INBAR Working Paper

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Technical Paper

Ecosystem Services and Cost-Benefit Analysis of Natural Forests and Mixed Bamboo Systems in Peru

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About this Working Paper

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List of Abbreviations

AMPA	Amazonians for the Amazon
ATFFS	Technical Administration for Forestry and Wildlife Administration
BAN	National Agricultural Library
CIFOR	Center for International Forestry Research
DEMA	Management Declaration
ES	Ecosystem Services
FIA – USMP	Faculty of Engineering and Architecture – San Martín de Porres University
GABAR	The Global Assessment of Bamboo and Rattan
Ha	Hectare
IBC	The Common Good Institute
IFAD	International Fund for Agricultural Development
INBAR	The International Bamboo and Rattan Organisation
IVUC	The Institute of Housing, Urbanism and Construction
IUV	Indirect Use Value
LV	Legacy Value
MINAM	Ministry of Environment of Peru
m.a.s.l.	metres above sea level
mm	millimetres
NC	Native Community
NGOs	Non-Governmental Organisations
NUV	Non-Use Value
OV	Option Value
PES	Payment for Environmental Services
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SERFOR	National Forest and Wildlife Service
tC	tonnes of carbon
TEEBs	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
UTM	Universal Transverse Mercator
UV	Use Value

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Executive summary

Two studies on ecosystem services were conducted in the northern and central jungle regions of Peru to better understand the ecosystem services that are provided by different land uses in the region. Through surveys conducted with the participation of local and regional actors, three types of land use (bamboo forest/plantation, natural forest and farm) were studied to evaluate ecosystem benefits.

The study sites were (i) 40 ha of forest that is adjacent to the Yarau River, Moyobamba province, Department of San Martín. This site hosts the dominant native bamboo species, *Guadua lynnclarkiae*, in which 10 ES were studied; highlighted were flood regulation, landslide prevention and the provision of fresh water; and (ii) 20 ha. of planted bamboo (6–7 years old), located close to the town of San Miguel de Bocaz, Oxapampa Province, Department of Pasco.

This site hosts:
Guadua aff. angustifolia bamboo species. Ten Ecosystem Services (ES) were selected for study highlighting freshwater provision, sediment retention, carbon sequestration and landscape restoration.

The results of this study indicate that regulatory ecosystem services were the most valued in both the study sites. The bamboo (*Guadua aff. angustifolia)* plantation in Oxapampa, Pasco, has brought multiple ecosystem services to that area.

Regarding the Total Economic Valuation (TEV) estimated for the study area, the “Maronal” in Moyobamba, San Martín was 855.77 USD per ha/year, while the “La Reserve” estate area in Oxapampa, Pasco was more than double amount with 1,908.38 USD per ha/year.

1. Introduction

Ecosystem services (ES) are those direct and indirect economic, social and environmental benefits that people obtain from the proper functioning of ecosystems, such as water regulation, maintenance of biodiversity, carbon sequestration and storage, scenic beauty, soil erosion control and provision of genetic resources, among others. Therefore, ES are important to conserve for the benefit of the environment and the welfare of the population.

In 2005, the United Nations recognised the importance of the ES through a study called the "Millennium Ecosystem Assessment". This study includes as one of its main conclusions is to value nature for the various goods and services that it provides and implements a mechanism to enhance the conservation and sustainable use of ecosystems and their benefit to human well-being (Millennium Ecosystem Assessment, 2005). Also, ES. were categorised into four categories: provisioning services, supporting services, regulating services and cultural services.

The ES that bamboo provides, either as a natural species or as a species that was introduced from other geographical regions, are important because of the tangible and intangible benefits that it provides (directly and indirectly) to the local or regional human population.

However, in Peru, little has been studied about the ecosystem benefits that bamboo provides for society. This study aimed to assess and quantify the ecosystem benefits of bamboo forests and/or plantations.

This study's objectives were as follows:

a) Provide tools for analysis and a better understanding of the ES that bamboo forests and bamboo-based agroforestry can provide for the well-being of nature and humans;
b) Raise awareness regarding the relative importance of bamboo forests among policymakers, programme implementers and broader stakeholders from the bamboo sector;
c) Support new opportunities for linking bamboo forests with markets for ES and carbon markets;
d) Guide decision-makers to understand user preferences and the relative value that local people place on ES.

2. Description of research sites

2.1 Yarau native community – Moyobamba

- **Geographic location:** This study area is located on both sides of the Yarau River (Mayo River Basin), between the native community (NC) of Yarau and the town centre of Bella Selva, Department of San Martín, Moyobamba province, Moyobamba district, Peru (refer to Figure 1).
- **Accessibility:** This location can be accessed from the city of Moyobamba, travelling for three hours by van on an unpaved road to Yarau.
- **Climate:** The average annual temperature of the Moyobamba district is 22.8°C, and the cumulative annual rainfall is 1,354 mm.
- **Altitude:** The study area is located between 870 and 900 metres above sea level.
- **Relief:** It has a wavy terrain with maximum slopes of 30 degrees.
- **Geographic coordinates** in the UTM system (Appendix 4).

2.2 “La Reserve” estate – Villa Rica

- **Geographic location:** This study area is surrounded by the San Miguel River and politically belongs to the department of Pasco, Oxapampa Province, Villa Rica district, Peru.
- **Accessibility:** The site can be accessed from Villa Rica, travelling for two hours by van on an unpaved road to the plantation site, “Bajo Bocaz.”
- **Climate**: The average annual temperature of the Villa Rica district is 19.3°C, and the cumulative rainfall per year is 1,978 mm.

  ***** It should be noted that the study area (“Bajo Bocaz” sector) has a slightly higher temperature (two to three degrees Celsius) than Villa Rica
- **Elevation:** The study area is located between 950 and 1,100 m.a.s.l.
- **Relief:** This area features sloping terrain, with slopes of more than 45 degrees of Inclination.
- **Geographic coordinates** are in the UTM system (Appendix 4).

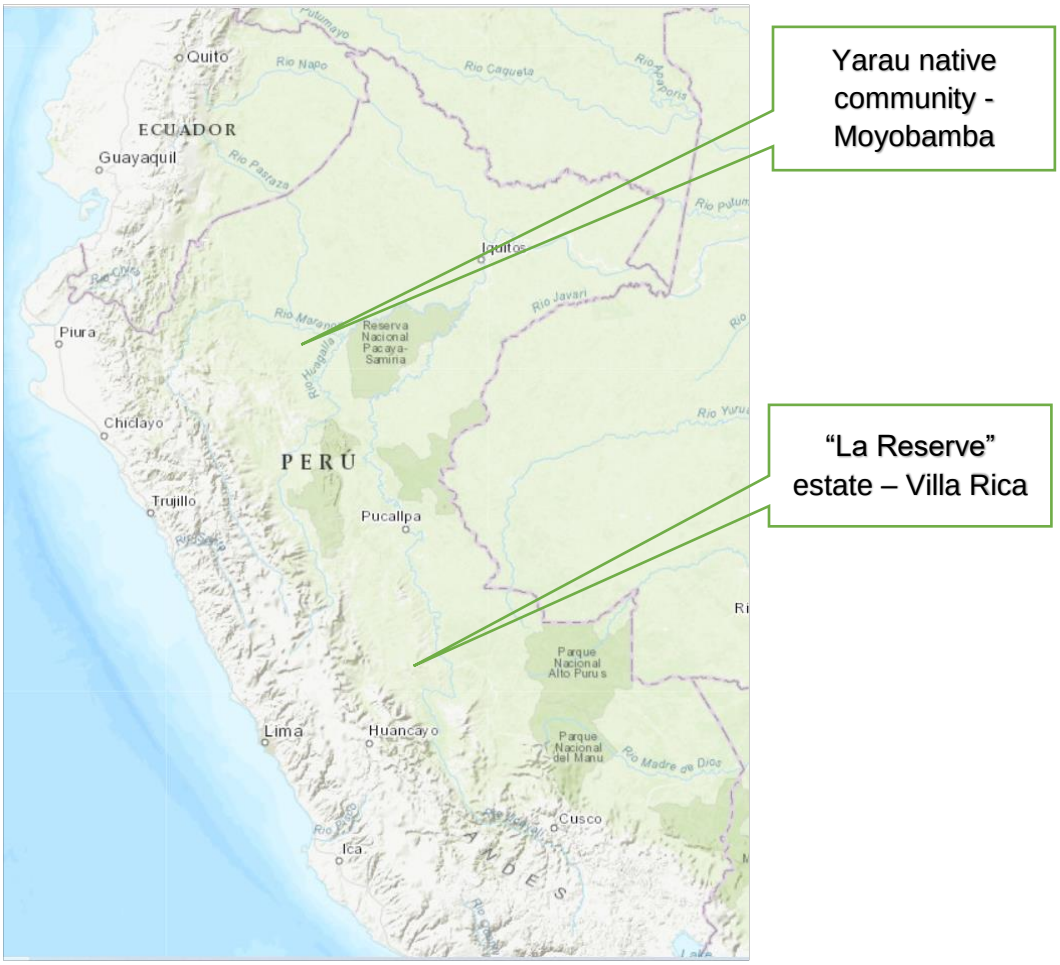

Figure 1. Location map of the two study zones

For the evaluation of ES in the two study areas, the following land uses were considered:

Natural forest with "marona" bamboo: a native forest ecosystem with the predominance of a bamboo species known locally as "marona" and taxonomically called *Guadua lynnclarkiae;*

Mixed bamboo plantation system: a bamboo plantation of the *Guadua aff. angustifolia* species, which was established about seven years ago amid degraded grasslands that are now dominated by this bamboo species (with little presence of shrubs and herbaceous growth);

Moyobamba natural forest: a tropical premontane wet forest that is dominated by trees of the genus: *Ficus, Virola, Ormosia*, among others; palm trees of the genus: *Iriartea, Geonoma*, etc.; shrubs of the genus: *Inga;* herbaceous vegetation *Heliconias*; and, of economic importance, the "bombonage" *Carludovica palmata*.

This forest has undergone several disturbances, but it is intact and performs ecological functions that allow it to provide important environmental services.

Villa Rica natural forest: a tropical premontane wet forest that is dominated by trees of the genus: *Juglans*, *Lauracea*, *Podocarpus*, *Cedrela*, among others; palm trees of the genus: *Ceroxylon* and *Prumnopitys*, etc.; shrubs of the genus: *Inga* and the herbaceous vegetation of *Heliconias*; and, of economic importance, the "bombonage" *Carludovica palmate,* abundant orchid species belong mainly to the *Pleurothallis*, *Epidendrum*, *Phragmipedim* and *Masdevallia* genera

This forest has undergone disturbances but still maintains important ecological functions that allow it to provide important environmental services.

Farm: Land uses, mainly under a traditional and/or modern farming system that is according to the location and capacity of the owner and/or investor, include crops such as "coffee" *Coffea arabica,* "corn" *Zea mays,* "banana" *Musa paradisiaca*, and "cassava" *Manihot esculenta*.

3. Methodology

3.1 General methodology

3.1.1. Literature review: means and instruments to obtain information regarding bamboo-related ES

Information search: The secondary data is derived from various sources (e.g., scientific articles, books, the official press, journals, theses, etc.) that were retrieved from:

- INBAR's publication database (https://www.inbar.int/es/resources/inbar-publications/);
- Reviewing repositories of pre-and post-graduate studies of the main Peruvian universities;
- Search engines: Academia.edu, Ecosia, Bibliocolabora, SCielo;
- A virtual catalogue of the BAN National Agricultural Library of the National Agrarian University La Molina (http://ban.lamolina.edu.pe/);
- A virtual catalogue of the Bamboo Center, Peru of IVUC-FIA-USMP's publications (https://www.usmp.edu.pe/centro_bambu_peru/nosotros.php).

3.1.2. Stakeholders analysis

This was done after conducting a pre-identification of the following interest groups:

- Producers (individual and association persons, agricultural or other);
- Public institutions (forestry directorates of regional governments at the district or provincial level, district municipalities, among others);
- Private institutions;
- Non-governmental organisations operating in the study areas.

3.1.3. Semi-structured interviews with local and national actors

This consisted of meeting with the interviewee, presenting the study's objectives, and then asking about the concept of ES and their benefits (as perceived by the interviewee). (Appendix 2: survey questionnaire for the evaluation of ES for natural bamboo forests, planted bamboo, natural forest and crops "farms").

3.1.4. Focus group

Meetings were organised with a group of actors, such as producers, public or private institutions, technicians of NGOs and projects and the general population of the districts of Moyobamba and Villa Rica.

Due to COVID-19 pandemic restrictions conducting focus group discussions in person, two virtual focus group discussions were organised using WhatsApp. The table consisting of 10 ES was sent in advance. (refer to Appendix 2).

3.1.5. Field trips and transects in ecosystems

This consisted of entering the places where the initiatives to be evaluated were located. Transects were developed for assessing the different land-use characteristics by observing and guiding the key actors and informants.

3.1.6. Photographs

Interviewees, focus group meetings and transects were photographed to generate evidence of information gathering, as well as document the ecological processes of the ES

3.2 Methodology for ES assessment

The “Framework for the Evaluation of ES of Bamboo Forests: Lessons from Asia and Africa” (Paudyal et al. 2019) was used as a basis for studying the ES The identification of the main ES is considered by the global initiative “The Economics of Ecosystems and Biodiversity” (TEEBs), which classifies ES into four groups—provisioning services, regulating services, habitat services and cultural services—was addressed first. The methods and tools for the ES evaluation of the bamboo forests in Paudyal et al. (2019) were used to analyse the various land uses (mixed forest systems with native forests or bamboo plantations). For each ecosystem service, a value of 1 to 10 was assigned, with one being the lowest value of importance and 10 being the most important.

The following table shows the details of the ES that were evaluated at both study sites.

Table 1. ES identified in the study areas

Ecosystem Services		Moyobamba	Villa Rica	*Law 30215
Provisioning Services	Timber (construction materials)	X	X	
	medicinal resources	X		
	freshwater provision	X	X	X
Regulating Services	carbon sequestration	X	X	X
	landscape restoration		X	
	sediment retention		X	X
	floods/landslides control	X	X	X
	moderation of extreme events	X	X	
Habitat Services	habitat provision	X	X	X
Cultural Services	landscape beauty	X	X	X
	recreation and ecotourism	X	X	X
	cultural/religious values	X		

*Law 30215: Law of compensation mechanisms for ES. from Peru

The 12 ES., as shown in Table 1, were selected for the study. The list of ES. from bamboo forests, including the description and indicators of each ES., unit of measurement, beneficiary and the scale of ES., is derived from the framework for assessing ES. (Paudal et al. 2019) from bamboo forests, where 21 ES. are detailed. From this, 12 ES. were evaluated and selected for each study area*:* Maronal of Yarau in Moyobamba, San Martín; a mixed plantation system with *Guadua aff. angustifolia* in the “La Reserve” farm (Villa Rica, Pasco).

The factors for the selection were based on the preliminary evidence found during the field trips: interviews with the actors who benefit from the services provided by these evaluated ecosystems; actors who know the study sites but do not necessarily live adjacent to the study areas but do live in the province; literature review.

Description of the identified ES for the two study zones:

- **ES1.** Timber (construction materials): the source of raw material that is used for construction in the area, using their entire culms, called reeds or flattened or crushed reeds;
- **ES2.** Medicinal: traditional medicine resources for the healing of ailments;
- **ES3.** Freshwater provision: contributes significantly to the protection of water sources and the freshwater supply;
- **ES4.** Carbon sequestration: capture and fix carbon on the plant structures of the species that comprise the ecosystem (measured by tC/ha);
- **ES5.** Landscape restoration: restoration of degraded land through plantations or the natural succession of species;
- **ES6.** Sediment retention: stabilises the slope and prevents soil erosion while improving soil conditions and controlling floods and landslides; these phenomena reduce deposition or siltation in downstream water bodies;
- **ES7.** Floods/landslides control: performs, to a greater or lesser degree, the control of floods and landslides by holding soil particles through the network of rhizomes or roots of the plant species that are present;
- **ES8.** Moderation of extreme events: protection against strong winds, storms, landslides and other disasters and thus reducing harmful impacts;
- **ES9.** Habitat provision: provides suitable habitats for the locality's different flora and wildlife species;
- **ES10.** Landscape beauty: beautify the landscape through the prevention of land degradation and the improvement of landscape and greenery restoration;
- **ES11.** Recreation and ecotourism: promote ecotourism opportunities and recreation activities through the promotion of greenery and landscape beautification;
- **ES12.** Cultural/religious value: use with the society's culture and religiosity.

3.3 Methodology for Costs - Benefits analysis

Estimation of the Total Economic Value (TEV) of a natural forest with bamboo – "maronales" case of Yarau, Moyobamba in Peru's native community

TEV is broken down into Use Value (UV) and Non-Use Value (NUV). According to Bateman et al. (2002), as cited by Orihuela (2009), UV equals the sum of the current use value (CUV) and option value (OV). And NUV comprises legacy value (LV) and the value of existence (VE).

TEV is schematically displayed with the following formula: TEV = UV + NUV (UV = CUV + OV).

CUV = Direct Use Value (DUV) and Indirect Use Value (IUV): NUV = LV + VE.

DUV: calculated from the sale value of bamboo stems or culms multiplied by the number of them that are usable in one hectare.
The values are as follows:

- The sale price of one culm of bamboo of six metres x one sol (according to an interview with the buyer and manager of DEMA, Mr. Wilfredo Su Castro);
- The number of usable bamboo culms per hectare in one year: 1,000 units/year (according to DEMA and an interview with DEMA buyer and manager, Mr. Wilfredo Su Castro).

  This is the DUV of 1,000 soles in one hectare of "maronal" per year: equivalent to 278 USD/ ha/year at the exchange rate of 1 USD ≡ 3.6 soles.

Indirect Use Value (IUV): calculated based on the reference value of 919 US/ha/year, considered by Orihuela (2009), and based on the value found by Torras (2000) for the Brazilian Amazon (414 USD ha/year) which was estimated using the method of profit transfers that are based on the values of flow control, water regulation and erosion control. This value of 919 soles/ha/year that adapts Orihuela (2009) for the Peruvian case is a considered value for four ecosystems: wet low-hill forest, the humid forest of mountains, bales and swamps), thus including the ecosystem where this study's native bamboo forest is located. Converting the value of 919 soles/ha/year to the 2009 exchange rate, 1 USD = 2.8 soles/USD, resulting in USD 328 per ha/year.

Option Value (OV): This is represented by carbon fixation or capture because this service is quantifiable and has a potential market. However, carbon prices have significantly fluctuated. In

2003, the World Bank estimated the price of tC as USD 20/tC. However, carbon prices have declined considerably in recent years.

For the San Martín region (one of the study sites), a REDD+ project in the Alto Mayo protected forest area managed to sell carbon bonds to Disney for USD 8/tC in 2013. Moreover, another REDD+ project located in the Alto Huayabamba conservation area (concession of the NGO AMPA) sold carbon bonds to the ISA REP (i.e., an electricity transmission company) for USD 2.5/tC. Thus, the value of USD 2.5/tC, for this study was taken as a conservative reference.

The carbon content/storage for one hectare was estimated based on the study by MINAM. (MINAM -Estimation of the carbon content of air biomass in the forests of Peru), which determines 172.53 tC/ha in above ground carbon in the case of high ecozone forests. Saatchi et al. (2007) estimated above ground carbon of 125 tC/ha (oil lot 103), where our study site is also located. Finally, SERFOR (2016) estimated a carbon content of 138.9 tC/ha for lowland Amazon forests. Thus, conservatively and taking into account that the "maronal" ecosystem is involved, it is decided to take a value of 100 tC/ha of carbon for this study.

Non-Use Value (NUV): comprises the legacy value (LV) plus the VE. In the case of Peru, limited studies have been carried out about this (Orihuela, 2009). The estimated value could be wide range thus large uncertainty therefore, it was decided not to consider this value until we had further case studies.

TEV estimation of a mixed planting system *in Guadua aff. angustifolia* case plantation in the "La Reserve" fund area – Villa Rica, Peru

DUV: calculated from the sale value of bamboo stems or culms, multiplied by the amount that is usable in one hectare, with the following values being the:

- Sale price of one cane or bamboo pole of six metres x five soles (according to an interview with the buyer, Ms. Nelly Ponce Condori).
- Number of canes or bamboo rods usable per hectare in one year ≡ 1,000 units (quantity projected by owner Mr. Phillippe Bigourd).

Thus, the DUV was 5,000 soles/ha/year, which is equivalent to 1,388.88 USD/ha/year at the exchange rate of 1 USD ≡ 3.6 soles.

Indirect Use Value (IUV): The value to be considered was USD 328 per ha/year.

Option Value (OV): The carbon price used in this study was USD 2.5/tC.

Camargo et al. (2010) estimated 76.6 tC/ha for 1 hectare of *Guadua aff. angustifolia* plantation. The studied site in Pereira, Colombia has a similar agro-climate to Villa Rica: the annual precipitation of Pereira is 1,900 mm, whereas Villa Rica is 1,978 mm; the annual average temperature of Villa Rica is 23°C, whereas Pereira's is 24°C.

Non-Use Value (NUV): considers the legacy value (LV) plus the VE. In the case of Peru, limited studies have been conducted about this (Orihuela, 2009), The estimated value could be wide range thus large uncertainty therefore, it was decided not to consider this value until we had further case studies.

4. Results

4.1 Study zone 1: ES associated with “The “Maronal”” in Yarau, Moyobamba, Peru

Table 2. Assessment of the ES provided by different land uses in the Moyobamba, Peru study area.

Land Use / Ecosystem Services	Timber (construction materials)	Medicinal Resources	Freshwater Provision	Carbon Sequestration	Floods / Landslide Control	Moderation of Extreme Events	Habitat Provision	Landscape Beauty	Recreation and Ecotourism	Cultural and/or Religious Value
Natural forest with bamboo	8	4	9	8	9	8	8	8	6	5
Natural forest	6	7	8	7	6	6	8	8	6	7
Farm	2	5	3	3	2	2	4	4	4	5

ES of natural forest with bamboo ("El Maronal")

The natural bamboo forest (*Guadua lynnclarkiae*) called "El Maronal" is located on the banks of the Yarau River in an area of 40 ha. No other land-use systems/vegetation exist here.

According to the evaluation results, the most valued ES for the natural bamboo forest was the provision of freshwater (ES 3) with nine points and flood control (ES 7) with nine points. Water infiltrates and recharges during rain/flood situations and releases during drier periods, thus regulating part of the Yarau River’s flow. Also, interviewees mentioned that due to the morphological structure of this bamboo, forming a "plant wall" with its extensive and interwoven rhizome and root system, the effects or impacts of the river’s flooding were mitigated. This claim is supported by a study on a young plantation (10 years) of *Guadua aff. angustifolia* (Dueñas 2019). The findings show that bamboo forest has an optimal infiltration value (0.471 cm/sec$^{0.5}$), thus demonstrating that this bamboo species contributes to flooding aversion and water recharge.

The third-ranked ES was the provision of construction material (ES 1), with eight points. This is because the culms of this bamboo are widely used by the Yarau community and the town centre of Bella Selva for the construction of their houses, rural warehouses, small animal pens,

planters and even as functional stairs for local use, as shown in photographs N° 1 and N° 2. It should also be noted that the culms of this bamboo species are extracted with authorisation from the regional forestry authority and as stipulated in the Management Declaration (DEMA). The harvested bamboo poles/culms are also sold in the region for local construction and for the production of handicrafts.

Another ES that is highly valued by the actors is carbon sequestration (ES 4), with a value of eight. This is because “The “Maronal”" performs the function of quickly capturing carbon from the environment and setting it stably on its culms, which are the structures of the highest volume and number (see photograph N° 3).

The habitat provision service (ES 9) also has a value of eight points. It has importance for wildlife, including a great diversity of mammals: "deer" (*Mazama americana*); "Sajino" (*Tayassu tajacu*); "añuje" (*Dasyprocta Fuliginous*); "majaz" (*Agouti paca*); "carachupa" (*Dasypus novemcinctus*); "pichico monkey" (*Saguinus fuscicollis*); "tocón monkey" (*Plecturocebus oenanthe*); birds: "Great egret" (*Ardea alba),* "Golden-olive woodpecker" (*Colaptes rubiginosus),* "Groove-billed Ani" (*Crotophaga sulcirostris*) and "Grai Tinamou" (*Tinamus tao*). These mammals seek habitat in this bamboo species’ foliage, as well as feed on the tender leaves of foliage and the tender shoots of *Guadua lynnclarkiae*.

Finally, the cultural service value (ES. 12) has a value of five, given the importance of the NC’s fishing activity; this bamboo’s culms are used to make fish traps (see photograph N° 4).

ES of the natural forests:

The most important ecosystem service from the natural forest is the provision of freshwater (ES 3). Throughout the province and district of Moyobamba, a payment scheme for environmental services (PES) is operational for water supply by the Misquiyacu Rumiyacu and Almendra basins in the city of Moyobamba. One ‘sol’ is charged by the water service provider on the inhabitants’ water receipts, and the revenue is used for conservation of the forest in these basins (see photograph N° 6). Thus, the ES of natural forests provide fresh water and the landscape beauty of the natural forest throughout the San Martín region. Together with recreation and tourism services, these do not alter or damage the forest.

Similarly, valued services are the provision of medicinal resources (ES 2), with a value of seven points, and cultural service values (ES. 12) that are associated with natural forests, with a value of seven points. Traditional medicine that involves making use of many species of flora that exists in the natural forest, such as the "renaco" (*Ficus antihelmintica*), "cat's nail" (*Uncaria tomentosa*), "dragon blood" (*Croton lechleri*) and "matico" (*Piper sp.*), among others; this is framed in a culture that is transmitted from generation to generation and that is in force, demonstrating its application in the relief of discomfort that is caused by various diseases that are locally present.

ES of Farm Land

Regarding the ES. that are identified for areas with crops, known locally as "farms", the provisioning service of medicinal resources (ES. 2) and the service associated with cultural service values (ES. 12) stand out, with values of five points both.

For this land use, crops such as "coffee" *Coffea arabica*, "corn" *Zea mays*, "banana" *Musa paradisiaca* and "yuca" *Manihot esculenta* (see photograph N° 5) are distributed in small areas of one, three and five hectares as usual. There are medicinal and aromatic plants in this ecosystem, such as: "mullaca bag" *Physalis angulate*; "chiric sanango" *Brunfelsia grandiflora*; "cordoncillo or matico" *Piper aduncum;* and the "turmeric" *Curcuma longa,* in miniscule areas (10–50 m^2) called "orchards" that are part of the district of Moyobamba's societal culture.

4.2 Study zone 2: ES associated with a mixed bamboo planting system—Case "La Reserve" estate in Villa Rica, Peru

Table 3. Assessment of ES — Villa Rica study area

Land Use / Ecosystem Services	Timber (construction materials)	Freshwater Provision	Landscape Restoration	Sediment retention	Carbon Sequestration	Floods / Landslides Control	Moderation of Extreme Events	Habitat Provision	Landscape Beauty	Recreation and Ecotourism
Mixed bamboo planting system	9	9	9	9	9	9	8	8	8	7
Natural forest	6	7	6	6	7	6	7	8	7	7
Farm	3	3	3	4	4	4	3	5	5	6

ES of mixed bamboo planting system (*Guadua aff. angustifolia*)

According to the survey, the plantation was originally established on livestock pasture land. The soil was compacted and unproductive. First, the owner cultivated coffee, which did not give him favourable results. Then he subsequently decided to plant bamboo *Guadua aff. angustifolia* in 2013 with an area of 20 ha. Genetic material was brought from Florida, Department of Cajamarca, Peru. Currently, bamboo plantations are growing well, with culms of more than 10 centimetres in diameter and 15 metres in height (photograph N° 7).

Six ES received a score of nine points, including the provision of materials for local construction (ES1), freshwater supply service (ES3), carbon sequestration service (ES4), the restoration of the landscape of a degraded ecosystem (ES5), sediment retention (ES6), and the control of landslides (ES7). In Peru, few studies have been carried out that demonstrate the benefits of a *Guadua aff. angustifolia* plantation. Research by Dueñas's (2019) illustrates a 10-year-old plantation with *Guadua aff. angustifolia*, which resulted in the creation of a 7-cm layer of litter on the ground (as bamboo produces and drops leaves throughout the year) and an increase in 20% humidity on the ground, even in dry seasons. Thus, this information complements the benefits of Guadua *aff. angustifolia* regarding the ES it provides.

The provision of materials for local construction (ES1) scored nine because the current plantation provides bamboo culms, locally known as reeds. Carbon sequestration services (ES4) were also important. In the second order is the service of moderation of extreme events (ES8) about the weather and the provision of habitat (ES9) to wildlife, both with a score of eight. Highlighting that, in the ES9, stand out the bird "Andean cock-of the rock " *(Rupicola peruvianus*), Dusky-cheeked foliage-gleaner (*Anabazenops dorsalis*) and mammals such as the "añuje" (*Dasyprocta* sp.), the "picuro" *(Agouti paca*) and the "machetero" (*Dinomys branickii*) that they indicate feed on the shoots of this species of bamboo.

ES of the natural forest

The natural forest in San Martín region is disturbed and degraded to a greater or lesser degree due to activities such as illegal logging and changes in land use. The ES that are best-valued by the actors include the provision of habitat to wildlife (ES9) and carbon sequestration service (ES4) with eight points, followed by freshwater provision (ES3), the moderation of extreme

events (ES8) about the weather, recreation and ecotourism associated with landscape beauty (ES10, ES11) with seven points each. Stressing that the landscape beauty associated with recreation and ecotourism revolves around the waterfalls that exist throughout the area of the district of Villa Rica, which are part of the tourist route existing in the area. Finally, the provision of materials for local construction (ES1) received a score of six. Currently, the sawn wood is rare, as the area lacks fewer trees with large dimensions.

ES of farm land

Under crops known locally as "farms", the best-valued ecosystem service was recreation and ecotourism (ES11) with a value of six. In Villa Rica, there is a whole tradition in the cultivation of coffee, associated with tourism, where tourists travel through the coffee farms on tours, which are called as “coffee route”. Villa Rica coffee is known as the best quality in Peru and sometimes one of the best in the world.

Second, the best-rated ES for "farms" were habitat provision (ES9) and landscape beauty (ES10), with a score of five, both associated with coffee crops (Photograph N° 8) and, in recent years, associated with plantations of "eucalyptus" *(Eucalyptus grandis), Pinus (Pinus tecunumanii) and, to* a lesser extent, the crops of "granadilla" *(Passiflora ligularis*) (Photograph N° 9) and "rocoto" (*Capsicum pubescens*).

4.3 Comparative analysis of different land uses

Figure 2. Comparative analysis of the ES approach to different land uses in the two study areas

The natural forest is most valued for its biodiversity aspect (habitat and the provision of medicinal resources), which is linked to cultural and religious values.

In the Villa Rica study area:

- The mixed bamboo planting system stands out for its regulation services, compared to the other two land uses.
- The natural forest is most valued for habitat services, providing food and shelter for the area's wildlife. Moreover, ecotourism activity is highly valued, due to waterfalls that are located in the locality.
- Notably, land use is best valued as being ecotourism-linked to coffee cultivation; that is, agrotourism attracts a significant number of visitors per year to the Villa Rica area.

4.4 Cost-Benefit analysis

Table 4. TEV of the study areas

Study Areas	DUV (USD)	IUV (USD)	AUV (USD)	OV (USD)	UV (USD)	TEV (USD)/ha	TEV - total (USD)
"The "Maronal"" in Yarau, Moyobamba – Peru (bamboo forest)	277.77	328	605.77	250	855.77	855.77	34,230.8
"La Reserve", Villa Rica – Peru (mixed bamboo planting system)	1,388.88	328	1,716.88	191.5	1,908.38	1908.38	38,167.6

TEV = 855 USD/ha/year, considering that the "maronal" forest, according to DEMA, has an area of 40 hectares; it has an estimated value of 34,230 USD/ha/year, or the equivalent of 123,230 soles/ha/year.

TEV = 1,908 USD/ha/year, considering that the plantation, according to the owner's estimate, has an area of 20 ha. This plantation has an estimated value of 38,167USD/ha/year, or the equivalence of 137,403 soles/ha/year.

5. Conclusions

The natural forest with bamboo ("maronal"), in which the *Guadua lynnclarkiae* species predominates, provides important ES, such as the provision of fresh water and flooding regulation; this contributes to the well-being of the environment and the population of Moyobamba province, San Martín department.

The ES., notably the provisioning of freshwater, flood regulation, as well as landslide mitigation, are recognised by the actors of Moyobamba as important ES. of the natural forest. Moreover, ecotourism activities (e.g., hot springs and waterfalls), scenic beauty and the habitat for both fauna and flora are also highly valued by the actors.

For the mixed plantation system with bamboo species, *Guadua aff. angustifolia*, the most important ES. is erosion control and sediment retention. Actors recognised the restoration of a degraded ecosystem as one of the main ES. of bamboo plantations.

The economic value of the bamboo poles (culms) of the *Guadua lynnclarkiae* species, due to its wider use and commercialisation (through the legal mechanism: DEMA), also contributes directly to the Yarau community and Moyobamba's economy. The bamboo poles are widely used in the ecotourism sector for the construction of lodges.

The mixed system with *Guadua aff. angustifolia* is more profitable, considering the TEV, compared to the natural forest with bamboo *Guadua lynnclarkiae, which is more* than double the value. However, this value should be taken relatively because, in the present study, there was only a referential value of the indirect use, which is related to that ES that indirectly affects the well-being of society, such as water provision, erosion control, flood prevention and biodiversity conservation.

6. Recommendations

— Undertake morphological, ethnobotanical and distribution studies of the species known as "marona" *Guadua lynnclarkiae* in the San Martín Department, as well as throughout Peru, in order to demonstrate and visualise this species' benefits;

— Integrate bamboo in plantation/restoration/watershed conservation programmes for the rapid re-greening restoration of degraded ecosystems and enhance the watershed functions in the catchment areas that are amid the Mayo River sub-basins of the San Martín Department;

— Promote bamboo planting as shelterbelts/strips along rivers, streams and water bodies to mitigate/reduce the impact of floods and improve water quantity and quality;

— The plantations of *Guadua aff. angustifolia* in the district of Villa Rica should be promoted by the authorities in degraded and marginal lands to restore them and contribute to the socio-economic development of Peru's central forest region;

— Disseminate the value of a mixed plantation system with bamboo *Guadua aff. angustifolia* to promote the enterprise and value chains for local employment, income and investments for local and national economic development.

— Support economic valuation studies of ES to generate information on the value of the indirect or intangible benefits of ecosystems and thus improve economic valuation; this would avoid the destruction of ecosystems that fulfil vital functions and provide ecosystem services that are undervalued by Peruvian society.

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Appendix

Appendix 1: Actors surveyed for the field study

Actors from the Moyobamba Study Area, San Martín

N	Names	Type Of Activity	N° Cellular	Email
1	Mr. Wilfredo Galo Su Castro	Extractor, transformer and marketer of "marona" and president of the technical group of bamboo of the department of San Martín	964487520	galo.su.1268@gmail.com
2	Mr. Abel Tsapipat Ikam	President of the drinking water administration board of the Yarau native community	925881075	-
3	Mr. Emer Yaun Petsayit	Bilingual teacher from the Yarau native community	942442324	eyaun_2016@hotmail.com
4	Mr. Damian Vasquez Tineo	Farmer in the town centre: "Bella Selva"	950410492	-
5	Eng. Andreina De La Cruz Castañeda	Secretary of the technical group of bamboo of San Martín and environmental assistant of the Executive Directorate of administration and conservation of natural resources of the regional government of San Martín	956538667	andriu0895@gmail.com
6	Bach. Hitler Panduro Salas	Member of the technical group of bamboo San Martín and technician of the NGO URKU	968514545	hitler.pansa65@yahoo.com
7	Eng. Laura Garcia Brancacho	Coordinator SERFOR CAF - San Martín	942481759	lgarcia@serfor.gob.pe
8	Ms. Reina Lobato Leyva	Beekeeper from the Rumiyacu basin, Moyobamba	976030809	reinalobatoleyva@gmail.com
9	Eng. John Joaquin Esteban Romero	Forestry specialist United Nations Program and former head of the Moyobamba headquarters of the executive directorate of administration and conservation of natural resources	949836575	aguaytia@hotmail.com
10	Eng. Erick Cachique Ysuiza	Specialist of the executive directorate of administration and conservation of natural resources	955645007	eduardocachique@hotmail.com
11	Eng. Rita Vilca Lucana	Director of the conservation programme of the NGO AMPA	943856367	rvilcalucana@gmail.com

*Interview N° 11 was not able to get the evaluation of the ES However, the experience regarding the carbon credits for the Alto Huayabamba conservation concession in the San Martín region was known

Actors from the Villa Rica Study area, Pasco

N	Name	Type of Activity	N° Cellular	Email
1	Mr. Philippe Bigourd	Investor and owner of the *Guadua aff. angustifolia* plantation from the Bajo Bocaz sector in Villa Rica	999635426	agroforestalselvaperuanasac@gmail.com
2	Mr. Justo Poma Sarmiento	Technician, farmer of the area, producer of bamboo and secretary of the association of agroforestry producers Villa Rica - Palcazú	932275545	villa.rica.palcazu@gmail.com
3	Mr. Jhonny Castro Mayhua	Farmer from the San Miguel de Bocaz town centre	962968638	-
4	Mr. Hector Reynaga Arenas	Farmer from the San Miguel de Bocaz town centre	-	-
5	Eng. Julia Esperanza Jiménez Solorzano	Economic and environmental development manager. District Municipality of Villa Rica	970589972	esperanzajimenez15@gmail.com
6	Lic. Cesar Raúl Laura Contreras	Technical team of the NGO IBC ProPachitea project, Oxapampa headquarters - Villa Rica	963925022	crlaura@gmail.com
7	Eng. Ricardo Villar Astigueta	Investor, producer and researcher of *Guadua angustifolia* plantations in the Villa Rica and Oxapampa areas	951593115	rivias@gmail.com
8	Eng. Ángel Agüero Huerta	Forest technician ATFFS Selva Central - SERFOR. Villa Rica sub-headquarters	945717098	aaguero@serfor.gob.pe
9	Ms. Nelly Ponce Condori	Bamboo merchant in the La Merced area - Villa Rica. Naomi Investments Company	984002745	-
10	Eng. Danitza Medina Velásquez	Entrepreneur of coffee with bamboo containers, teacher Alexander Von Humboldt Institute and former official Municipality of Villa Rica	938665592	danitzamedina88@gmail.com

Appendix 2: Table of ES that was sent to study respondents

Moyobamba Area	Provisioning Services			Regulating Services			Habitat Services	Cultural Services		
	1	2	3	4	5	6	7	8	9	10
Land use / Ecosystem services	Timber (construction materials)	Medicinal Resources	Fresh water Provision	Carbon Sequestration	Floods / Landslides Control	Moderation of Extreme Events	Habitat Provision	Landscape Beauty	Recreation and Ecotourism	Cultural and/or Religious Values
Natural forest with bamboo	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Natural forest	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Farm	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10

Villa Rica Area	Provisioning Services		Regulating Services					Habitat Services	Cultural Services	
	1	2	3	4	5	6	7	8	9	10
Land use / Ecosystem services	Timber (construction materials)	Fresh water Provision	Landscape Restoration	Sediment Retention	Carbon Sequestration	Floods / Landslides Control	Moderation of Extreme Events	Habitat Provision	Landscape Beauty	Recreation and Ecotourism
Mixed bamboo planting system	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Natural forest	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Farm	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10

Appendix 3: Photographs

Photograph N° 1. Rustic construction with “marona” in the Yarau native community (Moyobamba)

Photograph N° 2. Rustic construction with “marona” in Bella Selva, the town centre of Moyobamba

Photograph N° 3. Culms and sprout of “marona” in Yarau native community

Photograph N° 4. Use of the “marona” in passive fishing

Photograph N° 5. Crops of yucca and banana in the Yarau native community.

Photograph N° 6. River basin Rumiyacu (Moyobamba)

Photograph N° 7. Culms of *Guadua aff. angustifolia* on the plantation of Mr. Philippe Bigourd

Photograph N° 8. Coffee crop in Villa Rica

Photograph N° 9. Crop of “granadilla” (*Passiflora ligularis*) in Villa Rica

Appendix 4: UTM coordinates of the study areas

Yarau Community in Moyobamba

UTM Coordinates (Zone 18M, Datum WGS84)		
Vertexs	**East**	**North**
Sector A		
V1	289177	9346781
V2	289086	9346808
V3	288961	9346910
V4	288836	9347011
V5	288690	9347318
V6	288843	9347386
V7	289037	9347174
V8	289204	9347049
V9	289243	9347005
V10	289238	9346973
V11	289211	9346927
Sector B		
V12	287847	9347543
V13	287925	9347503
V14	288020	9347510
V15	288112	9347510

UTM Coordinates (Zone 18M, Datum WGS84)		
Vertexs	**East**	**North**
V16	288176	9347440
V17	288239	9347351
V18	288223	9347227
V19	287901	9347226
V20	287788	9347211
V21	287657	9347167
V22	287536	9347240
V23	287317	9347343
V24	287291	9347402
V25	287369	9347488
V26	287563	9347478
V27	287617	9347513
V28	287617	9347542
V29	287649	9347570
V30	287690	9347605
V31	287764	9347570
Total area: 40.4 ha		

"La Reserve" fund area in Villa Rica

UTM Coordinates (Zona 18L, Datum WGS84)		
Vertexs	East	North
C1	482500	8827700
C2	482200	8827600

C1: The centre of the first area (16 ha)
C2: The centre of the second area (4 ha)

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