brown, J.L. (2014) 'Increased stress in Asiatic black bears relates to food limitation, crop raiding, and foraging beyond nature reserve boundaries in China'. *Global Ecology and Conservation*, 2, pp. 267–276 [online]. Available at: <https://doi.org/10.1016/j.gecco.2014.09.010>
- Mao, F., Du, H., Li, X., Ge, H., Cui, L. and Zhou, G. (2020) 'Spatiotemporal dynamics of bamboo forest net primary productivity with climate variations in Southeast China'. *Ecological Indicators*, 116, 106505 [online]. Available at: <https://doi.org/10.1016/j.ecolind.2020.106505>
- Millennium Ecosystem Assessment (2005) *Ecosystems and human well-being: synthesis*. Washington, DC: Island Press.
- Miura, S., Amacher, M., Hofer, T., San-Miguel-Ayanz, J. and Thackway, R. (2015) 'Protective functions and ecosystem services of global forests in the past quarter-century'. *Forest Ecology and Management*, 352, pp. 35–46 [online]. Available at: <https://doi.org/10.1016/j.foreco.2015.03.039>
- Nath, A.J., Franklin, D.C., Lawes, M.J., Das, M.C. and Das, A.K. (2012) 'Impact of culm harvest on seed production in a monocarpic bamboo'. *Biotropica*, 44, pp. 699–704 [online]. Available at: <https://doi.org/10.1111/j.1744-7429.2012.00858.x>
- Nath, A.J., Lal, R. and Das, A.K. (2015) 'Managing woody bamboos for carbon farming and

- carbon trading'. *Global Ecology and Conservation*, 3, pp. 654–663 [online]. Available at: <https://doi.org/10.1016/j.gecco.2015.03.002>
- Nath, A.J., Sileshi, G.W. and Das, A.K. (2018) 'Bamboo based family forests offer opportunities for biomass production and carbon farming in North East India'. *Land Use Policy*, 75, pp. 191–200 [online]. Available at: <https://doi.org/10.1016/j.landusepol.2018.03.041>
- Nath, S., Das, R., Chandra, R. and Sinha, A. (2009) *Bamboo based agroforestry for marginal lands with special reference to productivity, market trend and economy* [online]. Available at: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.564.1866&rep=rep1&type=pdf> (Accessed: 22 June 2019).
- Nirmala, C. (2018) 'The healing touch of bamboo: soul, mind and body' in *11th World Bamboo Congress (14 - 18 August 2018, Xalapa, Mexico)*. Available at: <https://worldbamboo.net/wbcxi/keynotes/Chongtham,%20Nirmala.pdf> (Assessed on 21 Oct 2021).
- Nirmala, C. and Bisht, M.S. (2015) 'Bamboo: a prospective ingredient for functional food and nutraceuticals' in *10th World Bamboo Congress (Damyang, Korea, 17-22 September 2015)* [online]. Plymouth: World Bamboo Organisation. Available at: <https://www.researchgate.net/publication/342344855%0ABamboo>:
- Nirmala, C., Bisht, M.S., Bajwa, H.K. and Santosh, O. (2018) 'Bamboo: a rich source of natural antioxidants and its applications in the food and pharmaceutical industry'. *Trends in Food Science and Technology*, 77, pp. 91–99 [online]. Available at: <https://doi.org/10.1016/j.tifs.2018.05.003>
- Nirmala, C., Bisht, M.S. and Haorongbam, S. (2011) 'Nutritional properties of bamboo shoots: potential and prospects for utilization as a health food'. *Comprehensive Reviews in Food Science and Food Safety*, 10, pp. 153–169 [online]. Available at: <https://doi.org/10.1111/j.1541-4337.2011.00147.x>
- Nirmala, C., Bisht, M.S. and Laishram, M. (2014) 'Bioactive compounds in bamboo shoots: health benefits and prospects for developing functional foods'. *International Journal of Food Science and Technology*, 49, pp. 1425–1431 [online]. Available at: <https://doi.org/10.1111/ijfs.12470>
- Ocko, I. (2015) *As bamboo forests fade, can pandas survive?* [online]. Available at: <https://www.livescience.com/49596-as-bamboo-forests-fade-can-pandas-survive.html> (Accessed: 15 October 2021).
- Onozawa, Y., Chiwa, M., Komatsu, H. and Otsuki, K. (2009) 'Rainfall interception in a Moso bamboo (*Phyllostachys pubescens*) forest'. *Journal of Forest Research*, 14, pp. 111–116

- [online]. Available at: <https://doi.org/10.1007/s10310-008-0108-2>
- Panee, J. (2015) 'Potential medicinal application and toxicity evaluation of extracts from bamboo plants'. *Journal of Medicinal Plant Research*, 9, pp. 681–692.
- Partey, S.T., Sarfo, D.A., Frith, O., Kwaku, M. and Thevathasan, N.V. (2017) 'Potentials of bamboo-based agroforestry for sustainable development in sub-Saharan Africa: a review'. *Agricultural Research*, 6, pp. 22–32 [online]. Available at: <https://doi.org/10.1007/s40003-017-0244-z>
- Patra, S., Kaushal, R., Singh, D., Kumar, R., Gadedjisso-Tossou, A. and Durai, J. (2021) 'Surface soil hydraulic conductivity and macro-pore characteristics as affected by four bamboo species in North-Western Himalaya, India'. *Ecohydrology & Hydrobiology* [in press, online]. Available at: <https://doi.org/10.1016/j.ecohyd.2021.08.012>
- Paudyal, K., Adhikari, S., Sharma, S., Samsudin, Y.B., Paudyal, B.R., Bhandari, A., Birhane, E., Darcha, G., Long, T.T. and Baral, H. (2019) *Framework for assessing ecosystem services from bamboo forests: lessons from Asia and Africa*. Working Paper 235 [online]. Bogor: CIFOR. Available at: <https://doi.org/10.17528/cifor/007433>
- Paudyal, K., Baral, H., Lowell, K. and Keenan, R.J. (2017a) 'Ecosystem services from community-based forestry in Nepal: realising local and global benefits'. *Land Use Policy*, 63, pp. 342–355 [online]. Available at: <https://doi.org/10.1016/j.landusepol.2017.01.046>
- Paudyal, K., Putzel, L., Baral, H., Chaudhary, S., Sharma, R., Bhandari, S., Poudel, I. and Keenan, R.J. (2017b). 'From denuded to green mountains: process and motivating factors of forest landscape restoration in Phewa Lake watershed, Nepal'. *International Forestry Review*, 19, pp. 75–87.
- Perez, M.R., Rodriguez, L.G., Yang, X., Xie, J. and Fu, M. (2014). 'From basic raw material goods to cultural and environmental services: the Chinese bamboo sophistication path'. *Ecology and Society*, 19, 3 [online]. Available at: <http://dx.doi.org/10.5751/ES-06701-190403>
- Phimmachanh, S., Ying, Z. and Beckline, M. (2015). 'Bamboo resources utilization: a potential source of income to support rural livelihoods'. *Applied Ecology and Environmental Sciences*, 3, pp. 176–183 [online]. Available at: <https://doi.org/10.12691/AEES-3-6-3>
- Popp, J., Lakner, Z., Harangi-Rakos, M., Fari, M. (2014) 'The effect of bioenergy expansion: Food, energy, and environment'. *Renewable and Sustainable Energy Reviews*, 32, pp 559–578 [online]. Available at: <https://doi.org/10.1016/j.rser.2014.01.056>
- Power, A.G. (2010). 'Ecosystem services and agriculture: tradeoffs and synergies'. *Philosophical Transactionals of the Royal Society B*, 365, pp. 2959–2971 [online]. Available at: <https://doi.org/10.1098/rstb.2010.0143>
- Rebelo, C. and Buckingham, K. (2015). 'Bamboo: the opportunities for forest and landscape

- restoration'. *Unasylva*, 66, pp. 91–98.
- Reid, S., Díaz, I.A., Armesto, J.J. and Willson, M.F. (2004). 'Importance of native bamboo for understory birds in Chilean temperate forests'. *The Auk*, 121, pp. 515–525 [online]. Available at: <https://doi.org/10.1093/auk/121.2.515>
- Reij, C. and Winterbottom, R. (2017). *Can we restore 350 million hectares by 2030?* [online]. Available at: <https://www.wri.org/blog/2017/02/can-we-restore-350-million-hectares-2030> (Accessed: 21 June 2019).
- Schroder, S. (2021a). *Bamboo facts: bamboo produces water for rivers and streams* [online]. Available at: <https://www.guaduabamboo.com/blog/bamboo-produces-water-for-rivers-and-streams> (Accessed: 10 October 2021).
- Schroder, S. (2021b). *Environmental Impact of Guadua Bamboo* [online]. Available at: <https://www.guaduabamboo.com/blog/environmental-impact-of-guadua-bamboo> (Accessed 21 October 2021).
- Sharma, B., Gato, A., Bock, M., Mulligan, H. and Ramage, M. (2015) 'Engineered bamboo: state of the art'. *Proceedings of Institution of Civil Engineers: Construction Materials*, 168, pp. 57–67 [online]. Available at: <https://doi.org/10.1680/coma.14.00020>
- Sharma, M.L. and Nirmala, C. (2015) 'Bamboo diversity of India: an update' in *10th World Bamboo Congress (Damyang, Korea, 17-22 September 2015)*. Plymouth: World Bamboo Organisation, pp. 1–12.
- Sharma, P., Saikia, P. and Sarma, K. (2016) 'Diversity, uses and in vitro propagation of different bamboos of Sonitpur District, Assam'. *Journal of Ecosystem & Ecography*, 6, 1000184 [online]. Available at: <https://doi.org/10.4172/2157-7625.1000184>
- Sharma, R., Martins, N., Kuca, K., Chaudhary, A., Kabra, A., Rao, M.M. and Prajapati, P.K. (2019) 'Chyawanprash: a traditional Indian bioactive health supplement'. *Biomolecules*, 9, pp. 1–24 [online]. Available at: <https://doi.org/10.3390/biom9050161>
- Sharma, R., Wahono, J. and Baral, H. (2018) 'Bamboo as an alternative bioenergy crop and powerful ally for land restoration in Indonesia'. *Sustainability*, 10, 4367 [online]. Available at: <https://doi.org/10.3390/su10124367>
- Sheil, D., Ducey, M., Ssali, F., Ngubwagye, J.M., van Heist, M. and Ezuma, P. (2012) 'Bamboo for people, mountain gorillas, and golden monkeys: Evaluating harvest and conservation trade-offs and synergies in the Virunga Volcanoes'. *Forest Ecology and Management*, 267, pp. 163–171 [online]. Available at: <https://doi.org/10.1016/j.foreco.2011.11.045>
- Shen, M., Xie, Z., Jia, M., Li, A., Han, H., Wang, T. and Zhang, L. (2019) 'Effect of bamboo leaf extract on antioxidant status and cholesterol metabolism in broiler chickens'. *Animals*, 9, 9090699 [online]. Available at: <https://doi.org/10.3390/ani9090699>
- Shimono, K., Katayama, A., Kume, T., Enoki, T., Chiwa, M. and Hishi, T. (2021) 'Differences

- in net primary production allocation and nitrogen use efficiency between Moso bamboo and Japanese cedar forests along a slope'. *Journal of Forest Research* [online]. Available at: <https://doi.org/10.1080/13416979.2021.1965280>
- Sitas, N., Prozesky, H.E., Esler, K.J. and Reyers, B. (2014) 'Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level'. *Landscape Ecology*, 29, pp. 1315–1331 [online]. Available at: <https://doi.org/10.1007/s10980-013-9952-3>
- Sofiah, S., Setiadi, D. and Widyatmoko, D. (2018) 'The influence of edaphic factors on bamboo population in Mount Baung Natural Tourist Park, Pasuruan, East Java, Indonesia'. *Tropical Drylands*, 2, pp. 12–17 [online]. Available at: <https://doi.org/10.13057/tropdrylands/t020103>
- Sohel, M.S.I., Alamgir, M., Akhter, S. and Rahman, M. (2015) 'Carbon storage in a bamboo (*Bambusa vulgaris*) plantation in the degraded tropical forests: implications for policy development'. *Land Use Policy*, 49, pp. 142–151 [online]. Available at: <https://doi.org/10.1016/j.landusepol.2015.07.011>
- Song, Q., Lu, H., Liu, J., Yang, J., Yang, G. and Yang, Q. (2017) 'Assessing the impacts of bamboo expansion on NPP and N cycling in evergreen broadleaved forest in subtropical China'. *Scientific Reports*, 7, 40383 [online]. Available at: <https://doi.org/10.1038/srep40383>
- Song, X., Zhou, G., Jiang, H., Yu, S., Fu, J., Li, W., Wang, W., Ma, Z. and Peng, C. (2011) 'Carbon sequestration by Chinese bamboo forests and their ecological benefits: assessment of potential, problems, and future challenges'. *Environmental Reviews*, 19, pp. 418–428 [online]. Available at: <https://doi.org/10.1139/a11-015>
- Sousa, J.S.B., Longo, M.G. and Santos, B.A. (2019) 'Landscape patterns of primary production reveal agricultural benefits from forest conservation'. *Perspectives in Ecology and Conservation*, 17, pp. 136–145 [online]. Available at: <https://doi.org/10.1016/j.pecon.2019.08.001>
- Sujarwo, W. (2018) 'Bamboo resources, cultural values, and ex-situ conservation in Bali, Indonesia'. *Reinwardtia*, 17, p. 65 [online]. Available at: <https://doi.org/10.14203/reinwardtia.v17i1.3569>
- Sun, J., Ren, J., Hu, X., Hou, Y. and Yang, Y. (2021) 'Therapeutic effects of Chinese herbal medicines and their extracts on diabetes'. *Biomedicine and Pharmacotherapy*, 142, 111977 [online]. Available at: <https://doi.org/10.1016/j.biopha.2021.111977>
- Sun, Y.H., Zhang, H.J., Cheng, J.H., Wang, Y.J., Shi, J. and Cheng, Y. (2006) 'Soil characteristics and water conservation of different forest types in Jinyun Mountain [J]'. *Journal of Soil and Water Conservation*, 2.

- Tardio, G., Mickovski, S.B., Rauch, H.P., Fernandes, J.P. and Acharya, M.S. (2018) 'The use of bamboo for erosion control and slope stabilization: soil bioengineering works' in Khalil, H.P.S.A. (Ed.), *Bamboo – current and future prospects* [online]. IntechOpen, pp. 105–132. Available at: <http://dx.doi.org/10.5772/intechopen.75626>
- Tardio, G., Mickovski, S.B., Stokes, A. and Devkota, S. (2017) 'Bamboo structures as a resilient erosion control measure'. *Proceedings of the Institution of Civil Engineers – Forensic Engineering*, 170, pp. 72–83. Available at: <https://doi.org/10.1680/jfoen.16.00033>
- Teng, J., Xiang, T., Huang, Z., Wu, J., Jiang, P., Meng, C., Li, Y. and Fuhrmann, J.J. (2016) 'Spatial distribution and variability of carbon storage in different sympodial bamboo species in China'. *Journal of Environmental Management*, 168, pp. 46–52 [online]. Available at: <https://doi.org/10.1016/j.jenvman.2015.11.034>
- The Economics of Ecosystems and Biodiversity (2010). *The Economics of Ecosystems and Biodiversity: mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB* [online]. London; Washington, DC: Earthscan.
- Troy Mera, F.A. and Xu, C. (2014) 'Plantation management and bamboo resource economics in China'. *Ciencia y Tecnologia*, 7, pp. 1–12 [online]. Available at: <https://doi.org/10.18779/cyt.v7i1.181>
- Tuckett, A.G. (2005) 'Applying thematic analysis theory to practice: a researcher's experience'. *Contemporary Nurse*, 19, pp. 75–87.
- United Nations Convention to Combat Desertification (2019a) *Achieving land degradation neutrality* [online]. Available at: <https://www.unccd.int/actions/achieving-land-degradation-neutrality> (Accessed: 30 September 2019).
- United Nations Convention to Combat Desertification (2019b) *The Great Green Wall Initiative* [online]. Available at: <https://www.unccd.int/actions/great-green-wall-initiative> (Accessed: 30 September 2019).
- van der Lugt, P., Long, T.T. and King, C. (2018) *Carbon sequestration and carbon emissions reduction through bamboo forests and products*. INBAR Working Paper. Beijing: International Bamboo and Rattan Organisation.
- Vorontsova, M.S., Clark, L.G., Dransfield, J., Govaerts, R. and Baker, W.J. (2016) World checklist of bamboo and rattans. INBAR Technical Report No. 37. Beijing: International Bamboo and Rattan Organisation.
- Wang, Y., Chen, J., Wang, D., Ye, F., He, Y., Hu, Z. and Zhao, G. (2020) 'A systematic review on the composition, storage, processing of bamboo shoots: focusing the nutritional and functional benefits'. *Journal of Functional Foods*, 71, 104015 [online]. Available at:

<https://doi.org/10.1016/j.jff.2020.104015>

- Wood, S.L.R., Jones, S.K., Johnson, J.A., Brauman, K.A., Chaplin-Kramer, R., Fremier, A., Girvetz, E., Gordon, L.J., Kappel, C.V., Mandle, L., Mulligan, M., O'Farrell, P., Smith, W.K., Willemen, L., Zhang, W. and DeClerck, F.A. (2018) 'Distilling the role of ecosystem services in the Sustainable Development Goals'. *Ecosystem Services*, 29, pp. 70–82 [online]. Available at: <https://doi.org/10.1016/j.ecoser.2017.10.010>
- World Agroforestry Centre (2020) *Could bamboo-based agroforestry systems be the latest kind of climate-smart agriculture?* [online]. Available at: <https://www.worldagroforestry.org/blog/2020/05/18/could-bamboo-based-agroforestry-systems-be-latest-kind-climate-smart-agriculture> (Accessed: 15 October 2021).
- Wu, J., Zhong, Y. and Deng, J. (2019) 'Assessing and mapping forest landscape quality in China'. *Forests*, 10, 684. [online]. Available at: <https://doi.org/10.3390/f10080684>
- Xu, L., Shi, Y., Zhou, G., Xu, X., Liu, E., Zhou, Y., Zhang, F., Li, C., Fang, H. and Chen, L. (2018) 'Structural development and carbon dynamics of Moso bamboo forests in Zhejiang Province, China'. *Forest Ecology and Management*, 409, pp. 479–488 [online]. Available at: <https://doi.org/10.1016/j.foreco.2017.11.057>
- Yeasmin, L., Ali, M.N., Gantait, S. and Chakraborty, S. (2015) 'Bamboo: an overview on its genetic diversity and characterization'. *3 Biotech*, 5, pp. 1–11 [online]. Available at: <https://doi.org/10.1007/s13205-014-0201-5>
- Yeromiyan, T. (2021) *The culture and history of Chinese bamboo* [online]. Available at: <https://studycli.org/chinese-culture/chinese-bamboo>
- Yiping, L. and Henley, G. (2010) *Biodiversity in bamboo forests: a policy perspective for long term sustainability*. INBAR Working Paper 59. Beijing: International Bamboo and Rattan Organisation.
- Yiping, L., Yanxia, L., Buckingham, K., Henley, G. and Guomo, Z. (2010) *Bamboo and climate change mitigation: a comparative analysis of carbon sequestration*. INBAR Technical Report No. 32, The International Network for Bamboo and Rattan (INBAR), Beijing: China.
- Yu, C.P.(S.) and Hsieh, H. (2020) 'Beyond restorative benefits: evaluating the effect of forest therapy on creativity'. *Urban Forestry and Urban Greening*, 51, 126670 [online]. Available at: <https://doi.org/10.1016/j.ufug.2020.126670>
- Yusuf, S., Syamani, F.A., Fatriasari, W. and Subyakto (2018) 'Review on bamboo utilization as biocomposites, pulp and bioenergy'. *IOP Conference Series: Earth and Environmental Science*, 141, 012039 [online]. Available at: <https://doi.org/10.1088/1755-1315/141/1/012039>
- Zea Escamilla, E. and Habert, G. (2014) 'Environmental impacts of bamboo-based

- construction materials representing global production diversity'. *Journal of Cleaner Production*, 69, pp. 117–127 [online]. Available at: <https://doi.org/10.1016/j.jclepro.2014.01.067>
- Zhang, J., Pan, X., Gao, Z., Gao, W., Zhao, S., Shi, Q. and Lu, G. (2003) 'Landscape heterogeneity and net primary productivity (NPP) of mountain-oasis-desert ecosystems in western China'. *Ecosystems' Dynamics, Agricultural Remote Sensing and Modeling, and Site-Specific Agriculture*, 5153, 524183 [online]. Available at: <https://doi.org/10.1117/12.524183>
- Zhang, W., Ricketts, T.H., Kremen, C., Carney, K. and Swinton, S.M. (2007) 'Ecosystem services and dis-services to agriculture'. *Ecological Economics*, 64, pp. 253–260 [online]. Available at: <https://doi.org/10.1016/j.ecolecon.2007.02.024>
- Zhao, M., Xiang, W., Peng, C. and Tian, D. (2009) 'Simulating age-related changes in carbon storage and allocation in a Chinese fir plantation growing in southern China using the 3-PG model'. *Forest Ecology and Management*, 257, pp. 1520–1531 [online]. Available at: <https://doi.org/10.1016/j.foreco.2008.12.025>
- Zhou, B.-Z., Mao-Yi, F., Xie, J.-Z., Xiao-Sheng, Y. and Li, Z.-C. (2005) 'Ecological functions of bamboo forest: research and application'. *Journal of Forestry Research*, 16, pp. 143–147 [online]. Available at: <https://doi.org/10.1007/BF02857909>

Annex

List of ecosystem services from bamboo forests, including description and indicators, unit of measurement, beneficiary and scale

ES	Description of ES	Indicators of ES (unit of measurement)	Beneficiary/ use	Scale of ES	References
Provisioning services					
Food provision	More than 200 species of bamboos provide food (edible and palatable shoots) from wild and cultivated areas worldwide	<ul style="list-style-type: none"> No. of species producing edible shoots Amount of shoot production (tonnes ha⁻¹ yr⁻¹) 	Public/Private	O-R	(Basumatary et al., 2015; Choudhury et al., 2012; FAO, 2007; Nirmala, Bisht and Haorongbam, 2011; Troy Mera and Xu, 2014; Xu et al., 2018)
Forage production	Bamboo supplies forage that is popular for local livestock development everywhere	<ul style="list-style-type: none"> Amount of raw material supply (HL ha⁻¹ yr⁻¹ or tones ha⁻¹yr⁻¹) 	Private	O-R	(Partey et al., 2017)
Timber (construction materials)	Many bamboo species provide construction timber and are used for building raw materials, modern engineered bamboo products, composite panels and boards. Engineered bamboo may well replace steel, wood and concrete in many uses	<ul style="list-style-type: none"> No. of timber-producing bamboo species Extent of timber bamboo production (no. of clumps/stands per ha or tonnes ha⁻¹yr⁻¹) 	Private	O-G	(Ahammad, Stacey and Sunderland, 2019; Bock, 2014; Chaowana, 2013; FAO, 2007; Nath, Sileshi and Das, 2018; van der Lugt, Long and King, 2018; Yeasmin et al., 2015; Zea Escamilla and Habert, 2014)
Raw material supply	Bamboo provides raw materials for various types of enterprises for traditional domestic and industrial uses, such as different types of bamboo housing, flooring, crafts and fibre for pulp, paper and clothes	<ul style="list-style-type: none"> No. of bamboo clumps/stands supplying raw materials Amount of raw material supply (tonnes ha⁻¹yr⁻¹) Amount of revenue earned (USD ha⁻¹yr⁻¹) 	Public/Private	O-G	(Dai et al., 2017; FAO, 2007; Gupta and Kumar, 2008; Liese, Welling and Tang, 2015; Sharma, Saikia and Sarma, 2016; Yeasmin et al., 2015)
Bioenergy	Bamboo has traditionally been used as a source of domestic energy and as a substitute for wood charcoal and mineral coal. Biogas and oil can also be produced from bamboo. Bioenergy can replace fossil fuels and decrease the carbon footprint	<ul style="list-style-type: none"> Amount of charcoal (tonnes ha⁻¹yr⁻¹) Extent of oil production (ML ha⁻¹yr⁻¹) Extent of biogas production (e.g., pallets: tonnes ha⁻¹yr⁻¹ or electricity generated from bamboo gasification plants: KWh ha⁻¹yr⁻¹) 	Private	O-R	(Chin et al., 2017; Ladapo, Bello and Bello, 2017; Sharma, Wahono and Baral, 2018; Yusuf et al., 2018)
Medicinal resources	Traditional and indigenous medicine derived from bamboo products	<ul style="list-style-type: none"> No. of species of medical value Harvestable amount (tonnes ha⁻¹yr⁻¹) 	Public/Private	O-G	(FAO, 2007; Panee, 2015; Yeasmin et al., 2015)
Freshwater provision	Bamboo forests contribute significantly to water source protection and help in supplying freshwater	<ul style="list-style-type: none"> Presence of water bodies, such as no. of springs, ponds and streams Amount of water yield from a particular area (ML ha⁻¹yr⁻¹) 	Public/Private	O-L	(Liu et al., 2018)

		<ul style="list-style-type: none"> No. of projects using water (e.g. watermills, drinking water, irrigation and hydropower plants) 			
Regulating services					
Landscape restoration	Restoration of degraded land through planting bamboo	<ul style="list-style-type: none"> Total restored area (ha) 	Private/Public	O-R	(Rebelo and Buckingham, 2015)
Sediment retention	Bamboo forests stabilise the slope and prevent soil erosion, which improves the condition of the land and controls floods and landslides. These phenomena reduce the deposition load downstream	<ul style="list-style-type: none"> Rate of downstream siltation (tonnes ha⁻¹yr⁻¹) 	Public	O-R	(Embaye, 2000; Tardio et al., 2017; van der Lugt, Long and King, 2018; Zhou et al., 2005)
Carbon sequestration	Bamboo grows faster and can sequester carbon from the atmosphere at a faster rate than many tree species	<ul style="list-style-type: none"> Extent of carbon sequestration annually (tonnes C ha⁻¹yr⁻¹ or Mg ha⁻¹yr⁻¹) No. of bamboo clumps/stands per ha 	Public	O-G	(FAO, 2009; Liese, 2009; Song et al., 2011)
Carbon stock	Increased bamboo biomass indicates a higher amount of carbon storage	<ul style="list-style-type: none"> Area of bamboo forest (no./ha) No. of clumps/stands per ha Amount of carbon stored (tonnes C ha⁻¹) 	Public	O-G	(Chen et al., 2009; P. Li et al., 2015; Teng et al., 2016)
Air quality and local climate regulation	Bamboo forests filter the air and remove odours, pollutant gases (nitrogen oxides, ammonia, sulphur dioxide and ozone) and dust particles from the air through the action of leaves and bark. Improved air quality makes the local climate better	<ul style="list-style-type: none"> Total leaf area (TLA ha⁻¹) Number of pollutants absorbed by bamboo forest 	Public	O-R	(Troy Mera and Xu, 2014)
Flood/ landslide control	Bamboo forests control floods and landslides by holding soil particles together through a complex network of roots and rhizomes	<ul style="list-style-type: none"> No. of landslide/flooding events Amount of soil loss (tonnes ha⁻¹yr⁻¹) 	Public	O-R	(Lin et al., 2017; van der Lugt, Long and King, 2018; Zhou et al., 2005)
Groundwater recharge	The increased area of bamboo forests reduces the run-off rate and assists water percolation	<ul style="list-style-type: none"> Water volume availability downstream (ML ha⁻¹yr⁻¹) 	Public	O-N	(Yeasmin et al., 2015)
Water purification	Bamboo forests induce landscapes to filter out and decompose organic waste introduced into land and water and can assimilate and detoxify compounds through soil and subsoil processes	<ul style="list-style-type: none"> Amount of quality/pure water throughout the year (ML ha⁻¹yr⁻¹) 	Private/Public	O-N	(Das and Saha, 2013)
Moderation of extreme events	Bamboo forests act as a natural buffer, helping to protect against wildlife attacks, strong winds, storms, landslides and other disasters and hence reducing damaging impacts	<ul style="list-style-type: none"> Number of extreme events protected against (no. yr⁻¹) 	Public	O-L	(FAO and INBAR, 2018)
Healing	Bamboo forest is related to the psychological and spiritual healing of bamboo. Bamboo forests are increasingly being used as a healing	<ul style="list-style-type: none"> Number of people visited per year 	Public	O-R	

	landscape in many countries, such as China and Japan				
Habitat services					
Habitat provision	Bamboo forests provide suitable habitat for different species (flora & fauna)	<ul style="list-style-type: none"> No. of endangered species in the forest 	Public	O-N	(Coggins, 2000; Linderman et al., 2005; Yeasmin et al., 2015)
Maintenance of biological diversity	Bamboo forests maintain and/or enhance biodiversity by promoting different varieties of bamboo species and providing habitat for wild animals	<ul style="list-style-type: none"> No. of species, ecosystems and genetic diversity 	Public	O-G	(Sharma and Nirmala, 2015; Yeasmin et al., 2015)
Net primary production	Bamboo has greater efficiency of land use – that is, there is a higher land equivalent ratio in the agroforestry system compared to sole-crop systems.	<ul style="list-style-type: none"> Extent of biomass production (tonne/ha) Number of ES supported 	Private/public	O-G	(Dev et al., 2020)
Cultural services					
Landscape beauty	Bamboo forests facilitate landscape beautification by preventing land degradation and enhancing landscape restoration and greenery	<ul style="list-style-type: none"> Area of the landscape covered by bamboo forest (area in ha) No. of visitors appreciating the views of the landscape covered by bamboo forest 	Public	O-R	(Gang, 2018; van der Lugt, Long and King, 2018)
Recreation and ecotourism	Bamboo forests provide opportunities for ecotourism and recreational activities through the promotion of greenery and landscape beautification	<ul style="list-style-type: none"> No. of recreation sites No. of visitors per year 	Public/Private	O-R	(Troy Mera and Xu, 2014)
Cultural/religious values	Bamboo materials have been used from the cradle to the grave in many countries because of religious and cultural values associated with bamboo	<ul style="list-style-type: none"> No. of cultural and religious events associated with bamboo 	Public	O-L	(van der Lugt, Long and King, 2018)

Note: Ecosystem services (ES) are further classified into provisioning, regulating, cultural and habitat services based on the Economics of Ecosystem and Biodiversity (2010) ES categories. The scale of ES is as follows: 'O' – on-site (in situ delivery); 'L' – local (offsite, 100 m–10 km); 'R' – regional (10–1,000 km); and 'G' – global (>1,000 km). Key to the scale of users: 'O' – on-site users (who live within bamboo and adjoining forests and have protected and managed ES), 'L' – local users (who are offsite but are living within the forest surroundings up to 10 km from bamboo forests and also have protected and managed bamboo for ES); 'R' – regional users (who live between 10 km and 1,000 km downstream of bamboo 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 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; 'Mg' - megagrams 'ML' – megalitres; 'HL' – head load (30 kg); 'tonnes' – metric tonnes (1,000 kg); 'ha' – hectare; 'ha⁻¹' – per hectare; 'yr⁻¹' – per year; 'TLA' – total leaf area.



www.inbar.int

@INBAROfficial