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ESTIMATIVA DAS IDADES DAS ÁRVORES NUMA FLORESTA NATURAL INVADIDA NA ILHA DE SÃO MIGUEL, AÇORES

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TREE AGE ESTIMATION IN AN INVADED NATURAL FOREST IN SÃO MIGUEL ISLAND, AZORES

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ABSTRACT

Natural forests have been estimated to occupy about 10% of the land surface in the Azores. One aspect that merits further attention is tree age determination in natural forests. This would allow a more complete understanding of temporal forest dynamics. We analyzed forest structure and estimated tree age at breast height at two stands of laurel forest located at the "Área Protegida para a Gestão de Habitats ou Espécies da Serra de Água de Pau" (SMG07, Parque Natural da Ilha de São Miguel), located at 569 (ST1) and 612 m (ST2). We used T-square sampling to estimate tree density and measured tree height, basal diameter and canopy volume. A Pressler borer was used to collect wood samples at breast height that were treated to allow annual tree ring counting. At ST1 *Morella faya* was the most frequent tree species and had the largest basal area but was surpassed in biovolume by *Pittosporum undulatum*; At ST2 *Erica azorica*, *Ilex azorica* and *Laurus azorica* were most frequent, *L. azorica* showed the largest basal area but *P. undulatum* equaled its biovolume. Tree ages at breast height, at ST1 ranged 10-52 years in *L. azorica*, 15-82 years in *M. faya*, and 34-79 years in *P. undulatum*; at ST2 tree ages ranged 10-39 years in *L. azorica*, 17-38 years for *Ilex azorica*, 9- 31 years for *E. azorica*, 13-34 years for *M. faya*, and 29-51 years for two specimens of *P. undulatum*. Forest soil was almost completely covered by *Hedychium gardnerianum* therefore seedlings and saplings were seldom found. This research also revealed different types of annual ring patterns for the different taxa. This is one of the first studies revealing tree age at a laurel forest stand in the Azores.

Keywords: Azores; Laurel forest; Structure; Tree age; Tree density; T-square sampling

RESUMO

As florestas naturais ocupam cerca de 10% da superfície terrestre nos Açores. Um aspeto que merece maior atenção é a determinação da idade das árvores em florestas naturais, uma vez que permitiria uma mais completa compreensão da dinâmica florestal. Foi analisada a estrutura da floresta e estimada a idade das árvores através da altura do peito em dois talhões de floresta laurifólia localizados na “Área Protegida para a Gestão de Habitats ou Espécies da Serra de Água de Pau” (SMG07, Parque Natural da Ilha de São Miguel), localizada a 569 (ST1) e 612 m (ST2). Utilizou-se o método de amostragem “T-Square” para estimar a densidade das árvores e mediu-se a altura das árvores, o diâmetro basal e o volume de copa. As amostras de madeira foram colhidas à altura do peito, utilizando a sonda de Pressler, e tratadas, para permitir a contagem dos anéis anuais de cada espécie. Na ST1 *Morella faya* foi a espécie mais frequente, sendo também a que apresentou maior área basal, contudo foi superada em biovolume por *Pittosporum undulatum*; Na ST2 *Erica azorica*, *Ilex azorica* e *Laurus azorica* foram mais frequentes, e *L. azorica* obteve maiores valores de área basal, mas *P. undulatum* apresentou um biovolume idêntico. A idade da árvore à altura do peito, na ST1 variou entre 10-52 anos para *L. azorica*, 15-82 anos, para *M. faya* e 34-79 anos para *P. undulatum*; na ST2 as idades das árvores variaram entre 10-39 anos para *L. azorica*, 17-38 anos para *I. azorica*, 9- 31 anos para *E. azorica*, 13-34 anos para *M. faya*, e 29 e 51 anos para duas amostras de *P. undulatum*. O solo da floresta estava praticamente coberto por *Hedychium gardnerianum* e raramente foram encontrados plântulas ou plantas jovens. Este estudo também revelou diferentes tipos de padrões de anéis de crescimento para as diferentes espécies. Este é um dos primeiros estudos que revela as idades das árvores numa floresta laurifólia nos Açores.

Palavras-chave: Açores; Floresta Laurifólia; Estrutura; Idade da árvore; Densidade de árvores; Método T-Square.

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INTRODUCTION

Dendrochronology (dendron, wood, chronos, time, and logos, study), established in 1929 by Andrew Ellicott Douglass (Douglass, 1929), is a science that studies and interprets the history of the trees based on the analysis of patterns of tree rings, also known as growth rings (Worbes, 2004; Oliveira, 2007).

Dendrochronology is a science based on seven fundamental principles, namely (Worbes, 2004): the uniformitarian principle, the principle of limiting factors, the principle of aggregate tree growth, the principle of ecological amplitude, the principle of site selection, the principle of crossdating and the principle of replication. According to the principle of uniformity, the changes that occurred in the environment were also recorded in the past by tree species; therefore this principle is applied to paleoenvironmental studies. According to the principle of the limiting factors, there are factors that limit the growth of the rings such as temperature, humidity, rainfall and also human factors; therefore this principle is applied to paleoclimatic studies. According to the third principle, the growth of a tree can be decomposed on a sum of environmental factors, affecting the growth rings. The sum is represented by $R_t = A_t + C_t + DD_1 + DD_2 + E_t$, where R_t is the growth ring, A_t the trend of relative age growth, C_t weather, DD_1 and DD_2 represent factors caused by occasional events within and outside the habitat, respectively, and E_t errors caused by other factors. The fourth principle is important because in dendrochronology it is essential that the sampled species will be within the latitude and altitude limits of their habitat. According to the fifth assumption, the choice of the species to be studied must be made according to the criteria that determine the sensitivity of species to factors such as temperature and precipitation. The principle of crossdating, essential in dendrocronology, is based on the assignment of calendar dates for each of the growth rings. The last principle, consists in the collection of as many samples per tree in a large number of trees per habitat as possible, in order to reduce the level of environmental noise (Gonçalves, 2012).

This science has revealed to be of great interest in the study of environmental variation throughout history, especially in the present context of climate change (Luz, 2011). Moreover, the study of tree growth and its relationship to environmental factors such as climate, human influence, pollution, among others, plays a decisive role in forest management. The study of tree age, as well as data on growth rates, is crucial to better understand the dynamics of tree populations (Brienen *et al.*, 2005). For this, it is necessary to estimate the age of the trees making up the forest.

Tree age can be defined as the number of years from seed germination until the moment the tree is observed or measured. To determine the age of a forest the average age of the trees can be used as an approximation. Tree age is a very important variable, allowing to evaluate the increase in terms of diameter, basal area, volume and height of a species in a given location, and to compare growth in different locations (Pinto *et al.*, 2005).

Knowledge of tree age is important for several scientific and practical reasons. Tree age information is needed in many forest growth models. For example, in nature conservation tree age is an indicator for a tree's ecological value, since structural diversity and the associated biodiversity generally increase with tree age (Rohner *et al.*, 2013).

The age can be estimated in three ways: simple visual analysis of the size and appearance of the tree, the number of verticils and the number of growth rings counted (Pinto *et al.*, 2005).

Many studies are based on tree ring analysis because of its potential for obtaining reliable age estimates and long-term growth data (Brienen *et al.*, 2005). Studies with growth rings are becoming more usual since the formation of rings is directly related with the seasonality of the environment. For example, Brienen *et al.* (2005) conducted a tree ring study in the Bolivian Amazon, focusing on the presence of tree rings and their relationship with the local rainfall, showing a positive relationship between tree growth and rainfall in certain periods of the year, indicating that rainfall plays a major role in tree growth.

In addition to the studies mentioned above, involving the study of growth rings, other work has developed tree growth equations relating dendrometric variables with the number of rings. For example, the study develop by Peper *et al*. (2014) describes the development of allometric equations for *Fraxinus americana* and *F. pennsylvanica* growing in Oakville, Canada, where the best model relating tree age with diameter at breast height (DBH) was cubic. Tree growth equations are an important and common tool used to effectively assess the yield and determine management practices in forest plantations (Peper *et al*., 2014). Rohner *et al*. (2013) tested a simple linear relationship between tree age and DBH, as well as quadratic, cubic and other non-linear models.

Growth rings correspond to anatomical structures resulting from the growth of secondary xylem that, when seen in cross-sections or in increment cores, appear as more or less continuous concentric circles around the medulla. Both gymnosperms and dicotyledonous angiosperms can form growth rings, while woody monocotyledons never form tree rings due to the absence of secondary xylem (Worbes, 2004; Oliveira, 2007). Growth zones can be classified into four basic anatomical types (Worbes, 2004) according to the features at the ring boundaries, many species combining several of the four growth zone features. In the first type, boundary is marked by multiple rows of thick-walled fibers with short radial diameter; with examples in the Annonaceae, Lauraceae, Euphorbiaceae, among others. In the second type, the marginal parenchyma bands run around the entire cross-section, with examples in the Leguminosae and Euphorbiaceae. In the third type, rings are characterized by periodical patterns of parenchyma and fiber tissue, as in the Sapotaceae, Moraceae, Euphorbiaceae and Lecithidaceae. The fourth type has vessel distribution in the growth zone, with examples in *Fissilis*, *Cedrela*, and the Meliaceae (Worbes, 2004). However, the same species can show different types of growth rings or even indistinct rings, depending on the growth stage and the environmental conditions (Palermo *et al*., 2002; Worbes, 2004).

In mainland Portugal a study was conducted in order to analyze the factors of radial and axial thickness variation of the growth rings of *Pinus pinaster* Aiton (Pinaceae), based on image analysis techniques, and with the ultimate aim to include the variation in growth rings in quality assessment of sawed off wood end products of this species (Margarido *et al*., 2005). In Central-Africa the potential of applying tree-ring analysis on commercial tree species in a wet tropical forest was evaluated. For this purpose the wood anatomy of 22 tree species was screened for the presence of tree-ring structures and, on a subset of five species, crossdating potential was assessed and the annual character of tree-ring formation was evaluated by radiocarbon dating (Groenendijk *et al*., 2014). In this study, many species showed distinct tree-ring boundaries and radiocarbon proved annual tree-ring formation. This study showed that tree-ring analysis can thus be applied on tree species growing in wet tropical forests to obtain growth rates.

In the Azores, only a few studies were performed dedicated to tree age determination. Tree growth analysis has been performed by the Forest Service in particular for the most important production forest species, *Cryptomeria japonica* D. Don. (Taxodiaceae) Given the importance of the areas occupied by *Pittosporum undulatum* Vent. (Pittosporaceae), the most important woody plant invader in the Azores, within the framework of research devoted to the evaluation and valorization of its biomass (Lourenço *et al*., 2011; Teixeira *et al*., 2015; Silva *et al*., in press), preliminary studies were undertaken to estimate tree age at several stands.

Other research areas would clearly benefit from tree age determination studies. As an example, research was developed in the Azores to quantify carbon sequestration per unit area, for the native forest in Terceira Island, where a relationship between the sequestered carbon and the diversity of tree species was detected (Mendonça, 2012). However, tree ages and growth rates of those native forest species are largely unknown.

The archipelago of the Azores is relatively young, with a relatively low number of native species, therefore, the vascular plant flora, with 1002 taxa, is presently dominated by non-indigenous taxa (69%) (Silva & Smith, 2004, 2006; Silva *et al*., 2008). The flora of the Azores is characterized by an endemism rate of 7%, contrasting with the other Macaronesian archipelagos, about 20% to Madeira and 30% for the Canaries (Borges *et al*., 2010). This is due to the large component of non-indigenous taxa, thus, when considering only the indigenous plants, the rate of endemism ranges 30%.

Silva et al. (2009) conducted a study of the vascular flora of the Azores and according to these authors, about 179 indigenous plants only seven (3.9%) were officially recognized as being studied and evaluated according to the current official criteria.

Currently, only eight species are evaluated by the International Union for Conservation of Nature (IUCN) as endangered. The number of indigenous rate subject to some kind of threat continues to rise. Considering it 52 of the 72 endemic vascular plants are under threat, it appears that the number rose in just two decades, from 23 to 52.

Natural forests of the Azores had a considerable importance in the past, covering large areas on all islands, including coastal scrubland. According to Dias *et al*. (2007a), in the Azores there are four basic types of zonal forests, based on the structure and functional processes: mesic laurel forest at low altitude; humid and hyper-humid laurel forest; and juniper woodland. The mesic laurel forest formations are currently almost extinct since, due to climatic conditions most favorable for agriculture this type of forest was largely replaced. Those formations consist essentially of two woody species, *Morella faya* (Aiton) Wilbur (Myricaceae) and *Picconia azorica* (Tutin) Knobl. (Oleaceae); sometimes also with *Erica azorica* Hochst. ex Seub. (Ericaceae) and *Laurus azorica* (Seub.) Franco (Lauraceae), the latter in most ombrophytic areas; with an herbaceous cover of *Polypodium azoricum* (Vasc) R. Fern. (Polypodiaceae) and *Carex hochstetteriana* Gay ex Seub (Cyperaceae). It is characterized as a tall forest with open structure and occupying the more thermophilic regions of the archipelago. The humid laurel forest, located at the higher elevations, below the ceiling of permanent clouds, and now very rare, has a high level of structural and floristic diversity, being dominated by *L. azorica*, with *P. azorica* in low-lying areas, with *Frangula azorica* V. Grubov (Ramnaceae) at high elevations. The hyper-humid laurel forest, above the cloud ceiling, develops in areas with intense fogs, being exposed to humid winds, with lower species richness it is the most abundant type of forest nowadays. The tree layer is characterized by a combination of species such as *L. azorica*, *F. azorica*, *Ilex azorica* Gand. (Aquifoliaceae) and *Vaccinium cylindraceum* Sm. (Ericaceae), the herbaceous community being dominated by two tall ferns *Dryopteris azorica* (Christ) Alston and *Culcita macrocarpa* C. Presl. The juniper woodland has its distribution limited to high elevation areas in mountains, with large extensions on the islands of Terceira and Flores. This community is formed by a continuous and homogeneous tree layer of *Juniperus brevifolia* (Seub.) Antoine (Cupressaceae).

Currently, human activities are a determining factor in the distribution of vegetation, due to space constraints they impose, leaving available only those soils that have no use in agriculture or forestry (Dias 1996). Several historical texts, as is the case of Gaspar Frutuoso (Dias 1996), indicate a high diversity of terrestrial communities existing at the beginning of human settlement, as well as the existence of dense and stratified forests.

Meanwhile, the natural forests have being changed and cleared, with extensive areas currently occupied by exotic plants (Lourenço *et al.,* 2011).

Forest covers about 30% of the Azores islands surface area, with about one third for each of the three main categories, namely natural forest, exotic woodland and production forest (Estratégia Florestal dos Açores, 2014).

Cryptomeria japonica occupies about 60% of the production forest, being one of the more common forest species (Dias *et al*., 2007). Other species, with some expression in the Azorean production forest include *Eucalyptus globulus* Labill. (Myrtaceae), *Acacia melanoxylon* R. Br. (Fabaceae) and *Pinus pinaster* Aiton (Pinaceae) (Lourenço *et al.,* 2011). Some invasive plants prevent the regenaration of Azorean forests, such as *Hedychium gardnerianum* Sheppard ex Ker-Gawl. (Zingiberaceae) (Cordeiro *et al*., 2003), in different types of forests, *P. undulatum* form sea level up to 600 m (Lourenço *et al*., 2011) and *Arundo donax* (Poaceae) at coastal woodland and scrubland (Silva *et al*., 2008).

In the Azores it is known that canopy disturbances have a major influence in forest communities' structure and organization, since gaps formed by disturbances will influence germination, growth and survival of tree seedlings (Elias *et al.,* 2009). According to Dias and Elias (2009), tree response to disturbance depends on the regeneration of species and gap features, such as size, age and morphology. Despite all this dynamic change of forests, where exotic woods became increasingly dominant, little is known about tree age, whether native or invasive, which currently dominate the forest in the Azores. This lack of information limits the understanding of invasion processes and a more effective management of invasive species. In this context, the development of dendrological studies dedicated to forest species in the Azores should be viewed as a priority.

In this research we aim to estimate the age of the native and invasive trees that make up an area of invaded natural forest, in the island of São Miguel (Azores).
In particular it is intended:

- study changes in vegetation structure along a invasion gradient;
- estimate the ages of native and invasive trees;
- infer about the invasion process.

METHODS

Study area

The Azores archipelago, located in the North Atlantic Ocean, approximately between 37° to 40° coordinates N latitude and 25° to 31° W longitude, constituted by nine islands and several islets, all of volcanic origin, constituting three groups: Western Group, composed by Flores and Corvo, Central group, which includes the islands of Terceira, Graciosa, São Jorge, Pico and Faial and the Eastern Group, which comprises the islands São Miguel and Santa Maria (Silva *et al*., 2010). São Miguel Island, in the Azores, approximately covers a total area of 757 km^2 and is the largest island of the archipelago, with a maximum elevation of 1103 m (Silva *et al*., 2010). The islands of the Azores have a temperate maritime climate with low-seasonal temperature variations, high rainfall and high relative humidity (Secretaria Regional do Ambiente e do Mar, 2011). These conditions are important factors in order to understand how the forests are distributed in the region. Rainfall is one of the factors dependent on movements of air masses, which explains its decrease from west to the east (Dias *et al*., 2007a). Wind is also considered as a factor in the distribution of forests in the case of the Azores, being a limiting factor, particularly at very exposed locations both at low and high elevation. The study area includes two laurel forest stands invaded by *P. undulatum* and *H. gardnerianum*, located in Lombadas (Ribeira Grande), São Miguel Island (FIGURE 1). Both stands, located at altitudes of 569 m with coordinates 26s 0634520 UTM 4183455(ST1) and 612 m with coordinates 26s UTM 4183432 (ST2), are included in "Área Protegida para a Gestão de Habitats ou Espécies da Serra de Água de Pau" (SMG07, Parque Natural da Ilha de São Miguel).

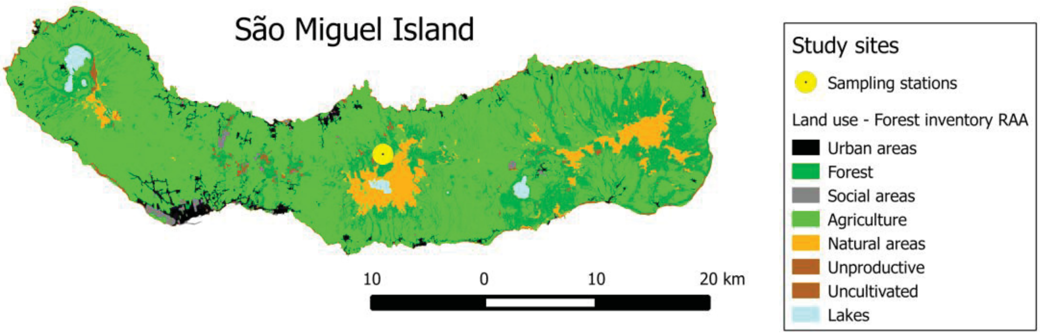

Figure 1. São Miguel Island. Sampling sites.

We used T-square sampling to estimate tree density and we also measured tree height, basal diameter and canopy volume. The T-square sampling was first described by Besag and Gleaves (1973). In this method, random points are located in the study area and at each random point two distances are measured: i) the distance from the random point to the nearest tree; and ii) the distance from the tree to its nearest neighbor with the proviso that the angle between the random point and the nearest neighbor tree should be greater than 90° (Krebs, 2014). The species were identified and the following dendrometric variables were recorded: diameter at breast height (DBH), total tree height, canopy height, and canopy diameter. DHB was measured using a diameter tape, while total tree height and canopy height were measure using a Vertex IV and Transponder T3 (HAGLÖF, Sweden). Canopy diameter was estimated by measuring two perpendicular diameters, measured at the extreme vertical projections of canopy, using a 10 m metric tape. To collect wood samples a Pressler borer was used - a specialized tool used to extract a cylindrical radial section of a tree trunk in a non destructive way to estimate tree age. Identified samples were packed into individual plastic containers until laboratory processing. Wood samples were al taken at breast height so that a possible relation between the number of growth rings and DBH could be deduced. Therefore, we were not determining total tree age, but only tree age at breast height.

Tree growth ring analyses

In the laboratory, the samples were mounted on wood and left for drying in the laboratory. Samples were sanded using a sequence of gradation sandpapers: 100, 150, 180, 220, 320 and 600 of average grit size in micrometers. *Pittosporum undulatum* samples were treated following the phloroglucinol method (Wiesner Test). The reading of the rings was performed under a stereomicroscope.

Statistical analyses

For each species, four parameters were analyzed: DBH, tree height, canopy height and canopy diameter. Canopy biovolume was obtained with the formula suggested by Dias (1996): $B_v = \pi r^2 h$, where B_v is the biovolume, r is the canopy radius and h is canopy height. The individual biovolume is the average volume of the crown of individuals of a species and the total biovolume is the sum of the canopy volumes of all individuals of a species (Elias *et al*. 2009). To assess forest structure and species dominance, we calculated the frequency and percentage of each species in each zone. We also calculated mean values for tree height, canopy height, canopy diameter, biovolume and basal area, for each species, and the percentage contribution of each species for the total. Basal area was calculated as $\pi(DBH/2)^2$.

We used IBM SPSS Statistics 21 regression module to verify whether there was a significant relationship between DBH and the number of growth rings. To estimate the relationship between GNR (growth rings) and DBH we tested the following models: Linear, Quadratic, Cubic and Logarithmic.

RESULTS

Forest composition

We analyzed two stands of laurel forest with different degrees of invasion for *P. undulatum*. Forest soil was almost completely covered by *H. gardnerianum* therefore seedlings and saplings were seldom found. The species identified in both areas were: *L. azorica*, *I. azorica*, *M. faya, E. azorica*, *M. africana* and *P. undulatum*, the latter being the only woody plant invader recorded. However, although not collected by the sampling procedure, *A. melanoxylon* and *Psidium cattleianum* Sabine (*Myrtaceae*) were also observed at that area. A total of 122 trees were identified and a total of 89 wood samples were collected.

Morella faya was the most frequent species at ST1 (63%) while the most frequent species at ST2 were *E. azorica* and *I. azorica* (Fig. 2).

Forest structure

Tree height ranged from about 3 m for *M. africana* up to about 14 m for *P. undulatum* and *I. azorica*. The tallest species at ST1 were *I. azorica* and *P. undulatum,* while at ST2 were *P. undulatum* and *M. faya* (Fig. 3). In terms of density, at ST1 it has 1642 trees per hectare and at ST2 it has 2630 trees per hectare

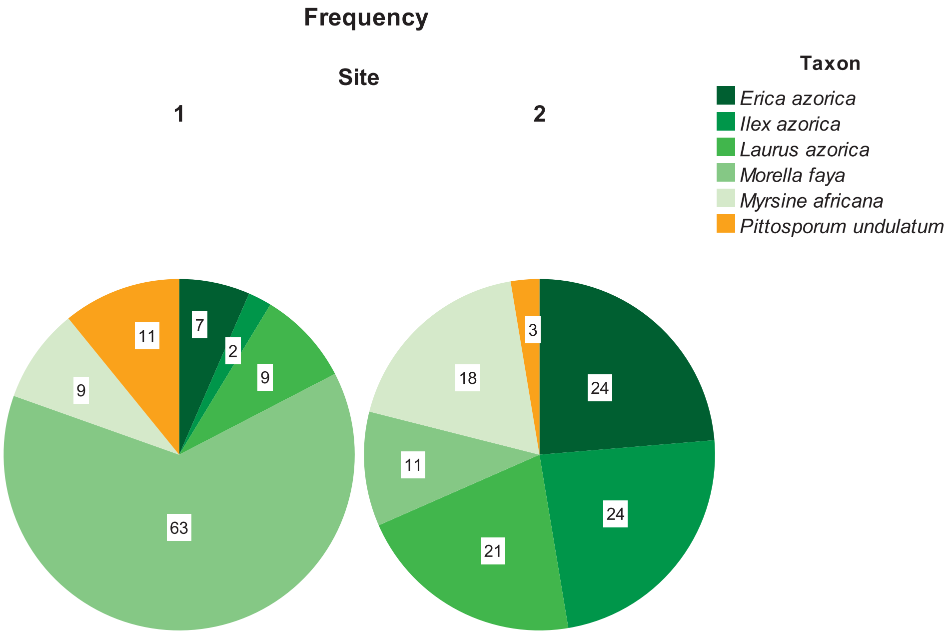

Figure 2. Frequency of each woody species identified in laurel forest stands at two study sites located at SMG07, São Miguel Island Natural Park.

Tree canopy height ranged from about 1 m for *I. azorica* up to about 6 m for *M. faya*. Canopy height was largest for *M. faya* at ST1 and for *P. undulatum* and *M. faya* at ST2 were (Fig. 4). Canopy diameter ranged from about 1 m for *M. africana* up to about 8 m for *P. undulatum*. It was largest for *P. undulatum*, *I. azorica* and *L. azorica* at ST1, and for *P. undulatum*, *L. azorica*, and *M. faya* at ST2 (Fig. 5). There was a very large variation in biovolume, according to the different species (Fig. 6). The species with the largest mean biovolumes were *I. azorica* and *P. undulatum* at ST1, and *P. undulatum* at ST2 (Fig. 6). A very similar situation was found for basal area (Fig. 7).

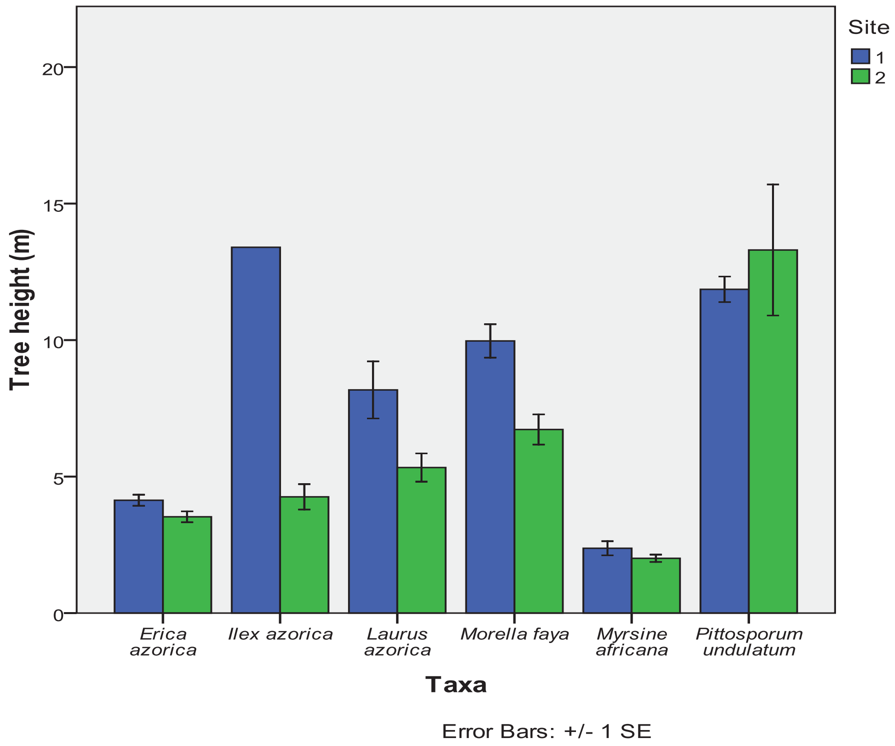

Figure 3. Mean tree height (m) in laurel forest stands at two study sites located at SMG07, São Miguel Island Natural Park.

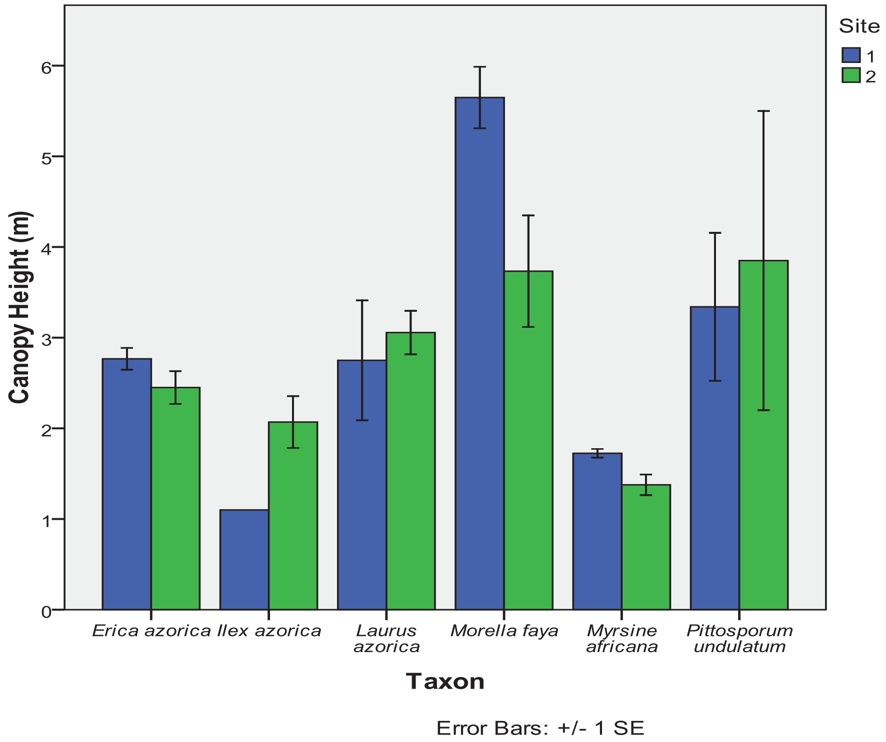

Figure 4. Mean canopy height (m) in laurel forest stands at two study sites located at SMG07, São Miguel Island Natural Park.

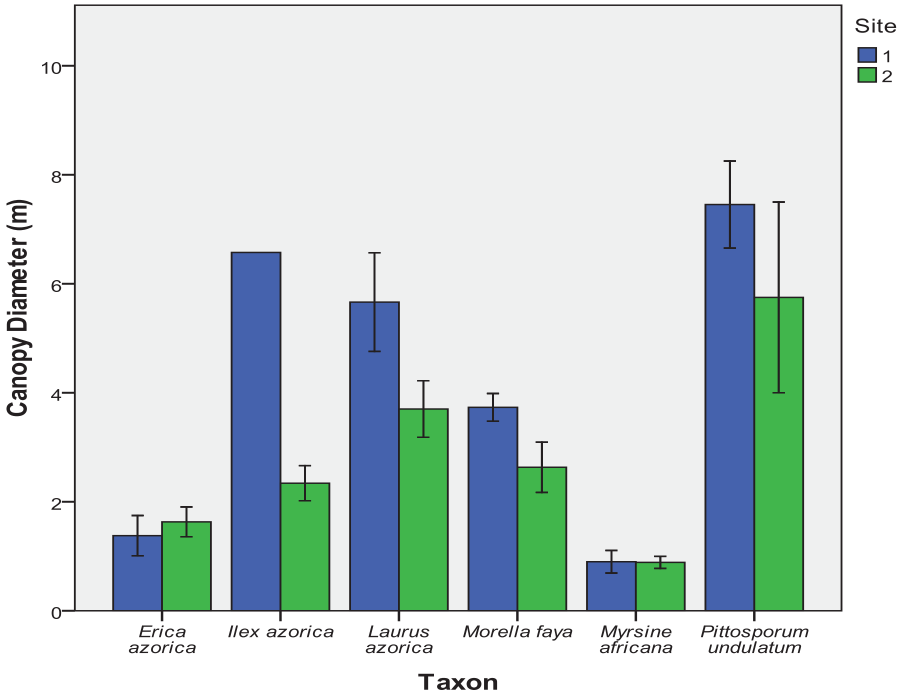

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Figure 5. Mean canopy diameter (m) in laurel forest stands at two study sites located at SMG07, São Miguel Island Natural Park.

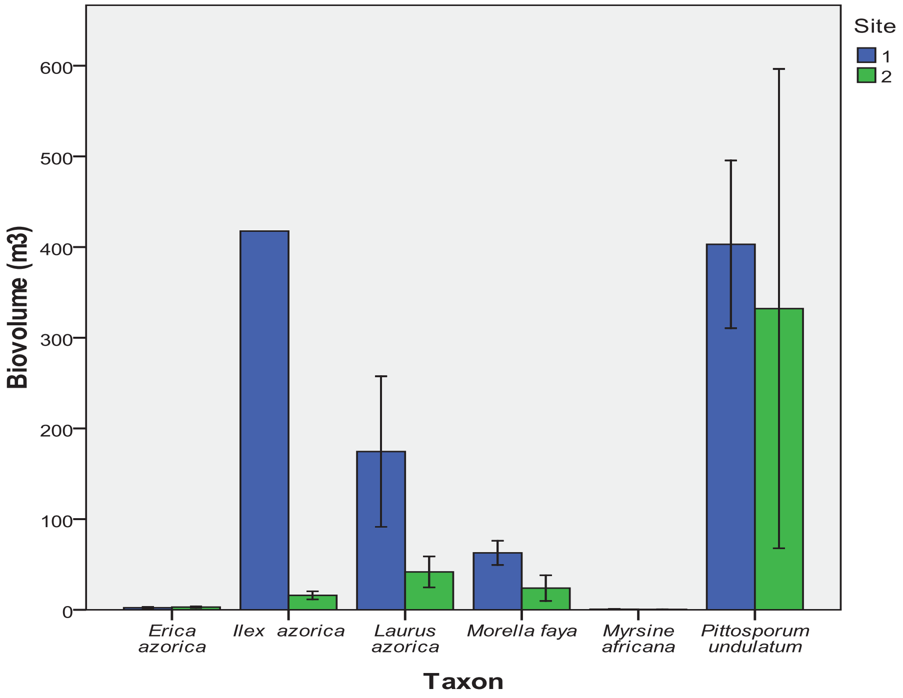

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Figure 6. Mean biovolume (m^3) in laurel forest stands at two study sites located at SMG07, São Miguel Island Natural Park.

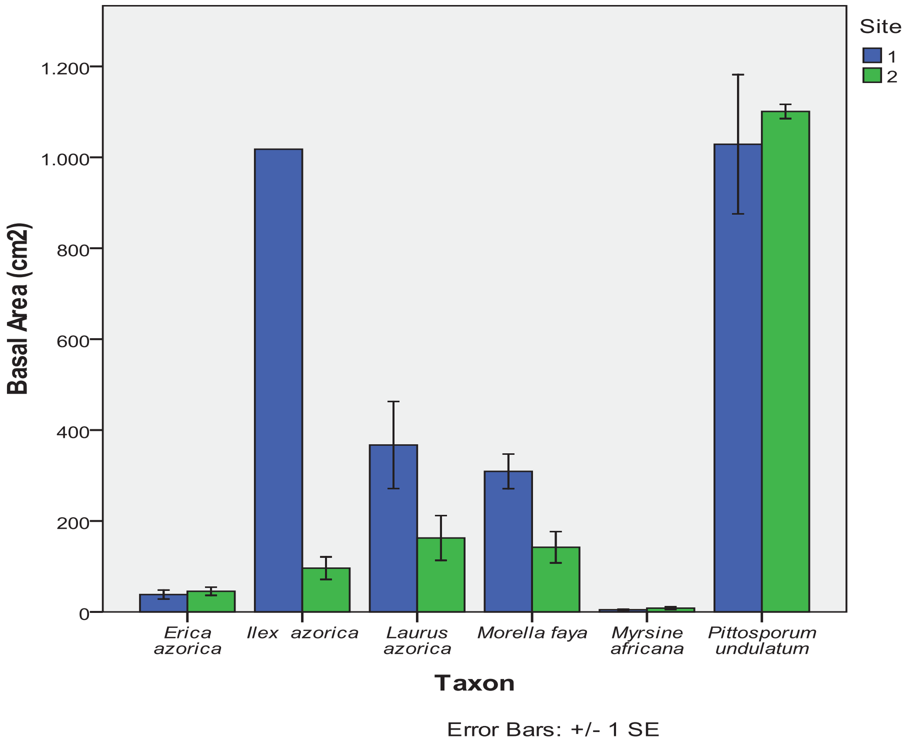

Figura 7. Mean basal area (cm^2) in laurel forest stands at two study sites located at SMG07, São Miguel Island Natural Park.

Species dominance

In terms of the percentage of total biovolume (Fig. 8), *P. undulatum* dominated at both sites. Regarding the native species, *M. faya* dominated at ST1, and *L. azorica* at ST2 (Fig. 8).

In terms of percentage of total basal area (Fig. 9), the situation was similar to that observed for biovolume, although with a larger dominance of *M. faya* at ST1, and a lower dominance of *P. undulatum* at ST2, with an increase in the dominance of the native taxa, with the exception of *L. azorica*.

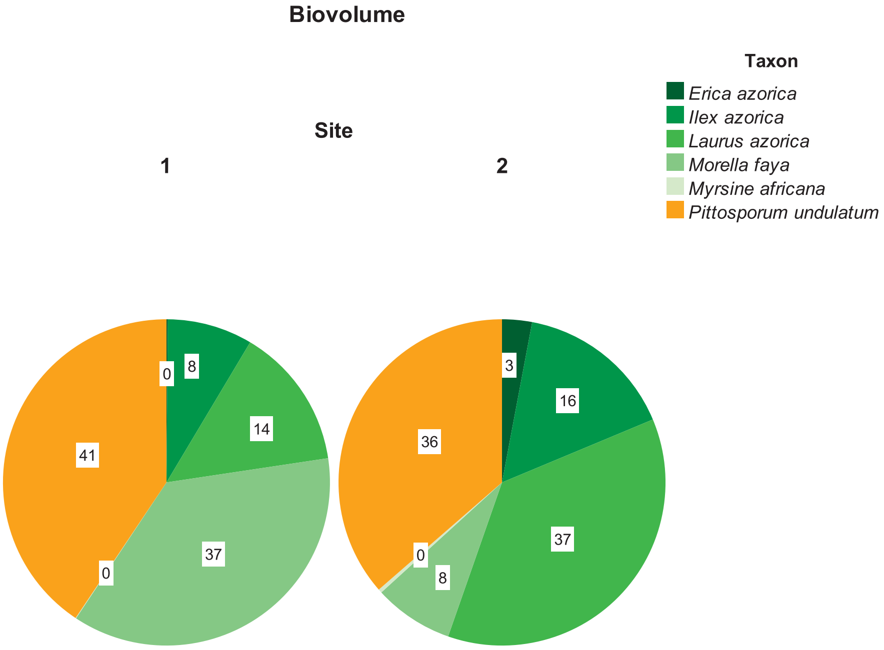

Figure 8. Forest composition represented as the percentage of biovolume allocated to each woody species in laurel forest stands at two study sites located at SMG07, São Miguel Island Natural Park.

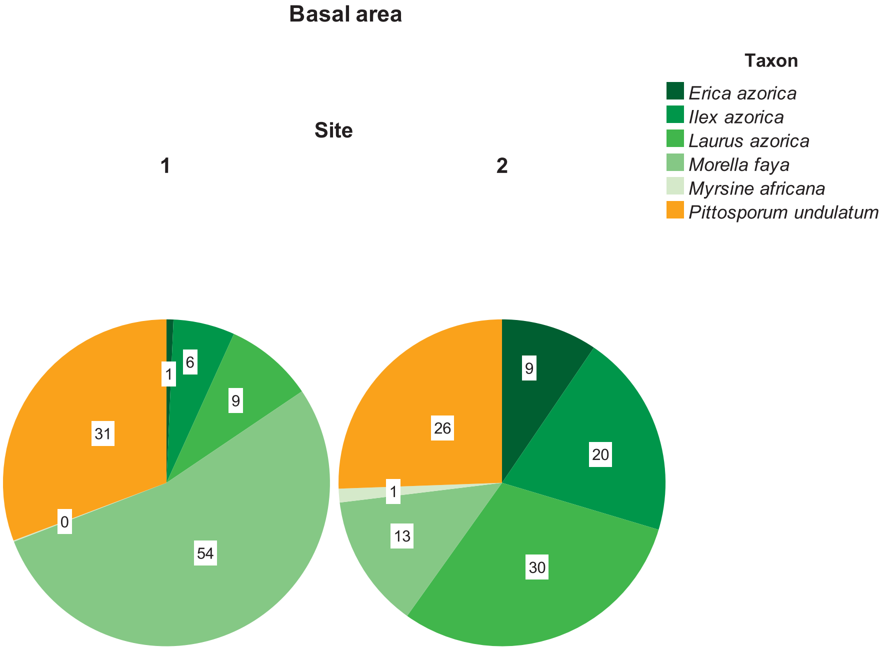

Figure 9. Forest composition represented as the percentage basal area allocated to each woody species in laurel forest stands at two study sites located at SMG07, São Miguel Island Natural Park.

Tree growth ring analyses

The growth rings of *L. azorica* and *I. azorica* were the easiest to read, due to the existence of sharp difference between a wide vessel band corresponding to the fast growing season, and a thin linear band corresponding to the transition among growing seasons. *Erica azorica* growth rings were ooften difficult to read due to the very dark color of the wood. The growth rings of *P. undulatum* were the most difficult to read, due to low contrast between growth rings formed at the two growing seasons. Therefore, the phloroglucinol method was applied. Likewise, the reading of *M. faya* growth rings was very difficult due to doubtful/vague ring-boundaries (Fig. 10; Table 1). It was collected samples of *M. african* species since the diameter of the trunks were very low and it is impossible to use the probe. Based on the descriptions of Worbes (2004), the five species show growth rings of type 4, corresponding to the type B - boundaries marked by a marginal parenchyma band - cited by Groenendijk *et al.* (2014).

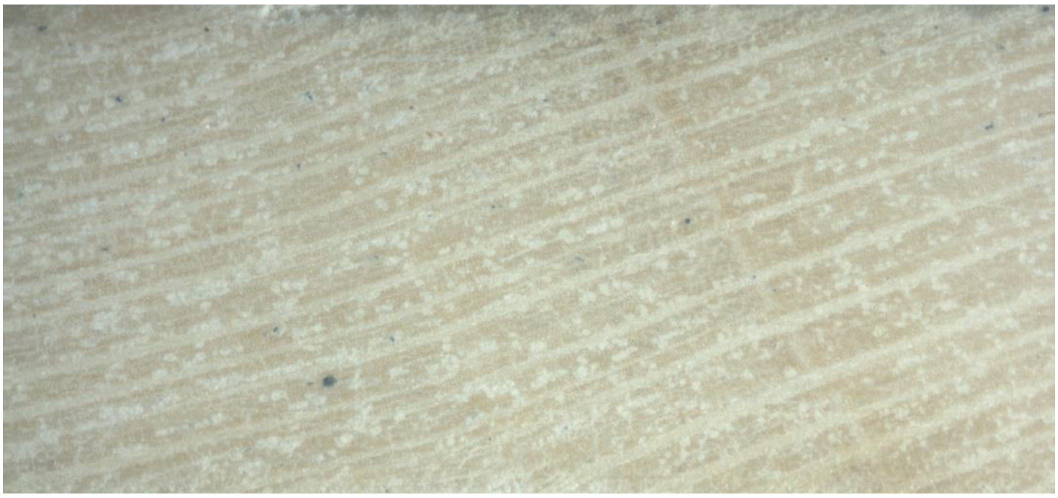

Figure 10. Tree ring of *I. azorica* (type B).

Figure 11. Tree ring of *L. azorica* (type B).

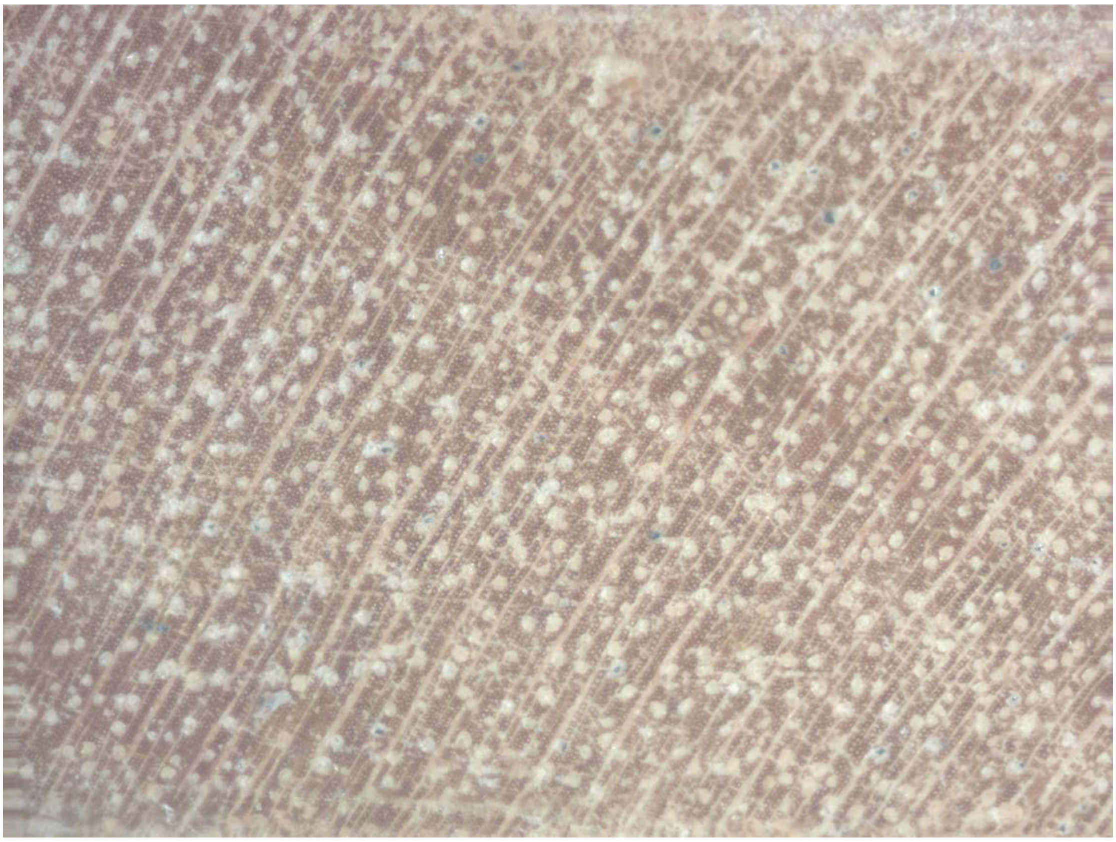

Figure 12. Tree ring of *M. faya* (type B).

Table 1. Type of the tree growth rings (B, marginal parenchyma band; Worbes, 2004). Total number of trees collected. Difficulty in reading the rings of each species (+++ Difficult; ++ Medium; + Easy).

Species	**Tree-ring type**	**# Trees**	**Difficulties**
E. azorica	B	16	++
I. azorica	B	14	++
L. azorica	B	20	+
M. faya	B	31	+++
P. undulatum	B	9	+++

In general, most of the trees showed a number of growth rings varying between 20 and 40. Tree ages at breast height, at ST1 ranged 10-52 years in *L. azorica*, 15-82 years in *M. faya*, and 34-79 years in *P. undulatum*; at ST2 tree ages at breast height ranged 10-39 years in *L. azorica*, 17-38 years for *I. azorica*, 9-31 years for *E. azorica*, 13-34 years for *M. faya*, and 29-51 years for two species of *P. undulatum* (Fig. 13).

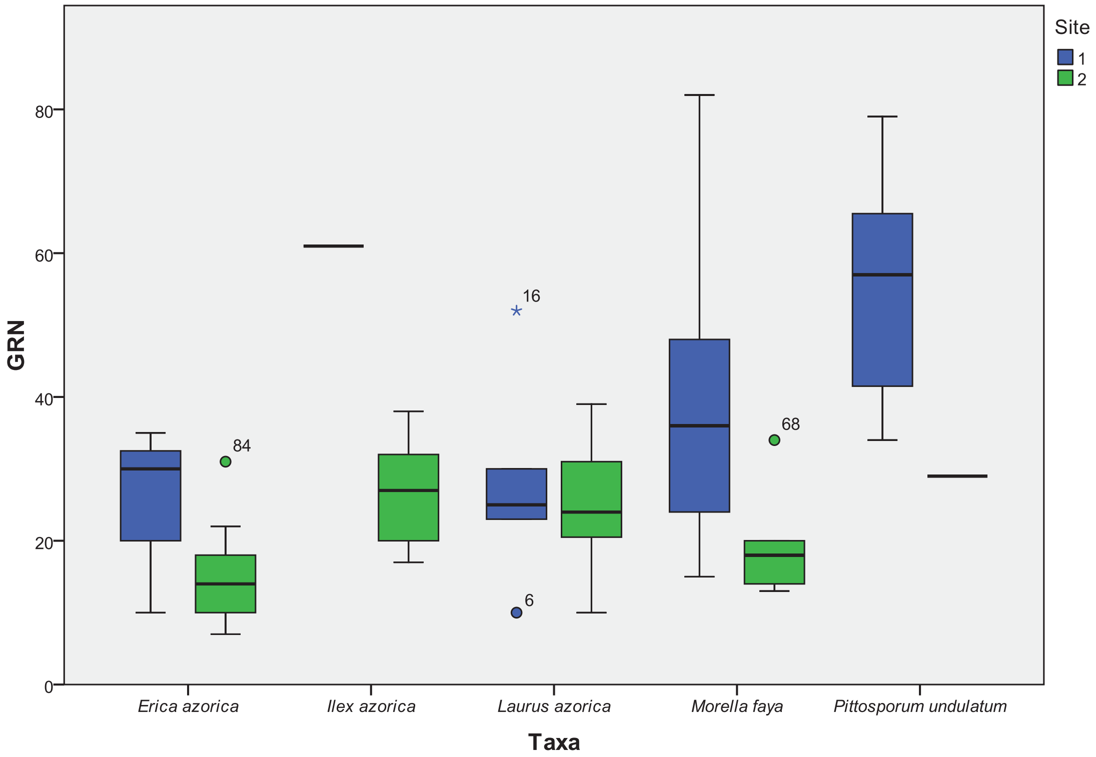

Figure 13. Growth ring number (GRN) at breast height for five species of woody plants by taxa with minimum, maximum and median for each species.

The model tested was Linear, Quadratic, Cubic and Logarithmic, in SPSS, in order to verify the relationship between two variables, GNR and DBH and the species tested were the three endemic: *M. Faya*, *L. azorica*, *I. azorica*.

For *M. Faya* the only significant model was Logarithimic, none of the other three was significant (P > 0.05). For *L. azorica*, only the Cubic model was not significant, the model Linear and Logarithmic showed more consistency for this specie. In the case of *I. azorica* four models were significant.

Table 2. Regressions between growth ring number and diameter at breast height for three woody species collected at the study site.

Model	**Species**								
	Morella Faya			***Laurus azorica***			***Ilex azorica***		
	R^2	F	P	R^2	F	P	R^2	F	P
Linear	0.35	4.051	0.054	0.275	6.843	0.018	0.831	26,738	<0
Quadratic	0.380	2.366	0.112	0.324	4.082	0.036	0.843	13,533	0.001
Cubic	0.398	1.692	0.192	0.330	2.630	0.086	0.860	9,465	0.003
Logarithmic	0.367	4,515	0,042	0,307	7,958	0,011	0,751	15,509	0,002

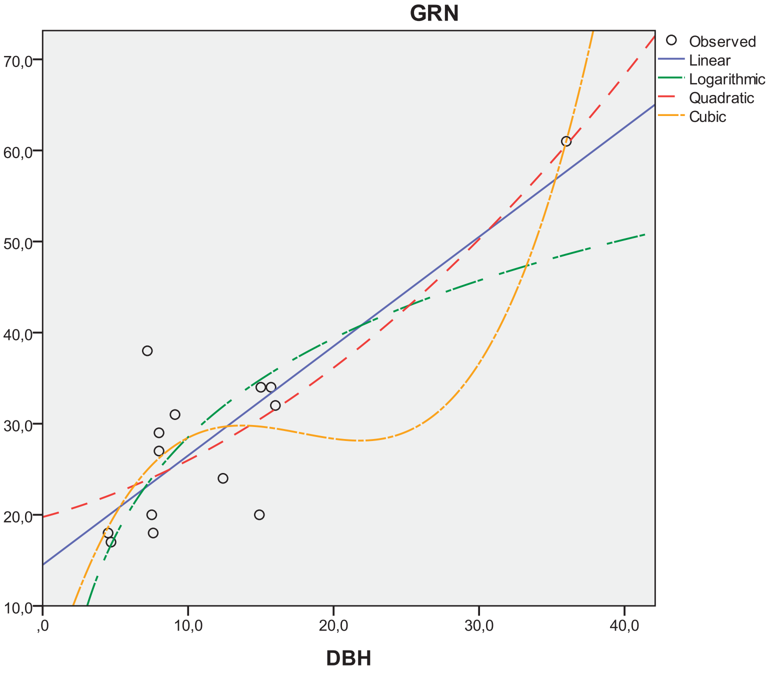

Figure. 14 Relationship between the number of growth rings (GRN) and DBH of *I. azorica*.

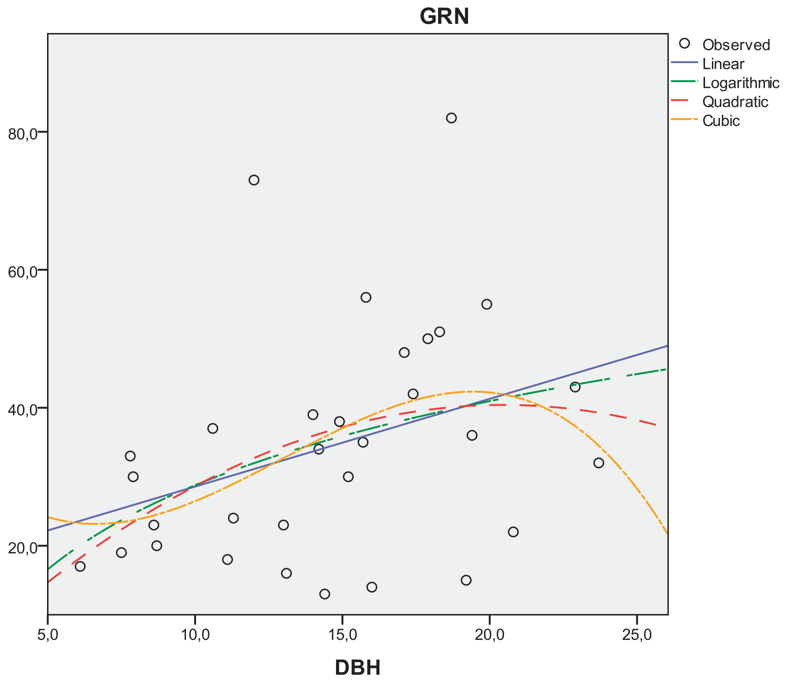

Figure. 15 Relationship between the number of growth rings (GRN) and DBH of *L. azorica*.

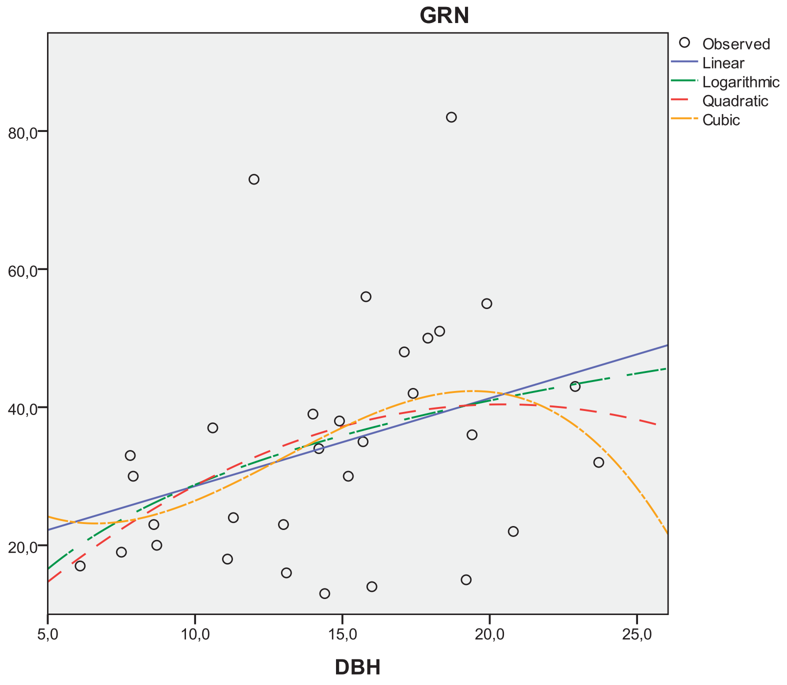

Figure. 16 Relationship between the number of growth rings (GRN) and DBH of *M. faya*.

DISCUSSION

Forest composition

The Azores forests are composed, for example, by *Morella*, *Erica*, *Laurus*, *Juniperus*. The Azores present a large proportion of native and endemic plant species occurring in most islands, which is associated to the high compositional uniformity of the Azorean native forest (Costa *et al*. 2013). Currently, the archipelago landscape includes pastureland (65 %), *Cryptomeria japonica* dominated production forest (about 20 % of the forested area), mixed woodland, field crops, orchards, vineyards, hedgerows and gardens (Silva and Smith 2006).

At the study site, the forest soil was almost completely covered by *H. gardnerianum* therefore seedlings and saplings were seldom found. This invasive was introduced in the Azores during the 19th century as an ornamental plant. It is one of the most frequent and abundant plant invaders in the Azores (Cordeiro *et al*., 2003). According to a study by Cordeiro and Silva (2003) on the island of São Miguel the number of *H.* gardnerianum seeds per spike ranged from 300 to 500 and according to the same authors a cutting of native forests is frequently followed by a potent invasion of *H. gardnerianum*.

The species, dominant in the study area, *E. azorica*, *I. azorica* and *L. azorica* are dominant and very important in laurel forest formations (Dias *et al*. 2007a).

The specie *E. azorica* is described as providing more favorable habitat conditions to a subsequent colonization, e.g. *Juniperus brevifolia*. It has large amplitude in terms of altitude. This species suffers the action of a large number of threats because often occur in local humanized as pastures and production forests. *I. azorica* belongs to the structuring species of Azorean forests. These types of forest, composed by *I. azorica*, are associated with extreme soaking conditions and shelter in shaded slopes. Currently, it presents a timely distribution, due to competition man by these spaces where this species occur naturally (Dias *et al*. 2007a). According to Dias *et al*. (2007a) the specie *L. azorica* is the symbol of Azorean flora. However, despite the laurel forests are still extensive in the archipelago, this type of forest tends to disappear due to landscape fragmentation, progressive transformation of land use and the invasion of exotic.

Forest structure

The parameters studied in each species are very important, for example growth and yield of trees are modeled using stem diameter-at-breast height relationships with tree height, crown height, and crown diameter (Diallo, 2013).

In forest structure, the species that were almost always dominant were *I. azorica*, *M. faya*, *L. azorica* and *P. undulatum* and this three endemic species are very important in the structure of forest formations laurifolia (Dias *et al*. 2007a). According to the literature, the *I. azorica* can reach, currently, a maximum height of 8m. This species is very important in the Azores ecosystem because is food for the Priolo (Dias *et al*. 2007a).

M. faya in the Azores reaches about 20 m high and is present in all the islands (Dias *et al*. 2007a). The beneficial ecological role of this native species in the Azores has been recognized as regards cloud water infiltration, soil nutrient availability and source of food and shelter for birds and endemic insects (Costa *et al*. 2012). This species in a study by Silva and Tavares (1997) with the provost to study the factors affecting *M. faya* demography in the azores, the species was the dominant plant at Lombadas relative dominance, based on basal diameter, of various shrubs compared to *P. undulatum*, *Erica azorica*, *Myrsine africana*, *Vaccinium cylindraceum* and *Ligustrum henryi*. This species presents very competitive characteristics, but has been losing the battle for territory for *P. undulatum*. Currently, *M. faya* has gradually disappeared from the Azorean landscape, because the potential distribution of faya formations corresponds to the area of greatest interest for human exploration (Dias *et al*. 2007a). According to DRRF (2007), *M. faya* is currently present in a total of 22% of the forested area in the Azores archipelago but in only 5% of that area, *M. faya* is the dominant species.

L. azorica is a broadly distributed in the archipelago, with an average height of around 10 m and is an important element of native forests altitude. This species provide food for the *Columba trocaz,* which feeds its berries, thereby promoting the spread of this species across the landscape (Dias *et al*. 2007a).

P. undulatum, native to Australia, invasive species and present in the forest formations laurifolia studied, can reach 10 to 15 m high and already occupies more than 30% of the forested areas and has the prospective to further spread being the most important woody plant invader in the Azores (Dias *et al*. 2007a, Silva et al., 2008 & Lourenço et al., 2011). It already occupies more than 30% of the forested areas and has the prospective to further 4 spread. It is currently used in the Azorean Islands mainly for honey production, compost for pineapple plantations in São Miguel Island, and in some islands as fuel wood for bakeries (Teixeira 2014). Another important factor which contributes to the dispersion of this species is that of native birds such as blackbirds feeding this species (Costa *et al*. 2012).

Tree growth rings

The tree-ring study allows empirically quantify and growth dynamics reconstruction forest over the years. As dendrochronological methods allow rebuilding and even quantify climatic and ecological phenomena have been raised about the global changes that can be answered through the study of growth rings (Nehrbass-Ahles *et al*., 2014).

Depending on the species and the climate where the trees are living, the rings could be viewed by only sandines it or in some cases we must do something with the wood. In the case of endemic did not need any treatment because their rings were quite visible, and some even visible to the naked eye, as was the case of some samples *L.azorica*. In case of *P. undulatum*, it was even necessary to apply a treatment to improve the visibility of the rings. The treatment of phloroglucinol was applied to color the lignin, where it was possible to observe a better contrast between the original wood and late wood. The floroglucine method is used in some studies of plants anatomy to color the lignin. If we apply the treatment of floroglucine to color the lignin we can expect a better contrast between the earlywood and laterwood.

For the five species found rings of growth. In this study it was not very focused type of each kind of ring, however, and the work of Worbes 2004 (preview of the photos of the four types of rings), species seem to be type 4. However, Worbes (2004) relates the Type 1 to the *Lauraceae* family, but our samples *L.azorica* appear to have the rings of type 4. Of the five species, *L. azorica* showed the most distinct tree ring boundaries. *M. faya* proved to be the most difficult kind of read, there is sometimes difficult to distinguish bands earlywood and laterwood. This appears to be due to the fact that some material is already dead and somewhat degraded when collected samples. This species requires detailed studies in order to better understand the type of ring, also making new count rings, taking into account the material which is to collect the samples, because observing our samples, the material collected branches seems practically no activity biological.

Tree growth equations are an important and common tool used to effectively assess the yield and determine management practices in forest plantations. In this work, we tried to use the equations were used by Peper *et al*. (2014) and Rohner *et al*. (2013), however it was not significant for the studied species.

The linear model applied to relate GNR and DAP was significant for three species (*I. azorica*, *L. azorica* and *M. faya*). The four models tested set relatively well for the case of the species *I. azorica*. However, in this case there are missing data, since for this species were few samples taken. The model types showed more consistency for specie *L. azorica*, this specie has the best results in all four models tested. Being that the models linear and the logarithmic were the most adjusted models for the *L.azorica*. In case the specie *M. faya* none of the four models fits. The rings in this species were difficult to read and many samples had a bit rotten parts, and even the collection of local wood of the trees seemed to be rotten. This species requires further studies.

In Teixeira *et al*. 2015 was developed a linear model relates to the rings number the specie *P.undulatum* with diameter at cutting height.

In this work the age of the trees of *P. undulatum* and its relation with DBH is consistent with results from Wunder (2011), predicting age from diameter data, appears promising. *P. undulatum* was a species with age in our sample, but is necessary to check this case, since they were sampled a few trees of this species. In Peper *et al*. 2014 describes the development of allometric equation for *Fraxinus americana* and *F. pennsylvanica* growing in Oakville, Canada. In this study, five allometric models were tested to develop equations estimating DBH, tree height, crown width and crown height, using age and DBH as explanatory variables. Of all the tested random coefficient models for both species,the cubic with weight 1/x provided the best fit for estimating DBH from age.

CONCLUSIONS

Currently estimates of the ages of the trees that are in the plant communities of the Azores are virtually nonexistent, so this is one of the first studies revealing tree ages at a laurel forest stand in the Azores. Tree-ring analysis should actually be applied in different areas to obtain accurate, site specific growth data. This data is required to design and improve sustainable forest management practices. Tree-ring analysis is also very important in the Azores in order to know better our endemic and implement conservation plans. The tree-ring analysis should actually be applied on more tree species from different areas to obtain accurate, site specific growth data.

Interestingly, in the sampled natural forest remains, the largest tree ages estimated at breast height were of the same order for the invasive tree *P. undulatum* and for several of the native taxa. This might suggest that this could be a secondary forest. However, more work is needed to improve growth ring analysis of native trees, since some of the more common species, such as *M. faya*, show complex growth ring patterns.

With this study it was possible to check that forest formations, which are integrated in the protected areas are completely covers by *H. gardnerianum* not being possible, thereby regeneration, so, and according Cordeiro and Silva (2003), it is urgent develop a management strategy that will guide actions to control the dispersal of this invader and prevent the appearance of new propagation focus in the Azores.

The case of *P. undulatum* species is also worrying, in fact, is already the dominant woody species in the Azores (Hortal *et al*. 2010). Second Costa et al. (2012) conservation actions based on *M. faya* reforestation should be considered, once the similar ecological preferences of both species. According to the results reported by them, São Jorge and Pico are the most favorable islands for *M. faya* reforestation. On the other hand, this specie not showed good results for the islands Graciosa, Corvo, Santa Maria and Flores. Therefore, for these cases, the authors, as for the remaining islands, other Macaronesian species should be taken into account. Hortal *et al*. (2010) lists some suggestions for the sustainable management of *P. undulatum* invasion in the Azores, referring among them, its progressive replacement by native and other non-invasive species in hedgerows.

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