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Thinning operations focusing on biodiversity conservation in protected forest of northern Vietnam. Effects on habitat value and economic yield

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RESUMEN

La superficie forestal en Vietnam ha tenido un aumento general desde los años 90 cuando se aplicó la actual política de protección forestal. A pesar de sus efectos positivos en la reforestación, la combinación de leyes estrictas y los insuficientes subsidios para las áreas cercanas de los bosques, ha causado la marginalización de esas áreas y el desplazamiento de la deforestación a los países vecinos, ya que las importaciones de madera en Vietnam aumentaron significativamente.

Este estudio está ubicado en el marteloscope establecido en el año 2018 en el marco del proyecto BioEcoN, en un bosque regenerado en el norte de Vietnam. Nuestro objetivo es comparar los efectos económicos y del valor del hábitat para la biodiversidad de diferentes criterios de claras. El valor de hábitat se ha evaluado utilizando los microhábitats relacionados con los arboles (TreMs) como bioindicadores.

Nuestros hallazgos muestran la influencia del criterio de conservación de la biodiversidad sobre el valor del hábitat en las dos simulaciones de clara. Los árboles codominantes resultaron en tener el valor de hábitat más alto, lo que coincide con los estudios previos en bosques templados. Además, hay especies de árboles comercializables y no comercializables por disposición del gobierno vietnamita. En nuestra área de estudio, el criterio de conservación de la biodiversidad tiene un efecto marginal sobre el beneficio económico. Este último resultado, junto con la relación positiva entre diámetro a la altura del pecho y el valor del hábitat, muestra que es posible un punto de encuentro entre la rentabilidad y la conservación de la biodiversidad.

Palabras clave: Microhábitat de árboles, marteloscope, biodiversidad, cortas, valor económico, política forestal

ABSTRACT

The forest surface in Vietnam faced an overall increasing since the 90's when forest protection policy was applied. Despite its positive effects on reforestation, the combination of strict laws and low subsidies for close to forest areas, caused the marginalization of those areas and the deforestation displacement to the neighbor countries, as Vietnamese imports of wood increased significantly.

This study takes place in the marteloscope established in 2018 under the framework of the BioEcoN Project in northern Vietnam in regenerated forest. The aim is to assess the economic and the habitat values of each tree, then, four thinning operations are proposed, and their effects on the forest are compared. The habitat value is assessed by using the tree-related microhabitats (TreMs) as bioindicators.

Our findings show the influence of biodiversity conservation criterion among the four thinning simulations. Codominant trees with a higher diameter at breast height (DBH) resulted to have the highest mean habitat value which coincide with the findings of previous studies of Temperate forest even with a weak relationship. Furthermore, there are marketable and non-marketable tree species by Vietnamese government disposition. In our study area, the biodiversity conservation criterion has a marginal effect on the economic benefit. This last finding, together with the positive diameter at breast height – habitat value relationship, show that a meeting point between profitability and biodiversity conservation is possible.

Key words: Tree related microhabitats, marteloscope, biodiversity, thinning, economic value, forest policy.

1.-INTRODUCTION

Tropical forests represent the highest biodiversity hotspot in the world (Gibson et al. 2011, Gardner et al. 2009), nevertheless their actual conservation status has never been in worse conditions since centuries (Bradshaw et al. 2009). The reason is that tropical biodiversity largely depends on the management of human-modified ecosystems, making this threat a challenge for researchers and forest managers (Gardner et al. 2009). In addition, the complexity of tropical forests makes evaluating forest operations with biodiversity conservation goals difficult (Magurran et al. 2003).

In the past few decades the world has seen an increasing interest in forest biodiversity conservation (Rocchini and Ricotta, 2007). Nevertheless, advances in that field have not been equally achieved among all countries. For example, while for some tropical countries deforestation is still a big threat, other countries are experiencing an overall forest growth (Pekka et al. 2006). This is the case for Vietnam that since the 90's, the country has not only seen its forest protection policies lead to a huge increase of the national forest area, but also a huge increase of wood import from other countries like Cambodia and Thailand (International Trade Centre, 2018), causing a displacement of the deforestation (Meyfroidt et al. 2009). Nevertheless, in the last 20 years Vietnam has achieved a remarkable reduction of poverty in both urban and rural areas (Muller at al. 2006).

At the same time, the strict forest protection policy of Vietnam made local people dependent on State funds (Tan, 2006) in the sense that they cannot take advantage of the forest anymore except of a very limited number of non-timber forest products (Vietnam, 2007). Sometimes, as protecting big forest areas require an abundant budget, funds might not be enough neither to fight poverty, nor to include all the ethnic groups scattered in the territory, inevitably leaving aside some of them (Quang & Ph, 2005, Tan, 2006). We must consider that before the 90's: "Some rural people have derived great benefit from the elimination of forest cover through increased access to arable land and through conversion of timber and other forest products into income and capital" (Sunderlin and Huynh, 2005).

As forest protection is one of the objectives of the Vietnam National Forest Policy, and there is not enough money to sufficiently pay those people who take care of protected forests, a solution could be offered by a different type of forest management (Quang & Ph, 2005). We hypothesize that it might be possible to perform some harvesting operations without affecting the biodiversity and the functioning of the forest. At the same time, the local people would have an additional income. This means a more sustainable management of the protected areas.

To contribute to the achievement of this objective, we must avail of tools that help foster a better understanding of the environment: when we talk about biodiversity, commonly we refer to three types which are compositional diversity, structural diversity and functional diversity (Kaennel, 1998, Michel and Winter, 2009). However, evaluating the biodiversity of an ecosystem by measuring the species diversity, is a very complex process, which requires time and experts in species recognition (Michel and Winter, 2009, Puumalainen, 2001). So, indirect methods such as the use of bioindicators have been developed to make the measuring of the biological diversity easier (Larrieu et al. 2018, Larsson, 2001, Lindenmayer et al., 2000). "Bioindicators are organisms or communities of organisms, which react to environmental influences by alterations of their life functions and/or by their chemical composition. Thereby it is possible to draw conclusions concerning their environmental conditions." (Arndt et al. 1996). At the same time, nowadays we have a wide range of bioindicators that imply we must select those that are meaningful for our purpose (Larsson, 2001).

In our research, we used the marteloscope established in the Melinh station for biodiversity in northern Vietnam. "Marteloscopes, are large plots designed for tree marking simulations, set up with human beings as the main focus: they are used for knowledge transfer activities, training of various categories of forestry workers, and even for the study of human tree selection behaviors" (Soucy et al. 2016). This marteloscope was established in 2018 under the framework of the BioEcoN Project (Erasmus +, Capacity Building in the field of Higher Education), by the Thai Nguyen University of Agriculture and Forestry, partner of the Project (http://bioecon.eu/).

More precisely, the marteloscope is a square plot with the size of 100x100m. It is important to choose the correct site giving particular attention to the representativeness that the marteloscope has of the rest of the forest: it shall embrace all the forest heterogeneity including gaps and the different kinds of vegetation and forest stages. Second, the selected forest must show a certain "need" to be managed in the sense that it has to be suitable for virtual management exercises. Third, the renouncing to the real management for at least 5-15 years justifies the set-up cost and ensures the medium-term site usage (Schuck et al. 2015).

The minimum scheduled variables that need to be assessed in each Marteloscope are six:

- tree-ID (tree number)
- tree position (polar co-ordinates)
- tree species
- DBH (diameter breast height)
- tree height
- crown base height (initiation of crown)

Starting from those six variables, we can already derive more parameters like the tree volume, the basal area and the single tree volume. Then, other variables can be optionally considered depending on the questions that want to be addressed with the Marteloscope. The more variables, the more questions can be addressed. For example, the evaluation of timber assortments or the evaluation of the tree habitat structures also called tree microhabitats or tree-related microhabitats (TreMs). "Tree-related microhabitats are an important determinant of forest biodiversity. Habitat trees, which typically provide many microhabitats such as hollows, crown dead wood, etc., are therefore selected to maintain those structural attributes within managed forests." (Großmann et al. 2018). For example, the TreMs have been revealed to be an important indicator of vertebrates and invertebrate's species diversity (Larrieu et al. 2018, Michel and Winter, 2009, Winter and Möller, 2008). Indeed, it has been found that many bat and bird species are strongly dependent on TreMs during their life-cycles for food, shelter, and breeding habitat (Regnery et al. 2013). Nevertheless, both marteloscope sites and studies on TreMs have taken place almost only in European temperate forests (European Forest Institute n.d.) and the newness of this method in proved by the fact that until now there are only 89 scientific papers containing the word 'marteloscope' (Scholar.google.com, consulted on the 15th of June 2019). All of those scientific papers are placed in Europe (Kraus et al. 2016, Soucy et al. 2016, Pommerening et al. 2015, Soucy et al. 2014). So far, we can affirm that this is the first marteloscope-based study in tropical forest setting.

In our study, we considered the TreMs variable with the aim of reconciling the biodiversity conservation with the profitability of forest management. A similar approach was followed in the study of Santopuoli et al. 2019, where they simulated four different scenarios by opposing the habitat conservation (valued through the TreMs) with the economic value of the trees. Then, they discussed the trade-off between the two parameters trying to address a better management of their specific forest area.

By our side, we will also discuss how valid the marteloscope approach is in tropical forest and the meaningfulness of its scheduled variables. Furthermore, we will provide guidelines to improve this type of research in tropical forests.

2.-OBJECTIVES

The aim of this study is to contribute to a better secondary tropical forest management and conservation in northern Vietnam through improving the understanding of its functioning and its biodiversity.

Our specific objectives are to:

1) Analyze habitat value of each tree within the marteloscope
2) Analyze the economic value of the trees
3) Study the consequences on biodiversity of thinning operations
4) Compare the effect of two different criteria for tree removal on the obtained profit and the remaining habitat value.

3.- MATERIAL AND METHODS

3.1. Study site

The study area Melinh station for biodiversity (Figure 1), is located in Ngọc Thanh, Municipality of Phúc Yên, Vinh Phuc Province (northern Vietnam).

The Melinh station for biodiversity was established in 1999, it belongs to the Institute of ecology and biological resource, supports for education and scientific research. The station is situated in the Southwest of Tam Đảo mountain Range.

The station covers an area of 175 ha and vaunts a rich plant diversity. Botanists have recorded 1,227 vascular plant species, 670 genera, 172 families and 6 divisions.

In 1992, in the location of the marteloscope, natural vegetation was clear-cut to plant *Acacia* spp and *Pinus massoniana*. However, forest plantations failed, and natural forest have been generating through light-demanding plants such as: Sau sau (*Liquidambar formosana*); Thành ngạnh (*Cratoxylum cochincinensis*); Thẩu tấu (*Aporosa dioica*); Hoắc quang (*Wendlandia paniculate*).

In 2002, native species were planted as enrichment planting. At the same time, shrub and grass layers were clear-cut. Planted species include: *Erythrophleum fordii*, *Lithocarpus corneus*, *Pelthophorum dasyrrhachis, Machilus bonii, Aphanamixis grandiflora*, *Dipterocarpus retusus,* etc.

This marteloscope, is placed on almost enterally on a flat area except of the subplots 1.1, 2.1 and 3.1 which are found at the beginning of a slope.

Nowadays, there are different kinds of ecosystem in the Melinh station: the flat area hosts plantations of tee trees and medical plants, and regenerated forest, while natural forest takes places where slope increases.

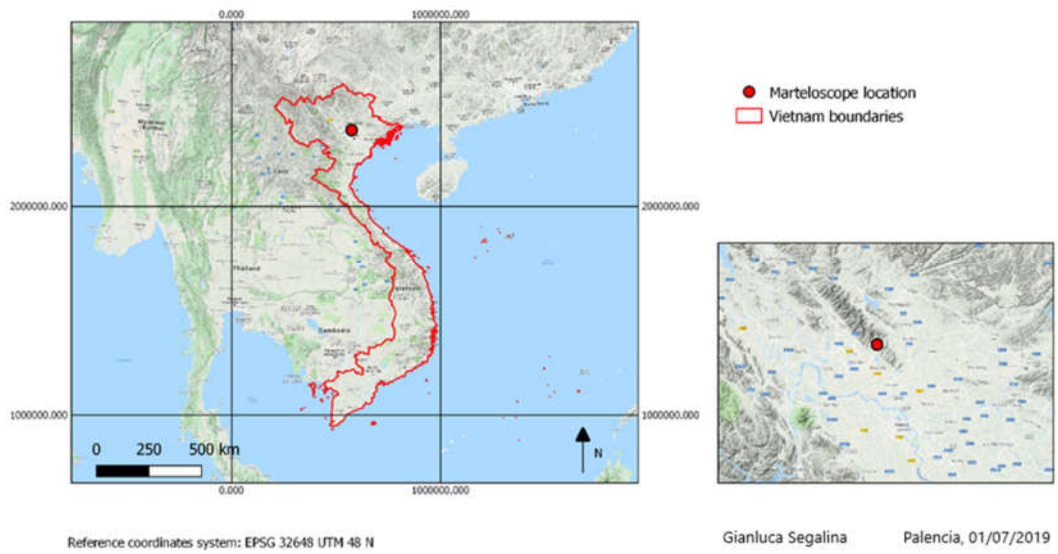


Figure 1: Location of the study area.

3.2. Data collection

The Marteloscope was installed under the activities of the BioEcoN project based on the following criteria:

1. The entire plot area must belong to Melinh station for biodiversity
2. It must be representative of the whole forest area
3. It must be placed on a relatively flat terrain
4. The area must have a good accessibility
5. Any harvesting operation is forbidden
6. It shall be divided in 16 square subplots of 25x25 meters each (Figure 2).

The first corner of the plot (1.1) was positioned by 2 reference points outside the plot by using GPS 64sx. Coordinates of each corner of each subplot were recorded starting from the first corner. Then, trees were censed by two teams of four people.

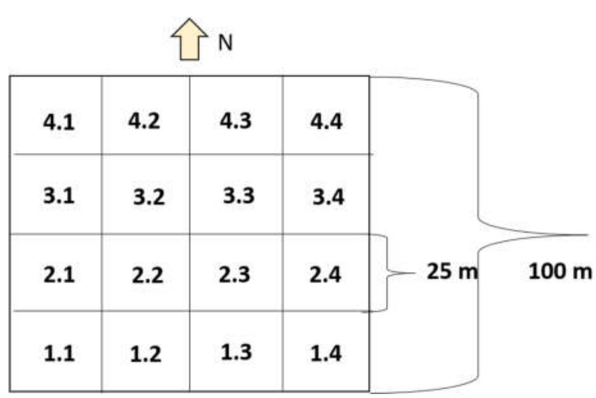


Figure 2: Scheme of the marteloscope plot.

All the living trees with a diameter at breast height (DBH) that is equal or higher than 7cm were considered. The DBH was measured indirectly by using a tape. The decision to consider trees starting from 7cm of DBH instead of 9cm as prescribed by Soucy, 2014, was taken because the average DBH was very low (Figure 5). The tree height at crown base and the height at largest crown width diameter were measured by using Terinox LRF 1800 and 1200 as well as the slope angle.

The basic recorded variables include:

- Tree id (number),
- Tree species,
- Tree diameter at breast height,
- Slope angle,
- Tree total height,
- Tree height to crown base,
- Tree height to largest crown width diameter,
- Timber quality,
- Stem straightness,
- Potential use,
- Tree health status,
- Tree microhabitats.

The tree id was assigned according to the succession criteria: starting from the first south-west corner of the plot 1.1, as the reference point number 1. From that point, we looked to the trees that are in our view from the left to the right side. The distance from the reference point and the angle of each tree was individually recorded. The angle is formed by the reference point and the measured tree compared to the north. The distance was measured by using a tape, and the angle, referenced to the north direction, was measured with a compass.

To obtain the $\sin$ and the $\cos$ of each angle, first we converted α from degrees to radians. Then, the coordinates of each tree were calculated by using the following formula:

$$\begin{cases} T_x = x_{ref} + (D * \cos\alpha) \\ T_y = y_{ref} + (D * \sin\alpha) \end{cases}$$

D = distance α = angle

Also the DBH was indirectly measured as mentioned before: through the meter tape, we measured the perimeter of the stem. The diameter has been obtained by dividing the perimeter by 3.14 (π).

To obtain the total height of the trees we used the following formula also represented in the figure 3:

$$Total\ height = \tan\beta\ * \ c$$

β= slope angle c= distance

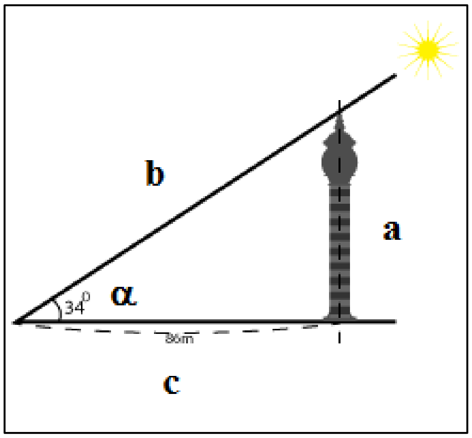


Figure 3: Representation of the total height of the trees calculation.

The timber quality and the health status were assigned to a scale from 1 (good) to 3 (bad) according to the marteloscope installation protocol criteria (Soucy, 2016). While the stem straightness was ranked from 1 (straight) to 6 (very curved).

The tree species were determined by experts, and the potential use of each tree species was assigned according to the book "The names of forest plants in Vietnam" by the Vietnamese Ministry of agriculture and rural development (2000). In total we found 58 tree species in the plot which the most abundant ones are reported in Figure 4.

Then, the timber volume was calculated by the following formula:

$$\mathrm{V}\ (m^3) = \ 0.00006341 * \mathrm{DBH}^{1.8786} * H^{0.9697}$$

V= Tree's timber volume

DBH= Diameter at breast height

H= Total height of the tree

This formula was developed by Hinh, V.T. (2012) and applies on natural forests in northern Vietnam.

The tree microhabitats (TreMs) classification used for the data collection is shown in table 1. It was done according to Larrieu et al. 2018 except of the height limit for the TreMs observation that was 3m instead of 5m. This decision was taken because the high forest density (805 trees/ha) combined with the well developed under canopy vegetation, and strong presence of liana, often reduces the visibility of the high part of the trunks making the evaluation of the TreMs very difficult.

All the data were collected during the month of February 2019, except for the TreMs that were recorded during the month of May 2019. In Annex 3 some pictures of the marteloscope are available. Those pictures have been taken on May 2019.

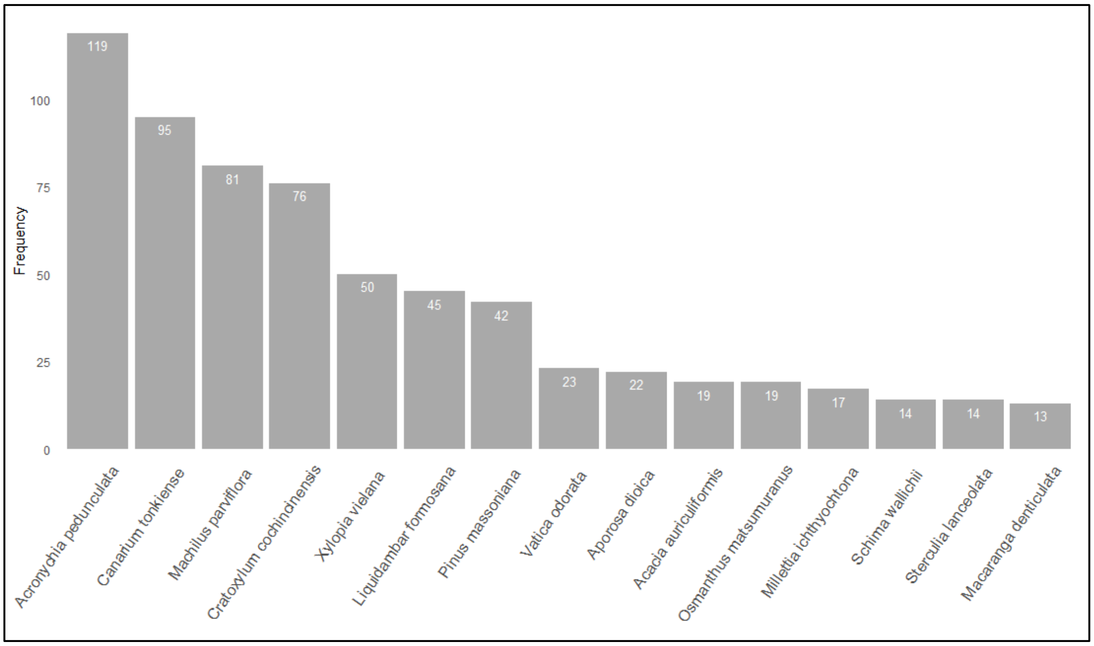


Figure 4: **Frequency distribution of tree species within the one-hectare plot. 58 tree species were found in the plot, for a total of 805 living trees. Here we reported the 15 most abundant ones.**

Summary DBH (cm)					
Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
6.529	9.172	11.943	13.779	15.669	54.14

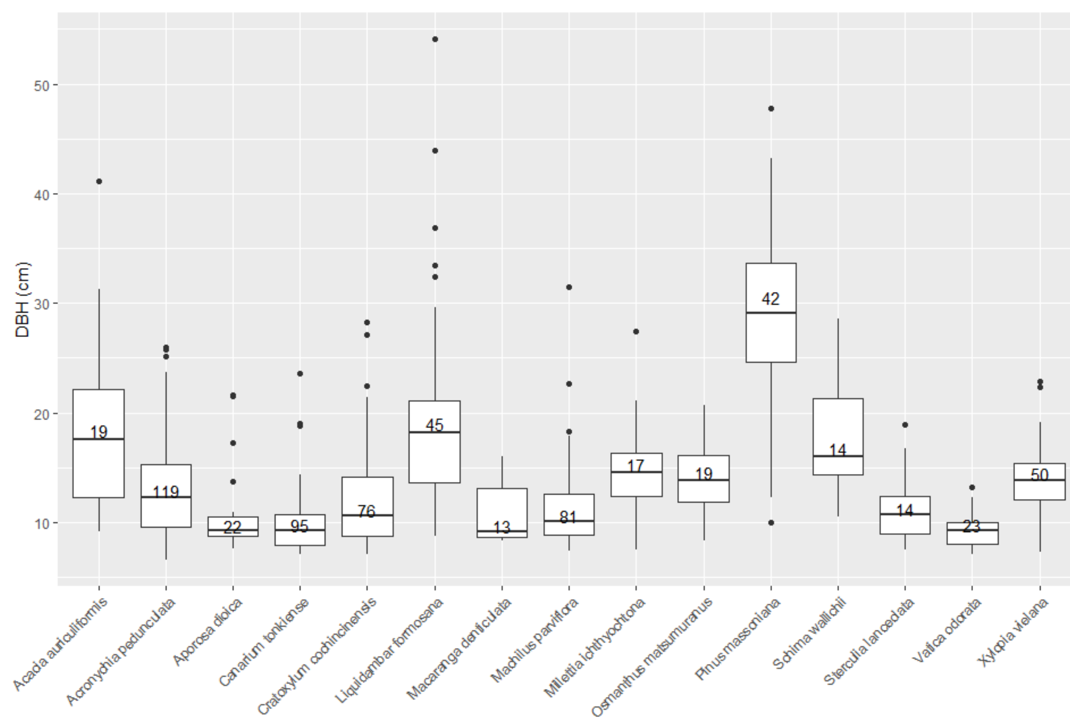
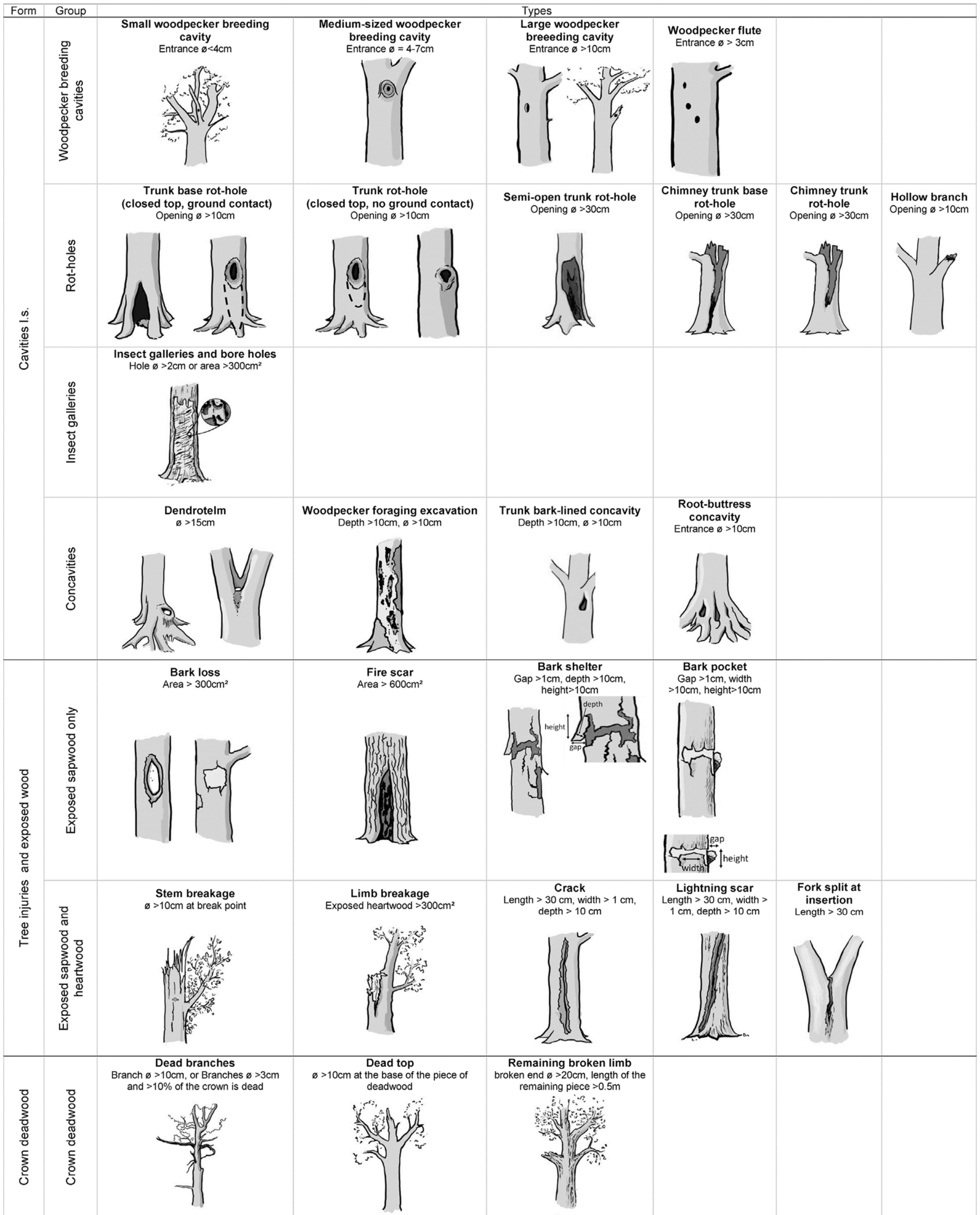
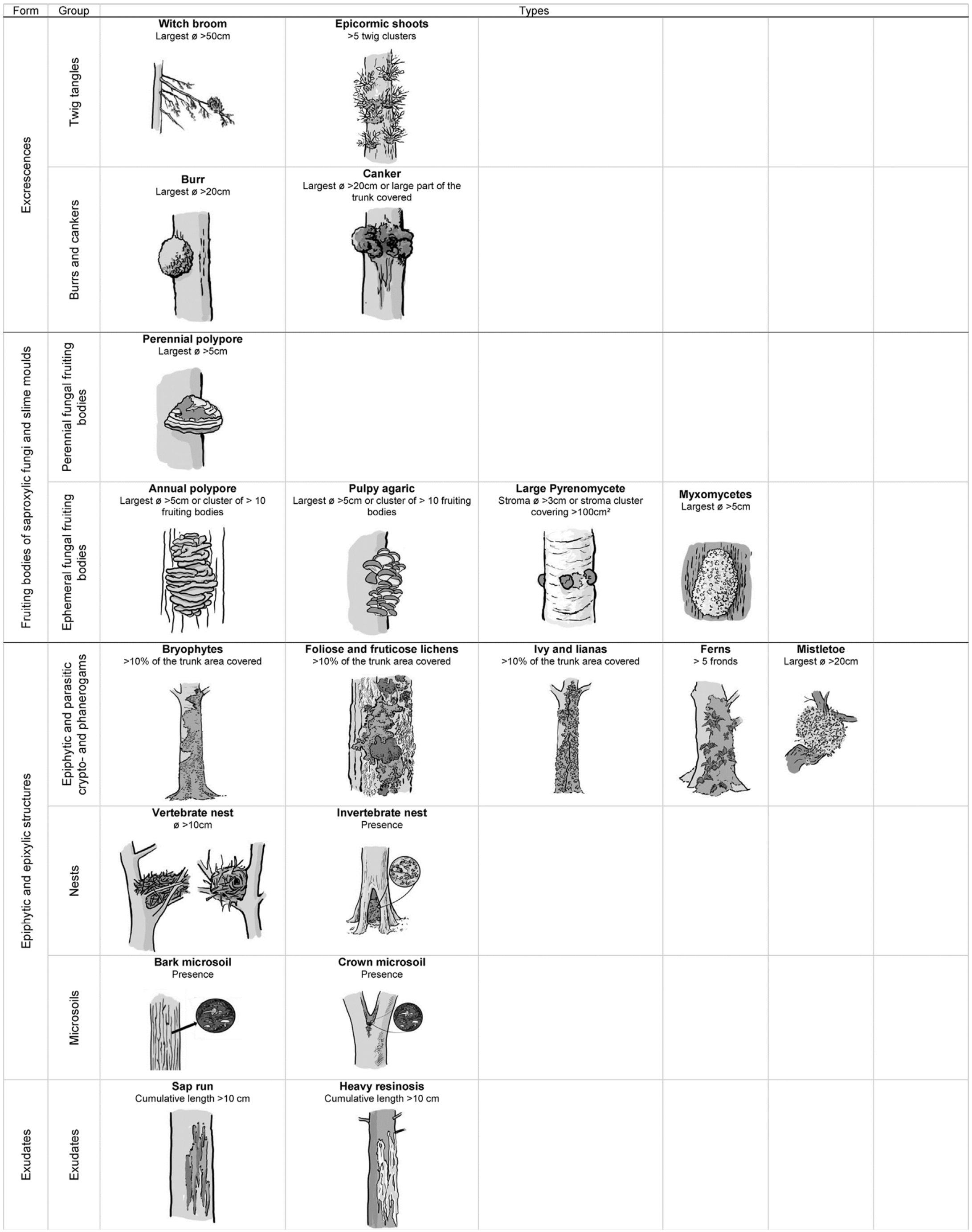


Figure 5: **Boxplot of the DBH of the 15 most abundant tree species in the marteloscope reporting the number of exemplars (number) and the mean (line inside the box) of each of those species. In its summary (above the graph) we can find the minimum, the first quartile, the median, the mean, the third quartile and the max of the DBHs.**

Table 1: Illustrations of the TreMs types in European temperate and Mediterranean forest from Larrieu et al. (2018) used for the data collection and to derive the habitat value of the trees.



Form	Group	Types					
Cavities l.s.	Woodpecker breeding cavities	**Small woodpecker breeding cavity** Entrance ø<4cm	**Medium-sized woodpecker breeding cavity** Entrance ø = 4-7cm	**Large woodpecker breeeding cavity** Entrance ø >10cm	**Woodpecker flute** Entrance ø > 3cm		
	Rot-holes	**Trunk base rot-hole (closed top, ground contact)** Opening ø >10cm	**Trunk rot-hole (closed top, no ground contact)** Opening ø >10cm	**Semi-open trunk rot-hole** Opening ø >30cm	**Chimney trunk base rot-hole** Opening ø >30cm	**Chimney trunk rot-hole** Opening ø >30cm	**Hollow branch** Opening ø >10cm
	Insect galleries	**Insect galleries and bore holes** Hole ø >2cm or area >300cm^2					
	Concavities	**Dendrotelm** ø >15cm	**Woodpecker foraging excavation** Depth >10cm, ø >10cm	**Trunk bark-lined concavity** Depth >10cm, ø >10cm	**Root-buttress concavity** Entrance ø >10cm		
Tree injuries and exposed wood	Exposed sapwood only	**Bark loss** Area > 300cm^2	**Fire scar** Area > 600cm^2	**Bark shelter** Gap >1cm, depth >10cm, height>10cm	**Bark pocket** Gap >1cm, width >10cm, height>10cm		
	Exposed sapwood and heartwood	**Stem breakage** ø >10cm at break point	**Limb breakage** Exposed heartwood >300cm^2	**Crack** Length > 30 cm, width > 1 cm, depth > 10 cm	**Lightning scar** Length > 30 cm, width > 1 cm, depth > 10 cm	**Fork split at insertion** Length > 30 cm	
Crown deadwood	Crown deadwood	**Dead branches** Branch ø >10cm, or Branches ø >3cm and >10% of the crown is dead	**Dead top** ø >10cm at the base of the piece of deadwood	**Remaining broken limb** broken end ø >20cm, length of the remaining piece >0.5m			


Form
Group
Types
Excrescences
Twig tangles
Witch broom
Largest ø >50cm
Epicormic shoots
>5 twig clusters
Burrs and cankers
Burr
Largest ø >20cm
Canker
Largest ø >20cm or large part of the trunk covered
Fruiting bodies of saproxylic fungi and slime moulds
Perennial fungal fruiting bodies
Perennial polypore
Largest ø >5cm
Ephemeral fungal fruiting bodies
Annual polypore
Largest ø >5cm or cluster of > 10 fruiting bodies
Pulpy agaric
Largest ø >5cm or cluster of > 10 fruiting bodies
Large Pyrenomycete
Stroma ø >3cm or stroma cluster covering >100cm²
Myxomycetes
Largest ø >5cm
Epiphytic and epixylic structures
Epiphytic and parasitic crypto- and phanerogams
Bryophytes
>10% of the trunk area covered
Foliose and fruticose lichens
>10% of the trunk area covered
Ivy and lianas
>10% of the trunk area covered
Ferns
> 5 fronds
Mistletoe
Largest ø >20cm
Nests
Vertebrate nest
ø >10cm
Invertebrate nest
Presence
Microsoils
Bark microsoil
Presence
Crown microsoil
Presence
Exudates
Exudates
Sap run
Cumulative length >10 cm
Heavy resinosis
Cumulative length >10 cm

3.3. Data analysis

A large part of the data analysis was done by using the software RStudio for the R version 3.5.3. that was marginally integrated with Microsoft Excel.

The first part of the analysis consisted in assigning the habitat value to each tree: the habitat value is calculated for each tree based on the number of recorded TreMs by using the formula proposed by Kraus et al. 2018. The calculation considers the relative rarity of a habitat in the forests and the time span needed for it to develop.

$$H_i = \sum_{j=1}^{n} N_j \times s_j \times (R_j + D_j)$$

The result (H_i) is then expressed in so called “habitat points”.

H_i is the habitat value of tree i, N_j the number of microhabitat type j, R is the value of the rarity of a TreMs, D is the value of the time that a microhabitat takes to develop or to be available, and S is the size score (physical size of a TreMs) within a TreMs type (see Table 1 and 2).

The R value was assigned by counting the frequency of each type of TreMs, and then rescaling the result from 1 to 5 where 1 is the minimum rarity and maximum frequency, and 5 is the maximum rarity and the lower frequency.

The second part of the analysis consisted in calculating the economic value of the trees through the consultation of Vietnamese timber companies’ websites and looking for the prices for the standing trees of each tree species per cubic meter. After multiplying the price per cubic meter with each tree volume, we simulated 4 thinning operations whose aim is to compare the effects on the basal area and trees distribution, the economic value and the habitat value: two criteria were used to assume harvesting operations (Table 3). The first criterion aims to thin the codominant or the dominated trees. The second aims to preserve trees with high habitat value. Those criteria have been applied at the subplot level which means that each thinning simulation have been implemented individually for each of the 16 subplots. And the removed quantity of basal area was fixed at the 30% ± 1% of the total in all the four scenarios.

At the same time, we excluded from the thinning operation those species which count at most 5 exemplars in the marteloscope (which excludes also the *Erythrophleum fordii* which is the only endangered species), in that we stated 5 as a reasonable number for the tree diversity conservation. It also means that the thinning simulations save at least 5 exemplars of each tree species.

After that, we fitted four linear models, one for each scenario, where the habitat value of each removed tree is function of the tree DBH.

Table 2: R and D values for TreMs

Rarity gradient (R-value)		Development time (D-value)		Size	
very common	1	fast or linked to very common event	1	ø ≤ 4 cm	1
common	2	fairly fast or linked to fairly common event	2	4 cm < ø ≤ 10 cm	2
fairly rare	3	from fairly slow to slow or linked to uncommon event	3	10 cm < ø ≤ 15cm	3
rare	4	slow or linked to rare event	4	15 cm < ø ≤ 20 cm	4
very rare	5	very slow or linked to very rare event	5	ø > 20 cm	5

Table 3: Criteria used to simulate the harvesting operations (tree removal).

Scenario	Criterion1	Criterion 2
S1	Dominated trees	Any habitat value
S2	Dominated trees	Low habitat value
S3	Codominant trees	Any habitat value
S4	Codominant trees	Low habitat value

4.- RESULTS

4.1. Forest inventory

The inventory revealed 805 trees with a DBH of 7cm or higher. At the same time, the average DBH is very low being 13.67cm (Figure 5). The tree species which reach the larger DBH is the *Liquidambar formosana* with 50.4 cm, and the *Pinus massoniana* has the second largest DBH (47 cm).

Furthermore, we estimated the amount of 89.2 m^3 of wood in the plot, which divided by the number of trees, gives the average of 0.11 m^3 of wood per tree. The amount of valuable timber is 48.2 m^3.

The only endangered or vulnerable tree species found in the marteloscope was the *Erythrophleum fordii* (IUCN 2019) which counts 5 exemplars. All the other species are classified as least concern or lack of information.

Particular attention should be given to the spatial distribution of tree species. It is visually recognizable that the *Pinus massoniana* is mainly grouped on one side of the plot (Figure 6).

The 89.2 m^3 of timber found in the marteloscope have been developed almost entirely since the year 2002 when shrubs were removed, and native trees were planted to enrich the forest composition. The mean annual increment since that year is 5.25 m^3/year.

4.2. TreMs and tree habitat value

The total number of TreMs found in the marteloscope was 4755 among all the TreMs types, which is very high if compared with the number of records of the study of Santopuoli et al. (2019) which was 754.

The most abundant TreMs type was the epiphytic and parasitic crypto – and phanerogams with 2079 records among Bryophytes, Foliose and fruticose lichens, and Ivy and lianas (Annex 1) which is the 43% of the total TreMs records. On the other hand, some of the TreMs described from Larrieu et al. 2018 are not present at all in our plot. Those TreMs are all the kinds of woodpecker cavities, the fire scar, the perennial polypore, the witch broom, the mistletoe and the fern. We didn't find also any vertebrate nest, but for the reason of low visibility inside the forest.

On 3 trees, about 50 insect holes on each tree (below the 3 m height threshold) with a diameter equal or higher than 2 cm were found. One of them belongs to the species of *Itea chinensis* and the other two belong to the *Archidendron clypearia* species. At the same time, these 3 trees have very low DBH (less than 10 cm) which makes us guess that their economic value should be almost zero because of the defects making their timber useless for the industry. The same 3 trees are also the ones with the highest number of TreMs recorded (67, 54 and 53 respectively). We must also consider that the *Itea chinensis* is the tree with the highest habitat value (2296 habitat points) calculated, and the other two *Archidendron clypearia* trees are among the 15 trees with the highest habitat value (1164 and 1195 habitat points). This shows that despite the low rarity of the insect galleries and holes, they can give a significant contribution to the habitat value of the trees.

We found only 3 trees without any TreMs belonging to 3 different species: *Cratoxylum cochincinensis, Acacia auriculiformis* and *Machilus parviflora*. Their DBH are 9.8, 17.5 and 15.8 cm, and their total height are 7.5, 11 and 9.2 m respectively.

Generally, the TreMs of bigger size like the semi-open trunk rot-hole, the dead top or the chimney trunk base rot-hole are also less frequent than little TreMs (bark shelter and dead branches) or biotic ones like bryophytes, foliose and fruticose lichens, insect galleries and bore holes, invertebrate nests, ivy and lianas and resin flow which are the most abundant ones. For example, we found only 1 chimney trunk base rot-hole, 1 trunk bark-lined concavity and 1 annual polypore. The hosting trees of these TreMs are: one *Acronychia pedunculata* of 10.3 cm DBH and 6.43 m of total height, one *Xylopia vielana* of 7.8 cm DBH and 8 m total height, and one *Liquidambar formosana* of 20.3 cm DBH and 9 m total height. Those trees have a total height which is slightly below the average (Table 4). Their DBH, is above the average (Figure 5) except of the *Xylopia vielana,* which DBH is among the lowest measured.

4.3. Economic value

By analyzing the economic value of the timber of each tree species, many issues are raised. Firstly, the Ministry of agriculture and rural development & Ministry of trade, general department of customs Vietnamese government published a joint circular on the 22nd of December 1995 (Bộ nông nghiệp và phát triển nông thôn-bộ thương mại-tổng cục hải quan) about the simplification and regulation of timber trade, where they identified the least endangered most valuable tree species on the market in terms of timber quality and they divided them in 8 timber classes. After the publication of this document, Vietnamese enterprises could provide buying prices depending on the timber class, overcoming the need of evaluating each tree species every time. In total, they listed 354 tree species. We must remember that Vietnam hosts more than 4000 tree species according to the book "The names of forest plants in Vietnam" (2000). That is why in such list we found only 19 of the 58 tree species which are present in the marteloscope plot. In total, we found 360 trees with an associated economic value (Table 6), which is the 45% of the total number of trees (805). Nevertheless, many of those species have low occurrence making them not harvestable from a sustainable/conservational point of view because, if there are only one or two trees of the same species, we don't know if their harvesting may reduce their reproduction chances too much.

Secondly, the most abundant tree species found in the plot, is the *Acronychia pedunculata* (Table 3) with 119 individuals which destination use is mainly for traditional medicine (Ministry of agriculture and rural development, 2000), and it does not appear in the joint circular by the Vietnamese government (suggesting that it has a relatively poor timber quality). Consequently, even that species' timber has some use value, and in the past, it was also used for construction (Ministry of agriculture and rural development, 2000), in our analysis, the result was that it is not marketable and its economic value is equal to zero.

After that, we looked to the prices that Vietnamese timber companies pay for each timber class. We selected the price list provided by the Chúc mừng năm mới website (Nguyễn, 2018) because it referenced, it was the most updated one and its list was derived by the average of other price lists coming from other companies. It was consulted on the 16th of June 2019 and it shows prices for standing trees belonging to the different timber classes (Table 5). They don't provide any information about possible reductions of the buying price depending for example on the wood quality (straightness and presence of defects) or depending on other factors like the transportation cost etc.

We found only one tree belonging to the timber class 1 (Table 6) and no one belonging to the timber class 2. The classes 1 and 2 are the most valuable timber classes.

4.4. Thinning scenarios

In the study area of one hectare, at the data collection time, the economic value found was 3219 USD, the total basal area 14.75 m^2 and the habitat value 189'360 habitat points.

Over the different forest interventions, thinning simulations impact on the forest structure and on all the parameters mentioned above. The equal amount of removed basal area within each scenario which is the 30% ± 1%, allows us to compare the effects of different tree selection criteria. Between scenarios 1 and 2 (S1 and S2), we see that there is a big difference in the removed habitat value which means both a different quantity and quality of removed TreMs (Figure 7). At the same time, the removed economic value in S2 is higher than the S1 one, while the timber volume is the same (23 m^3). What is also significant, is the difference between the amounts of removed trees in S1 and S2: 324 and 288 trees respectively.

The difference between the two criteria is also visible in S3 and S4 where the number of thinned trees is higher in S4 than in S3. In S4 there is a strong reduction in removed habitat value in comparison with S3, and the economic value obtained by S4 is close to the S2 one. The highest removed economic value is the one of S3 but without big differences: among all the 4 scenarios, all the revenues oscillate from 500 to 600 USD.

In the Table 7 are shown the summaries of the linear regressions of the DBH as function of the habitat value for the marked trees in S1, S2, S3 and S4. In Figure 8 are shown the relationships between the same two variables. We can notice that by considering the average of the habitat value of all the marked trees within each scenario, the expected value of the DBH (Intercept) is smaller in S1 than S3. Its slope, although it is significant in both cases, is very small and positive: 0.0026 and 0.0062 for S1 and S3 respectively, which means the relationship between the DBH and the Habitat value is very small, but if the DBH grows so the Habitat value does. To help the interpretation of the result, we also calculated the average habitat value of the removed trees for each scenario, finding that the highest values are given by S3 and S4 (Table 8).

In Figure 6 it is possible to appreciate the spatial distribution of removed trees among the different scenarios versus the current situation. We can also see that the trees with the highest basal area, are often the trees with the highest economic value. For example, *Pinus massoniana* are very large and tall trees (Figure 5 and 6), and consequently they hold a high amount of timber which leads to a high economic value. At the same time, the habitat value of *Pinus massoniana* is low because of the few TreMs they have.

Table 4: Summary of the total height of the trees in the marteloscope.

Summary Total height (m)					
Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
2.14	7.700	9.440	9.713	11.459	32.190

Table 5: Timber groups with relative average prices in 2018 per cubic meter of roundwood in the Vietnamese and the USA currencies.

Wood type	price (m^3 roundwood) Dongs	price (m^3 roundwood) USD
group 1	3600000.00	154.8
group 2	2500000.00	107.5
group 3	2700000.00	116.1
group 4	1900000.00	81.7
group 5	1700000.00	73.1
group 6	1300000.00	55.9
group 7 + 8	1100000.00	47.3

Table 6: Number of species, names of the tree species, number of exemplars of each species of the marteloscope plot, ordered by frequency and timber class classified according to the Vietnamese government in the joint circular of the 22nd of December 1995.

Count	Tree species	Number	Timber class
1	*Acronychia pedunculata*	119	
2	*Canarium tonkiense*	95	6
3	*Machilus parviflora*	81	6
4	*Cratoxylum cochincinensis*	76	
5	*Xylopia vielana*	50	
6	*Liquidambar formosana*	45	5
7	*Pinus massoniana*	42	5
8	*Vatica odorata*	23	
9	*Aporosa dioica*	22	
10	*Acacia auriculiformis*	19	
11	*Osmanthus matsumuranus*	19	
12	*Millettia ichthyochtona*	17	7
13	*Schima wallichii*	14	6

Count	Tree species	Number	Timber class
14	*Sterculia lanceolata*	14	8
15	*Macaranga denticulata*	13	8
16	*Canthium horridum*	11	
17	*Styrax tonkinensis*	11	8
18	*Archidendron clypearia*	10	
19	*Cansjera rheedii*	10	
20	*Elaeocarpus griffithii*	10	
21	*Eucalyptus citriodora*	9	6
22	*Chaetocarpus castanocarpus*	7	
23	*Phoebe tavoyana*	7	
24	*Canarium album*	6	7
25	*Engelhardtia roxburghiana*	6	
26	*Ficus hispida*	6	
27	*Acacia mangium*	5	
28	*Clausena excavata*	5	
29	*Erythrophleum fordii*	5	
30	*Itea chinensis*	5	
31	*Mallotus mollissimus*	5	
32	*Actinodaphne pilosa*	4	6
33	*Choerospondias axillaris*	3	
34	*Lithocarpus fissus*	3	7
35	*Clausena dunniana*	2	
36	*Hydnocarpus hainamensis*	2	
37	*Michelia balansae*	2	
38	*Toxicodendron succedanea*	2	
39	*Bischofia javanica*	1	
40	*Carallia diplopetala*	1	7
41	*Castanopsis indica*	1	3
42	*Diospyros apiculata*	1	1
43	*Endospermum chinense*	1	
44	*Eurya ciliata*	1	
45	*Garcinia hainanensis*	1	
46	*Garcinia multiflora*	1	
47	*Hymenodictyon orixense*	1	
48	*Litsea cubeba*	1	
49	*Litsea umbellata*	1	
50	*Memecylon edule*	1	
51	*Mischocarpus pentapetalus*	1	5
52	*Peltophorum dasyrrhachis*	1	5
53	*Stereospermum colais*	1	
54	*Symplocos laurina*	1	8
55	*Wendlandia paniculata*	1	
56	*Wrightia pubescens*	1	
57	*Xanthophytum polyanthum*	1	
58	*Zanthoxylym avicennae*	1	

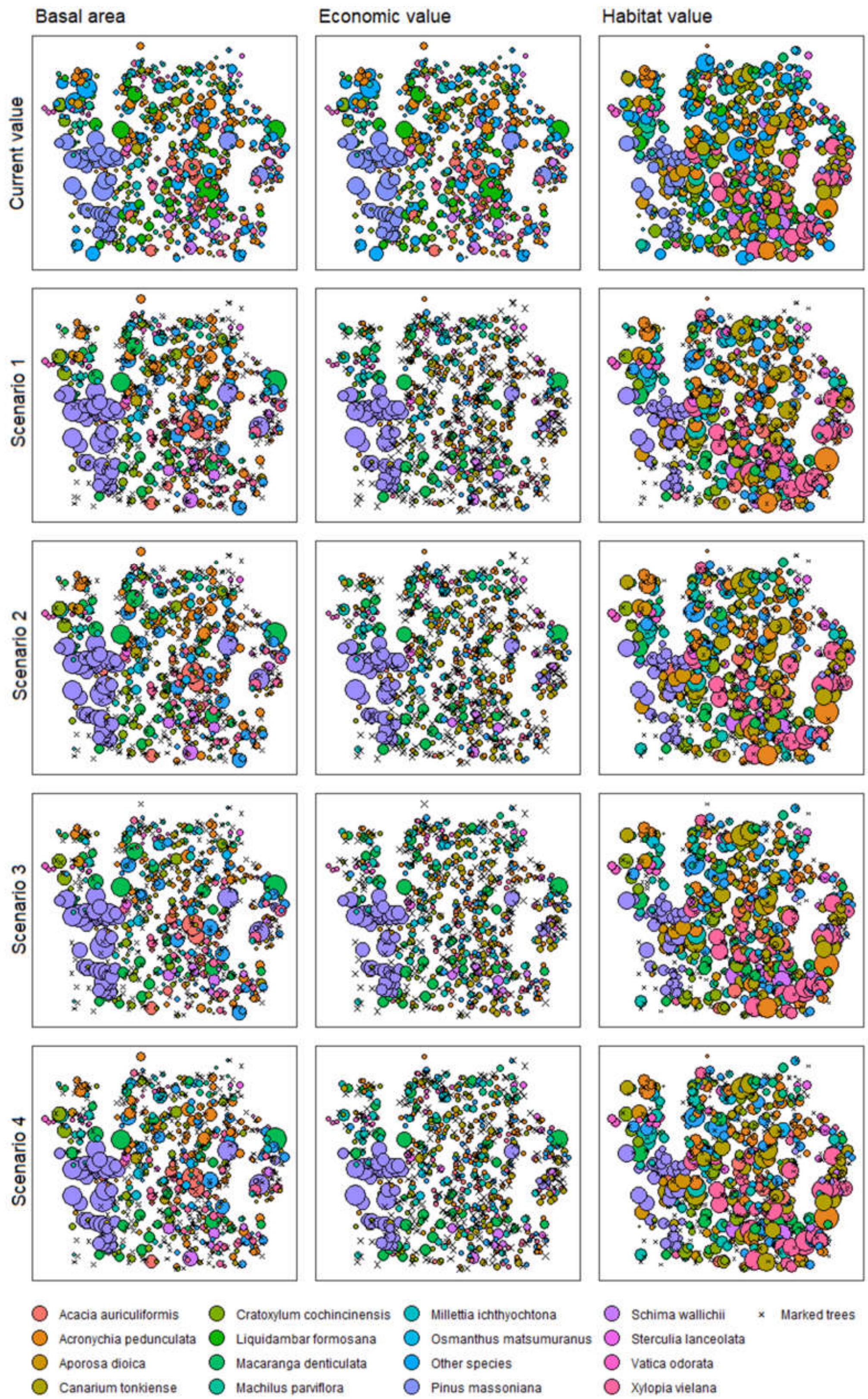


Figure 6: Forest intervention scenarios showing the tree spatial distribution inside the marteloscope of basal area, economic value and habitat value. The color reflects the 15 most abundant tree species while the others are grouped under the name "Other species" to simplify the view. The removed trees are marked with a "x". The dimension of the circle reflects: the basal area (m^2) in column1, the economic value (USD) in column 2 and the habitat value (Habitat points) in column3.

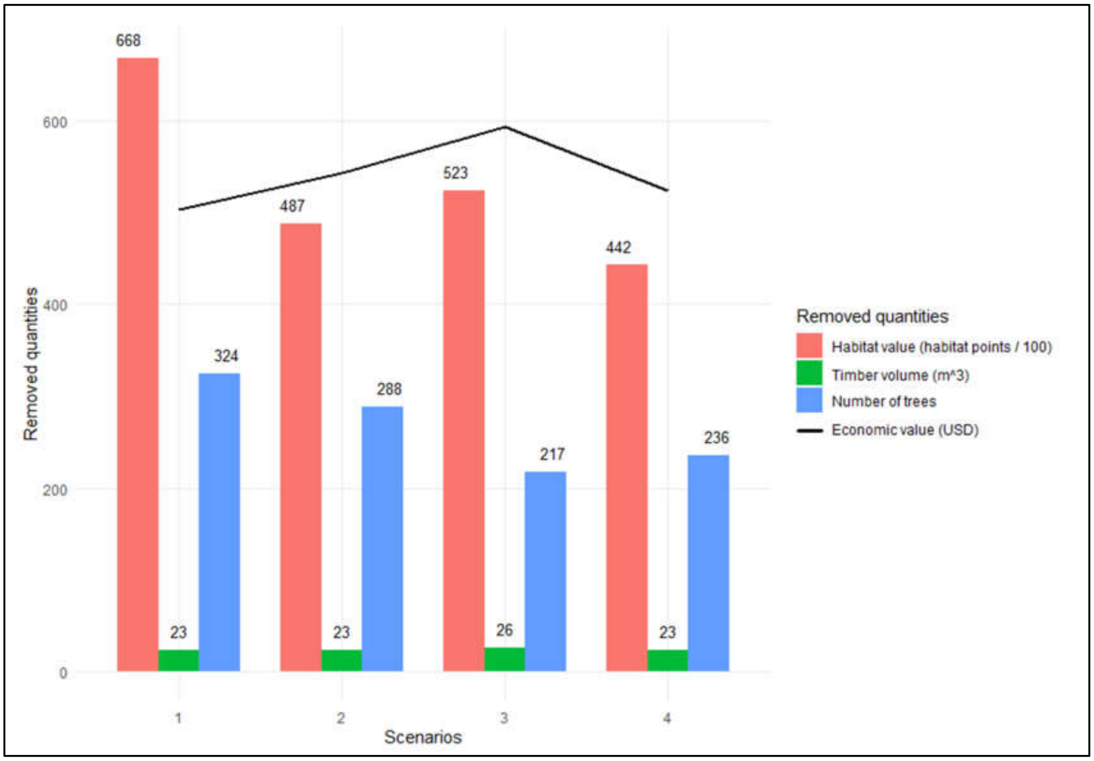


Figure 7: **Comparison among the simulated scenarios (S1, S2, S3 and S4). Removed quantities in terms of habitat value divided by 100 (habitat points) for a better visualization, timber volume (m^3), number of trees and economic value (USD) obtainable from the harvested trees.**

Table 7: Summaries of the relationship between DBH and habitat value within the marked trees of each scenario

Summary Scenario 1

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 10.976229   0.346725  31.657   <2e-16 ***
total        0.002617   0.001192   2.195   0.0289 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.542 on 322 degrees of freedom
Multiple R-squared:  0.01475,	Adjusted R-squared:  0.01169
F-statistic: 4.819 on 1 and 322 DF,  p-value: 0.02886
```

Summary Scenario 2

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 10.792173   0.377002  28.626  < 2e-16 ***
total        0.007536   0.001594   4.727 3.59e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.676 on 286 degrees of freedom
Multiple R-squared:  0.07246,	Adjusted R-squared:  0.06921
F-statistic: 22.34 on 1 and 286 DF,  p-value: 3.587e-06
```

Summary Scenario 3

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 12.635195   0.625492  20.200  < 2e-16 ***
total        0.006227   0.001880   3.312  0.00109 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.637 on 215 degrees of freedom
Multiple R-squared:  0.04855,	Adjusted R-squared:  0.04412
F-statistic: 10.97 on 1 and 215 DF,  p-value: 0.001086
```

Summary Scenario 4

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 11.862991   0.581139  20.413  < 2e-16 ***
total        0.008249   0.002193   3.761 0.000214 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.617 on 234 degrees of freedom
Multiple R-squared:  0.05699,	Adjusted R-squared:  0.05296
F-statistic: 14.14 on 1 and 234 DF,  p-value: 0.0002142
```

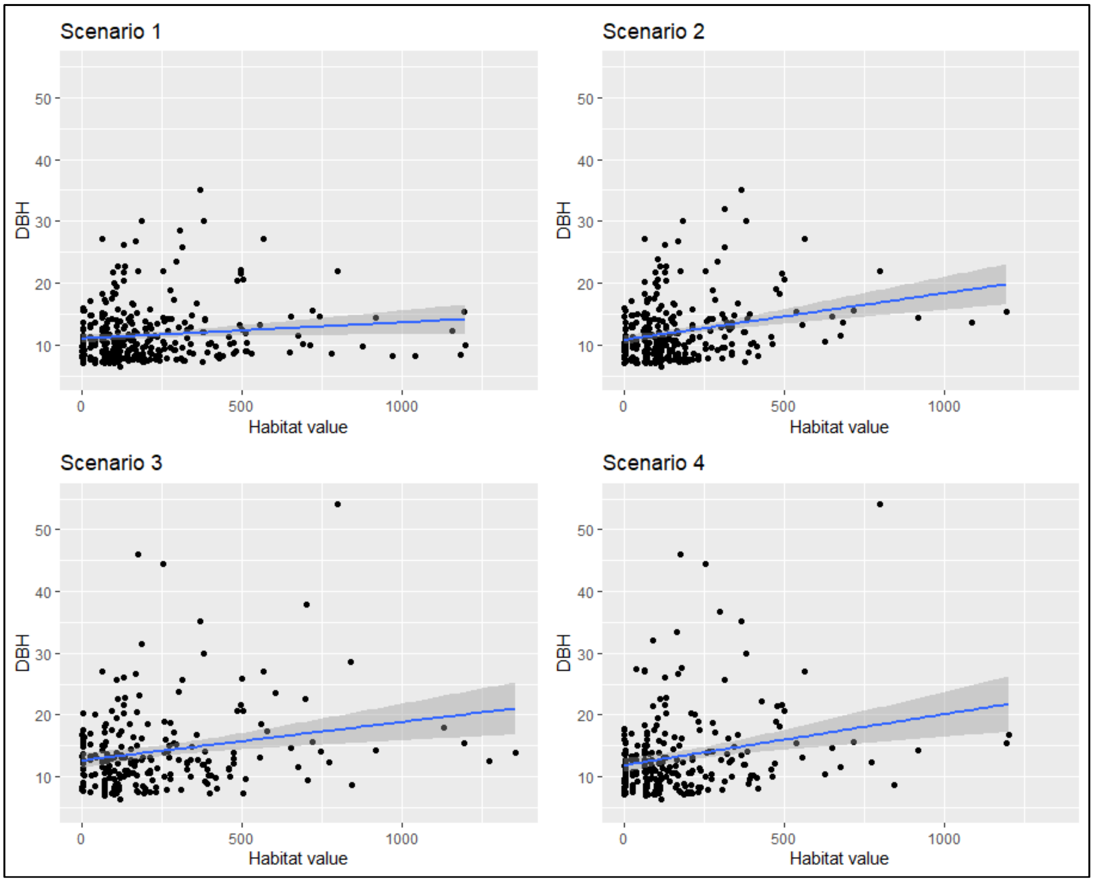


Figure 8: Relationship between DBH and habitat value of the marked trees among the four intervention scenarios.

Table 8: Average habitat value (habitat points) of the marked trees within each thinning scenario.

Scenario	Mean tree habitat value
1	199.50
2	161.37
3	230.80
4	177.86

5.- DISCUSSION

5.1. Forest inventory and TreMs

The number of TreMs recorded in the marteloscope (4755), is more than 6 times higher than the number recorded in the study of Santopuoli et al. (2019) placed in the Mediterranean region (754). Another difference between the two studies is the most abundant TreMs category: in our case, the 52% of TreMs is represented by epiphytic and parasitic crypto – and phanerogams while in the Mediterranean study the 42% of TreMs is represented by cavities. This proves that there are important differences between Mediterranean and Tropical forest.

More precisely, the epiphytic and parasitic crypto – and phanerogams category includes 895 bryophytes, 888 foliose and fruticose lichens, and 701 ivy and lianas (Annex 1). While bryophytes and lichens simply do live on the bark of the trees, ivy and lianas rely on the tree stem for structural support while looking for the light twisting around the tree stem. Furthermore, the same liana can twist around more than on tree causing difficulties during the thinning operation by bonding more than one tree and by developing stems sometimes thicker than the supporting tree stem (Jacobs, 1976). In our study, lianas were only censed as TreMs, but it was not considered their timber volume, basal area and the TreMs they host.

The most occurring TreMs type on the same tree, is the insect bore hole in 3 cases. About the single *Itea chinensis* tree and the two *Archidendron clypearia* trees, it is unexpected that pests attack the same tree for more than 50 times without attacking the surrounding trees neither attacking other trees of the same species (in total we found 5 *Itea chinensis* and 10 *Archidendron clypearia* trees). As mentioned above, the DBH of those trees is below the 10 cm. The reason for that are still unexplored and further research is needed to clarify which dynamics are the cause.

The first concern is that some of the TreMs defined by Larrieu et al. (2018) were not present at all in our plot: the woodpecker cavities, fire and lighting scars, and perennial polypore. On the contrary, we didn't find TreMs types which are not classified by the Table 1. Furthermore, in Larrieu et al. (2018) TreMs type groups come together with a table which links each TreMs with one or more specific invertebrates' and vertebrates' orders (Annex 2). In our study area, we don't know if all those links do coincide with ours or not. This type of information would help us to understand exactly which orders are linked to each TreMs type.

Secondly, particular attention should be given to two types of TreMs: the nests, and the insect galleries and bore holes. It was not possible to verify the presence of vertebrate nests on the crown by looking from the ground because of the high density of the canopy and because of the massive presence of lianas. Then, there was a high presence of termites on most of the trees. What we noticed, is that those insects, sometimes make their nests as galleries along the bark and inside the stem (Yanagihara et al. 2018) making difficult to distinguish between the insect-only galleries and insect galleries plus invertebrate nest. Furthermore, the nesting inside the trees causes a coincidence of the two TreMs definitions: insect galleries and invertebrate nest becomes the same. During our data collection we tried to distinguish that, but the difficulty of the task makes possible the existence of some human error. Anyway, the effect of this error on the average tree habitat value should be low because of the low habitat value of both the TreMs types (Annex 1). Also, it was not possible to relate the health status of the tree with the presence of those termites because we observed trees classified as healthy, which were completely covered by termite galleries and we found weak trees on which insect gallery presence was almost null. This means that the health status of a tree does not only depend on the TreMs it hosts, but also on other factors. Further research is needed to understand which factors predict the tree health status.

Thirdly, to explain the Pinus massoniana distribution (Figure 6), we think that the site characteristics are uneven among the study area (as mentioned in the paragraph 3.1) including topographic variables like slope and orientation which means different microclimates along the marteloscope. This also means differences in solar radiation and soil characteristics (Holland & Steyn, 1975, Noguchi et al. 1999) favoring different tree species in different plot areas (Podwojewski et al. 2011). At the same time, those Pines might have been spared by the last clear-cut occurred in the 90's. To verify that, we would need data about soil characteristics and solar radiation, as well as data about the age of the trees which was not considered in the marteloscope set up. To understand the spatial distribution of the Pinus massoniana we should also consider the experience of the past: when the forest plantation in this location failed during the 90's, as explained in the paragraph 3.1, the main reason was because the planted species (Acacia spp. and Pinus massoniana) were dominated by more light-demanding species. Consequently, it could be that Pinus massoniana trees are grouped where the solar radiation is less than on other parts of the plot.

5.2. Economic and habitat values

The economic and the habitat values, were the key elements for evaluating this research. The economic value was calculated based on the value of the timber itself, without considering any possibility of additional harvesting costs which could reduce the revenue.

The habitat value was evaluated by the rarity, size and development time of each TreMs type. Our results also showed that DBH can predict the habitat value as was found by previous studies in Mediterranean and Temperate forests (Asbeck et al. 2019, Michel and Winter, 2009, Vuidot et al. 2011, Regnery et al. 2013, Santopuoli et al. 2019), but with a weak correlation (Table 8). This suggests that there are more complex forest dynamics and factors determining the TreMs type and the habitat value of the trees and again, this is a challenge for future studies.

Then, the average of the annual increment of the timber in the marteloscope is 5.25 $m^3/year$ and the 54% of it has an economic value. It is known that plantations for timber production of *Acacia* spp. in Vietnam can produce from 10 to 25 $m^3/(ha * year)$ within the period of ten years depending also on the inputs like fertilizers that are used (Nambiar et al. 2015). Our forest showed having a production of valuable timber which is not comparable with an *Acacia* plantation (it would mean an increase from 20 to 50% of timber volume per year).

5.3. Thinning scenarios

The different thinning scenarios have shown very different results: by comparing S2 and S4, we see that the habitat value, number of trees and economic value parameters are higher in S2. The timber volume resulted to be the same between S2 and S4 as expected, because we are comparing the removal of dominated vs. codominant trees and in S4 we are removing 52 trees less than S2.

It is very clear how; by including the criterion 2 in the tree selection, the removed TreMs after the thinning reduces significantly. This can be appreciated both for the S1 - S2 and for the S3 - S4 comparisons.

The average habitat value of the marked trees within each scenario (Table 8) shows that despite the highest removed habitat value is the S1 one, this is because we are removing more trees to get the 30% of basal area, and generally, the habitat value slightly increases with the DBH. The determinant factor is the combination of the removed basal area and the criterion 1 about dominated/codominant trees.

Finally, we would recommend the thinning from above of S4 rather than the thinning from below of S2 because we are removing 52 trees less, but the same amount of timber volume. At the same time, the removed economic value is very similar (544 vs. 524 USD) which makes S4 more efficient than S2 in terms of revenue per removed tree. The difference in the removed habitat value is irrisory if we consider that it is only 4'500 habitat points by the total of 189'360 (2%).

5.4. Future perspectives

Considering the above discussed results, this study demonstrates that estimating the habitat value of each tree within the marteloscope is easy. We cannot say the same about estimating the economic value which resulted to be a very complicated task. We also demonstrated how easy it is evaluating the effects of thinning on biodiversity. The comparison between economic benefit and TreMs conservation among the scenarios shows a win-win situation as the two objectives do coincide.

At the same time this study opens to other questions: how will the forest value evolve in the future? For example, if we have a high economic revenue today, in the future we might have less valuable timber, making us turn back to the original problem of people harvesting only high value trees.

Are the links between the TreMs and the species who live in them the same for Mediterranean and Tropical forest?

The marteloscope is a good instrument to see the immediate effects of forest management, but it is not good yet for medium and long term forecasting of tropical forests dynamics.

This study compares habitat value and economic value among different thinning simulations, but it cannot forecast the forest response. If we know which tree species would have more chances to grow after the prescribed interventions, we might improve our understanding of this vast ecosystem, defining more precise instructions for the forest intervention.

6.- CONCLUSIONS

The higher habitat values were associated to the dominated trees with a low DBH. Despite of that, the general trend shows that TreMs and habitat value increases by increasing the tree DBH.

The forest protection policy in Vietnam, made evaluating the economic value of each tree a very controversial task: only the 45% of the total number of trees were marketable.

Among the four thinning operations, it is evident the contribution of the biodiversity conservation criteria in forest management making us prefer S2 and S4 instead of S1 and S3. At the same time, S4 resulted to be the best for the biodiversity conservation.

The best scenario in terms of revenue and efficiency was S3. Despite of that, S4 is the best compromise between profit and habitat conservation measures.

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ANNEX 1

TREMS RECORDS AND FREQUENCY TABLE

TreMs	count	frequency
Bryophytes	895	1.11180124
Foliose and fruticose lichens	888	1.10310559
Insect galleries and bore holes	701	0.87080745
Invertebrate nests	566	0.70310559
Ivy and lianas	296	0.36770186
Resin flow	263	0.32670807
Bark shelter	174	0.21614907
Fork split	171	0.21242236
Sap flow	171	0.21242236
Dead branches	167	0.20745342
Myxomycetes	115	0.14285714
Crown micro soil	90	0.11180124
Hollow branch	84	0.10434783
Bark pocket	68	0.08447205
Bark loss	55	0.06832298
Trunk rot-hole	41	0.05093168
Dendrotelm	34	0.04223602
Canker	33	0.04099379
Crack	22	0.02732919
Bark micro soil	14	0.01739130
Trunk base rot-hole	7	0.00869565
Burr	7	0.00869565
Root-buttress concavity	5	0.00621118
Steam breakage	5	0.00621118
Limb breakage	3	0.00372671
Pulpy agaric	3	0.00372671
Semi-open trunk rot-hole	2	0.00248447
Dead top	2	0.00248447
Witch broom	2	0.00248447
Epicormic shoots	2	0.00248447
Chimney trunk base rot-hole	1	0.00124224
Trunk bark-lined concavity	1	0.00124224
Annual polypore	1	0.00124224

ANNEX 2

TREMS ASSOCIATED TABLE FROM LARRIEU ET AL. (2018)

Link between tree-related microhabitats (TreMs) groups and biodiversity in European temperate and Mediterranean forests. 'x' indicates that several species of the taxonomic group occur; these species are not necessarily strictly associated with the TreM group. « * » (used for Hymenoptera only) indicates that TreM-associated species are mostly parasitoids. See Appendix A for supporting references and the list of the experts consulted.

	Invertebrates									Vertebrates					Bryophytes	Fungi	Lichens
	Insects						Arachnids		Gastropods	Birds	Mammals			Amphibians & Reptiles			
TreM groups	Coleoptera	Diptera	Hemiptera	Hymenoptera	Lepidoptera	Collembola	Mites	Aranea, & Pseudoscorpionida			Rodents	Bats	Carnivores				
Woodpecker breeding cavities	x	x		x*	x		x	x		x	x	x	x			x	
Rot-holes (containing mould)	x	x		x*		x	x	x	x	x	x	x	x	x	x	x	x
Insect galleries and bore holes	x	x		x*			x	x				x				x	
Concavities	x	x		x*				x		x	x		x	x	x	x	
Exposed sapwood only	x			x	x				x	x		x				x	
Exposed sapwood and heartwood	x	x						x	x	x		x				x	x
Crown deadwood	x	x		x			x	x		x						x	x
Twig tangles								x		x							
Burrs and cankers					x										x	x	
Perennial fungal fruiting bodies	x	x	x	x*	x	x	x		x						x	x	
Ephemeral fungal fruiting bodies and slime molds	x	x	x		x	x	x									x	
Epiphytic or parasitic crypto- and phanerogams	x	x		x	x		x	x	x	x	x		x			x	
Nests	x	x			x		x	x		x	x		x			x	
Microsoil		x				x	x								x	x	
Fresh exudates	x	x		x												x	

ANNEX 3

MARTELOSCOPE PICTURES