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Creation of the Route of Bamboo, a Contribution to Net Zero by 2050 in Vietnam

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Abstract

The Phu An bamboo village, created in 1999, maintains over 200 taxa of living bamboo, collected in Viet Nam, Laos and Cambodia, and was awarded the UNDP Equatorial Prize in 2010. This ex situ conservation not only provides data for basic research and preserves biodiversity resources, but also contributes to actions on CO_2 to reduce the greenhouse effect in climate change and create sustainable livelihoods for the community. From the Phu An Bamboo village, the "Bamboo Route" has been built since 2016 from the north to the south of Viet Nam, with the aim of multiplying bamboo in situ conservation sites, associated with research programs and public awareness actions on the importance and environmental benefits of bamboos. Along the bamboo route, an ex situ conservation site has been developed at Dong Thap with plants of 67 different vernacular species, another at Phan Rang, in the arid region, with 62 species, and a third at Dak Nong, where the climate is more favourable, with 12 different vernacular species from the in situ conservation site at Chieng Ban, Son La, where 19 vernacular species have been recorded. Thanks to its fast-growing characteristics and large biomass production, bamboo plays an important role in carbon sequestration. Research to mesure CO_2 absorption was done in three different habitats on three different bamboo species. The CO_2 absorption capacity of Bambusa blumeana Schultes in Gao Giong, Dong Thap province, indicates an important role of this thorny bamboo under climate change conditions. On the " Route of Bamboo", we studied also the surface area of bare soil from north to south, except in the Mekong Delta, we can plant more than 200,000 ha of thorny bamboo to complete the existing surface area of 1.5 million ha which could contribute 30% of Viet Nam's CO_2 absorption. This enables us to estimate how planting 50% of these areas could contribute to Viet Nam's Net 0 2050 target.

Keywords: Carbone absorption, conservation, environmental benefits, Bamboo Route.

1. Introduction

Bamboo, belonging to the Poaceae family, subfamily Bambusoidae, and including around 200 species in Vietnam, is one of the country's important natural resources with unique characteristics, great genetic diversity, and multiple properties and uses [1] [2]. Bamboo is associated with the Vietnamese people throughout life, from literature and art, to use in food, agriculture, fishing, construction, crafts, industry, etc. Recent studies show that bamboo is also used to treat wastewater or decontaminate soil [3]. With its fast-growing characteristics and large biomass production, bamboo also plays an important role in carbon sequestration [4] reducing the impacts of climate change by revegetating bare land and combating desertification, and protecting soils from degradation through erosion [5, 6].

Viet-Nam has an *ex situ* bamboo study and conservation center in Phu An (province Binh Duong), with over 200 bamboo taxons planted in the botanical garden [1] The aim of this new project was to trace a route from the north to the south of Viet Nam (Fig 1.), linking conservation sites, *in situ* and *ex situ*, for contribution to Net 0 2050 in Viet Nam. To study the impact of route, studies on CO_2 absorption were done in different habitats and for different bamboo species.

The "Route of Bamboo", real and virtual, linking small bamboos with giant species, dry regions with seasonally flooded ones, steep areas with flat ones, aims to rally goodwill for the cultivation and preservation of bamboos along its route.

The "Route of Bamboo" is aimed at farmers who expose their backs to the sky and their faces to the earth to feed people, and who must adapt to climate change. It links communities in different regions around the bamboo, and scientists whose studies aim to contribute to maintaining a healthy living environment while maintaining the use and conservation of bamboo.

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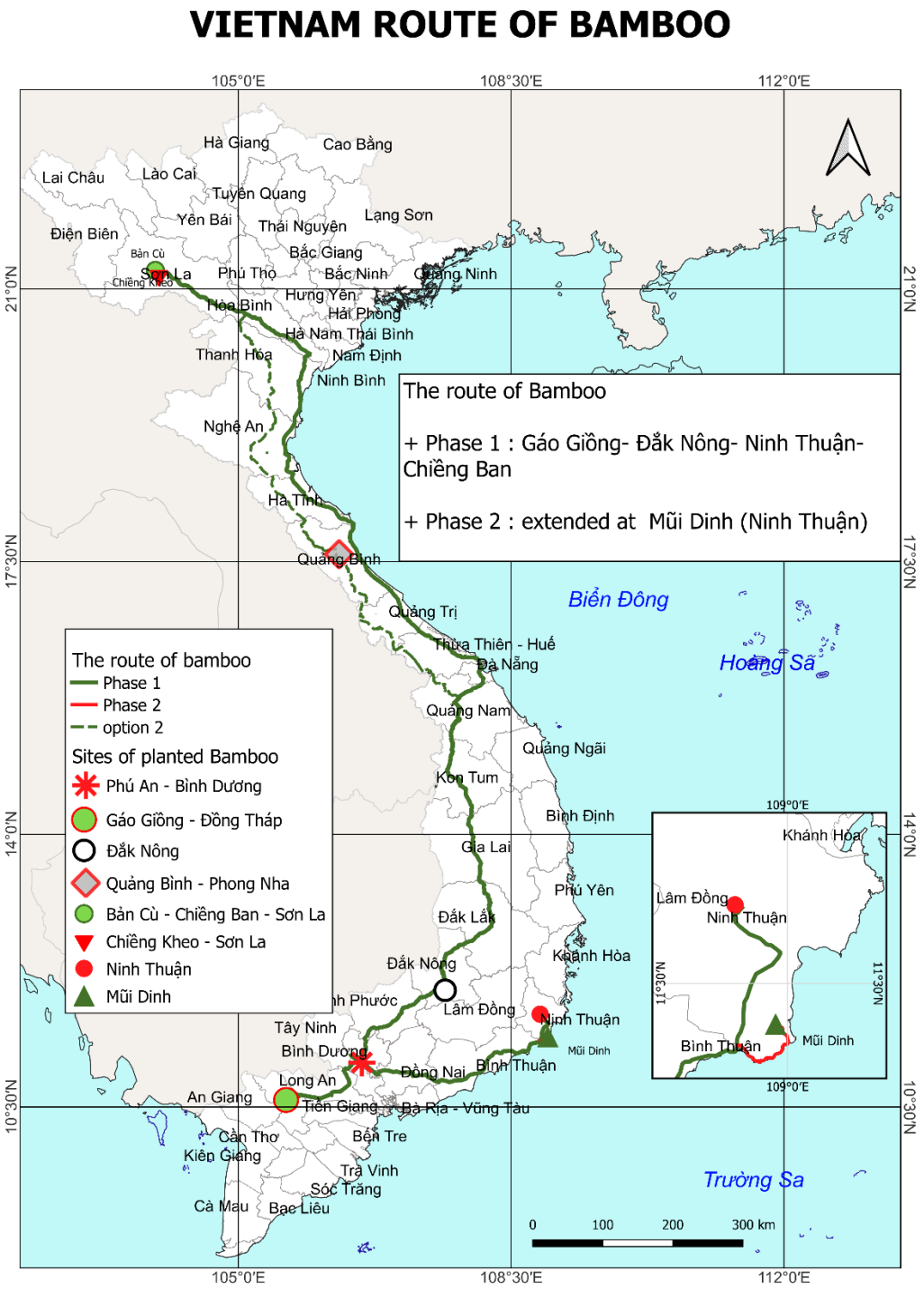

Fig. 1. Map of Viet Nam Route of Bamboo.

2. Materials and Methods

CO_2 absorption by plants is linked to the biomass produced which varies according to species and environmental conditions [7]. To measure CO_2 absorption along the future bamboo route, we studied the biomass produced by 3 bamboo species in 3 different types of habitats. We also studied and compared the growth of several species *in situ* and *ex situ.*

2.1. Study on CO_2 Absorption

2.1.1. Site selection criteria

Based on remote sensing with Landsat ETM images and Center for Earth Resources Science and Observation (EROS) (USGS) imagery, and taking into account field availability and access, the sites of Le in Dak Nong, Lồ ô in Dong Nai as well as the thorny bamboos of Gao Giong were selected for the study of CO_2 absorption (Fig. 1).

- Dak Nong is located on the Highlands at an altitude of 337 m.
- Dong Nai, Vinh Cuu district, in the South-East region of Viet Nam, at an altitude of 89 m, leaving Lồ ô in the forest, named "The Sea of Bamboo" [8].
- Dong Thap, Cao Lanh district, Gao Giong village, located in the flood zone in the Mekong Delta at the altitude of one meter, where people plant the thorny bamboo to protect the banks of river.

2.1.2. Protocol to measure CO_2 absorption

The protocol to measure CO_2 absorption based on a study project was carried out from 2010-2012, by the same group of researchers [9, 10]. The study protocol has been summarized as following [11, 12].

At first, build a regression equation for the estimation of biomass organic carbon content without culm destruction, only measure the diameter of the culm at 1,3 m ($D_{1,3}$) in each plot. This method is used in many studies [9, 13, 14]. After that, harvesting the aboveground parts (stems, branches, leaves) to calculate bamboo biomass.

Study realized in two parts:

- Study in the field: select in each study area, 6 sample plots 1,000 m^2 wide (50 m x 20 m) are set up. In each plot, 45 standard bamboos with increasing diameters were selected for carbon analysis and the creation of a correlation equation.

+ The diameter $D_{1,3}$ of the bamboo stem is measured at 1.3 m from the ground, as is the circumference of the section.

+ The fresh weights of leaves is *Wlt*, of branches is *Wct*, of branches is *Wck*, and stems is *Wtt* are recorded.

- Study in laboratory:

+ The fresh samples is *Wt*, are then dried at 65°C to constant weight, to calculate the dry biomass of leaves is *Wlk*, of branches is *Wck* and of stems is *Wtk*.

+ The dry biomass will be analysed in the laboratory using Walkley-Black method [15] to define carbon content. Carbon content is then calculated as a % of biomass.

+ CO_2 absorption is calculated using the NIRI (Nissho Iwai Research Institute - Japan) method applied by Bao Huy *et al.* [13, 16]: CO_2 absorbed = C*44/12 i.e. One ton C equivalent to 3.67 tons of CO_2.

Data are analyzed and processed with Excel 2007 and Statgraphic Plus 3.0 software.

2.2. Route of Bamboo and Conservation Areas

The route of bamboo was established with the aim to develope the different conservation sites in different ecological regions, depending on the available area. Each conservation site on the route of bamboo will be a test of adaptability and also a propaganda site to raise local people's awareness of the benefits of bamboo conservation, and the positive effects of bamboo in the future: environmental protection with high absorption of CO_2, protects river banks, prevents sloping land erosion.

Some sites are natural (*in situ* conservation), others created by plantations (*ex situ* conservation):

- *In situ* conservation: the Chieng Ban site is located in the province of Son La, in the North-West region of Viet Nam, at an altitude of 805 m, and covers a hilly area of 5 ha. The bamboo forest is maintained to maintain its plant diversity, with our technical advice including the reasonable harvesting of shoots for consumption, and to declaw older stems and rejuvenate the clump.

- *Ex situ* conservation:

The Phu An Bamboo Village conservatory [17] covering 4.5 ha already existed in the south-east zone. Three other sites were planted with seedlings of different species selected from the Phu An bamboo village collection:

+ In the Mekong Delta, the site is in Gao Giong, Dong Thap province, included 6 ha plantation of 67 vernacular species.

+ In the Highlands, the site is in Dak Nong province, included 2 ha plantation of 12 different vernacular species.

+ In the Phan Rang province, included 5 ha, semi-arid region of Central Viet Nam, conservation on this site is called the Green Wall to conserve in the special climatic condition with the plantation of 62 different vernacular species.

Bamboo growth is monitored by bamboo height and number of stems per clump.

2.3. Databasing

Information and awareness-raising brochures on the diversity and environmental importance of bamboos have been produced to accompany local populations along the bamboo route.

These documents are based on preliminary work to define botanical terminology on bamboos published in a trilingual work published by the National University of HCM Viet Nam [18].

Following all 125 characters defined in this book, 204 bamboo clumps from conservation sites along the bamboo route were computerized with Xper2 software [19, 20]. The characters with the greatest diversity (discriminating power) were then extracted by analysis from this knowledge base. To do this, all the specimens described were compared 2 by 2 for each character, and for each descriptor, the number of pairs

that differed, i.e. that had completely different values for that descriptor, was counted.

3. Results

3.1. Carbone Absorption

C content of Le (*Gigantochloa sp*.) is 48,11% of dry biomass (*Wtk*) (*C* content = 0,4811**Wtk* or *Ct* = 48,11%**Wtk*).

C content of Lồ ô (*Bambusa procera*) is 45,61% of dry biomass (*Wtk*) (*C* content = 0,4561**Wtk* or *Ct* = 45,61%**Wtk*).

C content of Tre gai (*Bambusa blumeana*) is 49% of dry biomass (*Wtk*) (*C* content = 0,49**Wtk* or *Ct* = 49%**Wtk*).

Following litterature [11], in cases of limited budget and time to analysis carbon of samples in laboratory, carbon content can estimate as 47% * dry biomass. In [20] the average *C* content for *Bambusa tulda* Roxb. is found near 47%.

The results of the study on the CO_2 absorption capacity of the 3 sites are presented in Table 1a. From these results, we can compare the CO_2 absorption capacity of the test sites in relation to the current bamboo area in Viet Nam in Table 1b.

The results of the study on thorny bamboo at Gao Giong show that the CO_2 absorption capacity of *Bambusa blumeana* is 21.68 kg/tree and the total amount of CO_2 that this bamboo can absorb is equivalent to an average of 191.26 tons/ha, equivalent to a carbon fixation capacity of 52.16 tons/ha. The equation that best describes the relationship between the ability of bamboo to absorb CO_2 and *D* has the following form (1):

$$CO_2t = 0.626 * D^{1.965} \quad (1)$$

with (2.93 cm < $D_{1,3}$ < 8.98 cm)

In Dak Nong region, the average CO_2 absorption capacity of Le trees (*Gigantochloa* sp.) is 6.48 kg/tree and the total amount of CO_2 absorbed by Le forest is 58.07 tons/ha on average. The equation that best describes the relationship between Le tree's ability to absorb CO_2 and $D_{1,3}$ has the following form (2):

$$CO_2t = 0.5685 * D^{2.5442} \quad (2)$$

with (1.1 cm < $D_{1,3}$ < 3.85 cm)

In the Vinh Cuu area of Dong Nai province, the average CO_2 absorption capacity of Lồ ô tree (*Bambusa procera*) in the trunk is 13.50 kg/tree and the total amount of CO_2 absorbed by Lồ ô forest is 53.84 tons/ha on average. The equation that best describes the relationship between the CO_2 absorption capacity of Lồ ô and $D_{1,3}$ has the following form (3):

$$CO_2t = 0.5532 * D^{2.083} \quad (3)$$

with (1.59 cm < $D_{1,3}$ < 9.07 cm)

Table 1a. Comparison of CO_2 absorption capacity of some bamboo species (tons/ha).

Taxons	**Culms**	**Branches**	**Leaves**	**Total**
Le (*Gigantochloa* sp.) Dak Nong	30.71	18.27	9.09	58.07
Lồ ô (*Bambusa procera* A. Chev. et A. Camus*)* Dong Nai	37.23	13.53	7.20	53.84
Tre gai (*Bambusa blumeana* Schultes.) Gao Giong	118.95	61.36	10.95	191.26

Table 1 b. Comparison of CO_2 absorption estimated at experimental sites, in new plantation and in Viet Nam

Sites	**Area (ha)**	**Species**	**CO_2 absorption (Tons/ha)**	**CO_2 total (Tons)**
Gao Giong	13	Tre gai	191	2 388
Dak Nong	2 141	Le	58	124 328
Vinh Cuu - Dong Nai	5 000	Lồ ô	54	269 250
Total sites	**7154**		**101**	**395 965**
Total bamboo areas in VN	1 592 205	Various species	100	159 220 500
Estimation if new plantation of 25% of bare areas in Viet Nam	200 000	Tre gai + other species	100 and more	20 000 000
sites + new plantation CO_2 absorption / 600 Mt emission CO_2 in Viet Nam	1 792 205		100 and more	30% of total

Table 2. Summary of the taxa in the *ex situ* conservation sites of Dong Thap, Phan Rang, Dak Nong, and Chieng Ban.

N°	Genus	Number of taxa for different sites			
		ex situ			*in situ*
		Dong Thap	Phan Rang	Dak Nong	Chieng Ban
1	*Ampelocalamus*	0	0	0	01
2	*Arundianaria*	01	01	02	06
3	*Bambusa*	35	35	05	07
4	*Cephalostachyum*	01	01	01	01
5	*Dendrocalamus*	07	07	03	03
6	*Gigantochloa*	15	10	0	0
7	*Melocalamus*	01	01	0	0
8	*Schizostachyum*	02	02	01	01
9	*Thyrsostachys*	01	01	0	0
10	*Vietnamosasa*	04	04	0	0
	Total	**67**	**62**	**12**	**19**

Table 3. Comparison of some bamboo's growth on *ex situ* and *in situ* conservation sites.

	Name	Growth (H= height in meter - C= number of stems)							
		Dong Thap		Phan Rang		Dak Nong		Chieng Ban	
		H	C	H	C	H	C	H	C
1	Tre Vàng scc- *Bambusa vulgaris var. strictata*	14	27	14	10	x	x	x	x
2	Lồ ô vàng- *Bambusa Gurgandii*	12.5	25	6.3	20.0	x	x	x	x
3	Tầm vông- *Thyrsostachys siamensis*	6.7	40.5	7.2	50.8	x	x	x	x
4	Nọ Bói- *Bambusa burmanica*	x	x	x	x	5.3	27	9.4	28
5	Nứa lá lớn- *Schizostachyum funghomii*	x	x	x	x	7.9	25	12.6	30

x: no plantings or no original

This result shows that the thorny bamboo species in Gao Giong, besides its high CO_2 absorption ability, is superior to other bamboo species, can also live in flooded conditions, for several months a year. It is a precious resource of nature for the Mekong Delta.

3.2. Conservation Ex situ

The results of Table 2 show that, from the conservation *ex situ* in Phu An Bamboo village , we have propagated and planted other *ex situ* conservation sites on the bamboo route, and have investigated the adaptation on different species in different ecological areas, both extending the bamboo route to different communities, contributing to CO_2 absorption, helping to reduce the greenhouse effect, and creating jobs for local people in future [1, 5, 17].

Plant growth is monitored at the various sites (Table 3).

3.3. Conservation in situ

Located at GPS position: 21°23'9.729" N, 103°9'31.732 "E, altitude 792 m, the Chieng Ban site preserves in the forest 19 varieties of bamboo used for human consumption (Table 4). However, these are now exploited in a reasoned way. Most of these bamboos, identified by distinct vernacular names, have yet to be scientifically identified, as their floral characteristics are rarely observed.

3.4. Database

The knowledge base, computerized in Xper2 [19], includes 125 morphological descriptors concerning turion, culm, nodes and internodes, branches, sheaths, leaves and flowers [18].

We used discriminant power analysis to select 20 descriptors (Table 5). These 20 descriptors were used to produce a standardized, compact information-gathering sheet to help identify bamboo diversity in the field.

Table 4. List of bamboos *in situ* in Chieng Ban (Son La).

N°	Vernacular name	Genus	Species
1	Mạy Lợi= Trúc dây	*Ampelocalamus*	sp.
2	Mạy Lay	*Arundinaria*	sp.1
3	Mạy Pặt (măng dê)	*Arundinaria*	sp.2
4	Mạy Khôm Ban	*Arundinaria*	sp.3
5	Mạy Púa Khôn Đen	*Arundinaria*	sp.4
6	Mạy Pầu	*Arundinaria*	sp.5
7	Mạy Ban	*Arundinaria*	sp.6
8	Nọ Bói	*Bambusa*	*burmanica*
9	Nó Bó	*Bambusa*	sp.7
10	Mạy Hốc	*Bambusa*	sp.8
11	Mạy Luông	*Bambusa*	sp.9
12	Tre Gai	*Bambusa*	sp.10
13	Mạy Pao	*Bambusa*	sp.11
14	Mạy Sọt	*Bambusa*	sp.12
15	Mạy Khao lam	*Cephalostachyum*	*pergracile*
16	Vương	*Dendrocalamus*	sp.13
17	Mạy Púa Cấy	*Dendrocalamus*	sp.14
18	Mạy Sang	*Dendrocalamus*	sp.15
19	Mạy Hịa= Nứa lá lớn	*Schizostachyum*	*funghomii*

Table 5: The 20 morphological descriptors with highest discriminant power.

Characters	Number of distinct values	Number of discriminated couples
80. Characteristics of intern culm-sheath ligule	8	11688
81. Margins of intern sheath ligules	8	11110
53. Thickness of the culm sheath	4	10484
115. Leaf veination	4	10282
33. Characters of zone G	6	9569
76. Presence of hairs on inner surface of sheath blade	5	9292
12. Length of culm	6	9123
96. Presence of pseudo rhizome at insertion of branches	3	9034
48. Thickness of diaphragm at mid culm	4	9013
13. Culm diameter at mid-culm	6	9012
38. Internode surface: presence and type of hairiness	6	9006
79. Shape of sheath ligules	5	8900
61. Present of hairs on the outer surface of culm sheath	5	8659
124. Ciliation of foliar auricles	5	8610
37. Grooved longitudinally on the internodes	5	8571
69. Shape of sheath blade	5	8434
96 Architecture of branches	4	8252
85. Presence of hairs on culm auricles	5	8190
7. Present of hairs on sheath of shoot	5	7758
11. Orientation of the sheath blade on the shoot	4	6435

The number before the character label is its identifier in the database.

In a last future they will be used also to offer a brochure presenting bamboos to the general public, enabling local people to discover the morphological diversity of bamboos.

4. Discussion

The Geographic Information System (GIS) was applied to map the Route of Bamboo and the Green Wall area. Coordinates of planting bamboo sites were obtained by using the GPSs (datum WGS-84, geographic coordinates) for the Phu An Bamboo Village (Binh Duong province) and other locals [provinces of Dong Thap, Phan Rang (Ninh Thuan), Dak Nong, Son La]. These sites were linked together and displayed as a connection of bamboo sites making the Route of Bamboo based on the existing national roads. From the central region connecting the North, there are two options, either following National Highway 1, or following the Truong Son Road. The Green Wall site is located at the Ninh Son district, Phan Rang (Ninh Thuan), of which coordinates are identified by GPSs and shown on available high-resolution satellite images of Google Earth as a base image of the map.

The results show that the CO_2 absorption capacity of Le (*Gigantochloa* sp.) at Dak Nong is

4.48 ± 0.59 kg/individual, and over the whole forest it is 58.07 ± 6.45 tons/ha. For Lồ ô (*Bambusa procera* A. Chev. and A. Camus) at Vinh Cuu (Dong Nai)

is 19.6 ± 2.45kg/individual, and 53.85 tons/ha. For Spiny Bamboo (*Bambusa blumeana* Schultes.), a species with many long and thin branches growing from the basal part of the culm, the absorption capacity is higher with 21.68 ± 1.79kg/individual and 191.26 tons/ha.

In the Gao Giong area, during the flood season in the Mekong Delta, spiny bamboo has the highest CO_2 absorption capacity, up to 3 times higher than other species studied. Its environmental contribution to the region is significant. The Mekong's special geographical situation, with its dense network of rivers and canals, offers a shoreline length of 28,550 km. If we could plant 10% of this length, i.e. 2,855 km, this would require a quantity of 571,000 bamboo clumps covering 1,428 ha, and would absorb 272,653 tons of CO_2. This is a significant figure for contributing to Net 0 in 2050. In 5 years of planting, 2,855,000 stems could be reconnected and used as raw material to manufacture bamboo products, without reducing the quantity of biomass for CO_2 absorption, because as we said, in plantation management it's the older stalks that are harvested and quickly replaced by younger ones. In the Mekong Delta, the route of bamboo, in addition to protecting the banks and fighting storms, can replace wood for construction. We can compared that the tensile strength of thorny bamboo is 147.05 N/m^2 while that the wood of first category is 139.5 N/m^2, the flexural strength of bamboo is 196.89 N/m^2 while wood is 130 N/m^2 and the tensil shear strength of bamboo is 41.69 N/m^2 while the wood is 12.5 N/m^2 [21].

In situ conservation means not only conserving species for research, but also protecting resources while making a profit. Despite of the 19 species existing in their area, much work remains to be done to scientifically identify the species [22].

On the computer side, the 20 most discriminating descriptors concern the different parts of bamboos: turion (2), culm (2), node (2), internode (2), branch (2), leaf (2), culm leaf sheath (2), culm leaf blade (3) and culm leaf ligule (3). The presentation of these descriptors is designed to introduce the different parts of a bamboo plant, the terms used to describe them, and to encourage careful observation. Logically, the more descriptors have different possible values, the more effective they are at differentiating bamboos (e.g. descriptors for the inner ligule of the thatch leaf). Size descriptors (length of culm, diameter at mid-culm, diaphragm thickness) are by nature continuous numerical characters, but here they are discretized into intervals. We have considered that these 20 descriptors are all accessible to observation, even without botanical expertise, but some require meticulous observation, and texts and photos to learn how to observe them. They enable anyone who takes the trouble to do so, to discover how bamboos that may look very similar, are in fact very diverse. Without this awareness of specific plant diversity, it's hard to understand the justification for protection, when bamboos seem inexhaustible. This is one of the aims of the Route of Bamboo.

5. Conclusion

The project of “Route of Bamboo” would not have been possible, nor could it continue, without collaboration between scientists, local communities and administrations.

The results showed that CO_2 uptake by thorny bamboos was very high, at 191 tons/ha.

CO_2 uptake by Le and Lồ ô species is lower, at around 50 tons/ha.

With bamboo's high CO2 absorption capacity and the possibility of extending the bamboo route and covering bare soil, Viet Nam bamboo can help reduce until 30% of Viet Nam's current emissions.

What a bright future for the route of bamboo: contributing to the environment, supplying raw materials, protecting the forest and the soil, and creating jobs for the people to ensure sustainable development.

Conservation studies and the absorption of CO2 by bamboos have a twofold benefit: not only is

biodiversity increased, but also the contribution to climate change. Future work will provide a better understanding of Vietnam's bamboo plant diversity, its properties and its environmental impact.

Credit authorship contribution statement:

Diep Thi My Hanh: conceptualization, methodology, funding acquisition, writing – original draft, review & editing. Jacques Gurgand: conceptualization, investigation. Pham Bach Viet: methodology & writing. Nguyen Khac Dieu: investigation. Marc Pignal: methodology & review. Régine Vignes Lebbe: databasing, original draft, writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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