INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 21, No. 4, p. 1-14, 2022
http://www.innspub.net

REVIEW PAPER OPEN ACCESS

Bamboos (Bambusiadeae): plant resources with ecological, socio-economic and cultural virtues: A review

N. Kambale Ndavaro[*1,3], ADMT. Hegbe[3], JD. Minengu Mayulu[2], W. Muhindo Sahani[1], SSH. Biaou[3], AK. Natta[3]

[1]*Catholic University of Graben, Faculty of Agronomic Sciences, Laboratory of Ecology, Studies and Forest Research (LERF), Butembo, Democratic Republic of Congo*

[2]*University of Kinshasa, Faculty of Agronomic Sciences, Kinshasa, Democratic Republic of Congo*

[3]*University of Parakou, Faculty of Agronomy, Laboratory of Ecology, Botany and Plant Biology (LEB), Parakou, Benin*

Article published on October 03, 2022

Key words: Bamboos, Ecosystem services, Environmental protection, Income, Cultural heritage

Abstract

Bamboos (Bambusiadeae) are plant resources with several virtues and uses. However, the fragmentary, partial and dispersed aspect of the information relating to the benefits of bamboo does not make it possible to easily understand the potential of the latter, in order to promote their sustainability. This article reviews knowledge on the ecological, socio-economic and cultural importance of bamboos throughout the world in the light of the various studies that have been carried out on these subjects. Literature data show that bamboos play an invaluable role in environmental protection. They sequester large quantities of atmospheric carbon dioxide, stabilize slopes against edaphic erosion and intervene in ecological sanitation. A privileged habitat for several animal and plant species, bamboos play a major ecological role in the conservation of biodiversity. In addition, bamboos represent an important source of income for many households. There are, in fact, several products made from bamboo, from textiles to paper and cooking. Bamboos are also used in housing construction, handicrafts and traditional medicine. Finally, in some societies, bamboos are among the plants that have become true cultural markers or emblems of human history. Considering the ecosystem goods and services of bamboos, it is necessary to promote their conservation on the basis of conclusive technical data. Thus, future studies should be conducted to identify current threats to bamboo worldwide.

***Corresponding Author:** N. Kambale Ndavaro ✉ abbenorbertmarie@gmail.com

Introduction

Bamboos (Bambusiadeae) are one of the largest groups of *Poaceae* and comprise about 75-107 genera (Bhatt *et al.,* 2005) distributed between 1250-1600 species (Yuen *et al.,* 2017; Polesi *et al.*, 2021). Generally considered cumbersome and not very useful plants, bamboos are nevertheless among the most precious plant resources in the world, as they have several virtues and several uses (Kalanzi *et al.*, 2017; Dje Bi *et al.,* 2020). Indeed, bamboo contributes to the socio-economic development not only of marginalized areas, but also of urban environments (Somashekar *et al.*, 2018; INBAR, 2020). All the organs of these giant grasses are used by humans for multiple purposes (Bitariho and Mosango, 2005; Hessavi *et al.*, 2019; Dje Bi *et al.*, 2020). Some ethnobotanical and ethnoecological studies report a diversity of uses of bamboo by populations in several countries in tropical regions (Kalanzi *et al.*, 2017; Shahzad *et al.,* 2021). Through their various uses, bamboos represent an important source of income and employment for many households, both rural and urban (Ramananantoandro *et al.*, 2013; Dje Bi *et al.*, 2017; Mridusmita, 2018). A privileged habitat for several animal and plant species, bamboos play a very important ecological role in the conservation of biodiversity (Bystriakova *et al.*, 2004; Randrianarimanana *et al.*, 2012; Safari *et al.,* 2015). In the current context of global changes, bamboos contribute effectively to the protection of the environment (Ramananantoandro *et al.*, 2013; INBAR, 2020) and also constitute an important element of the cultural heritage of several peoples around the world (Eblic, 2008; Dougoud, 2013; Guichard-Anguis, 2017).

However, the fragmentary, partial and dispersed aspect of the information relating to the benefits of bamboo does not allow us to grasp the enormous potential of these tall grasses. In fact, bamboos are still relatively little used in certain countries in the tropics where these giant grasses grow. Certainly, this comes from a lack of local tradition and technique for their use, on the one hand, but also and above all from a lack of documented information in a global, structured and very precise way on the multiple virtues of bamboos, on the other hand. These deficits of structured and precise documentation constitute a major limit to the optimal valorization of these phytoresources as well as to their conservation and sustainable management. To deal with this problem, this study takes stock of the state of knowledge on the ecological, socio-economic and cultural importance of bamboos in the world.

The interest of this bibliographic research is therefore operational. It serves to facilitate access to a greater range of information relating to the ecosystem services of bamboos, with a view to optimizing their uses and motivating human communities in the rural world of tropical regions to promote their sustainability, in order to be able to contribute effectively in achieving the Sustainable Development Goals (SDGs) which aim, among other things, to eliminate poverty, hunger and ensure food security in the world (Dje Bi *et al.,* 2020).

To achieve this, a documentary search was carried out on the Web using the search engines Google, Google Scholar, Scopus and ScienceDirect. The research equations were formulated using the following key words: Bamboos, ecosystem services, environmental protection, income, cultural heritage. In addition to these search engines, two bibliographic databases were queried, namely AGORA and OARE. As suggested by Gillet *et al.* (2016), books and scientific articles that were redundant and deviated from the research topic were eliminated, retaining only those containing as many bibliographic references as possible. This made it possible to select the references appearing in this bibliographical synthesis and whose automatic recording in Harvard style was done using the Zotero software. A total of 144 documents (articles, books and theses) relating to the importance of bamboo in the world were selected.

From a structural point of view, this documentary research is organized around four points: the botanical description, the global distribution and

ecology of bamboos, the ecological functions of bamboos, the socio-economic and cultural roles of bamboos and the ecosystem analysis of the ecological, socio-economic and cultural importance of bamboos.

Botanical description, distribution and ecology of bamboos

Botanical description

Bamboo is not just a single plant. This is a whole group, a subdivision of the grass family bringing together more than a thousand different varieties (Yuene *et al.,* 2017; Polesi *et al.*, 2021). This is why it is generically referred to in the plural under the concept of "bamboos" (Chao Chi-son and Renvoize, 1989; Cirad, 1962; INBAR, 2020). Bamboos are fast-growing herbaceous plants belonging to the subfamily Bambusoideae (*Bambusiadeae*) (Yuen *et al.*, 2017; Dje Bi *et al.*, 2020). They are grasses, in the same way as common wheat (*Triticum aestivum*), rice (*Oryza sativa*), palm trees (*Arecaceae*) or common reed (*Phragmites australis*), hence its name "giant grass" (Razak *et al.*, 2007; Shahzad *et al.*, 2021). It is classified among non-timber forest products, although technologically it has characteristics very close to those of wood (Dje Bi *et al.*, 2020).

From the morphological point of view, bamboo has different characteristic parts (Fig.1). The stems, called rhizomes, are underground (CIRAD, 1962). From these rhizomes emerge roots and buds. It is from the buds that the rhizomes develop into shoots or shoots then branch out into aerial hollow culms, partitioned off at the nodes. The largest specimen of bamboo can reach 35 m in height with a diameter of 15cm. Most often, the culm is surrounded by sheaths which fall off when it reaches full growth (Cirad, 1962; Chao Chi-son and Renvoize, 1989; Razak *et al.,* 2007). It also bears branches furnished with leaves of variable dimensions. There are striped leaves of different colors. They can be destroyed by drought or cold and are regularly renewed (Chaiyalad *et al.*, 2013). Bamboos are one of the plants with rare or irregular flowering. This morphological aspect makes the botanical identification keys based on the constitution of the spikelets, elementary units of the inflorescence of grasses, unusable in bamboos (Cirad, 1962; Tewari, 1992). In only a few cases is the bamboo plant able to flower each year. In most cases, it takes 65, 70, and even 130 years for a bamboo to begin to form flowers (CIRAD, 1962; Chao Chi-son and Renvoize, 1989).

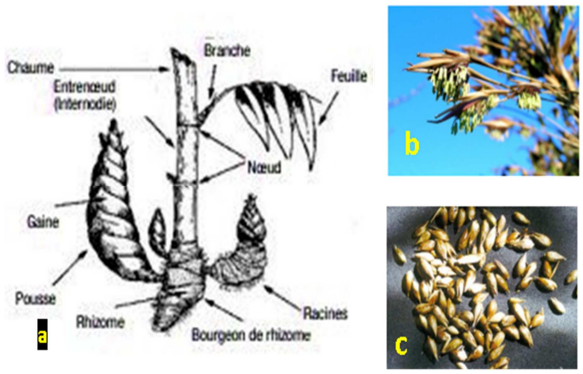

Fig. 1. Elements of the morphological structure of the bamboo plant: a) Main parts of the bamboo plant; b) Bamboo flowers; c) Bamboo fruits/grains (adapted from Chaiyalad *et al.*, 2013).

Distribution and ecological requirements

Bamboos are widely distributed throughout the world (Fig.2). They are typically found in tropical and subtropical regions of the world (Dje Bi *et al.*, 2020; Shahzad *et al.*, 2021). Most bamboo species have existed for around 30 to 40 million years (Chaiyalad *et al.*, 2013). Representatives of these species are found on all continents except Antarctica (Ramananantoandro *et al.*, 2013). Indeed, the different species of bamboo are distributed in countries of tropical and subtropical climatic zones. Bamboo forests extend worldwide over nearly 31.5 million hectares, which represents 0.8% of the world's forest areas (Tewari, 1992; El-Bassam and Jakob, 1996; Yuen *et al.,* 2017). Nearly two-thirds (65%) of bamboo species are geographically distributed in Southeast Asia (China, India, Burma, Indonesia, Taiwan, Malaysia, Japan, Vietnam, Philippines, Thailand, Pakistan and Bangladesh), 28% grow in South America (Chile, Argentina, Brazil, Ecuador, Guatemala, Colombia, Costa Rica and Peru), and the rest (7%) in Africa (south of the Sahara, from East Africa to West Africa in passing through all of Central Africa), Madagascar and Oceania (Polesi *et al.,* 2021). The natural distribution of bamboo in the

world goes from the 46th parallel North to the 47th parallel South but it is cultivated beyond the 60th parallel North (Tewari, 1992; El-Bassam and Jakob, 1996; Zhaoa *et al.,* 2018; Polesi *et al*., 2021).

From the point of view of ecological requirements, bamboos are plants that can be grown on all continents of the planet. They are likely to grow in almost any type of climate (Doat, 1967; Tewari, 1992). Indeed, bamboos prefer heat and can withstand the cold. They can also grow in temperate zones, such as in Europe where it was imported, even in cold zones and at very high altitudes, such as Ecuador or the Himalayas (up to 4,000 m altitude and at a temperature reaching -25° C in winter). Some species tolerate severe droughts, others floods and some even resist frost (INBAR, 2020). This great adaptability to climatic conditions is a major asset for the introduction and cultivation of bamboo all over the world (Tewari, 1992; Somashekar *et al*., 2018). Bamboos grow even in the poorest soils, very rich in limestone but without excess acid.

They do not need any fertilizer or phytosanitary products to grow properly (Tewari, 1992). However, bamboos prefer well-drained soils to heavy soils (Doat, 1967), since the rhizomes need to breathe (CIRAD, 1962; INBAR, 2020).

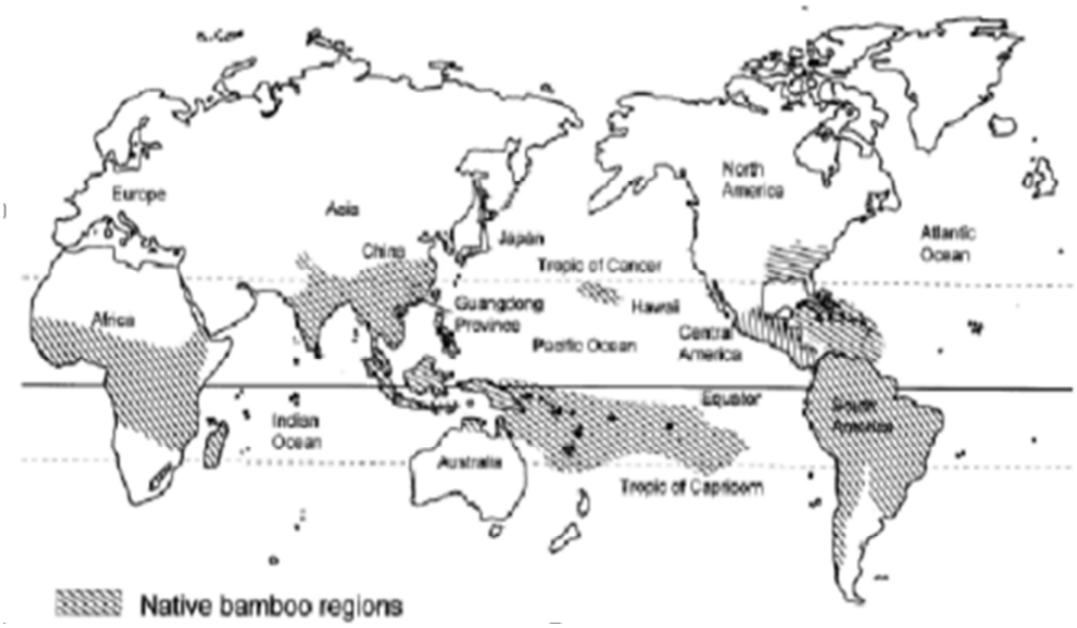

Fig. 2. Natural range of bamboos in the world (Adapted from El-Bassam and Jakob, 1996).

Ecological functions of bamboos

The ecological functions of bamboos are of several types: climate change mitigation, ecological remediation, ecological corridors and biodiversity conservation (Lobovikov *et al*., 2011; Teshoma, 2019). Indeed, with more than 1600 different species (Polesi *et al.*, 2021), bamboos play a very important role in climate change mitigation (Yuen *et al*., 2017). These giant grasses have a high potential for biomass production for atmospheric carbon sequestration, contributing to climate change mitigation, adaptation and green development (Song *et al*., 2011; Dje Bi *et al*., 2017). Indeed, bamboos sequester ranges of total ecosystem carbon on par with those of rubber plantations and orchards, but greater than those of agro-forests, oil palms, various types of fallows, grasslands , shrubs and pastures (Yuen *et al*., 2017 ; Teshoma, 2019). Other studies (Somashekar *et al*., 2018; INBAR, 2020) have shown that bamboos release 35% oxygen (O_2), and in addition can fix four times more carbon dioxide (CO_2) than trees on the same space. Thus, by comparing a deciduous forest to a bamboo plantation or bamboo grove, the bamboo grove can fix up to 12 tons of CO_2/ha/year against 3 tons of CO_2/ha/year, for the deciduous forest (Thousand and Louppe, 2015; INBAR, 2020). It is in

view of this ecological virtue of bamboos that it is estimated that they can contribute to achieving one of the objectives of the Kyoto protocols in 1997 and the Hague in 2000 (Rougier, 2020). Indeed, one of the solutions proposed by these two protocols to combat global warming consists of planting trees capable of fixing a lot of CO_2 (Nganje, 2017; INBAR, 2020), with, as a backdrop fundamentally, the objective of bequeathing a viable planet to future generations (Mille and Louppe, 2015).

Furthermore, the role of bamboo in ecological sanitation is remarkable in many respects. Indeed, bamboo can also be used for the purification of municipal, industrial or agricultural effluents (Petiot, 2017). This is a real ecological function of "phyto-purification" or "phytoremediation" or even "bio-sanitation" by which bamboos eliminate or degrade environmental contaminants present in water, soil or air, in this case organic, industrial, agricultural and domestic effluents (Emamverdian *et al*., 2018). One of the illustrative models of the “Bamboo-Sanitation” process consists of setting up a bamboo plantation made up of islets and equipped for the treatment of organic effluents.

These islets are real wastewater treatment plants. Thanks to the significant bacterial activity generated by the rhizomes, the organic matter is quickly mineralized and assimilated by the bamboos. The contaminants are therefore found fixed in the thatch (aerial stem) which, once cut, is used for multiple purposes (Arfi *et al*., 2007; Brouillet *et al*., 2008).

In addition, bamboos play a special ecological role in mountainous landscapes where they serve either as core areas or as corridors with dispersal, barrier or funnel effect for biodiversity migrating from upper to lower levels and vice versa (Randrianarimanana *et al.,* 2012; Andrianandrasana *et al.,* 2013). In some African mountain areas, bamboo is a fast-growing resource for reforesting degraded land. It is in this context that the environmental role of bamboo in stabilizing slopes against accelerated soil erosion and in improving soil fertility is highlighted by certain studies (Mishra *et al.,* 2014). Indeed, thanks to their very dense root system, made up of rhizomes, bamboos are able to limit soil erosion in mountainous regions and restore depleted soils (Ngo, 2014). They can also contribute to the protection of watersheds and main water points (Mishra *et al.,* 2014).

The narrowness of bamboo leaves improves the infiltration of rainwater into the soil, twice as much as a forest of deciduous trees (Sabir *et al*., 2010). In addition, the foliage of bamboos, both living (roof of leaves on the plant) and dead (carpet of leaves on the ground), plays a dual role in protecting the soil: first against washing, during heavy rains, and also against excessive water evapotranspiration. This helps to maintain a certain humidity in the soil (Servier, 2009). Furthermore, bamboos protect the banks of watercourses against flooding (Sabir *et al*., 2010).

Another important ecological role of bamboos is the conservation of biodiversity. Bamboos serve as a preferred habitat and food for certain plant and animal species (Bystriakova *et al*., 2004; Sheil *et al*., 2012). Indeed, in several tropical regions of Africa, Madagascar, Southeast Asia and South America, bamboos are an essential component of the biotopes and diet of several animal species, such as the gorillas of mountains (*Gorilla beringei graueri* and *Gorilla gorilla rex pygmaerum*), blue monkeys (*Cercopithecus mitis* kandti), gold monkeys (*Cercopithecus mitis* sp.), Hoest's monkeys (*Cercopithecus l'Hoesti*), elephants (*Loxodonta africana*) (Bitariho and Mosango, 2005; Safari *et al*., 2015). The same is true for other wild animal species such as the giant panda (*Ailuropoda melanoleuca*) (Kang *et al*., 2014), the mountain (*Tragelaphus eurycerusisaaci*) (Sheil *et al.,* 2012), the bamboo lemur (*Hapalemur* sp) (Randrianarimanana *et al*., 2012; Andianandrasana *et al*., 2013; Randriahaingo *et al*., 2014), spectacled bear (*Tremarctos ornatus*), mountain tapir (*Tapirus pinchaque*), Brazilian tapir (*Tapirus terrestris*) and "bamboo rats" (*Dactylomys dactylinus*, *Dactylomys peruanus*, *Dactylomys boliviensis* and *Kannabateomys amblyonyx*) (Bystriakova *et al*., 2004). As a result, the reduction

or degradation of bamboo forests in tropical environments could have a detrimental impact on the composition and dynamics of wildlife (INBAR, 2020).

Socio-economic and cultural role of bamboos

Bamboos are not plants with only environmental advantages. Their socio-economic and cultural importance is sufficiently documented by several studies (Dje Bi *et al.*, 2020; Shahzad *et al.*, 2021). Bamboos are used by humans, either raw or after undergoing a transformation process (Bitariho and Mosango, 2005). They play an important role both in the local economy and in national and international trade (Ramirez, 1996; INBAR, 1999; Lobovikov *et al.*, 2007; INBAR, 2020; Mukul and Parvez-Rana, 2013). Their industrial exploitation generates significant revenue for populations and states in many places (Van der Lugt and Lobovikov, 2008; Mridusmita, 2018). To this end, Dje Bi *et al.* (2017) show that in Côte d'Ivoire, the exploitation and use of Chinese bamboo (*Bambusa vulgaris*) allows the rural population to save an average of €45.8 and the State to gain on average €96.1 per load of bamboo stems through taxes and operating permits. At the level of the macro-economic structure, the bamboos contribute enormously to inflate the turnover of several economies of the world. For their part, Van der Lugt *et al.* (2006) indicate that globally, in the 1980s, the use and trade of bamboo was estimated at US$4.5 billion/year and that in 2000 it reached US$10 billion/ year. Since then, these values have risen sharply because, despite being largely under-exploited, bamboo generates annually, through its cultivation, trade and various and varied applications, more than 90 billion US $ in turnover of the global economy (Dje Bi *et al.*, 2020).

In several countries in the tropics, there are more and more products made from bamboo, from the cradle to the coffin, from textiles to paper and including cooking (Doat, 1967; Bitariho and Mosango, 2005; INBAR, 2015; Shahzad *et al.,* 2021). The textiles obtained from bamboo are in 95% of cases made from bamboo viscose and in 5% of cases from bamboo fibers (Do, 2016). Fibers from bamboo allow the production of good paper pulp, the finished product of which is widely appreciated on international markets (Frison, 1951; INBAR, 2020). Numerous studies (Doat, 1967; Bystriakova *et al.*, 2004; Kamthai and Puthson, 2005) show that bamboo fiber works in the same way as wood fiber for the manufacture of paper pulp and does not require modification of the manufacturing process. However, the major drawback is the fact that bamboos contain a lot of silica; which makes them more difficult to cut (Do, 2016). Still in the technical field, bamboo provides raw material for the manufacture of high value-added products such as laptop computer shells, parquet boards, packaging, partitions, beams, bicycles, plates, cutlery, spoons, chests, cabinets, drawers, rulers, lanterns and torches, brooms, curtains, vases, guitars, etc. (Ramananantoandro *et al.*, 2013; Dje Bi *et al.*, 2020).

The socio-economic role of bamboo has been documented for most rural populations (CIRAD, 1962; Ogunjinmi *et al.,* 2009; Dje Bi *et al.*, 2017). Indeed, bamboos are widely useful forest products in households, with a multitude of uses, including stakes in plantations, poles for building houses (1 billion people in the world), walls of huts, fences, bridges, attics, making musical instruments (tubular bamboo zither), making beehives, rafts to cross a river, partitions, beams, baskets, hair combs, baskets, doors, beds, chairs, mats, kitchen utensils, fishing rods, laying of beans, basketry, the open pipe to carry water from the mountains to the houses, energy production, etc. (Sheil *et al.*, 2012; Andrianandrasana *et al.,* 2013; Honfo *et al.*, 2015; Nurdiah, 2016; Dje Bi *et al.*, 2020). Bamboo also proves to be the best candidate for solving the problem of exploitable energy in various forms of bioenergy: pieces, granules, briquettes, bio-oil, natural gas, etc. (Engler *et al.*, 2012; Ramananantoandro *et al.*, 2013; Issa *et al.*, 2021).

In addition, in some rural societies in Southeast Asia, Latin America and Africa, bamboos hold cultural significance. They are among the plants that have become true cultural markers of human history (Dougoud, 2013; Guichard-Anguis, 2017). Deeply rooted in the culture and traditions of several peoples

since the Neolithic Age (Dje Bi *et al.,* 2020), certain bamboo species are protected and valued as cultural and historical emblems (Kakudidi, 2004). Indeed, they characterize, in many aspects, the culture, for example the language, the art, the religion, the medicine, the politics, the social structure, the taboos, the proverbs, the totems and the festivals of the communities natives (Masharabu *et al.*, 2014; Guichard-Anguis, 2017).

By way of illustration, Djetcha (2003) reports that the word "bamboo" has a deep cultural meaning among the Bamiléké of Cameroon who use it in a proverb which translates the unbreakable link between the old and the new generations in the transmission, following a unequivocal way, of cultural heritage: "*You can't build a new hut without using old bamboo*". Indeed, for the Bamiléké, bamboo is both: "object of memory and transmission" and a "link" between the past and the present. In this same context, Eblic (2008) reports that in ancient and contemporary New Caledonia, the Kanak people use bamboo as a travel stick which they consider as viaticum to protect themselves from the dangers of the road when they venture out of their village. It is in this sense that Dougoud (2013) speaks of engraved bamboo as ambassador objects of Kanak culture. For his part, Deschênes (2020) evokes the *shakuhachi*, a bamboo flute which, once used as the exclusive spiritual tool of itinerant Zen monks, is currently used in the most heterogeneous genres of music all over the world. In Benin, Gnangle *et al.* (2012) mention the "*adjalin*", a Goun musical instrument made from bamboo stalks. Most tribes have always protected and preserved bamboo groves as places for sacrificial rites and religious initiation (Chaudhry and Murtem, 2015).

It should also be noted that some authors attest to the medicinal use of bamboo by many populations in tropical regions (Apema *et al.*, 2012; Ramananantoandro *et al.,* 2013; Hessavi *et al.*, 2019; Dje Bi *et al.*, 2020). Indeed, some species of bamboo have considerable and varied medicinal qualities: antioxidants, fiber, calcium, phosphorus, iron, thiamine (vitamin B1), riboflavin (vitamin B2), niacin (vitamin B3) and vitamin C (Nirmala *et al. ,* 2018; Hessavi *et al.*, 2019). This makes them very valuable as a cure for many common infections. In this context, several parts of the bamboo can be used for therapeutic purposes, more particularly the young shoots, the leaves and the exudate collected from the culm nodes (Hessavi *et al.*, 2019; Dje Bi *et al.*, 2020). However, some studies, such as Yang (2002), show that the species of bamboo to be used for therapeutic purposes depends on the characteristics sought. This is the case of black bamboo (*Phyllostachys nigra*) which is one of the species widely used against coughs, osteoporosis, lung inflammation, fever or to stop bleeding because of its varied properties.

In addition, some studies mention the food use of young bamboo shoots and leaves by humans not only in times of food shortages and lean seasons (Guérin, 2020), but also in times of food abundance (Sarita *et al.* , 2008; Ramananantoandro *et al.*, 2013; Bahru *et al.,* 2021). Indeed, the young shoots of some species of bamboo are very tender, just when they come out of the ground (Bhatt *et al.* 2005; Karanja *et al.* 2015; Nirmala *et al.* 2013, 2018; Dje Bi *et al.*, 2020). In this form, they provide a very valuable vegetable (Cirad, 1962; Hessavi *et al.*, 2019). China and Japan are the main production areas for bamboo shoots in the world (Dje Bi *et al.,* 2020). Especially in Chine, bamboo shoots *Moso* are commonly consumed by men and constitute the majority of the export of bamboo products (Bysrtiakova *et al.*, 2004; Dje Bi *et al.*, 2020). Their preparation can be done in various ways: fried, simmered, stewed, boiled, cold dish or in the form of soup. There are also bamboo beer, bamboo chutney and bamboo candy (Ferreira *et al.*, 1988; Hessavi *et al.*, 2019). Regarding the nutritional value of young bamboo shoots, some studies (Suwannapinunt and Thaiutsa, 1994; Choudhury *et al.*, 2012) indicate that they are low in fat, but high in potassium, carbohydrates, dietary fiber, vitamins and active ingredients. Moreover, compared to most vegetables, young bamboo shoots have a higher protein content so that their reasonable composition of essential amino acids (out of the 18 amino acids contained in bamboo, more than a third are

essential), which cannot be synthesized by the human body, make it a very nutritious plant food with very high digestibility (Kumbhare and Bhargava, 2007). However, some studies (Bhatt *et al.*, 2005; Hessavi *et al.,* 2019) point out that the nutrients present in young bamboo shoots vary not only according to age, but also according to the species used for consumption.

From all the above, it is clear that it is because of their multiple uses for humans that bamboos are often one of the sources of conflict between forest managers and the surrounding communities of protected areas colonized by these precious grasses. The data of the literature present various examples on this subject. Bitahiro and Mosango (2005) report frequent and massive violations of the National Forest Parks of Bwindi andmgahinga, in southwestern Uganda, by local populations who illegally take bamboo there for the construction of their houses, the staking of climbing bean, basketry, etc. On their part, Safari *et al.* (2015) mention the exploitation of the *Sinarundinaria alpina* among the causes of conflicts between Kahuzi-Biega National Park (DRC) and the surrounding population in the Democratic Republic of Congo.

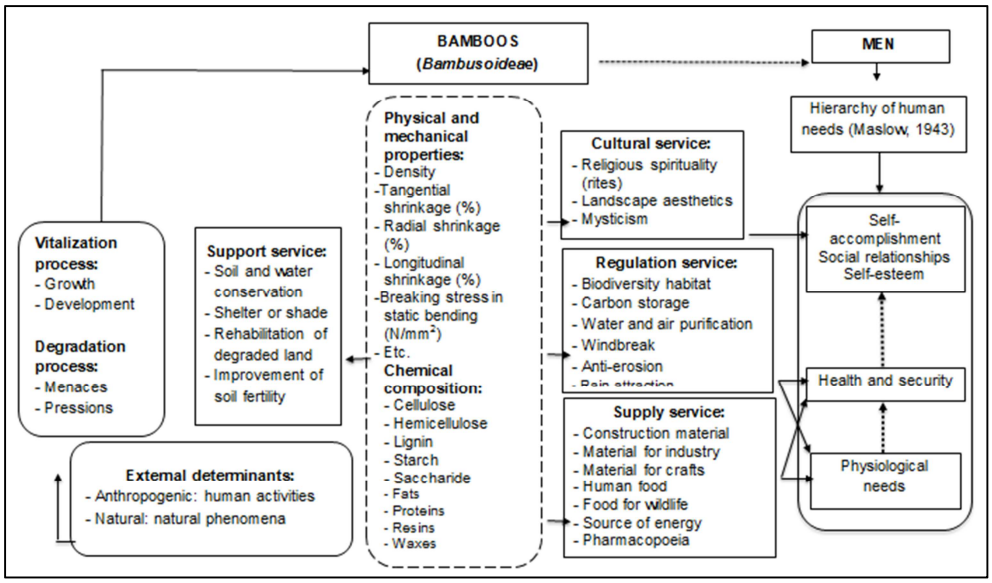

Fig. 3. Analytical diagram positioning bamboo as a natural resource generating ecosystem services in response to human needs (adapted from Dominati *et al.*, 2010 and Cissé *et al.*, 2018).

Ecosystem analysis of the ecological, socio-economic and cultural importance of bamboos

All the functions and uses of bamboos described above are part of a functional set called "ecosystem services", a term coined by Ehrlich in 1980 and defined by the same author in 1989 (Ehrlich, 1989). These “ecosystem services” are grouped into four main categories defined by the Millennium Ecosystem Assessment (2005): provisioning services, regulating services, cultural services and support or self-maintenance services. Many studies have made the ecosystem analysis of certain natural resources. In this case, Dominati *et al.* (2010) and Walter *et al.* (2015) have positioned the soil as natural capital, characterized by stocks of matter and biodiversity, but also by the flows it generates and which enable the provision of a certain number of services meeting human needs. Gnangle *et al.* (2017), for their part, studied the diversity and importance of “ecosystem services” provided by shea parklands in the commune of Savè in Center-Benin. These authors identified 18 types of “ecosystem services” that are socio-culturally, economically and ecologically important to local populations. Cisse *et al.* (2018), for their part, apprehended the perception of agroforestry species and their "ecosystem services" by three ethnic groups in the Boura watershed in Burkina Faso. These authors identified 64 woody species that provide communities with 17 “ecosystem services”.

More recently, Ilou *et al*. (2019) characterized the "ecosystem services" in the W Transboundary Biosphere Reserve (RBTW) in northern Benin. Inspired by the analytical models of the authors cited above and based on data from the literature concerning the ecological functions and the socio-economic and cultural uses of bamboo, we propose an analytical scheme of the "ecosystem services" rendered by the different species of bamboo (Fig. 3). In this scheme, the physico-mechanical properties and chemical components of bamboos that determine their use for different purposes are considered (Do, 2016).

Conclusions

This documentary study has shown that bamboos are among the most important plants in the world, although they are little known and valued in certain countries in the tropics. They contribute to environmental protection through carbon dioxide (CO_2) sequestration, ecological sanitation, biodiversity conservation and their role as ecological corridors. They also play an important role in the socio-economic and cultural life of human communities as providers of jobs and income and emblem of the linguistic, dietary, religious and medicinal habits of certain peoples. As a result, bamboos are presented as a panacea for reconciling the two paradigms which seem very antagonistic these days: socio-economic development and environmental protection.

As we can see through this investigation, the range of ecosystem services that bamboos provide to planet Earth and to the living beings that inhabit it is very high and is expanding every day, so much so that we cannot claim to have described them here exhaustively. Certainly, the highlighting of the benefits of bamboos by this bibliographical synthesis will now be able to lead a large number of human communities who were still unaware of them to not hesitate to break the bank to promote them. But, at the same time, this knowledge of the benefits of bamboo should motivate these same communities to commit to the conservation of these tall grasses. Indeed, because of their ecological, socio-economic and cultural importance, bamboos must now be perceived as natural resources whose sustainable management must be envisaged, so that they become the future "green gold" which will boost economic and cultural needs of present and future generations. However, knowledge on the benefits of bamboo, which this study reviews, is insufficient to guarantee sustainable management of these phytoresources. To fill these knowledge gaps, certain aspects relating to the ecological and ethnobotanical status of bamboos will have to be elucidated during future research, the most important of which consist of (i) identifying the potential threats to bamboo species in Africa and (ii) Inventory bamboo specie that have not hitherto been used by African communities for socio-economic and cultural purposes.

Acknowledgments

The authors thank His Excellency Monsignor SIKULI PALUKU Melchizedek, Bishop of the diocese of Butembo-Beni, for having financed the research whose results are presented in this article. They would also like to thank the Professors-Researchers Dr Gerard N. GOUWAKINNOU and Dr. Lawrence G. HOUESSOU, for having provided them with rich documentation relating to the theme addressed. Finally, they address their sincere gratitude to the anonymous referees who read the manuscript with great attention and gave it very useful comments.

Conflict of interest

The authors declare that there is no conflict of interest related to this article.

References

Andrianandrasana ZA, Rasolofoharivelo T, Chamberlan C, Ratsimbazafy J, King T. 2013. Preliminary study of *Prolemur simus* ("Ramaimbangy") in the lowland forest of Vohibe, Nosivolo watershed, Madagascar, and implications for its conservation. Lemur News **17,** 43-49.

Apema R, Mozouloua D, Abeye J, Salamate FML. 2012. Medicinal plants used in the treatment of diabetes by traditional healers in Bangui. African Pharmacopoeia and Traditional Medicine **16,** 1-8.

Arfi V, Bagoudou D, Korboulewsky N, Bois G. 2007. Initial efficiency of a bamboo grove–based treatment system for winery wastewater. Desalination **246(1-3),** 69-77.

Bahru T, Kidane B, Mulatu Y. 2021. Ethnobotany of Highland Bamboo (*Arundinaria alpina*(*K. Schum.*)) in Southern Ethiopia. Small-scale Forestry **20,** 425-455.

Bhatt BP, Singh K, Singh A. 2005. Nutritional values of some commercial edible bamboo species of the North Eastern Himalayan region, India. Journal of Bamboo and Rattan **4(2),** 111-124.

Bitariho R, Mosango M. 2005. Abundance, Distribution, Utilization and Conservation of *Sinarundinaria alpina* in Bwindi andmgahinga Forest National Parks, South West Uganda. Ethnobotany Research and Applications **3,** 191-200.

Brouillet JL, Picot B, Sambuco JP, Gaillard L, Soteras G, Valarié I. 2008. Ecotechniques for domestic wastewater treatment: evolution and prospects. In: XIIIth World Water Congress, September 1-4, 2008, Montpellier. Monpelier (France) p. 1-17.

Bystriakova N, Kapos VLI, Stapleton C. 2004. Bamboo biodiversity: Africa, Madagascar and the Americas. Cambridge: INBAR (International Network for Bamboo and Rattan), 88 p.

Chaiyalad S, Sungkaew S, Siripatanadilok S. 2013. Morphology of Some Bamboos Commonly Used in Lao PDR. Thai Journal of Forestry **32(1),** 1-8.

Chao CS, Renvoize SA. 1989. A revision of the species described under *Arundinaria* (*Gramineae*) in Southeast Asia and Africa. Kew Bulletin **44(2),** 349-367.

Chaudhry P, Murtem G. 2015. Role of sacred groves, value education and spirituality in conserving biodiversity with special reference to Arunachal Pradesh state of India. International Journal of Society Systems Science **7(2),** 151-180.

Choudhury D, Sahu JK, Sharma GD. 2012. Value addition to bamboo shoots: a review. Journal of Food Science and Technology **49(4),** 407-414.

CIRAD. 1962. Bamboos in Africa (*Arundinaria alpine*, *Bambusa vulgaris*, *Oxytenanthera abyssinica*). Woods and Forests of the Tropics **85,** 24-32.

Cissé M, Bationo BA, Traoré S, Boussim IJ. 2018. Perception of agroforestry species and their ecosystem services by three ethnic groups in the Boura watershed, Sudanian zone of Burkina Faso. Woods and Forests of the Tropics **338,** 29-42.

Deschênes B. 2020. The Japanese shakuhachi, a bamboo flute in the lap of globalization. Hermes, The Journal **1(86),** 199-202.

Dje Bi DPV, Koffi JK, Vroh BTA, Kpangui KB, Yao CYA. 2017. Exploitation and socio-economic importance of Chinese bamboo, *Bambusa vulgaris* Schrad. ex JC Wendl. (Poaceae) in the region of Agnéby-Tiassa: case of the Sub-Prefecture of Azaguié (South-East of Côte d'Ivoire). International Journal of Biological and Chemical Sciences **11(6),** 2887-2900.

Dje Bi DPV, Koffi KJ, Yao CYA. 2020. Social importance of *Bambusa vulgaris* Schrad ex. JC Wendl. (Poaceae) in the Sub-prefecture of Azaguié, South-East of Côte d'Ivoire. Ethnobotany Research and Applications **19(10),** 1-17.

Djetcha S. 2003. You cannot build a new hut without using old bamboo, Face à face [Online], 5 | 2003, posted on March 01, 2003, consulted on December **21,** 2019.

Do Q. 2016. *Study of composite materials of polymer matrices from renewable resources and bamboo fibers*. Doctoral thesis: Doctoral School of Science, Technology, Health, Reims-Mame (France).

Doat J. 1967. Bamboos, a possible source of cellulose for Africa. Woods and Forests of the Tropics **113,** 41-59.

Dominati E, Paterson M, Mackay A. 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics **69,** 1858-1868.

Dougoud RC. 2013. Engraved bamboo, ambassador objects of Kanak culture. Journal of the Society of Oceanists 119-132.

Eblic I. 2008. About Kanak Bamboos. A passion of Marguerite Lobsiger-Dellenbach. Journal of the Society of Oceanists 126-127: Special environment in the Pacific pp. 311-317.

Ehrlich PR. 1989. The limits to substitution: Meta-resource depletion and a new economic-ecological paradigm. Ecological Economics **1(1),** 9-16.

El-Bassam N, Jakob K. 1996. Bamboo - a new source for raw materials. First experimental results. Landbauforschung Völkenrode **46(2),** 76-83.

Emamverdian A, Ding Y, Xiea Y. 2018. Phytoremediation potential of bamboo plant in China. Ecocology, Environment and Conservation **24(1),** 530-539.

Engler B, Schoenherr S, Zhong Z, Becker G. 2012. Suitability of bamboo as an energy resource: analysis of bamboo combustion values dependent on the culm's age. International Journal of Forest Engineering **23(2),** 114-121.

Ferreira VLP, Azzini A, Figueiredo IB, de Salgado ALB. 1988. Evaluation of bamboo shoots for human consumption. AGRIS since **16,** 23-36.

Frison E. 1951. Bamboo and the paper mill problem in the Belgian Congo. Belgian Congo and Ruanda-Urundi Agricultural Bulletin **62(4),** 965-988.

Gillet P, Vermeulen C, Feintrenie L, Dessard H, Garcia C. 2016. What are the causes of deforestation in the Congo Basin? Bibliographic summary and case study. Biotechnology, Agronomy, Society and Environment **20(2),** 183-194.

Gnangle CP, Ahonon FS, Dah-Dovonon JZ, Gbemavo C. 2012. Untapped potential of bamboo in Benin. National Institute of Agricultural Research of Benin (INRAB), Cotonou 16p.

Gnangle RM, Biaou SSH, Gnangle PC, Balagueman OR, Raphiou M, Dicko A, Kouagou M'M, Natta KA. 2017. Ecosystem services provided by shea parks and their contribution to the well-being of rural populations in the commune of Savè (Central Benin). Annals of the University of Parakou. Series "Natural Sciences and Agronomy **7(1),** 104-112.

Guérin M. 2020. Food in the Cambodian countryside of the 1930s, or the art of preparing rice. In: Mikaelian G, Sophearith S, Thompson A, Amicorum L, Ed. Mixtures gathered in tribute to Ang Chouléan. Paris: Association Péninsule & Association des Amis de Yosothor, Hors collection, Phnom Penh p. 413-429.

Guichard-Anguis S. 2017. Japanese intangible heritage, from the float parade to the bamboo basket. Geographic Information **81(2),** 55-74.

Hessavi BFM, Adjatin A, Ayena A, Agassounon M, Tchibozo D. 2019. Ethnobotanical investigation, phytochemical profile and cytotoxicity of *Bambusa vulgaris* Schrad. Former JC Wendl. (Poaceae), a multipurpose and underutilized species in Benin. Journal of Animal & Plant Sciences **39(2),** 6435-6453.

Honfo H, Tovissodé CF, Gnanglè C, Mensah S, Salako KV, Assogbadjo AE, Agbangla C, Glèlè Kakaï R. 2015. Traditional Knowledge and Use Value of Bamboo in Southeastern Benin: Implications for sustainable management. Ethnobotany Research and Applications **14,** 139-153.

Ilou BSL, Toko Imorou I, Vigninou T, Thoma O. 2019. Characterization of ecosystem services in the W Transboundary Biosphere Reserve (RBTW) in northern Benin. European Scientific Journal **15(36),** 278-293.

International Network for Bamboo and Rattan (INBAR). 1999. Socio-economic issues and constraints in the bamboo and rattan sectors: INBAR's assessment. Beijing (China): INBAR Working Paper 23.

International Network for Bamboo and Rattan (INBAR). 2015. Bamboo for Africa: a strategic resource to drive the continent's Green Economy. Policy Synthesis Report No. 2, Beijing (China): INBAR Working.

International Network for Bamboo and Rattan (INBAR). 2020. The latest news and activities in the bamboo and rattan sector. Bamboo and Rattan News **1(2),** 1-23.

Issa A, Rasoanaivo JL, Rakotosaona R. 2021. Bamboo charcoal, a convincing alternative source of energy appropriate to the Malagasy context: energy and ecological efficiencies compared to wood energy and briquettes made from sawdust in cylindrical and extruded models. International Journal of Progressive Sciences and Technologies **29(1),** 368-391.

Kakudidi EK. 2004. Cultural and social uses of plants from and around Kibale National Park, Western Uganda. African Journal of Ecology **42(1),** 114-118.

Kalanzi F, Mwanza C, Agaba H, Guuroh T. 2017. Potential of bamboo as a source of household income in South Western Uganda. Journal of Bamboo and Rattan **16(1),** 33-45.

Kamthai S, Puthson P. 2005. The physical properties, fiber morphology and chemical compositions of sweet bamboo (*Dendrocalamus asper* Backer). Kasetsart Journal (Natural Sciences) **39,** 581-587.

Kang D, Wang X, Yang H, Duan L, Li J. 2014. Habitat use by giant pandas (Ailuropoda melanoleuca) in relation to roads in the Wanglang Nature Reserve, People's Republic of China. Canadian Journal of Zoology **92(8),** 715-719.

Karanja PN, Kenji GM, Njoroge SM, Sila DN, Onyango AC, Koaze H, Baba N. 2015. Compositional Characteristics of Young Shoots of Selected Bamboo Species Growing in Kenya and Their Potential as Food Source. Journal of Food and Nutrition Research **3(9),** 607-612.

Kumbhare V, Bhargava A. 2007. Effect of processing on nutritional value of central Indian bamboo shoots. Part-1. Journal of Food Science and Technology-Mysore **44(1),** 29-31.

Lobovikov M, Schoene D, Yping L. 2011. Bamboo in climate change rural livelihoods. Mitigation and Adaptation Strategies for Global Change **17,** 261-276.

M Lobovikov S, Paudel M, Piazza H, Ren JW. 2007. World bamboo resources: a thematic study prepared in the framework of the Global Forest Resources Assessment 2005. Rome: INBAR, FAO.

Masharabu T, Manirakiza O, Ndayishimiye J, Bangirinama F, Havyarimana F. 2014. Diversity and conservation of native woody plants in anthropized landscape: case of the Kabuye Zone in Matongo Commune (Burundi). Scientific Bulletin of the National Institute for Environment and Nature Conservation **13,** 35-42.

Maslow AH. 1943. A Theory of human motivation. Psychological Review **50,** 370-396.

Mille DG, Louppe D. 2015. Memento of the tropical forester. Versailles (France): Quae.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and human well-being. Synthesis. A report of the Millennium Ecosystem Assessment, Island Press, Washington.

Mishra G, Giri K, Panday S, Kumar R, Bisht NS. 2014. Bamboo: potential resource for eco-restoration of degraded lands. Journal of Biology and Earth Sciences **4(2),** 130-136.

Mridusmita P. 2018. AA Study on Cane and Bamboo Handicraft Industry in North-East India. Journal of Humanities and Social Sciences **9(4),** 901-904.

Mukul SA, Parvez-Rana MD. 2013. The trade of bamboo (*Graminae*) and its secondary products in a regional market of southern Bangladesh: status and socio-economic significance. International Journal of Biodiversity Science, Ecosystem Services & Management **9(2),** 146-154.

Nganje M. 2017. Strengthening AFOLU-Based Climate Change Adaptation and Mitigation Policies and Interventions Relevant to the Forest Sector and the People of Africa: A Case Study for Francophone Africa. Nairobi (Kenya): African Forest Forum 114 p.

Ngo TP. 2014. Effects of exogenous organic amendments on organic matter composition and carbon storage of erosion-degraded soil in northern Vietnam. Doctoral thesis: Île-de-France environmental sciences doctoral school, Paris, France.

Nirmala C, Bisht MS, Bajwa HK, Santosh O. 2018. Bamboo: A rich source of natural antioxidants and its applications in the food and pharmaceutical industry. Trends in Food Science & Technology **77,** 91-99.

Nirmala C, Bisht MS, Laishram M. 2013. Bioactive compounds in bamboo shoots: health benefits and prospects for developing functional foods. International Journal of Food Science & Technology **49(6),** 1425-1431.

Nurdiah EA. 2016. The Potential of Bamboo as Building Material in Organic Shaped Buildings. Procedia - Social and Behavioral Sciences **216,** 30-38.

Ogunjinmi AA, Ijeomah HM, Aiyeloja AA. 2009. Socio-economic importance of bamboo (*Bambusa vulgaris*) in Borgu local government area of Niger State, Nigeria. Journal of Sustainable Development in Africa **10(4),** 2 84-298.

Petiot A. 2017. Ecological water pollution control processes - summary of knowledge. Paris: INRA (SCIENCE & IMPACT) 72 p.

Polesi LG, do Nascimento Vieira L, Guerra MP, Pachero de Freitas Fraga H. 2021. Somatic embryogenesis in bamboos: advances and prospects. In: Ahmad Z, Ding Y, Shahzad A, Ed. Biotechnological advances in bamboo. Singapore: Springer.

Ramananantoandro T, Rabemananjara ZH, Randrianarimanana JJ, Pommier R. 2013. Valorization of the bamboo sector in the eastern areas of Madagascar: constraints and opportunities. Woods and Forests of the Tropics **316(2),** 80-91.

Ramirez AR. 1996. The role of bamboo on the social, cultural and economic life of the Filipinos. In: Belcher B, Karki M, Williams T, Ed. Bamboo, people and environment. Proceedings of the Vth International Bamboo Workshop, 19-22 June, 1995, Ubud, Bali. Indonesia: INBAR 78-90.

Randriahaingo NTH, Ravaloharimanitra M, Randrianarimanana HLC, Chamberlan C, Ratsimbazafy J, King T. 2014. Study and conservation of the greater bamboo lemur (*Prolemur simus*) around the Andriantantely forest. Lemur News **18,** 67-72.

Randrianarimanana L, Ravaloharimanitra M, Ratolojanahary T, Rafalimandimby J, Rasolofoharivelo T, Ratsimbazafy J, Dolch R, King T. 2012. Status and conservation of *Prolemur simus* in the Ranomainty and Sakalava sites of the Ankeniheny-Zahamena Corridor. Lemur News **16,** 2-7.

Razak W, Janshah M, Hashim WS, Shirley B. 2007. Morphological and anatomical characteristics of managed natural Bamboo stands Gigantochloa scortechinii. Journal of Bamboo and Rattan **6,** 115-122.

Rougier C. 2020. Greening of the planet: trees, forests and people. L'Harmattan, Paris 183 p.

Rui-Perez PJ, Alarcon ZB, Mendozamg D, Barcena GR, Hernandez GA, Herrera HJG. 2001. Response of kudzu as protein bank on steers grazing African stargrass. Technology Pectoral of Mexico **39(1),** 39-52.

Sabir M, Roose E, Al Karkouri J. 2010. Traditional techniques for managing water, biomass and soil fertility. In:Roose E, Sabir M, Laouina A, Benchakroun F, Al Karkouri J, Lauri P, Qarro M, Ed. Sustainable water and soil management in Morocco: enhancement of traditional Mediterranean techniques. Marseilles: IRD 117-193.

Safari AC, Birhashirwa RN, Fatuma FK, Mangambu MJD. 2015. Exploitation of bamboo (*Sinarundinaria alpina* (K. Schum.) CS Chao & Renvoize), cause of conflicts between Kahuzi-Biega National Park and the surrounding population: conservation and conflict resolution strategy. International Journal of Environmental studies **72,** 265-287.

Sarita A, Satsangi R, Arya ID. 2008. Large-scale plant production of edible bamboo *Dendrocalamus asper* by somatic embryogenesis. Bamboo Science and Cultivation **21(1),** 21-31.

Shahzad A, Tahseen S, Wasi A, Ahmad Z, Khan A. 2021. Application of biotechnological tool in bamboo improvement. In: Ahmad Z, Ding Y, Shahzad A, Ed. Biotechnological Advances in Bamboo. Singapore: Springer 291-312.

Sheil D, Ducey M, Ssali F, Ngubwagye JM, Heist MV, 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(1),** 163-171.

Somashekar PV, Rathore TS, Fatima T. 2018. In vitro plant regeneration of *Dendrocalamus stocksii* (Munro) M. Kumar, Remesh & Unnikrisnan, Through somatic embryogenesis. American Journal of Plant Sciences **9(12),** 22429-2445.

Song X, Zhou G, Jiang H, Yu S, Fu J, Li W, Wang W, Ma Z, Peng C. 2011. Carbon sequestration by Chinese bamboo forests and their ecological benefits: assessment of potential, problems, and future challenges. Environmental Reviews **19,** 418-428.

Suwannapinunt W, Thaiutsa B. 1994. Food compositions of some Thai bamboo shoots. AGRIS: International Information System for the Agricultural Science and Technology **9(1),** 67-72.

Teshoma U. 2019. Carbon storage potential of Ethiopian highland bamboo (*Arundinaria alpina* (K. schum): a case study of Adiyo Woreda, South West Ethiopia. International Journal of Environmental Sciences & Natural Resources **16(5),** 1-11.

Tewari DN. 1992. A Monograph on Bamboo, International book Distributors. Dehra Dun (India) 498p.

Van der Lugt P, Lobovikov M. 2008. Markets for bamboo products in the West. Wood and Forest of the Tropics **295,** 81-90.

Van der Lugt P, Van der Lugt AAJF, Janssen JJA. 2006. An Environmental Assessment of Bamboo as a Building Material for Support Structures. Construction and Building Materials **20(9),** 648-656.

Walter C, Bispo A, Chenu C, Langlais-Hesse A, Schwartz C. 2015. Soil ecosystem services: from concept to valuation. Paris: Cahier Demeter, Agriculture and Land.

Yang Y. 2002. Chinese Herbal Medicines Comparisons and Characteristics. London: Churchill Livingstone.

Yuen JQ, Fung T, Ziegler AD. 2017. Carbon stocks in bamboo ecosystems worldwide: Estimates and uncertainties. Forest Ecology and Management **393,** 113-138.

Zhaoa Y, Fenga D, Jayaramanb D, Belayc D, Sebralac H, Ngugid H, Mainae E, Akomboe R, Otuomad J, Mutyabaf J, Kissaf S, Qig S, Assefab F, Oduorb NM, Ndawulab AK, Lib Y, Gonga P. 2018. Bamboo mapping of Ethiopia, Kenya and Uganda for the year 2016 using multi-temporal Landsat imagery. International Journal of Applied Earth Observation and Geoinformation **66,** 116-12